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Comparison of FDS Model Predictions with FM/SNL Fire Test Data

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Notice

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COMPARISON OF FDS MODEL PREDICTIONS WITH FM/SNL FIRE TEST DATA

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ABSTRACT

The Fire Dynamics Simulator (FDS), a recently developed field fire model based on large eddy simulation (LES), is used to simulate seven full-scale fire tests. The fire tests were conducted in a large mechanically ventilated enclosure with dimensions of 18.3 m x 12.2 m x 6.1 m high, with air injection rates ranging from 1 to 12 air changes per hour (ACH), and fire heat release rates ranging from 0 to 2 MW. Test measurements and simulation predictions are compared. Comparison methods are presented and discussed. Simulations are run with 6,000, 48,000, and 162,000 grid cells to evaluate the influence of grid resolution on prediction accuracy. One test series was run on six different personal computers to explore the effects of different hardware configurations on simulation times. A grid dependent plume study was performed to investigate the relationship of grid resolution and plume temperature predictions. Increasing the number of grid cells in the plume region does not improve temperature predictions significantly, but does result in more accurate simulation of plume turbulent structures.

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1 INTRODUCTION

A field fire model has been under development at the Building Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST) [1,2]. This model, currently known as the Fire Dynamics Simulator (FDS), is based on the concept of large eddy simulation (LES)[3]. It is a computational fluid dynamics (CFD) model that solves a modified version of the Navier-Stokes equations at each time step for each grid cell in a rectilinear domain. FDS simulations can take hours and even days to run on the latest personal computers (PC) due to the model's mathematical complexity. One of the most significant factors influencing this computation time is the size of the grid cells specified by the user. Because it is possible to over-resolve or under-resolve a space by specifying grid cells that are too small or too large, it is important to determine an appropriate size grid for a given scenario.

Until recently, the FDS model has only been available to its developers and a few fire researchers. The first public release of the FDS model occurred in February 2000, making the model available for fire protection engineers to use as part of their professional practice.

The purpose of this project has been two-fold:

- to provide feedback to the model developers regarding use of the FDS model

- to compare FDS model predictions with large-scale fire test data for a mechanically ventilated enclosure [4].

This report describes the results of the comparisons, the methodology by which they were performed, and lessons learned that may prove useful for users of the FDS code.

2 BACKGROUND

When this project was initiated, the FDS model (then known as LES3D) had not yet been implemented on a personal computer. The model developers at BFRL were working primarily on Silicon Graphics™ workstations using routines developed in AVS for data visualization. Similar resources were found at the University of Maryland, and preliminary work on this project was completed on this platform [5].

Over the course of this project, a number of significant changes have occurred in the implementation of the FDS model. These include:

- The FDS model has been ported to the PC platform, where it runs in a DOS window under Windows®. The model has been ported to other platforms as well.

- The **smokeview** data visualization program has been developed using the OpenGL environment for 3D graphics. This application permits the convenient visualization and animation of data, greatly enhancing the user interface of the model.

- The processing speed of the most powerful PCs continues to increase, which continually decreases the time it takes to perform a simulation. Some comparisons for different PC configurations are provided later in this report.

Together, these changes now make it practical for fire protection engineers to perform simulations using FDS on their desktop computers. What remains is to establish the accuracy of these simulations and to identify current limitations of the FDS model.

Over the course of this project, feedback has been provided to the model developers on an ongoing basis. This feedback has resulted in a number of changes to the model. Some of these have resulted in improved usability of the model, while others have resulted in improved accuracy. Since these changes have already been implemented in the FDS model before its public release, it is not important to chronicle them in detail. Some of the more significant changes resulting from this feedback include:

- Improvements in the specification of a fire source

- Improvements in the specification of mechanical ventilation rates

- Improvements to the usability of **smokeview**

- Improvements to make .csv output files more readable

- Improvements to make input files easier to build and understand

3 THE FIRE TESTS

Comparisons are made between the FDS model and 7 of 25 full-scale fire tests performed at Factory Mutual Research Corporation (FMRC) in the fall of 1985 [4]. These tests were directed by the Sandia National Laboratory (SNL) and sponsored by the U.S. Nuclear Regulatory Commission (USNRC). The test series is referred to as the FM/SNL tests. The test enclosure was an 18.3 m (60 ft) long by 12.2 m (40 ft) wide by 6.1 m (20 ft) high room with a concrete floor and 25.4 mm (1 in) thick Marinite™ wall and ceiling panels supported on an external wood frame. The enclosure was equipped with a forced ventilation system that was made up of six inlet ducts extending 1.2 m (4 ft) below the ceiling; the ducts were nominally 0.6 m (2 ft) square in cross section and were terminated with four-way air deflector caps. An exhaust vent measuring 0.6 m (2 ft) by 1.8 m (6 ft) was located in the ceiling on the west end of the enclosure. The room was designed and built to minimize leakage. However, the administrators noted leakage from the room during each test scenario. Details of the test enclosure and tests are provided in references [4,6,7].

The enclosure was extensively instrumented with more than 200 data channels that recorded data every five seconds during a 10 to 13-minute fire test. Figure 1 shows a plan view of the enclosure and the channels, fire source, and ventilation configuration of the test. Instrumentation included aspirated and non-aspirated thermocouples, large and small sphere calorimeters, vertical and horizontal flow probes, pressure differential analyzers, multiplexed gas analyzers (CO_2, CO, O_2, and total hydrocarbon), blue, red, and IR optical density meters, and heat flux meters for the walls, ceiling, and floor. For many years following these tests, only the data from Tests 4, 5, and 21 had been validated and released. In 1999 data for all 25 of the tests was released on CD-ROM [8].

In Figure 1, 'Sectors' and 'Expanded Stations' represent thermocouple trees arranged such that gas temperatures are measured at five elevations over the room height (H): 0.98H, 0.90H, 0.70H, 0.50H, and 0.30H. The difference between the two is that sectors are comprised of aspirated Type-K thermocouples, while expanded stations are comprised of bare bead Type-K thermocouples. This is significant because bare-bead thermocouples are not shielded from thermal radiation. 'Stations' consist of a single aspirated Type-K thermocouple located at 0.98H. There is only a single station located above the fire source. Sectors and stations are made up of five thermocouples at five different elevations. This arrangement creates five horizontal 'slice planes' over which temperatures may be averaged and compared or direct point-to-point comparisons may be performed.

Only temperature and ventilation rate measurements have been considered for the comparisons presented here. Other measured quantities, such as velocity and burner mass loss, were deamed unreliable due to excessive scatter. Chemical species were not tracked in the simulations due to the computational inefficiency associated with performing a direct numerical simulation (DNS) for such a large domain.

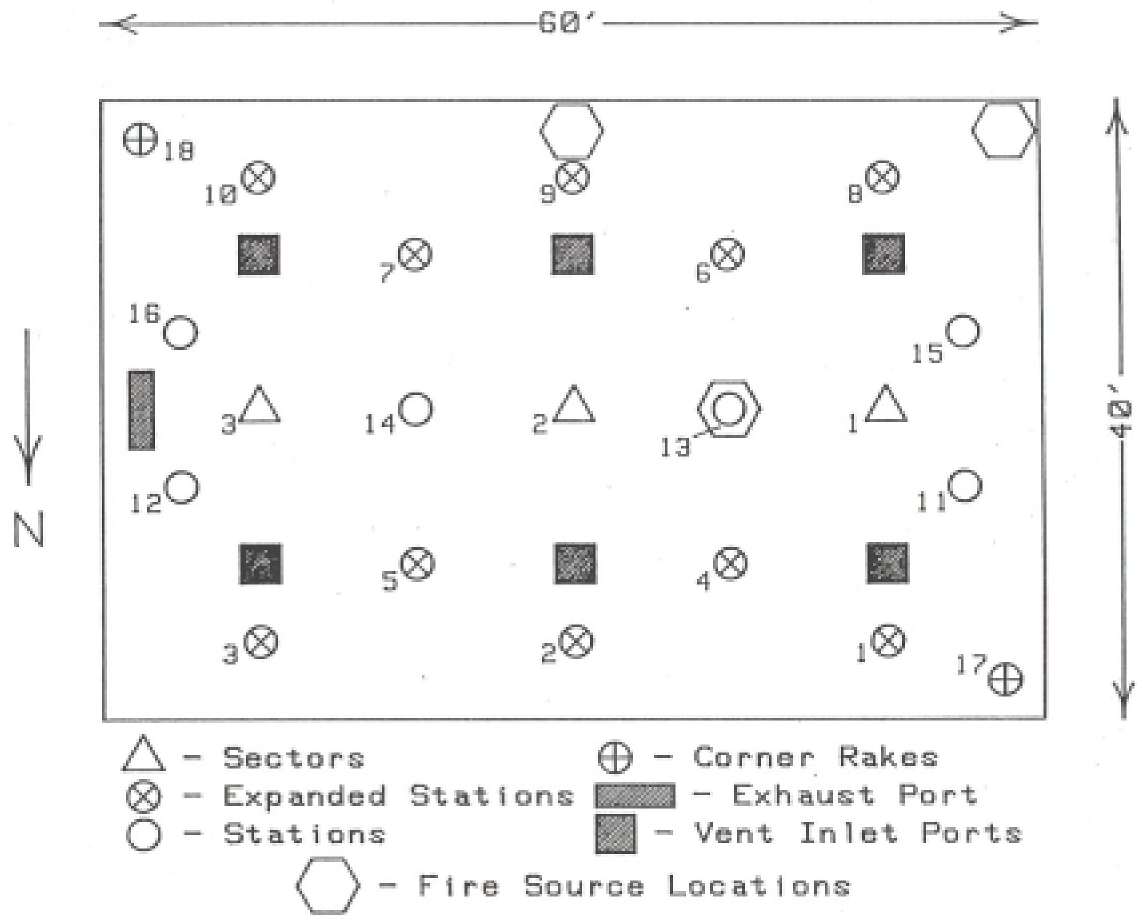

Figure 1. Plan View of the FM/SNL Enclosure with Instrumentation Details [4].

3.1 Material Properties

The temperature dependent thermophysical properties of Marinite™ were reported in the original "A Survivors Guide for Users of the Sandia Base Line Validation Enclosure Fire Test Data" [6]. Since FDS does not currently support temperature dependent thermal properties, it was left to the user to determine appropriate effective properties for input into FDS. More recently, the staff at SNL used a one-dimensional finite difference model and test data to determine an appropriate set of effective thermophysical properties to use as input for model comparisons [7]. At the time of the Test 5 comparisons the SNL recommended properties were not available, and nominal values were used. Another Test 5 case was run where the recommended properties were used, and the results did not vary significantly. All other tests were run using the SNL recommended thermal properties:

- Thermal Conductivity = 0.23 W/m-K
- Density = 1000 kg/m^3
- Specific Heat = 1.16 kJ/kg-K
- Thermal Diffusivity = 2.0x10^{-7} m^2/s

3.2 Test Details

The FM/SNL test cases compared here are referred to as tests 3, 4, 5, 8, 9, 12, and 13. In each test the administrators set out to collect data for a specific fire/ventilation scenario, but many of the tests did not proceed exactly as planned. For this reason, in some test cases both nominal and actual values are reported for fire heat release rates and mechanical ventilation rates. Actual air injection rates were measured and reported for each test. The two fire sources were a propylene gas burner and a heptane pool. The propylene burner was round and 0.9 m (3 ft) in diameter while the heptane pools were 0.9 m (3 ft) x 0.9 m (3 ft) square. Fires were either steady state or growing according to a 't^2' ramp, and peak fire intensities ranged from 500 kW to 2 MW. Nominal ventilation rates varied from 1 to 10 air changes per hour (ACH) with measured rates varying from 0.5 to 12 ACH. The propylene burner fires were located in the room 'center', while the heptane pool fires were located along the south wall. Figure 1 illustrates these locations and Table 1 summarizes the test variables for the tests compared here. It should be noted that the difference between nominal and measured parameters provides a potential source of error in the comparisons.

Table 1. Matrix of Test Variables

	Test 3	Test 4	Test 5	Test 8	Test 9	Test 12	Test 13
Fuel type	**Propylene**	**Propylene**	**Propylene**	**Propylene**	**Propylene**	**Heptane**	**Heptane**
Nominal Peak Fire Intensity (kW)	**2000**	**500**	**500**	**1000**	**1000**	**2000**	**2000**
Fire location	**Room 'Center'**	**Room 'Center'**	**Room 'Center'**	**Room 'Center'**	**Room 'Center'**	**South Wall**	**South Wall**
Growth Mode	**Steady**	t^2	t^2	t^2	t^2	**Steady**	**Steady**
Nominal Ventilation Rate (ACH)	**10**	**1**	**10**	**1**	**8**	**4.4**	**8**
Measured Ventilation Rate (ACH)	**10.9**	**1.7**	**12.0**	**1.4**	**10.8**	**8.0**	**11.1**
Maximum Measured Temperature (°C)	**369**	**133**	**115**	**290**	**229**	**222**	**208**

3.2.1 Test 3

Test 3 was characterized by a steady state 2 MW propylene burner fire with a measured ventilation rate of 10.9 ACH (nominally 10 ACH). About half way through the test a structural failure occurred that forced the administrators to terminate the test. For this reason Test 3 data comparisons were only attempted through the first 5 minutes of the test.

3.2.2 Test 4

Test 4 consisted of a growing propylene burner fire that reached a peak intensity of 516 kW in 4 minutes. The test duration was 10 minutes, and the measured ventilation rate was 1.7 ACH (nominally 1 ACH). No other test anomalies were noted.

3.2.3 Test 5

Test 5 consisted of a growing propylene burner fire that reached a peak intensity of 516 kW in 4 minutes. The test duration was 10 minutes, and the measured ventilation rate was 12 ACH (nominally 10 ACH). It was recently discovered that during this test there was an unscheduled shutdown of the air handling system at 9 minutes into the test that lasted throughout the remainder of the test. According to test administrators this impacted differential pressure data with “no other data anomalies encountered.”

3.2.4 Test 8

Test 8 consisted of a growing propylene burner fire that reached a peak intensity of 1000 kW in 8 minutes. The test duration was 13 minutes, and the measured ventilation rate was 1.4 ACH (nominally 1 ACH). No other test anomalies were noted.

3.2.5 Test 9

Test 9 consisted of a growing propylene burner fire that reached a peak intensity of 1000 kW in 8 minutes. The test duration was 13 minutes, and the measured ventilation rate was 10.8 ACH (nominally 8 ACH). No other test anomalies were noted.

3.2.6 Test 12

Test 12 consisted of a nominal 2 MW heptane pool fire. The test duration was 10 minutes, and the measured ventilation rate was 8 ACH (nominally 4.4 ACH). No other test anomalies were noted.

3.2.7 Test 13

Test 13 consisted of a nominal 2 MW heptane pool fire. The test duration was 10 minutes, and the measured ventilation rate was 11.1 ACH (nominally 8 ACH). No other test anomalies were noted.

3.3 Comments on Test Data Interpretation

Over the course of this project a number of issues have arisen concerning how to evaluate the FM/SNL test data and how much confidence to associate with it. Questions have arisen regarding the reported heat release rates, ignition times, ventilation rates, and what type of burning history to apply to the 'steady' burning pool fires. These issues have not been fully resolved. Consequently, some of the differences between measured and calculated values for different parameters are due to input uncertainties, not computational errors associated with FDS.

3.3.1 The Heptane Pool Fire Tests (Tests 12 and 13)

Heat release rates reported for the heptane pool fire tests are questionable. In the report provided with the test data [6] a heat release rate of 2 MW (nominal value) is given. With these tests, mass loss data was expected to provide confidence in the heat release information and possibly allow direct modeling of the actual fire growth ramp. Unfortunately, the fuel mass loss data had excessive scatter.

An approximate heat release rate was calculated from empirical data. Using data from the SFPE Handbook [9] the heat of combustion and unit mass loss rate for heptane are reported as 44.6 kJ/g and 101 g/m^2-s, respectively. Test administrators reported using 0.9 m (3ft) by 0.9 m (3 ft) square pans. A heat release rate for this configuration can be calculated using the following equation:

$$\dot{q} = \Delta h_c \dot{m}'' A \chi_{eff} \tag{1}$$

χ_{eff} is an efficiency factor for heptane fuel, taken as 0.92 [9]. Substituting these values into Equation (1) would result in a fire size of 3.7 MW. So, how big were the pool fires? Test administrators [10,11] suggest that the actual fire size for the pool fires was approximately 2.2 MW. Without belaboring the issue any further it was decided that 2.2 MW would serve as the value for model input, but it is emphasized that this value is uncertain, perhaps by as much as a factor of 1.7.

Another issue with the pool fires was how to ramp them up to the peak value. Heat release rates were not measured directly, and plume temperature data is the most convenient measure of the fire heat release rate. The plume temperature histories for the pool fires exhibited an asymptotic behavior, ruling out the suitability of a power law or exponential ramp. Figures 2 and 3 show the difference between the plume temperature data for a ‘steady’ burning pool fire and a propylene burner fire with a ‘t^2’ growth curve. Note the differences in the shapes of these.

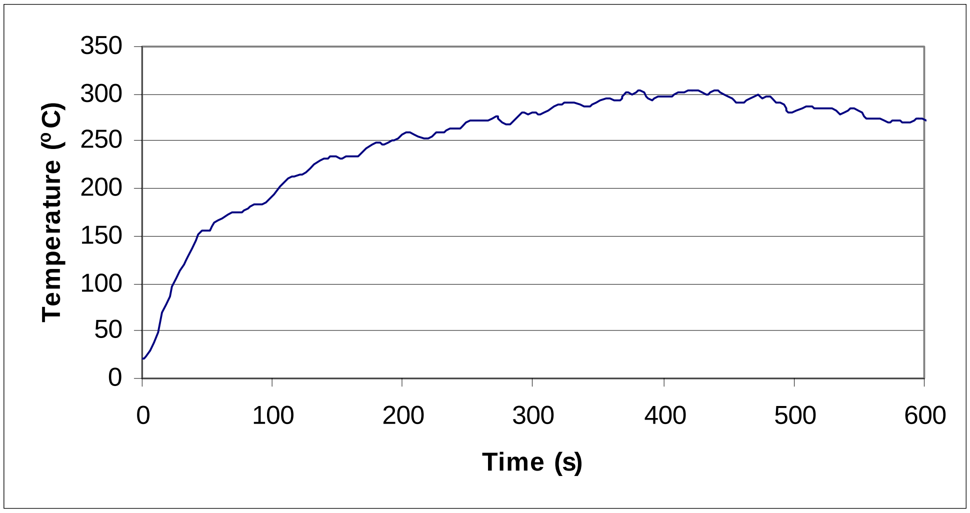

Figure 2. Test 13- Measured Near-Plume Thermocouple Temperature

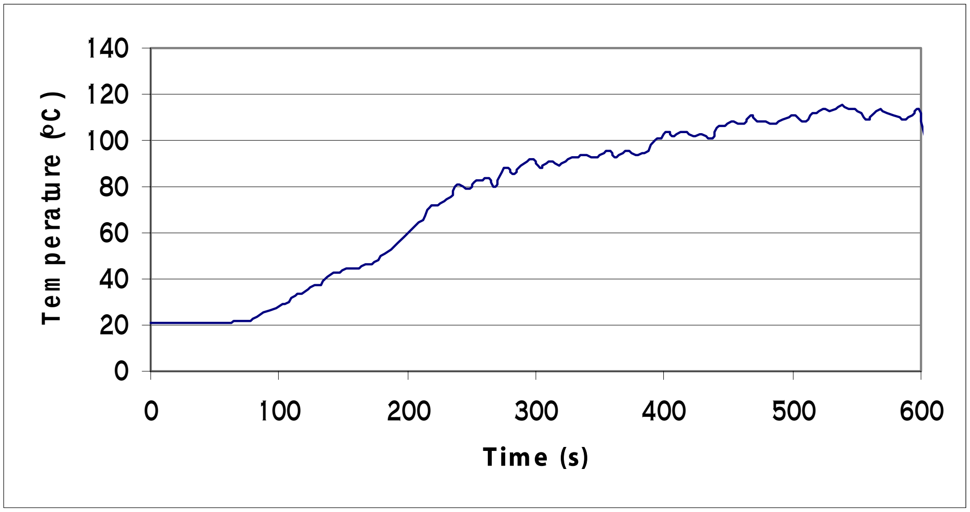

Figure 3. Test 5- Measured Centerline Plume Temperature

After reviewing the near-plume temperature data for Test 13, and observing an inflection at around 1 minute, it was determined that implementing a hyperbolic tangent ramp reaching a maximum heat release rate in 1 minute would be a representative way to characterize fire growth for Tests 12 and 13. The hyperbolic tangent ramp is conveniently built into the FDS code.

3.3.2 Ventilation Rates

Nominal ventilation rates were reported for each fire test. Actual air-mass flow rates were measured by means of an orifice plate just downstream of the blower. In many cases the nominal values vary significantly from the measured ventilation rate data. The measured data also varied over time. Figure 4 shows the variation over time of the measured ventilation rate for Test 8. For this analysis a single value, the measured ventilation rate reported in Table 1 and shown in Figure 4, was chosen for model input by time averaging the measured results.

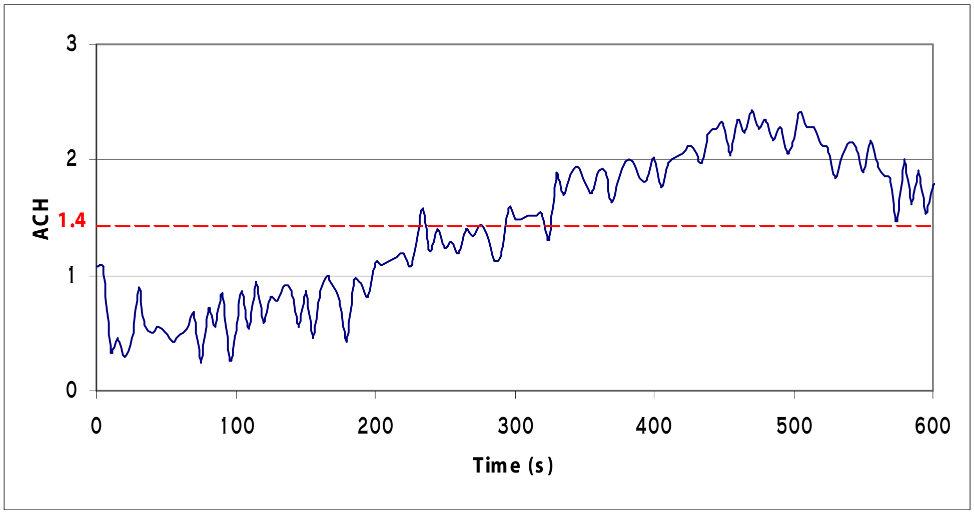

Figure 4. Test 8- Measured Ventilation Rate

3.3.3 Ignition Times

Initial comparisons of the model with test data showed lag times from 60 to 80 seconds between ignition and detection of a temperature rise by the centerline plume thermocouple. For example, in Test 5 the plume station did not detect a temperature rise until almost 80 seconds after ignition. Shifting the test data so that the ignition time was at 80 seconds did not improve agreement. It is not apparent what causes this delay in response; it might have been an actual ignition time different from the reported time.

4 THE FDS SIMULATIONS

The FDS model was run with varying grid sizes to determine the effect of this input parameter on the predictions. The selected grid sizes for the simulations were 0.6 m (2 ft), 0.3 m (1ft), 0.2 m (8 in), and 0.15 m (6 in), where the dimensions represent the length of a cubic cell. Several additional Test 5 cases were run to further explore grid resolution and heat transfer issues. These additional cases included three additional 0.3 m (1ft) grids where (1) the grid was transformed over a 9.3 m^2 (100 ft^2) area around the fire source (6 in. grid cells around the fire), (2) the radiation calculation was enabled, and (3) a combination of (1) and (2). Results of all the comparisons are provided in the next section.

4.1 Building the FDS Input File

The basic FDS input file used for these simulations follows. Input files for all the other cases are provided in Appendix B.

```
&HEAD CHID='test5(1ft)',TITLE='FMSNL Test #5- 1 ft. Grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21 /
&SURF ID='burner',HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',SURF_ID='wall' /east wall
&VENT CB='WEST',SURF_ID='wall' /west wall
&VENT CB='NORTH',SURF_ID='wall' /north wall
&VENT CB='SOUTH',SURF_ID='wall' /south wall
&VENT CB='TOP',SURF_ID='wall' /ceiling
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,SURF_ID='port' /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,SURF_ID='port' /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,SURF_ID='port' /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,SURF_ID='port' /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port' /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port' /
&VENT XB=11.79,12.60,5.69,6.50,0.30,0.30,SURF_ID='burner' / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5 /
```

This input file serves as a map for developing other FDS input files of interest. Much of the information presented below is also provided in the FDS User's Guide [2]. However, the descriptions of these simulations may be helpful for building other FDS input files. The `&HEAD` namelist group consists of two possible input parameters that contain general information about the simulation. `CHID` is the most important of these two parameters and is a character string of 30 characters or less used to name the output files generated by a simulation. For example, in the above data file the results will be output to files named 'test5(1ft).***', where *** represents various file name extensions. Using the same character string for the data file and CHID is recommended so that input and output files are easily associated after a simulation. A cautionary note: Remember to change CHID when a data file is modified and renamed so the old simulation results are not overwritten. The second parameter under the &HEAD namelist group is TITLE and serves as a placeholder where the user can describe the scenario being simulated. It has no effect on the simulation.

The &GRID namelist group contains three parameters, IBAR, JBAR, and KBAR, that allow the user to specify the number of grid cells in the x, y, and z-directions, respectively. For example, a 0.3 m (1 ft) grid cell is achieved by dividing the length of each domain dimension (&PDIM) by this desired cell size. Notice that grid specification is contingent upon the size of the physical domain even though it is discussed here and in the user's manual *before* the definition of the physical domain.

The physical domain is defined in the &PDIM namelist group with the three parameters, XBAR, YBAR, and ZBAR. The physical domain in the FDS virtual world is always rectilinear with a coordinate system that follows the 'right hand rule'. Notice in the 'test5(1ft).data' file that the input parameters are merely the dimensions of the FMSNL test room in meters.

By default the grid cells in the computational domain are uniform in size. Sometimes a user may wish to increase grid resolution over a particular area of the domain (i.e. near the fire source). This can be accomplished with a grid transformation using the optional namelist groups &TRNX, &TRNY, and &TRNZ. Two methods of transformation are possible: piece-wise linear and polynomial. The piecewise linear method is discussed here as it is the easiest and has the most practical application. With the piece-wise linear method the size of each grid cell is known exactly, and resolving a region for the sake of correctly placing obstructions is straightforward. It should be recognized that the grid may only be transformed in two of the three coordinate directions due to constraints associated with the numerical solver employed by the model. It is also important to note that the total number of grid cells is conserved after a transformation is performed. Thus, higher resolution in one area is offset by lower resolution in other areas.

Starting with the Test 5 case presented above, a grid transformation over the fire source was desired such that the 3.05 m by 3.05 m (10 ft by 10 ft) area around the fire source has grid cells that are 0.15 m (6 in) on a side as opposed to 0.3 m (1 ft). First, the center of the fire source must be located and in this case it is at x=12.19 m and y=6.10 m. Next, the physical coordinates (PC) need to be determined so that they can be 'mapped' back to an appropriate set of computational coordinates (CC) that will give the desired cell size. A 3.05 m (10 ft) region in each direction needs to be transformed such that the grid cells are half their original one-dimensional size. For the x-direction, 1.53 m (or 3.05/2) is added to and subtracted from each center dimension to give physical coordinates from 10.67 to 13.72. In the y direction the physical coordinates are 4.57 to 7.62. To obtain grid cells that are *half* their original size, the CC region should be *twice* that of the PC region. Adding and subtracting 3.05 to each center dimension gives CC's in the x-direction from 9.14 to 15.24 and 3.05 to 9.15 in the y-direction. The following lines represent the coding for the described transformation; the lines were added to the data file just after the &PDIM line for the transformed grid simulation.

```
&TRNX CC=9.14,PC=10.67 /
&TRNX CC=15.24,PC=13.72 /
&TRNY CC=3.05,PC=4.57 /
&TRNY CC=9.15,PC=7.62 /
```

The transformation yields the grid mesh shown in Figure 5 below.

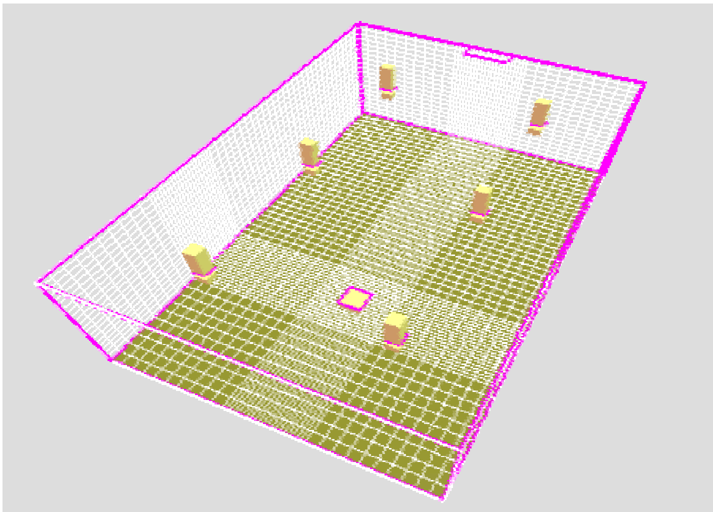

Figure 5. smokeview Graphic of the Grid Mesh Resulting from a 0.15 m (6 in) Plume Transformation for 3 m (10 ft) Around the Burner.

There may be instances when it is desirable to transform the grid next to one of the external boundaries of the domain. This is perfectly acceptable but requires that the mandatory constraints (i.e. &TRNX CC=0, PC=0) not be stated. Stating this implicit constraint causes the code to fail.

The &TIME namelist group contains two parameters DT, and TWFIN. DT is used to specify the beginning time step of the simulation; subsequent time steps are determined by the model. TWFIN is used to state the duration of the simulation in seconds. Test 5 lasted for 10 minutes and so 600 seconds is the desired input for the simulations.

The &MISC namelist group is reserved for numerous miscellaneous inputs. In this case the ambient temperature is stated as 21 °C with the parameter TMPA.

The &SURF namelist group contains a number of parameters to define thermophysical, velocity, and species boundary conditions, including the prescription of a fire. In this example the fire is specified on the SURF line with ID='burner'. Fire must originate from a VENT and is defined by its heat release rate per unit area (HRRPUA) in kilowatts and the burnout time of each thermal element (TBO) in seconds. TAU_Q states a characteristic ramp-up time for the heat release rate and the negative value indicates a 't^2' curve for the ramp-up. The properties of the enclosure walls are stated on the `SURF` line with `ID='wall'`. Here surface heat transfer is calculated according to the thermally-thick model for heat transfer; this requires the three parameters thermal diffusivity (`ALPHA`), thermal conductivity (`KS`) , and thickness of the wall (`DELTA`), respectively, to be specified in appropriate units. The values provided here are those for a 2.5 cm (1 in) thick Marinite™ wall covering. The parameter `RADIATION` tells the code whether or not to calculate radiation heat transfer. As noted in Figure 14, calculations with radiation take longer to complete than those without radiation. The flow rate and temperature of injected air are stated on the `SURF` line with `ID='port'` with the parameters `VOLUME_FLUX` (m^3/s) and `TMPWAL` (°C), respectively.

The `&OBST` namelist group is used to build solid objects or obstructions within the domain. The input parameter, `XB`, states the coordinates of a rectangular solid and requires the input of six numbers: (x_0, x, y_0, y, z_0, z). Complex geometries in FDS are built by arranging individual rectilinear boxes of varying size to obtain the desired shape. In the code, specified obstructions are implemented by filling in individual grid cells. A grid cell is either full or empty; meaning that an obstruction's accurate size and placement depend on grid resolution. In the Test 5 example, the grid is 1 ft on a side. This means that all specified obstructions will be built with one cubic foot blocks, regardless of the exact size and shape of the actual obstruction. For example, in this study the deflector plates for all six air injection ports were removed in the 2 ft. grid case because the larger grid size placed the deflector plates and vents in the same cell, causing the vents to be 'plugged' by the obstructions. If exact sizes are desired then the grid size should be at least as small as the smallest dimension that needs to be resolved within the enclosure.

The `&VENT` namelist group is used to create a two-dimensional surface or plane that is adjacent to an obstruction or external wall. In the example presented here the first application of a `VENT` line is used to prescribe universal wall properties for all exterior walls of the enclosure. The parameter `CB` allows the user to describe a whole domain boundary without having to enter the six coordinates of the wall. This is done by setting `CB` equal to one of the spatial directions: `EAST, WEST, NORTH, SOUTH, TOP,` or `BOTTOM`. The origin always lies in the southwest corner of the domain. The `SURF_ID` parameter refers back to the surface conditions with the same name stated earlier in the input file. The exterior walls are assigned the thermophysical properties associated with the `SURF` line labeled `'wall'`.

The ventilation inlet ports are defined with the second set of `VENT` lines. Statement of the six coordinates of the vent is necessary. Boundary conditions are assigned that correspond to the `SURF` line labeled 'port'. The burner is set up in the same manner. To actually create a vent that serves as an opening between adjacent spaces one only need state the six coordinates and then set `SURF_ID='OPEN'`. Notice when stating the six coordinates on a `VENT` line there will always be a pair of coordinates that are redundant. This redundancy indicates the plane in which the vent is located.

The two-dimensional planes defined on `VENT` lines are restricted to the boundaries of obstructions. If they are placed in the middle of an obstruction it will be moved to the closest boundary on the outside of the obstruction. For this reason special care is needed as vents are easily ‘plugged’ when they end up on the wrong side of an obstruction. For example, the propylene burner in the tests was 0.15 m (6 in) off the floor. If the burner vent is input this way into the case with 0.3 m (1 ft) grid cells, the code rounds down and the vent ends up on the bottom of the burner obstruction. No particles are released.

The last namelist group specified in the Test 5 data file is the `&THCP` (thermocouple) and allows the user to request specific kinds of relevant data at any specified point in the domain. The input parameters are `XYZ` which is the coordinate location from which data is sampled, `QUANTITY` which tells the code what kind of data to report, `LABEL` which allows the user to more easily identify data in the output format, and `DTSAM` which tells the code how often to report data. `THCP` data will be written to a .csv file that is easily converted to a Microsoft Excel file. In all data files for the simulations run here, an array of more that 70 thermocouples are output; they are not shown above but can be seen in the ‘Test 3- 2 ft. Grid’ data file in Appendix B.

4.2 Methods of Data Comparison

In past comparisons between fire model predictions and laboratory experiments, the level of agreement has been expressed mostly in qualitative terms (i.e. ‘good’, ‘bad’, ‘satisfactory’, etc.) [12]. This is due in part to real scale fire tests not being performed in replicate such that statistical treatments are inappropriate [13]. None of the FM/SNL tests were performed in replicate, limiting the available means of performing these comparisons. The methods eventually employed are those set out in the American Society of Testing and Materials (ASTM) guide for evaluating fire models [14] and a mathematical technique known as functional analysis. The details of these methods are presented below.

4.2.1 Comparison Methods According to ASTM E 1355 Recommendations

According to the ASTM guide, there are several techniques suggested for quantifying model evaluations [14].

> “For single point comparisons, these may be expressed as an absolute difference (*model value-reference value*), relative difference (*model value-reference value*)/ *reference value* or other comparison as appropriate. For steady-state or nearly steady-state comparisons, the comparison may be expressed as an average absolute difference or average relative difference.”

These guidelines were followed and led to the comparison methods described below.

After each FDS simulation the thermocouple data were transferred into a Microsoft Excel template containing the corresponding test data. The data were then formatted in the spreadsheet to allow for point-to-point temperature comparisons over time. One of the methods used to make comparisons involves averaging the temperature difference, predicted minus measured, across each slice at each time increment and then graphing these differences over time. This method shows in an absolute sense how much difference there is between the test temperature and that predicted by FDS. However, it ignores the issue of relative difference. For this reason, another method of comparison was needed.

Several different methods of calculating a relative error were attempted without success. The first attempts involved using either the measured temperature rise or an adiabatic temperature rise to normalize the error. The problem with these methods was that early measurements or calculations, especially in the lower layer or at very low heat release rates, resulted in a very small normalizing factor, which in turn created unreasonably large calculated errors. Another attempt was to calculate a percent error based on the formula:

$$|\text{predicted-measured}|/\text{measured} \times 100$$

To be meaningful the input values need to be in absolute terms. This resulted in errors that were deceivingly low. A method based on normalizing errors by a constant parameter was finally chosen as a means to represent the relative errors for these comparisons.

A *normalized error fraction* (NEF) is calculated for each horizontal slice according to equation 2.

$$\mathrm{NEF} = \frac{\Delta T_p - \Delta T_m}{\Delta T_{max}} = \frac{(T_p - T_a) - (T_m - T_a)}{(T_{max} - T_a)} = \frac{T_p - T_m}{\Delta T_{max}} \qquad (2)$$

T_p is the average predicted temperature of the slice, T_m is the average measured temperature of the slice, T_a is the average measured ambient temperature for each test case, and T_{max} is the maximum measured temperature for each test case. The maximum measured temperature, T_{max}, for each test case was invariably taken from the plume or near plume measurement. The values for T_{max} used in this analysis are presented in Table 2. The NEF is determined at each time increment and then plotted over the test duration. This method shows a relative error as a function of time. Its advantage is that the averaging effectively deals with the large amounts of data available for analysis.

The other method used was simple point-to-point temperature comparisons of a representative group of thermocouples. While certainly the least sophisticated method, it provides a physical sense of the accuracy of the predictions, both temporally and in terms of magnitude. For example, the room centerline sectors (1, 2, and 3) and station 13 (centerline plume) were chosen for the test cases where the fire source was at the room ‘center’. These measurement locations make up the centerline room length at ceiling height. For the two test cases with the fire source on the south wall, the ceiling height south wall thermocouples (stations 8, 9, and 10) make up one group of data points, and the ceiling height centerline room-width thermocouples (station 9, 2, and sector 2) make up another group. These comparisons focus on the ceiling jet region and investigate the model's prediction of enclosure flow dynamics.

Model output was visualized using **smokeview** to observe predicted fire behavior, temperature trends, and other gas quantities of interest (see Figure 6). In addition, some 3-dimensional plots of predicted vs. measured temperatures were generated at different snapshots in time to provide another means for comparing data.

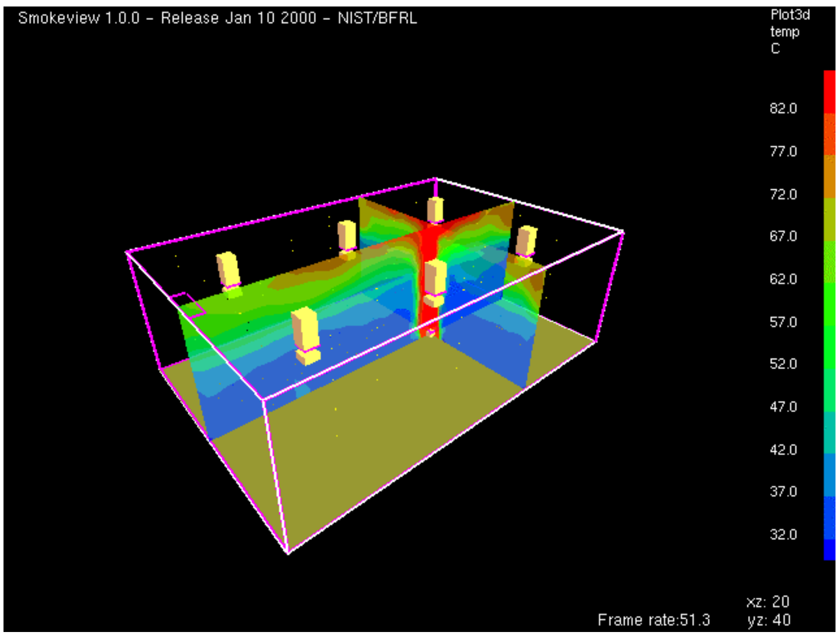

Figure 6. smokeview Graphic of the FM/SNL Enclosure with PLOT3D- 2D Temperature Contours

4.2.2   Comparisons Using Functional Analysis

Recent work by Peacock et. al. [15] has used functional analysis as a tool for quantifying fire model evaluation. The technique provides a way to quantify the difference between two curves in terms of magnitude and shape. Functional analysis is applied by describing a physical problem in terms of vectors, and then operating on the vectors to provide a quantitative measure related to the physical system. It is an attractive method for comparing data because the calculated parameters result in a single value that indicates the level of similarity between two curves.

The parameters considered here are the *norm* and the *inner product* or *cosine*.   The norm is a measure of the relative difference in magnitude of the two curves. It is based on describing the data points within each curve as a vector and then summing the vectors to give a single vector for each curve. The distance between the resulting vectors is an error that is normalized to provide a relative difference, or norm, between the curves. The inner product or cosine describes the angular difference between the resulting vectors and provides a quantitative measure of curve shape similarity. The norm approaches zero when two curves are identical in magnitude, and the inner product approaches unity when the curve shapes are identical.

Several geometries exist in which norms and inner products can be determined. Peacock et. al. [15] select the Euclidean and cosine geometries to calculate the norm and cosine for the following reasons:

> "The Euclidean norm provides both a straightforward interpretation and a measure of average curve separation that could be related to data uncertainties. The secant inner product cosine was chosen based on its noise handling ability and because it provides a measure of curve shape which was based only on the first derivatives of the two curves. The resulting cosine would be relatively easy to interpret compared with the other methods [15]."

Following these recommendations a Euclidean norm and a secant inner product are calculated for each of the point-to-point comparison charts according to equations 3 and 4, respectively.

$$\frac{\|E-m\|}{\|E\|}=\frac{\sqrt{\sum_{i=1}^{n}(E_i-m_i)^2}}{\sum_{i=1}^{n}(E_i)^2} \tag{3}$$

and

$$\frac{\langle E,m\rangle}{\|E\|\|m\|}=\frac{\sum_{i=2}^{n}(E_i-E_{i-s})(m_i-m_{i-s})/s^2(t_i-t_{i-1})}{\sqrt{\sum_{i=2}^{n}(E_i-E_{i-s})^2/\left(s^2(t_i-t_{i-1})\right)\sum_{i=2}^{n}(m_i-m_{i-s})^2/\left(s^2(t_i-t_{i-1})\right)}} \tag{4}$$

where E_i and m_i are the ith experimental and model values, t_i is the ith time increment, and s represents the number of data points to be considered in the time interval and serves to smooth results and provide better estimates of large scale differences. Here, s is taken as 2, or just less than half of the sampling interval of the FM/SNL tests. This comparison technique helps validate and quantify observations and conclusions that would otherwise rely on visual observation alone.

4.3 The Computer Dependent Study

The input files for the Test 5 cases were run on six computers, each having different hardware specifications. This study was performed to determine approximate calculation times based on differing grid sizes and machine configurations. The 0.15 m (6 in) case was not included in this study due to its excessive run time (211 hours) on the fastest available computer. All computers had Pentium® II/III processors running Microsoft Windows® 98 except as noted. The six machine configurations were as follows:

- 333 MHz with 64 MB SDRAM
- 400 MHz with 128 MB SDRAM (running Windows® 95)
- 450 MHz with 384 MB SDRAM
- 600 MHz with 256 MB SDRAM
- 700 MHz with 384 MB SDRAM
- dual 500 MHz processors with 256 MB SDRAM (running Windows® NT 4.0)

5 RESULTS

5.1 Results from Graph Comparisons

The complete set of data comparisons is provided in Appendix A. In general, predicted temperatures were higher than measured temperatures. Average temperature difference comparisons (Figures A60 to A84) show that FDS predictions are within 75 °C of the measured data for all horizontal slices at any given time, but this can be misleading as discussed below. Many cases showed agreement within 10 to 20 °C. Plume temperature agreement was slightly worse than other data point comparisons, with differences as large as 100 °C.

The Test 3 series provided some interesting results and an opportunity to determine the influence of implementing a heat release ramp to a steady fire. Initially, the 2 MW fire was modeled with no ramp up to the maximum heat release rate. The result was an early temperature spike in the predictions that becomes larger with increased resolution. Figure 7 shows the point-to-point comparisons from the 1ft grid simulation where no heat release ramp was implemented. This is similar to what might result from a very rapid increase in heat release rate. The measured data indicates no such event. For this reason it was decided that the Test 3 simulations should be run again with a ramped heat release rate. A 't^2' ramp reaching a maximum heat release rate in one minute was chosen. The results from this modified case are presented in Figure 8 and show significant improvement in agreement between the simulated and measured temperature histories. However, some differences remained, especially with respect to the fire growth period. An additional calculation was performed where the maximum heat release rate was reached in 50 seconds (see Figure 9). Again the improvements are apparent. These systematic improvements are verified quantitatively by the results of functional analysis and are also presented on the graphs. The norms all move closer to zero, and the cosines all move closer to unity as the predicted and measured temperature curves move closer together.

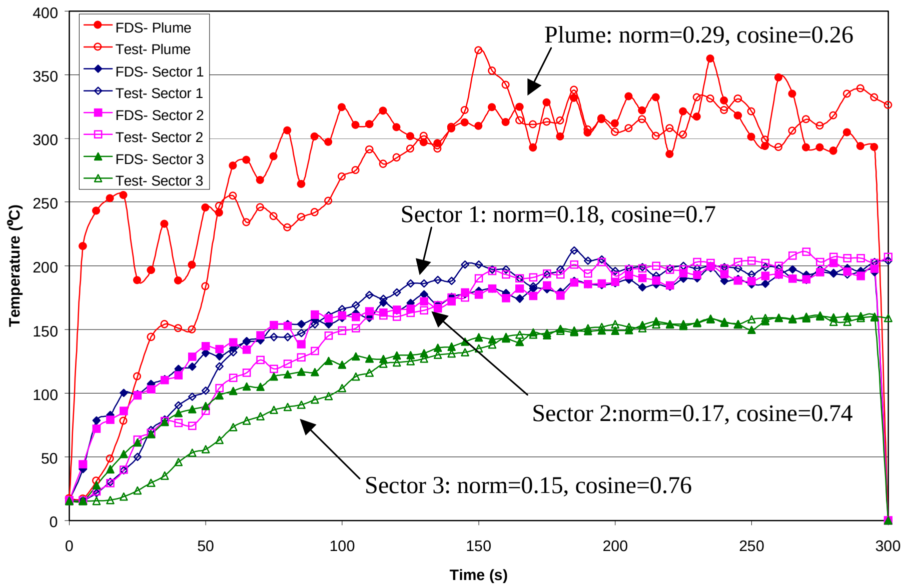

Figure 7. Test 3- 1 ft. Grid Cells:
Temperature Comparisons at 0.98H (Vertical Center Slice)

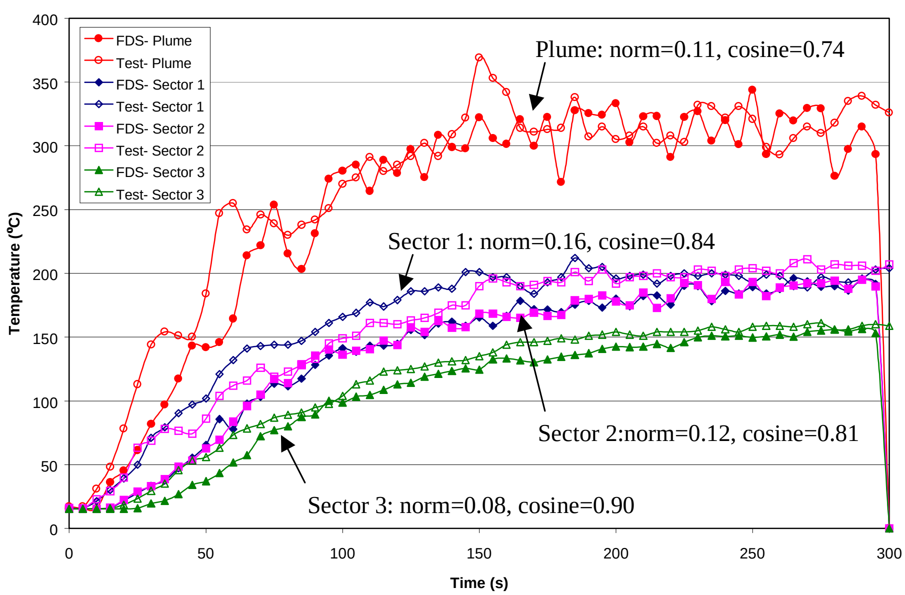

Figure 8. Test 3- 1 ft. Grid Cells (t^2 Ramp in 1 minute):
Temperature Comparisons at 0.98H (Vertical Center Slice)

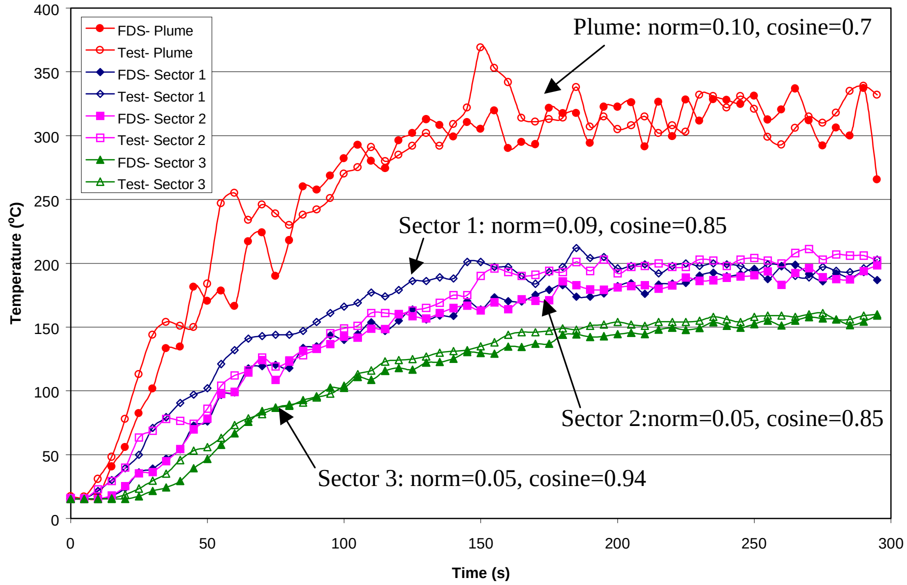

Figure 9. Test 3- 1 ft. Grid Cells (t^2 Ramp in 50 seconds): Temperature Comparisons at 0.98H (Vertical Center Slice)

Data comparisons using the normalized error fraction (NEF) method show fractional errors from –0.20 to 0.20 (i.e. less than 20%) for all horizontal slices. The exceptions are the Test 3 cases where the temperature spike results in a 0.60 error early in the simulation. Again, plume predictions are worse with errors remaining within –0.50 to 0.50. Figure 9 illustrates the general trend observed in most cases where all layer slices fall in the –0.20 to 0.20 NEF range while plume agreement is slightly worse.

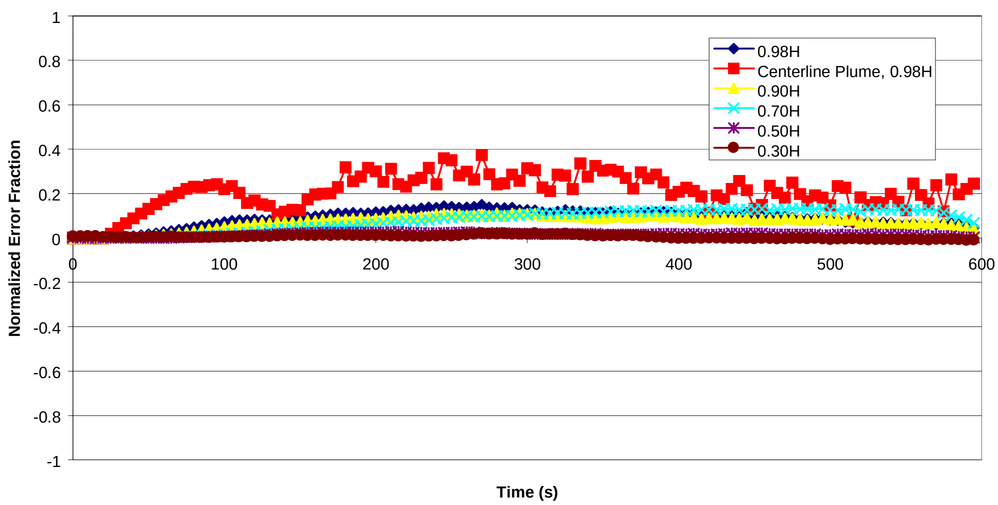

Figure 10. Normalized Error Fractions Between FM/SNL Test 5 and FDS w/ 1 ft. Grid

The point-to-point charts provided in Appendix A, Figures A29 to A59, verify earlier observations and ensure that important details regarding agreement are not covered up by the averaging techniques. Combining all three comparison methods and observing changes in agreement between cases with different grid specifications allows the following comments to be made regarding the effects of this parameter:

- in general, improvement is observed from the 2 ft to 1ft cases, but not from the 1ft to the 8 in. cases

- increasing grid resolution around the fire plume seems to cause more scatter in predicted plume temperatures

- transforming the area around the plume to 6 in. or 4 in. (for a 1 ft case) did not improve plume temperature predictions

Other general observations are:

- enabling the radiation calculation, which triples the run time, slightly improves plume predictions, but does not improve overall agreement

- the combination transformation/radiation case did not result in notable improvements and was computationally much more expensive

- FDS correctly predicts temperature trends within the FM/SNL enclosure. The 3D surface plot presented in Figure 11 illustrates this point.

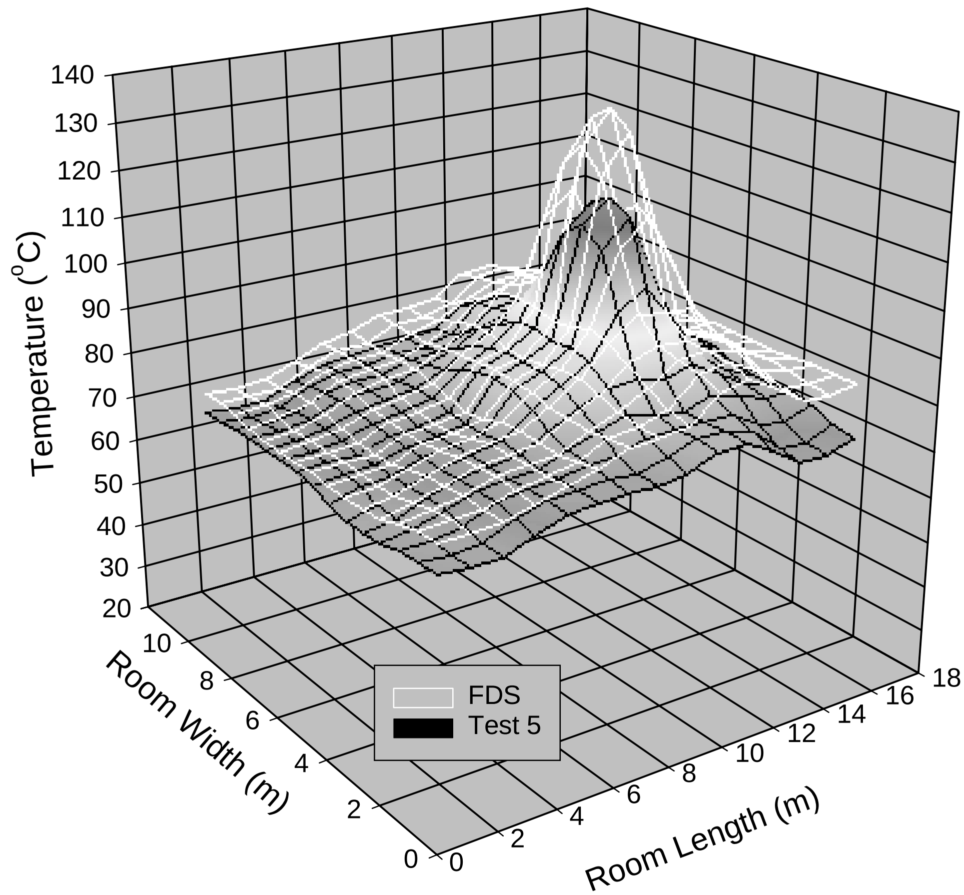

Figure 11. 3D Surface Plot of FDS Predictions vs. Test 5 Measurements (0.98H, t=540s, grid=1 ft.)

5.2 Functional Analysis Results

Functional analysis results of the point-to-point comparison graphs are presented in Figures 12, 13, 14, and 15. The charts show the calculated norms and inner product cosines for each test case. These parameters have expected magnitudes in that norms, a measure of the difference in curve magnitude, are closer to zero and the cosines, a measure of curve shape similarity, are closer to unity. Some Test 3 functional analysis results have been presented in Figures 7, 8, and 9. These results, coupled with the graphs from which they were derived, will add some meaning to the numerical results presented below. For the comparisons that follow, subjective statements (e.g. ‘best’, ‘worsened’, ‘improved’) are used to describe quantitative differences that result from the analytical method and should not be interpreted as independent judgments of model performance.

5.2.1 Test 3 Functional Analysis Comparisons

For the Test 3 cases (see Figure 12), the 1 ft grid case gives the best agreement. From the 2 ft case to the 1 ft case there is significant improvement in plume temperature magnitude and slight improvement in curve shape. For the 8 in. case the plume curve shape is poor; its magnitude is worse than the 1 ft case but better than the 2 ft case. These results are consistent with qualitative observations from comparing the graphs.

5.2.2 Test 4 Functional Analysis Comparisons

For the Test 4 cases (see Figure 12), the 2 ft grid provides the best agreement. The plume norm for the 2 ft case is around 0.11 while the 1 ft and 8 in grid norms are 0.3 and 0.4, respectively. Plume agreement is also better for the 2 ft case. Cosines for the plume range from 0.6 to 0.75 while sector cosines are better, ranging from 0.8 to 0.96.

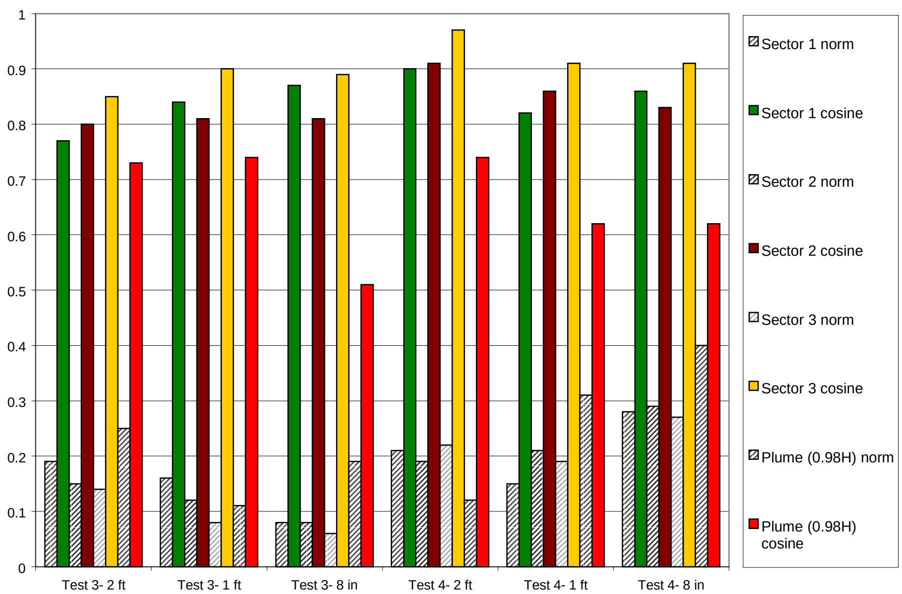

Figure 12. Comparison of Euclidean norms and Secant Inner Product Cosines for Tests 3 and 4

5.2.3 Test 5 Functional Analysis Comparisons

The Test 5 case norms (see Figure 13) show that 1 ft grid cells provided the best agreement between temperature magnitudes while the cosines indicate that 2 ft grid case has the greatest degree of curve shape similarity. Upon visual inspection the 1 ft plume temperature prediction curve appears just as similar to measurements as the 2 ft case. This is due to more scatter in the 1 ft plume predictions than in the 2 ft case and points to a weakness in the analytical method. The increase in grid resolution to 8 in. or 6 in. cells did not improve agreement of shape or magnitude. The similarity between the results of the 8 in. and 6 in. comparisons indicates that grid independence may have been achieved. Enabling the radiation calculation had little effect in the FM/SNL enclosure and transforming the grid to 6 in. cells around the burner worsens the plume norm while slightly improving the cosine.

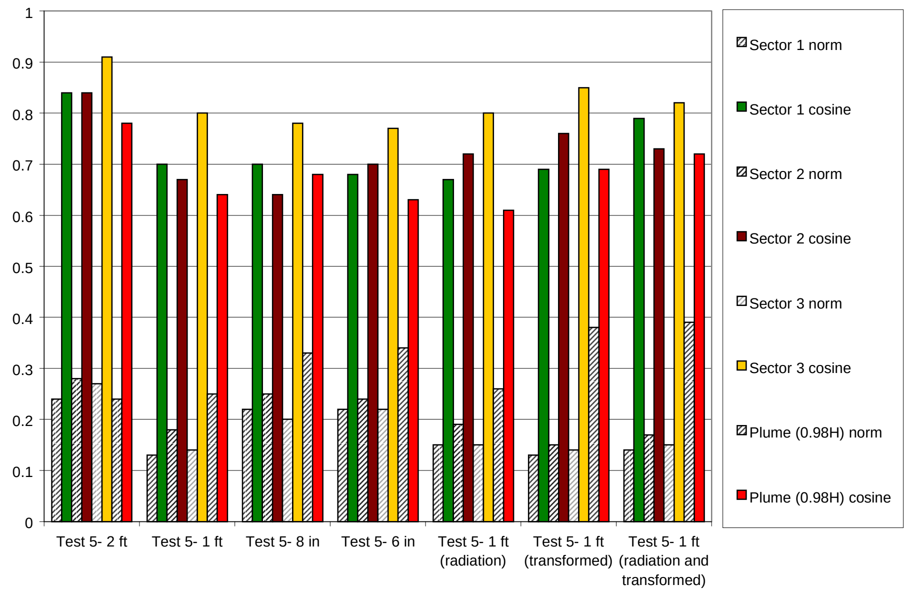

Figure 13. Comparison of Euclidean norms and Secant Inner Product Cosines of Test 5

5.2.4 Test 8 Functional Analysis Comparisons

With the exception of plume norm, functional analysis results from Test 8 (see Figure 14) indicate better overall agreement for the 2 ft grid case than 1 ft or 8 in grid cases. The best plume norm agreement is predicted for the 1 ft case. Again, increased scatter in plume predictions result in the analytical method determining 'worse' curve shape similarity. Curve similarity is demonstrated for all sectors with cosines ranging from 0.82 to 0.95. Plume cosines are worse, ranging from 0.64 to 0.74.

5.2.5 Test 9 Functional Analysis Comparisons

The Test 9 simulations (see Figure 14) result in plume temperature magnitudes that agree best for the 1 ft grid case. Plume cosines indicate that the greatest curve similarity is for the 2 ft grid case. Plume norms and cosines range from 0.1 to 0.2 and 0.5 to 0.8, respectively. Sector norms and cosines range from 0.08 to 0.19 and 0.64 to 0.94, respectively.

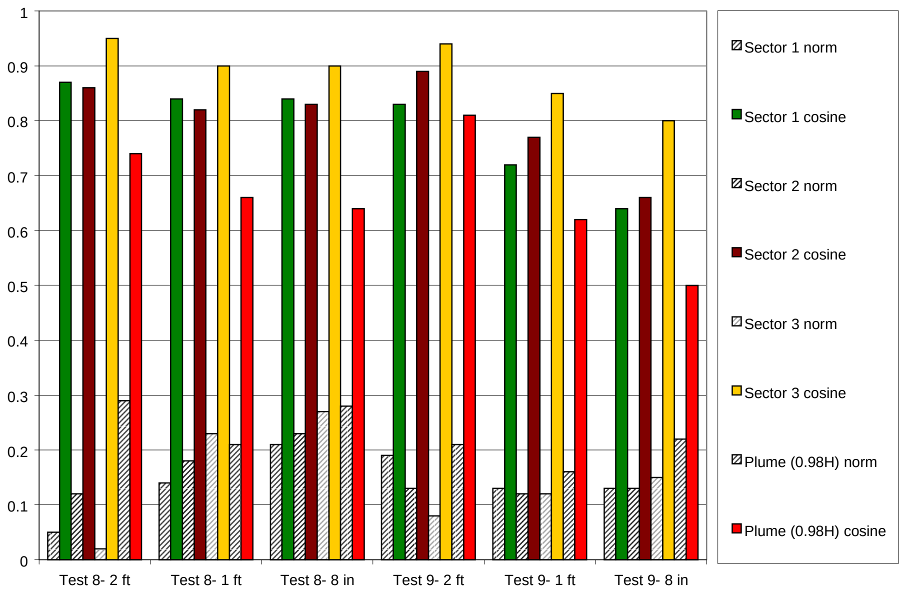

Figure 14. Comparison of Euclidean norms and Secant Inner Product Cosines of Tests 8 and 9

5.2.6 Test 12 and 13 Functional Analysis Comparisons

Test 12 and 13 heptane pool fire simulation results (see Figure 15) have the best agreement of all tests simulated. All norms range from 0.04 to 0.20 and cosines range from 0.71 to 0.94. Overall the 1 ft grid cases performed the best.

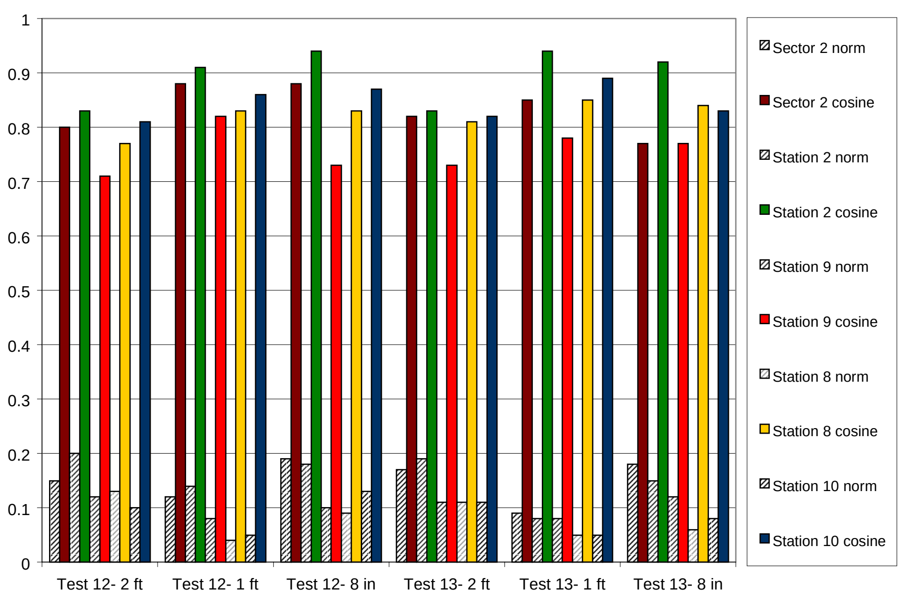

Figure 15. Comparison of Euclidean norms and Secant Inner Product Cosines of Test 12 and 13

5.3 Grid Dependent Plume Study

Attention was turned to plume predictions to investigate the role of the fire source and plume in overall model predictions. In this brief study the Test 5 fire was modeled in a 3 m (10 ft) by 3 m (10 ft) by 6.1 m (20 ft) tall open domain with no mechanical ventilation and a uniform grid. The ceiling was the only obstruction to the plume. Temperatures were sampled 12 cm below the ceiling as in the actual FM/SNL tests. Four grid sizes were implemented and simulated: 30 cm (1 ft), 15 cm (6 in), 10 cm (4 in), and 7.5 cm (3 in).

The results from these simulations are presented in Figure 16 where the predicted temperatures are contrasted with test measurements. Temperature predictions did not change drastically as grid resolution increased. However, **smokeview** animations from the four cases do show improvement in the prediction of plume turbulent structures. These structures are predicted more accurately given a finer grid because their formation is dependent on fluid motion that is occurring at smaller length scales than a larger grid is able to capture. Figure 17 illustrates that when smaller length scales are resolved in FDS, the plume begins to behave more naturally in terms of the formation of turbulent eddies. As shown in Figure 16, however, this does not seem to have a significant impact on the bulk temperature along the plume centerline.

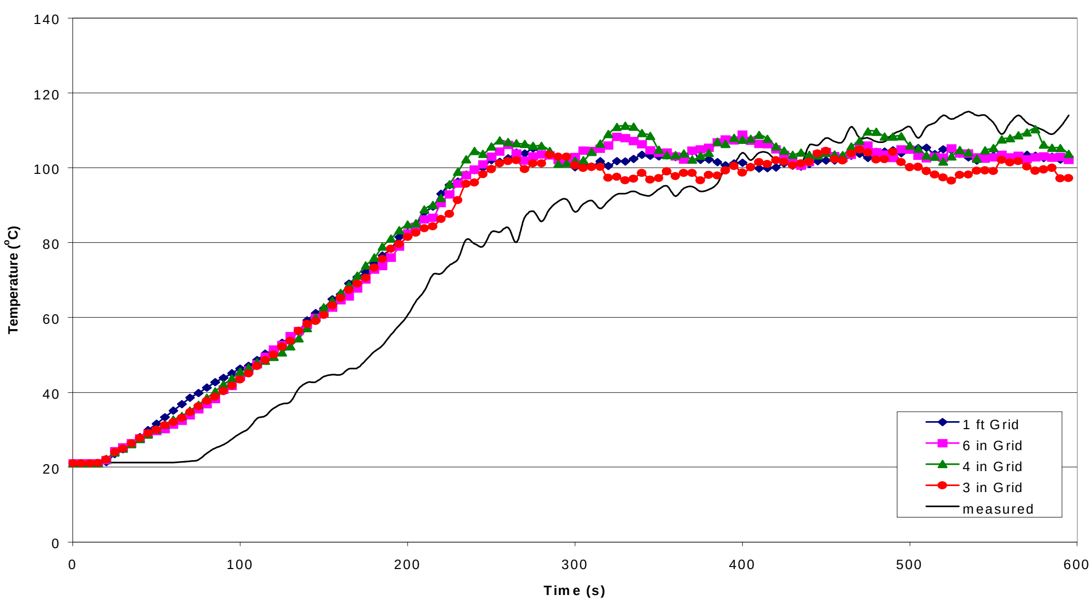

Figure 16. Grid Dependent Plume Temperature Comparisons (Smoothed Predictions)

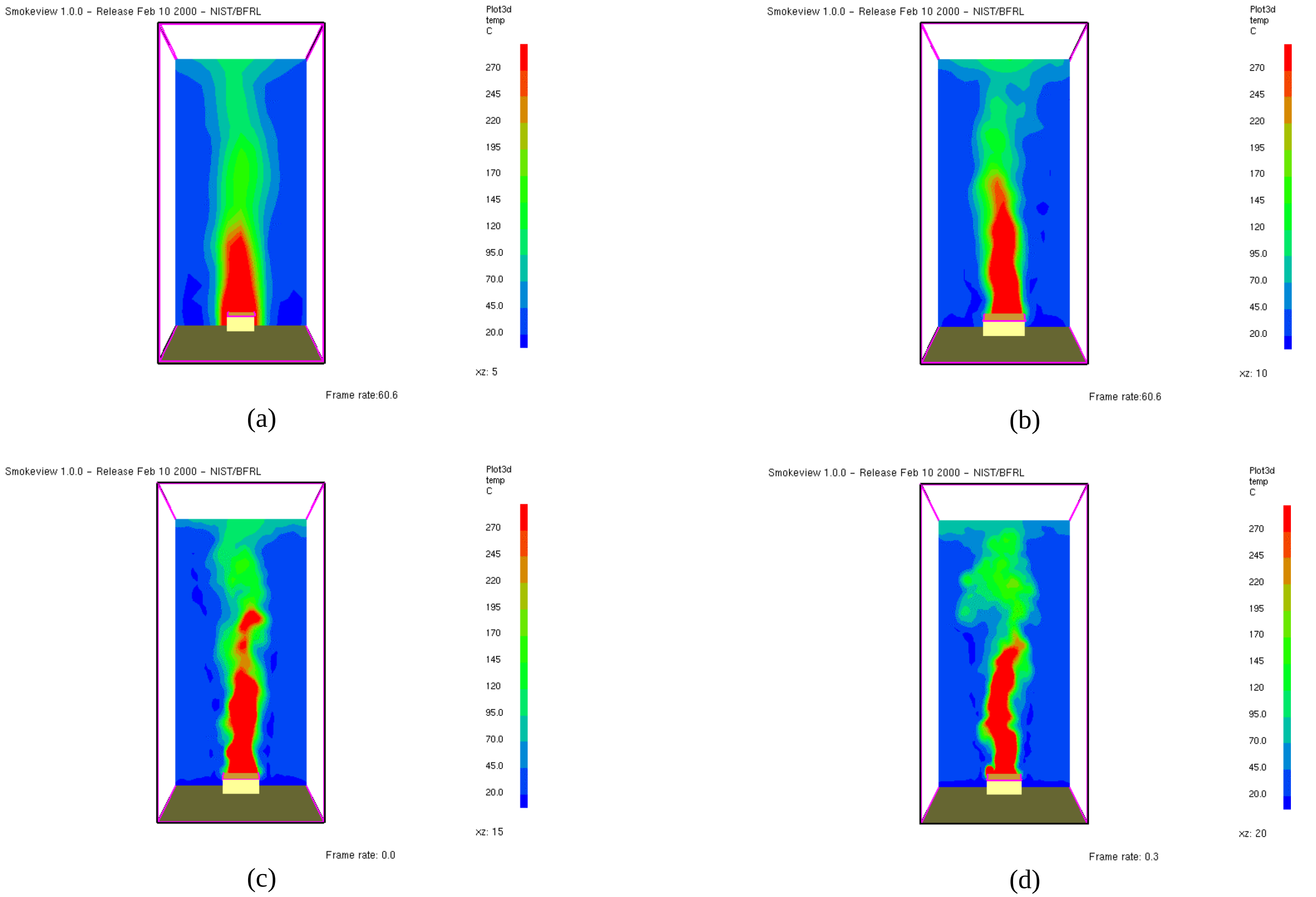

Figure 17. plot3d **smokeview** Contours of the Test 5 Fire Plume at 480 s with Grid Sizes: (a) 1 ft, (b) 6 in, (c) 4 in, & (d) 3 in

5.4 Results from the Computer Dependent Study

The computer dependent study showed that the simulations were more efficient with increasing processor speed and memory. Figure 18 and Table 2 show the detailed results from this study. It is worth noting again that a Test 5 simulation was run with a 15 cm grid, and the total simulation time was 211 hours on the 450 MHz computer.

Some interesting findings resulted from this study. For example, decreasing the grid size by one-half will theoretically increase the total computation time by a factor of 16[1]. Greater increases were observed and some explanation was needed. It was determined that as grid resolution increases, the centerline plume velocities increase [16]. This increase in particle velocity results in a time step that is *less than* one-half that of the original case. The result is a calculation time that is longer than expected. Also, previously it was reported that simulations require approximately 10 to 30 microseconds per cell per time step [1], but here the range was larger, ranging from 30 to 120 microseconds per cell per time step on a 450 MHz Pentium with 384 MB of RAM. In addition to increased particle velocities it is believed that Windows® memory allocation and disk caching procedures may have some effect to lengthen simulation times.

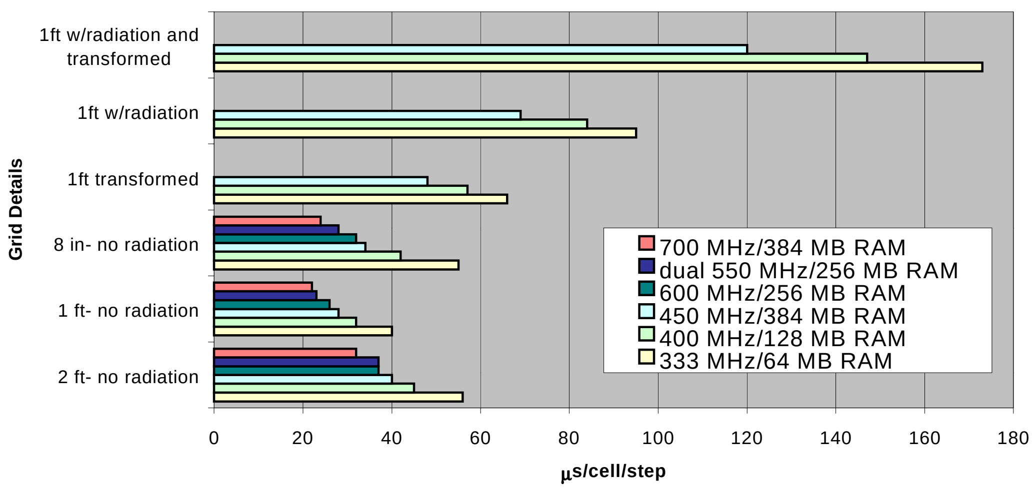

Figure 18. Computer Dependent Comparisons

[1] Reducing grid size by a factor of two creates eight times as many cells in the computational domain. Fluid particles are now traversing cells twice as fast, and the time step must be decreased by a factor of two in order to satisfy the CFL condition [2]. The result is that it takes nominally 16 (8x2) times longer to run the simulation.

Table 2. Computer Dependent Comparisons

	Total # of grid cells	Run Time (hours)					
		333/64	400/128	450/384	600/256	700/384	Dual 500/256
2 ft- no radiation	6000	0.40	0.32	0.29	0.26	0.23	0.26
1 ft- no radiation	48,000	7.8	6.7	5.6	4.8	4.0	4.3
8 in- no radiation	162,000	55.5	43.9	37.6	34.3	25.6	29.8
6 in- no radiation	224,000	-	-	211	-	-	-
1ft- transformed	48,000	14.6	12.5	10.6	-	-	-
1ft- w/radiation	48,000	21.4	18.7	15.3	-	-	-
1ft- w/radiation and transformed	48,000	40.2	35.7	29.0	-	-	-

6 SUMMARY AND CONCLUSIONS

The Fire Dynamics Simulator (FDS) was used to simulate seven full-scale fire tests from the FM/SNL test series. For each test case three different grid sizes were implemented to determine the effect of grid resolution on simulation accuracy. Several methods were used to compare test measurements and simulation predictions. Test 5 simulations were run on six computers with different hardware configurations to determine calculation times on state of the art PC's. A grid dependent plume study was performed to investigate the role of grid resolution around the fire source in overall model predictions.

Accuracy was seen to range from within a few degrees to 100 °C in cases where early temperature spikes resulted from an inappropriate heat release ramp. Temperature measurements and predictions in the plume region show the greatest differences. These observations are verified and quantified using an analytical technique known as functional analysis. Functional analysis, the quantitative comparison of two curves, is shown to accurately verify qualitative observations in most instances. However, the results from functional analysis should not be taken independently of other comparison methods.

The computer study demonstrates that processor speed, memory, and grid size play important roles in calculation time. The 20 cm cases took 6 to 8 times longer to run than the 30 cm case and 100 to 150 times longer to run than the 60 cm case. These results are contrary to theoretical expectations and are due to a combination of higher plume velocity predictions for finer grids and memory allocation/disk caching issues.

Grid resolution plays an important role in FDS prediction accuracy. There is an optimal grid for any given scenario. Under-resolution will result in simulations with unacceptable accuracy while over-resolution will result in unacceptably long simulation times. What this optimal grid is, and how to determine it *a priori*, is not clear. In the FM/SNL simulations the computational grid influenced the simulated dimensions of the gas burner. With 0.6 m (2 ft) grid cells the burner was 0.6 m (2 ft) tall or twice its real height, and with a 0.2 m (8 in) grid it was 0.2 (8 in) m tall or two-thirds its real height. With the exception of Tests 4 and 5, the centerline plume temperatures were predicted most accurately under a 1 ft grid, which specifies the correct burner height. The plume study demonstrates that a 64-fold increase in the number of grid cells did little to improve the plume centerline temperature predictions. These observations indicate that grid size may have as much to do with the accurate placement of fire sources and targets as with accurate temperature calculations in a large enclosure.

In simulations where the fire is steady state, beginning with a significant heat release rate, it may be necessary to implement some ramp to provide accurate results. This is because the fire is input into the FDS model and not predicted. For example, in order to correctly model pool fire growth one must understand that the delay to maximum heat release rate is a function of the fuel fire spread rate and pool diameter.

It is clear from this research that given appropriate inputs, the FDS model is capable of providing reliable results for scenarios similar to those simulated here. The model is seen to correctly predict general curve shapes, inflections, and magnitudes. The accompanying visualization software, **smokeview**, greatly enhances the model's usability. It allows users to visualize input and output, and is a powerful tool for interpreting results and troubleshooting problems.

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APPENDIX A- Comparison Charts

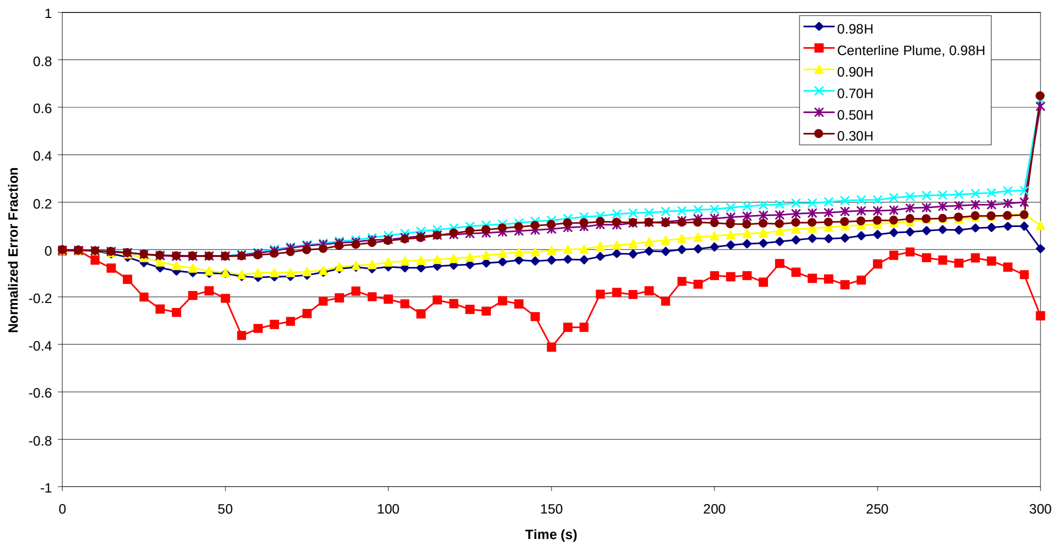

Figure A4. Normalized Error Fraction between FMSNL Test 3 and FDS with 2ft Grid

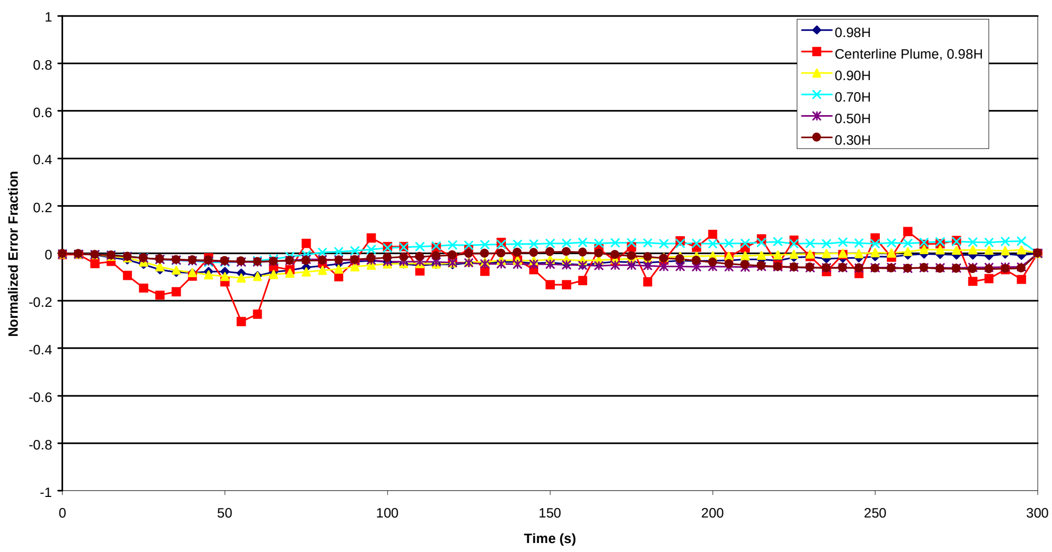

Figure A5. Normalized Error Fractions between FMSNL Test 3 and FDS with 1ft Grid

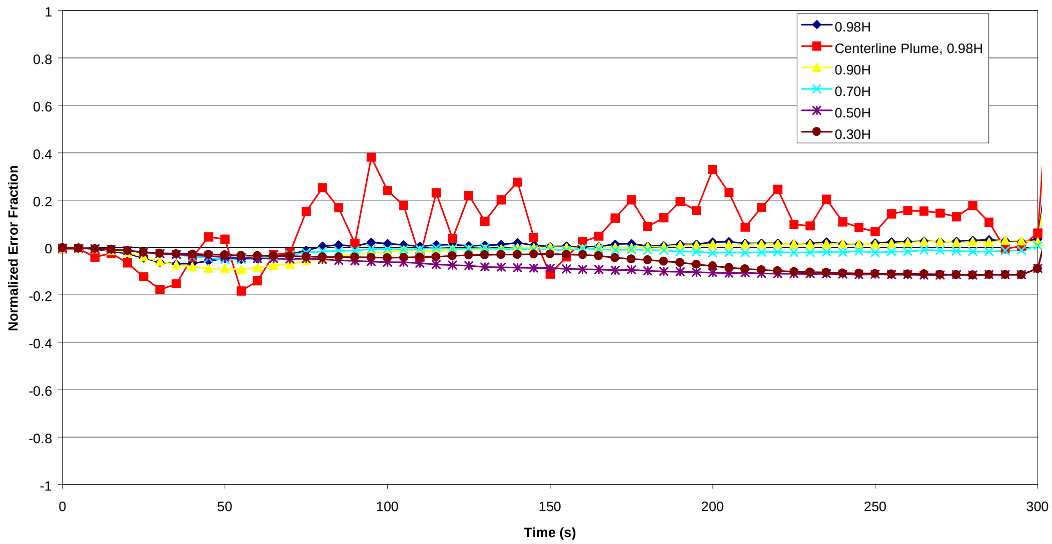

Figure A6. Normalized Error Fractions between FMSNL Test 3 and FDS with 8 in Grid

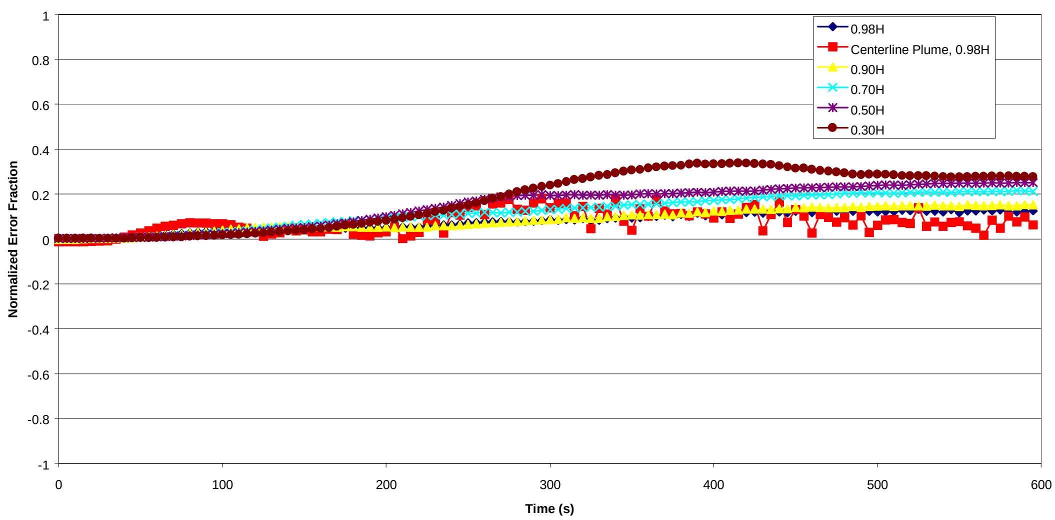

Figure A7. Normalized Error Fractions between FMSNL Test 4 and FDS with 2ft Grid

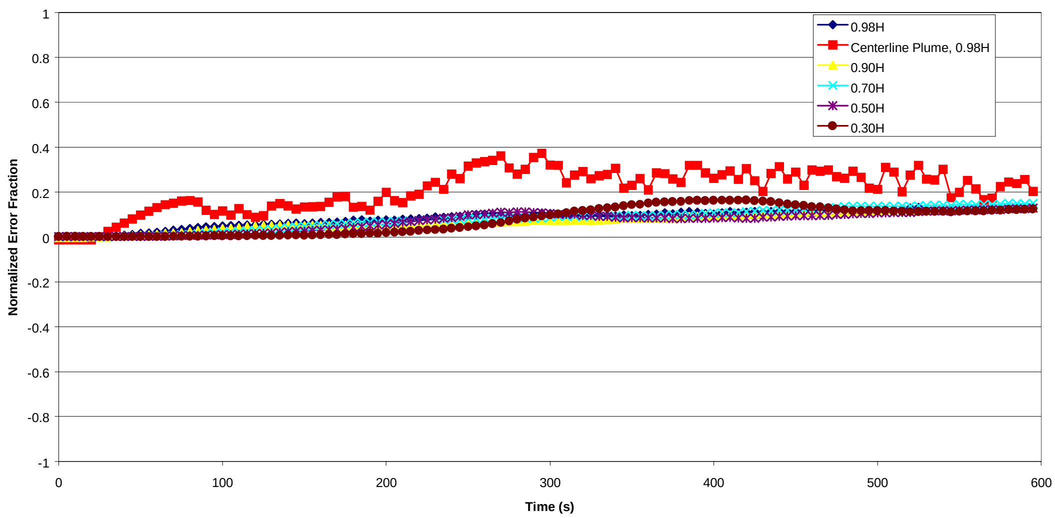

Figure A8. Normalized Error Fractions between FMSNL Test 4 and FDS with 1ft Grid

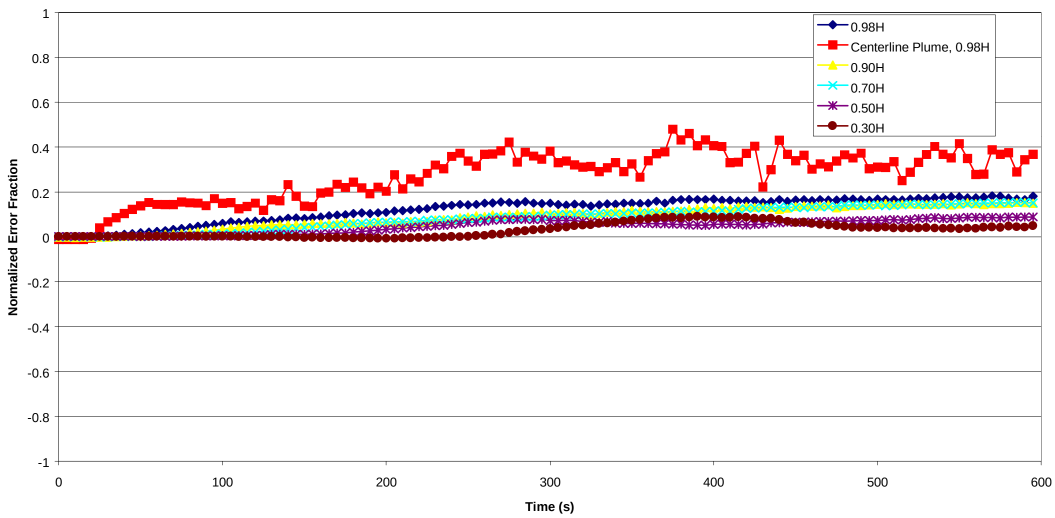

Figure A9. Normalized Error Fractions between FMSNL Test 4 and FDS with 8in Grid

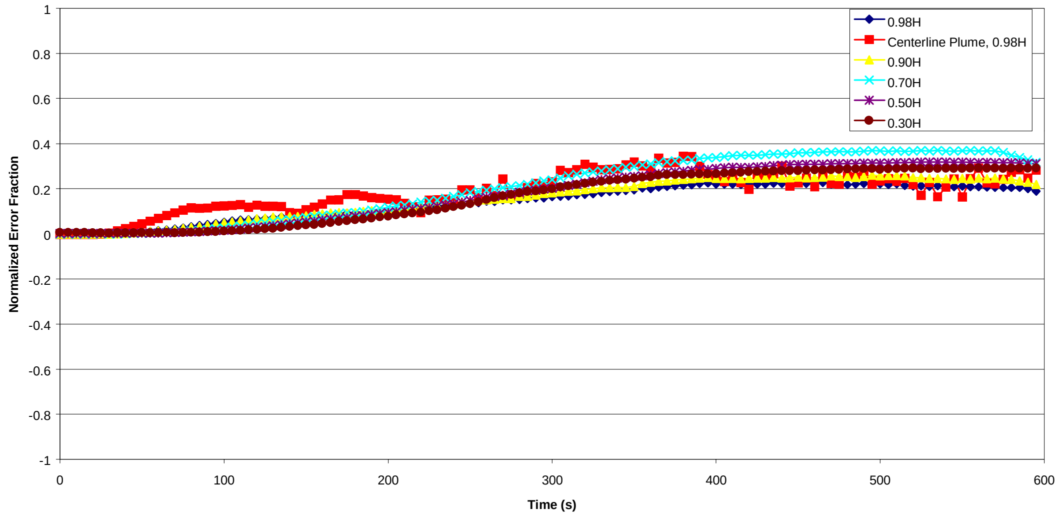

Figure A10. Normalized Error Fractions between FMSNL Test 5 and FDS with 2ft Grid

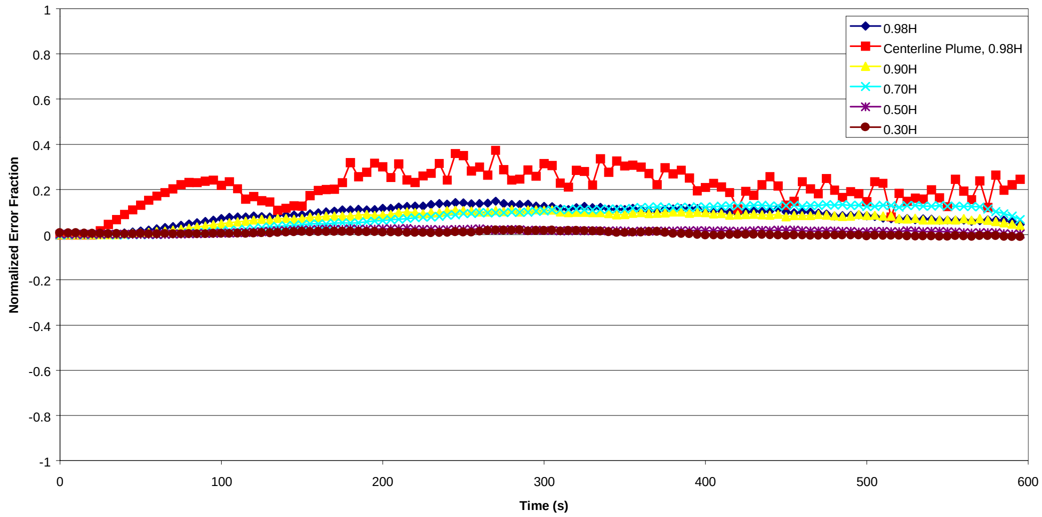

Figure A11. Normalized Error Fractions between FMSNL Test 5 and FDS with 1ft Grid

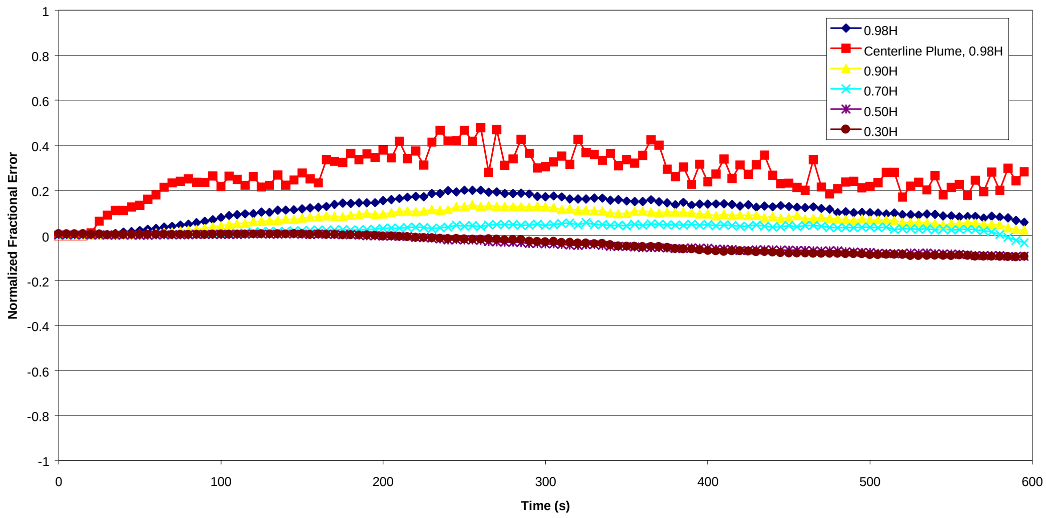

Figure A12. Normalized Error Fractions between FMSNL Test 5 and FDS with 8in Grid

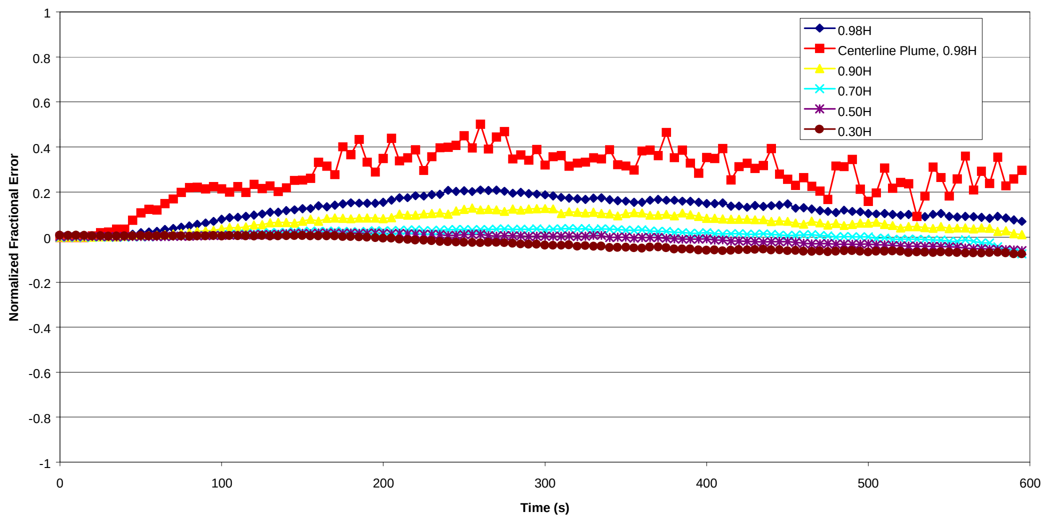

Figure A13. Normalized Error Fractions between FMSNL Test 5 and FDS with 6 in Grid

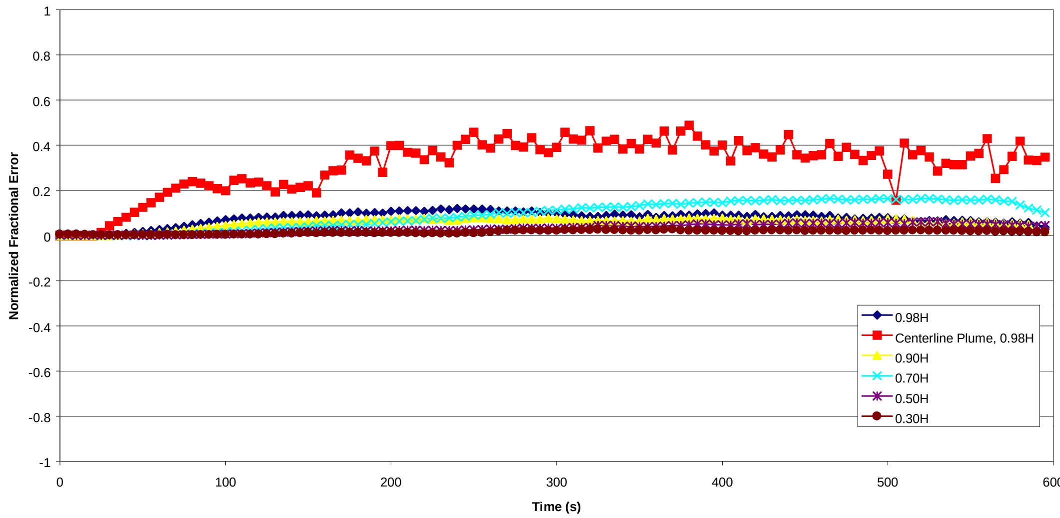

Figure A14. Normalized Error Fractions between FMSNL Test 5 and LES3D with 1ft Grid (Grid Transformed to 6 in. Around the Burner)

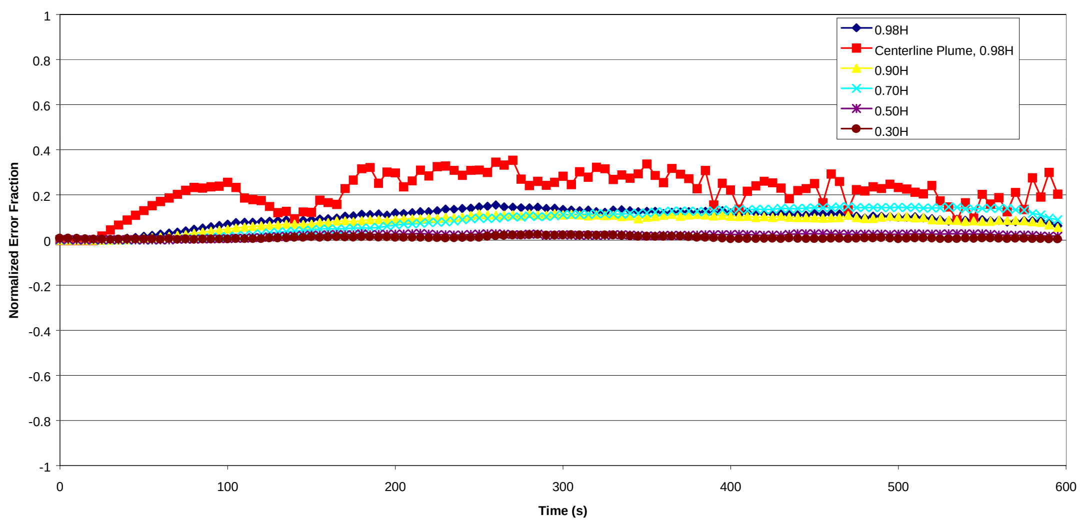

Figure A15. Normalized Error Fractions between FMSNL Test 5 and FDS with 1ft Grid (Radiation Calculation Enabled)

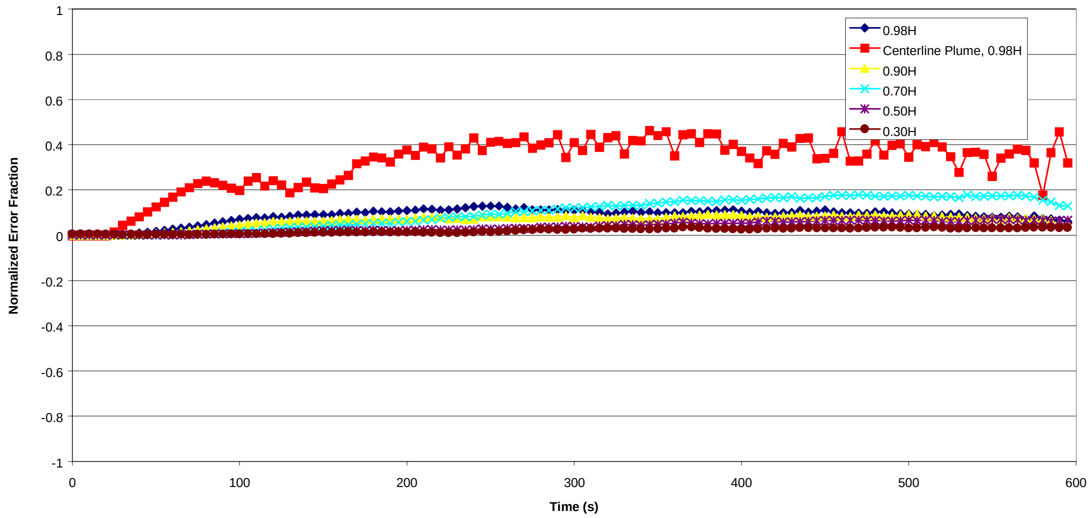

Figure A16. Normalized Error Fractions between FMSNL Test 5 and FDS with 1ft Grid (Grid Transformed to 6in. Around the Burner & Radiation Calculation Enabled)

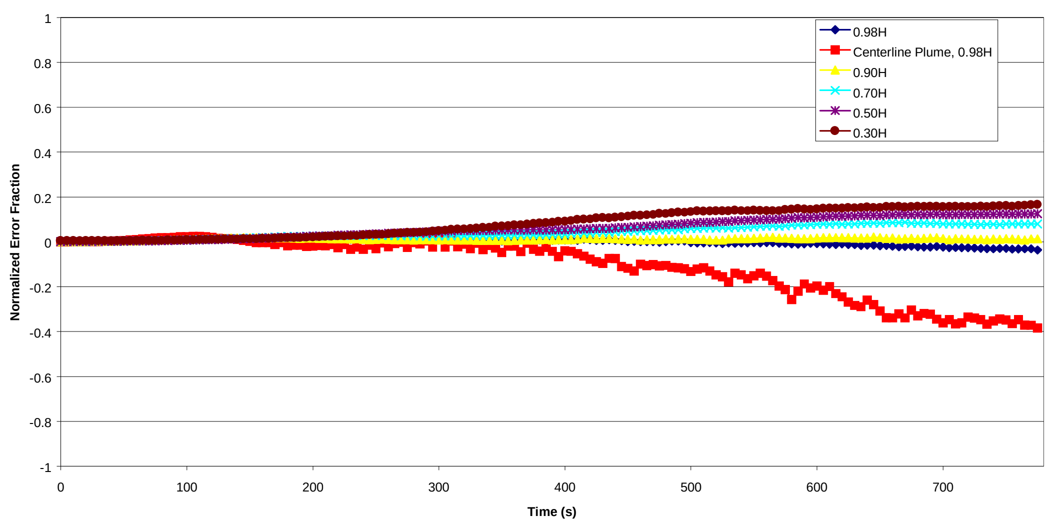

Figure A17. Normalized Error Fractions between FMSNL Test 8 and FDS with 2ft Grid

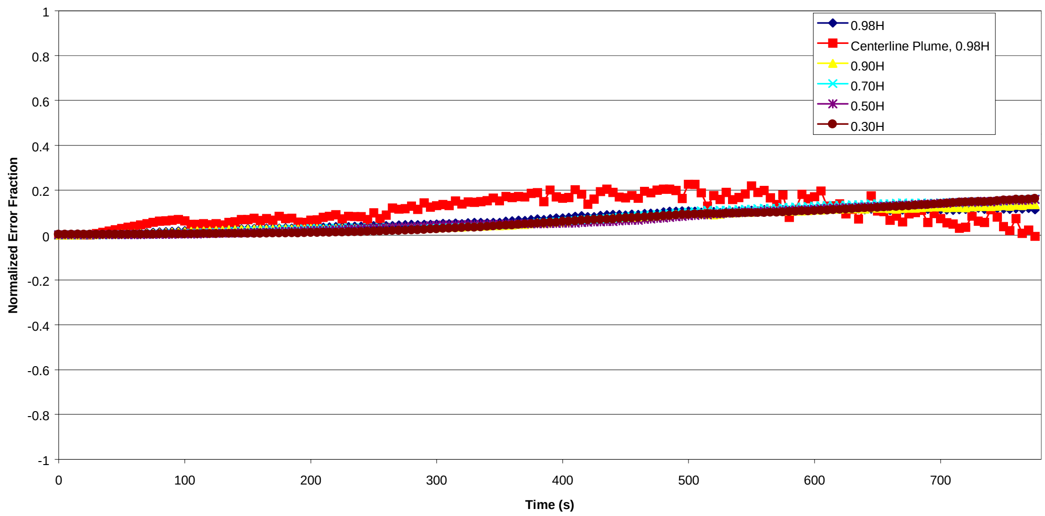

Figure A18. Normalized Error Fractions between FMSNL Test 8 and FDS with 1ft Grid

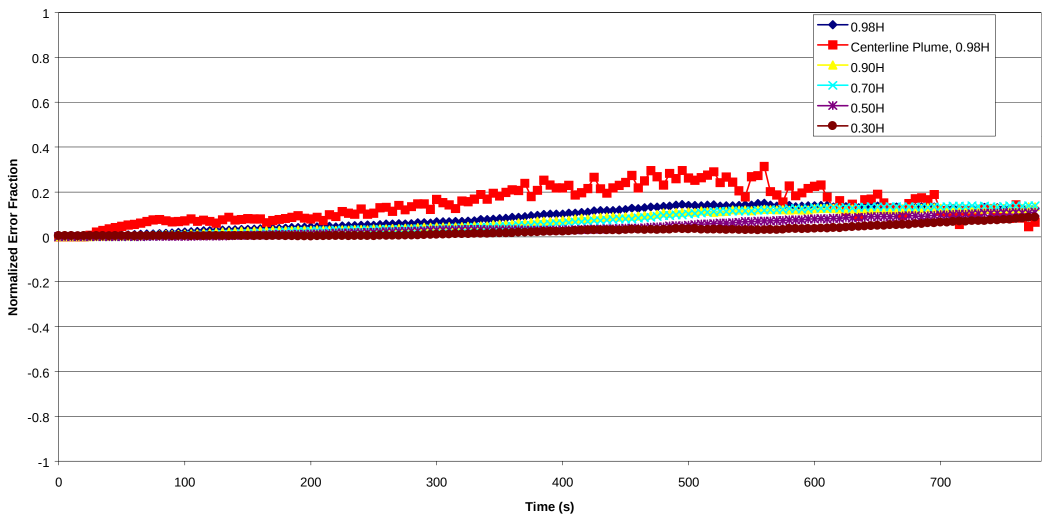

Figure A19. Normalized Error Fractions between FMSNL Test 8 and FDS with 8in Grid

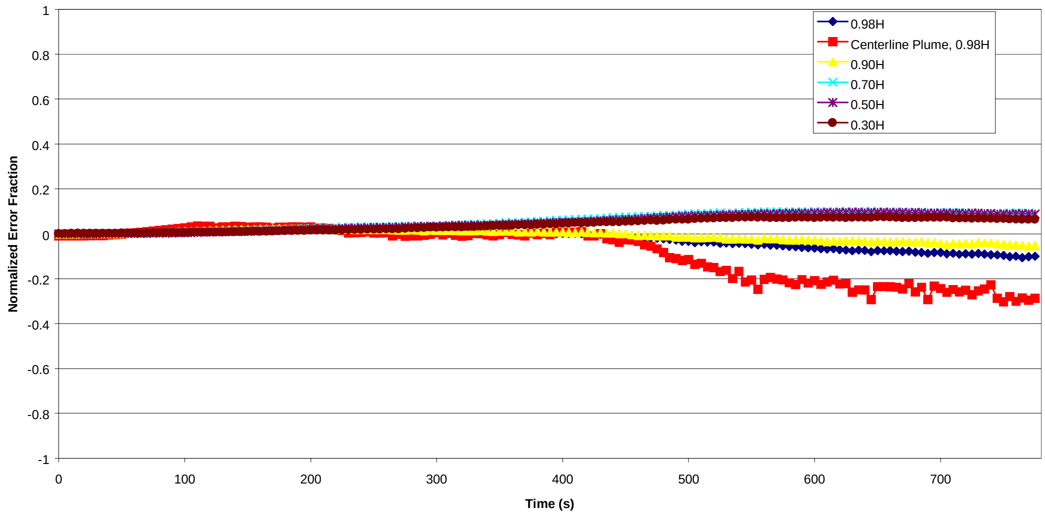

Figure A20. Normalized Error Fractions between FMSNL Test 9 and FDS with 2ft Grid

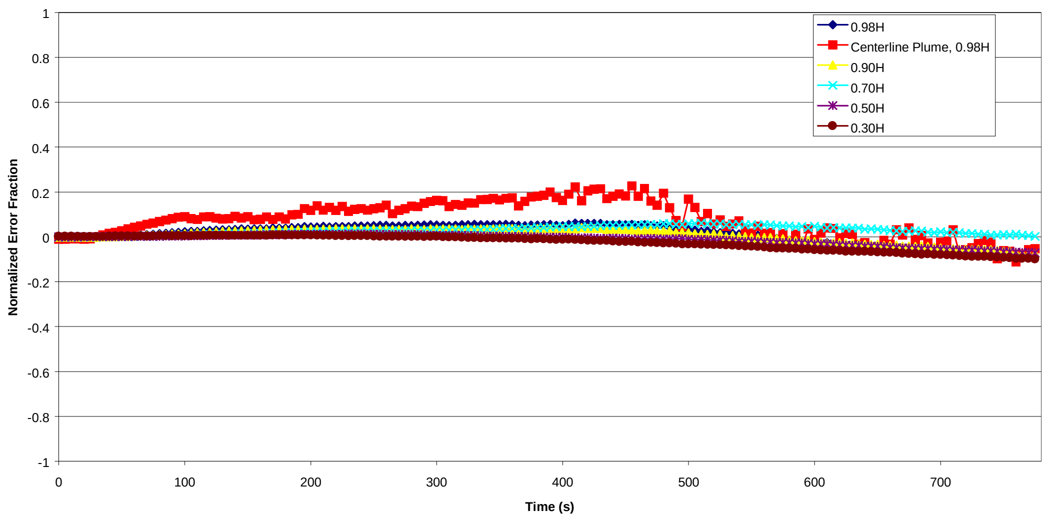

Figure A21. Normalized Error Fractions between FMSNL Test 9 and FDS with 1ft Grid

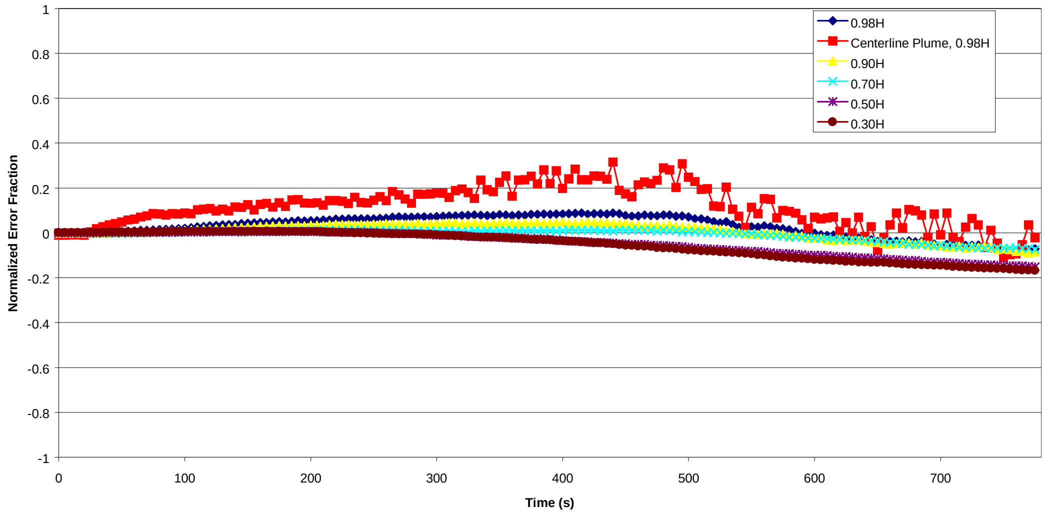

Figure A22. Normalized Error Fractions between FMSNL Test 9 and FDS with 8in Grid

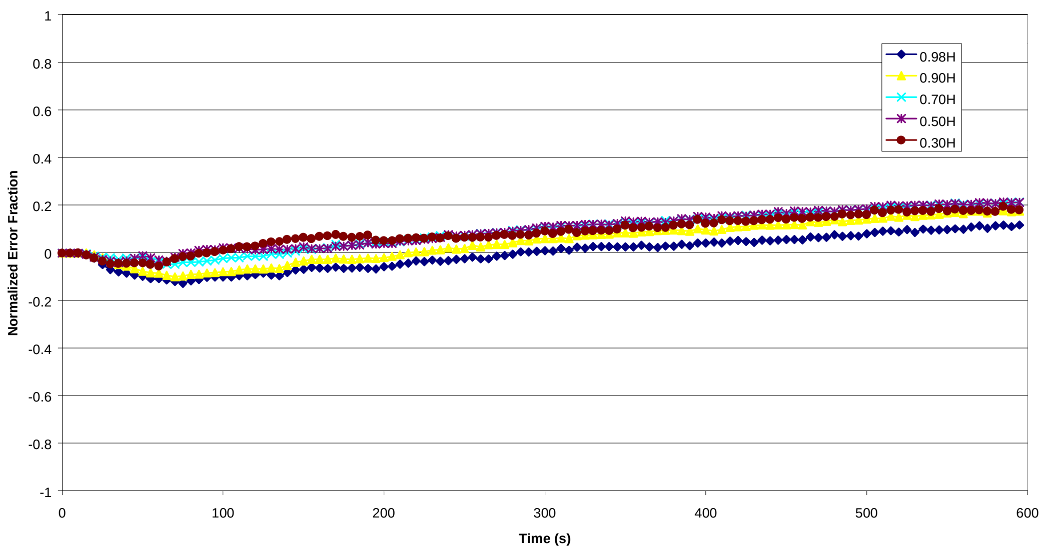

Figure A23. Normalized Error Fractions between FMSNL Test 12 and FDS with 2ft Grid

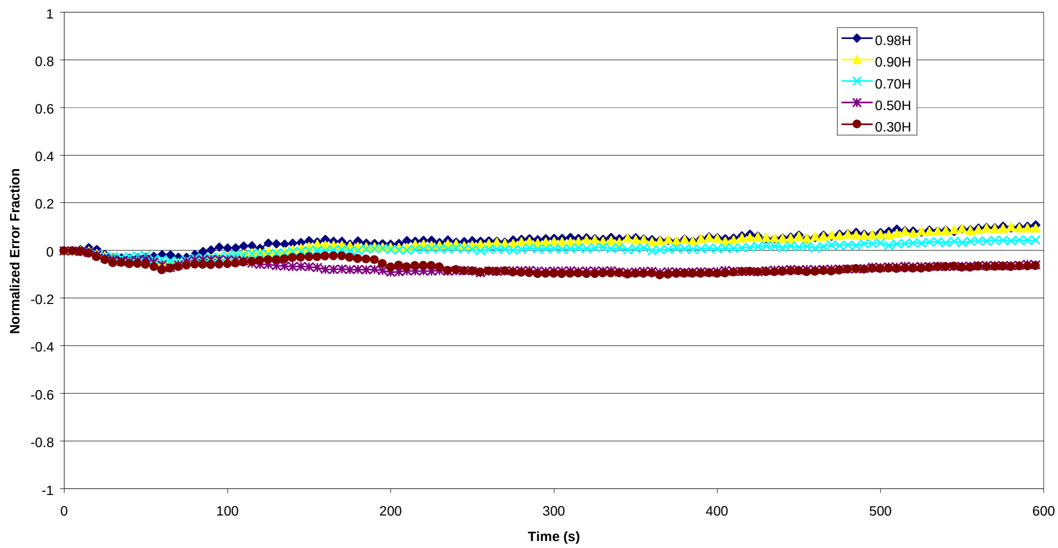

Figure A24. Normalized Error Fractions between FMSNL Test 12 and FDS with 1ft Grid

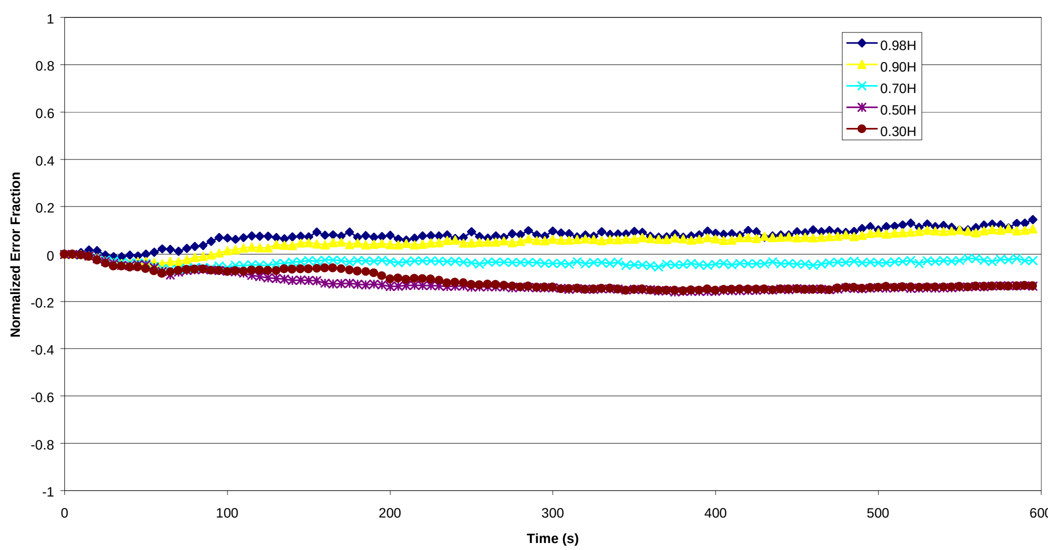

Figure A25. Normalized Error Fractions between FMSNL Test 12 and FDS with 8in Grid

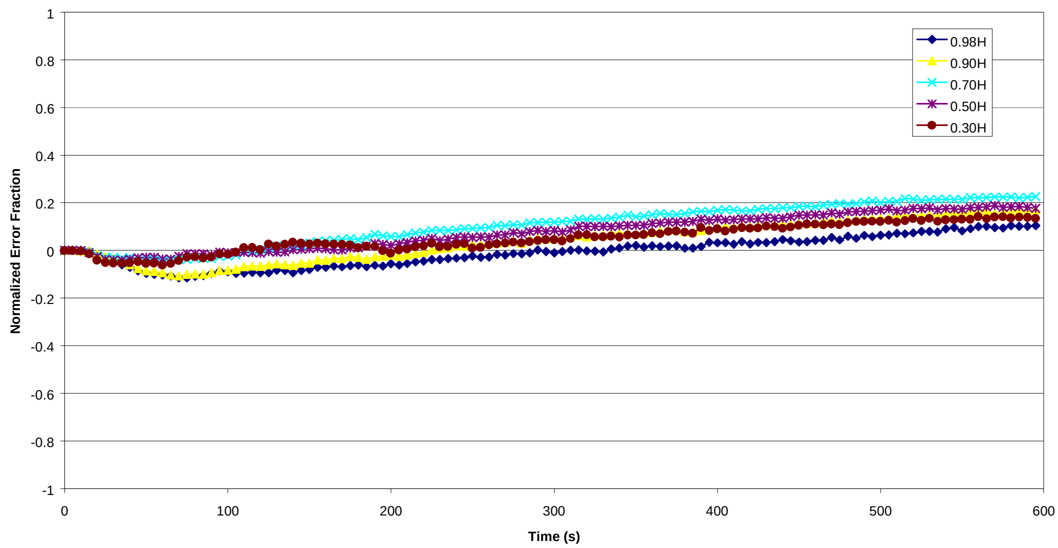

Figure A26. Normalized Error Fractions between FMSNL Test 13 and FDS with 2ft Grid

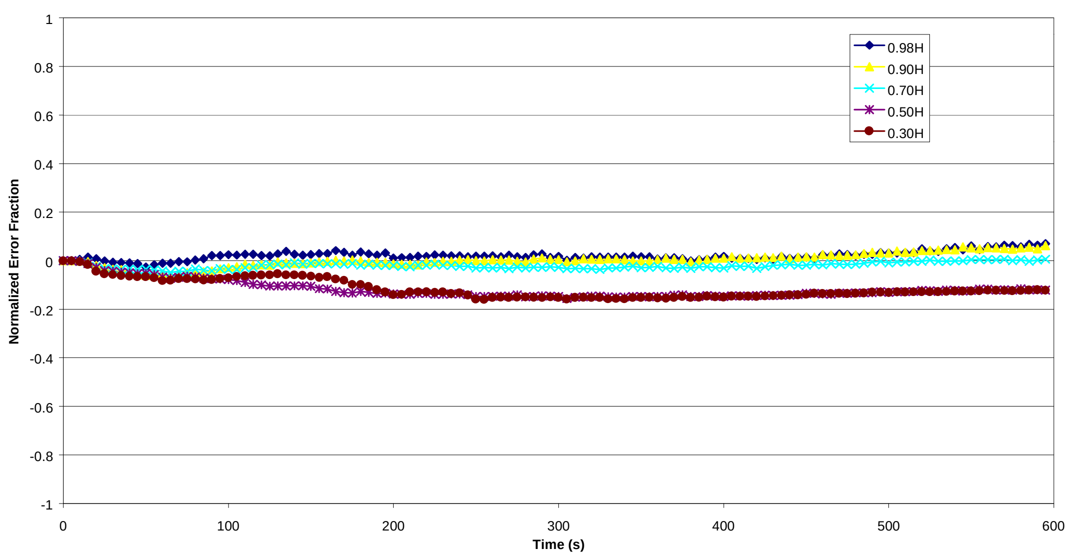

Figure A27. Normalized Error Fractions between FMSNL Test 13 and FDS with 1ft Grid

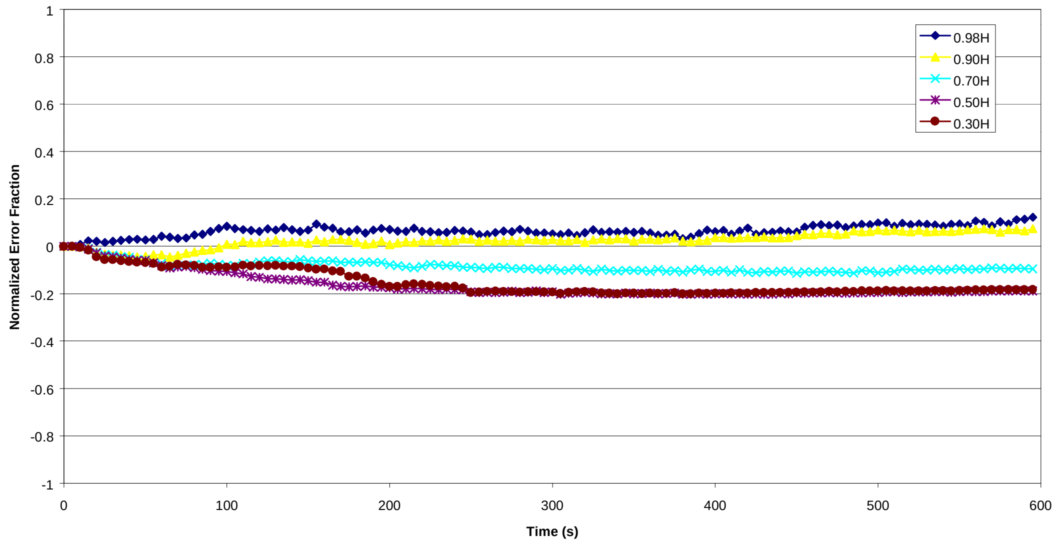

Figure A28. Normalized Error Fractions between FMSNL Test 13 and FDS with 8in Grid

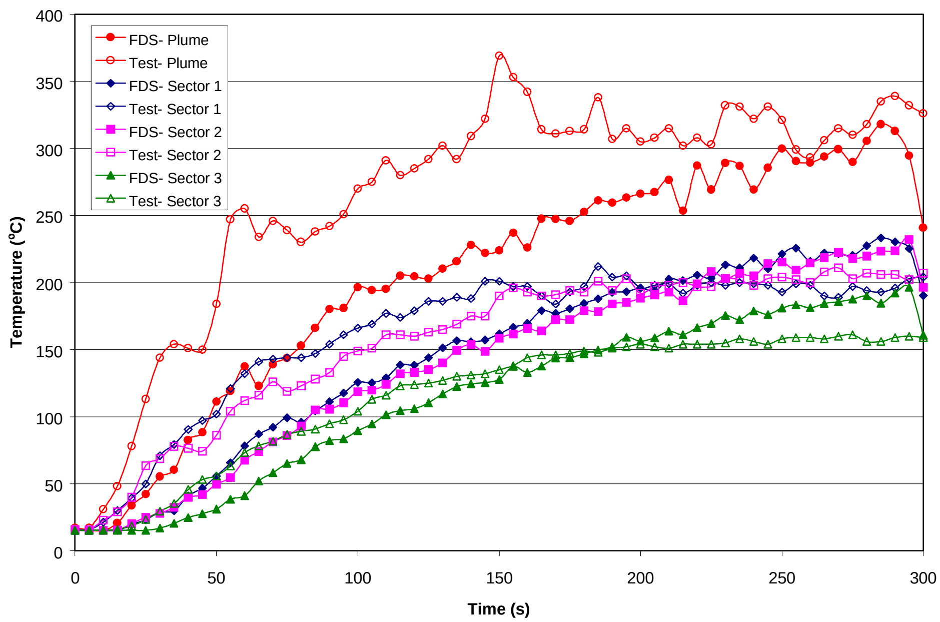

Figure A29. Test 3- 2 ft. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

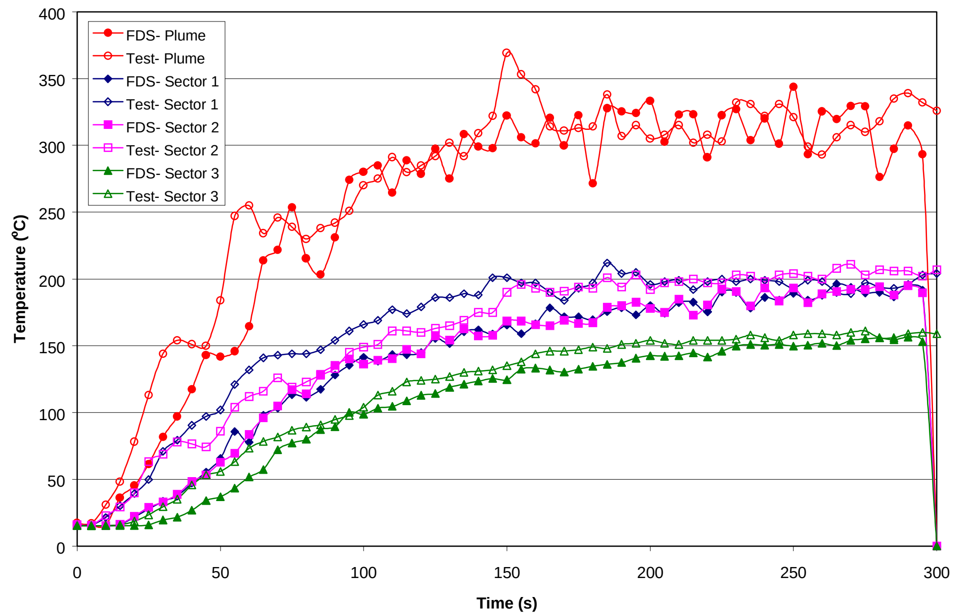

Figure A30. Test 3- 1 ft. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

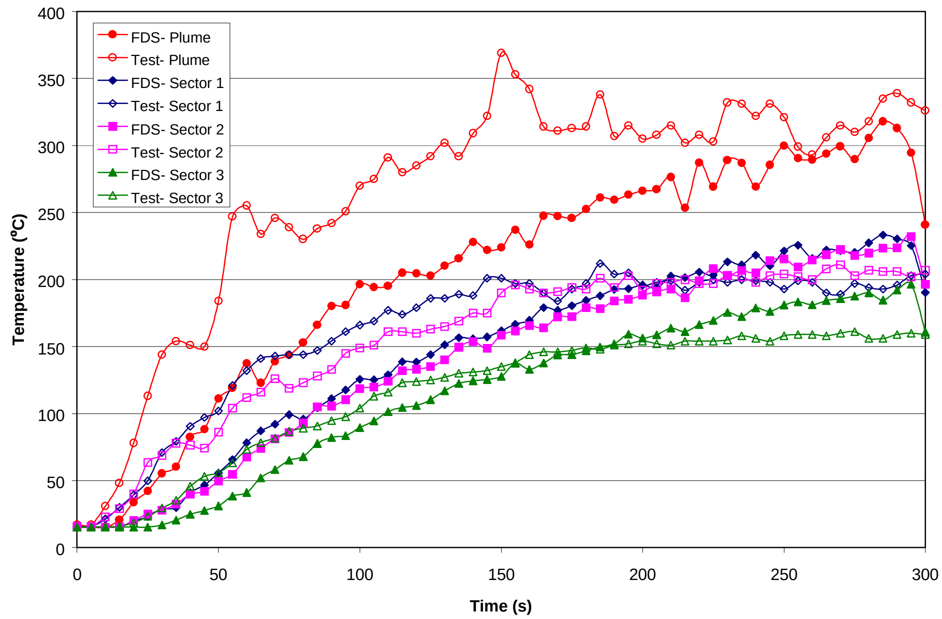

Figure A31. Test 3- 8 in. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

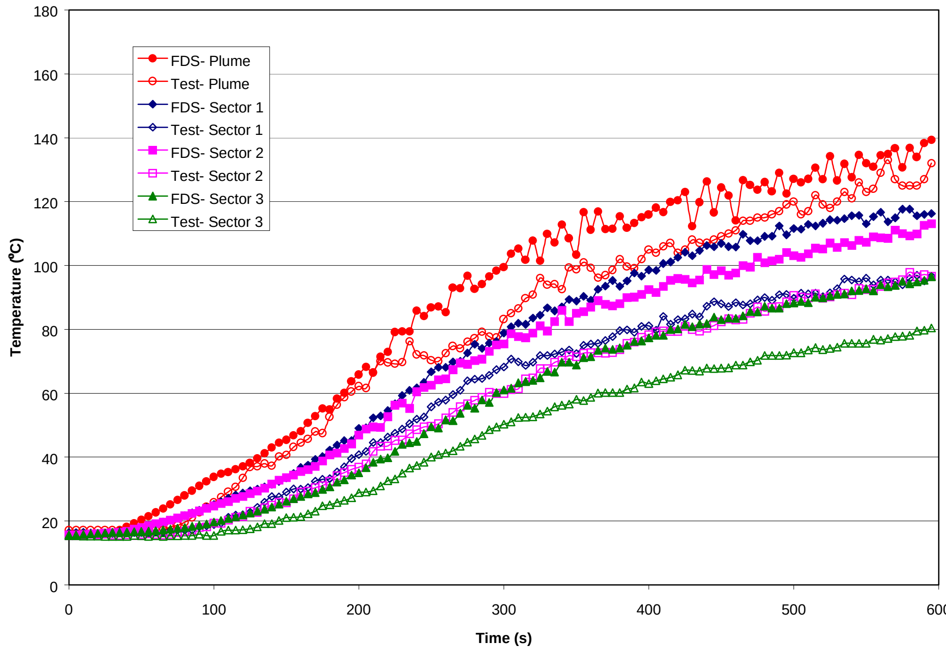

Figure A32. Test 4- 2 ft. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

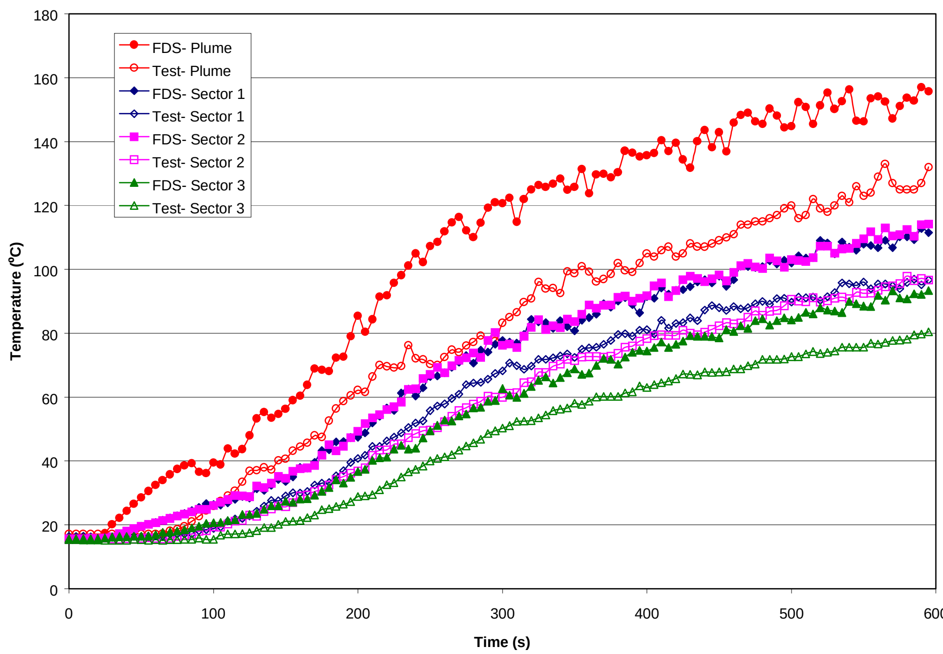

Figure A33. Test 4- 1 ft. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

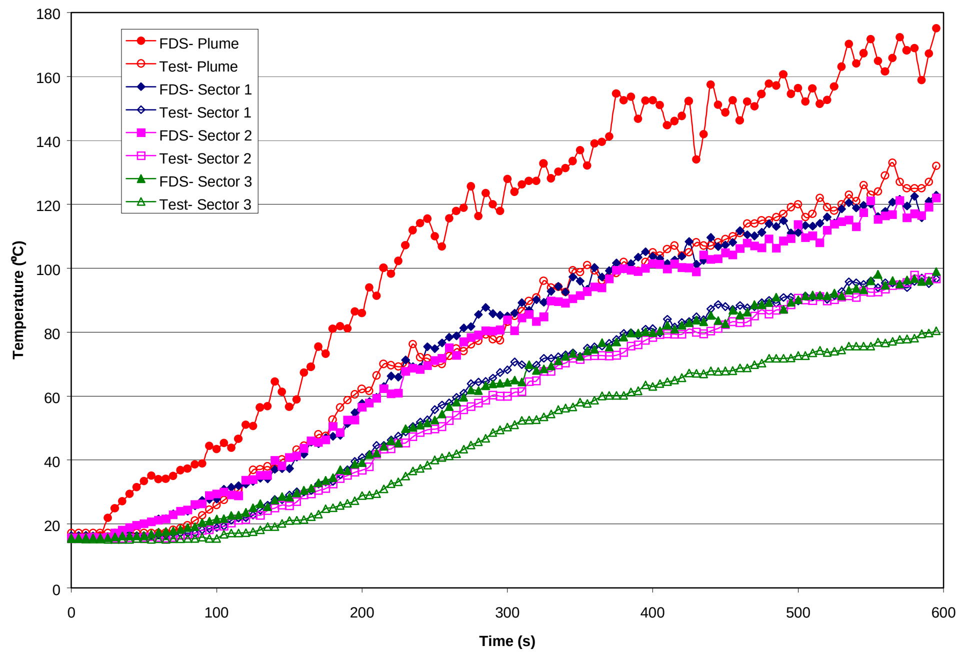

Figure A34. Test 4- 8 in. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

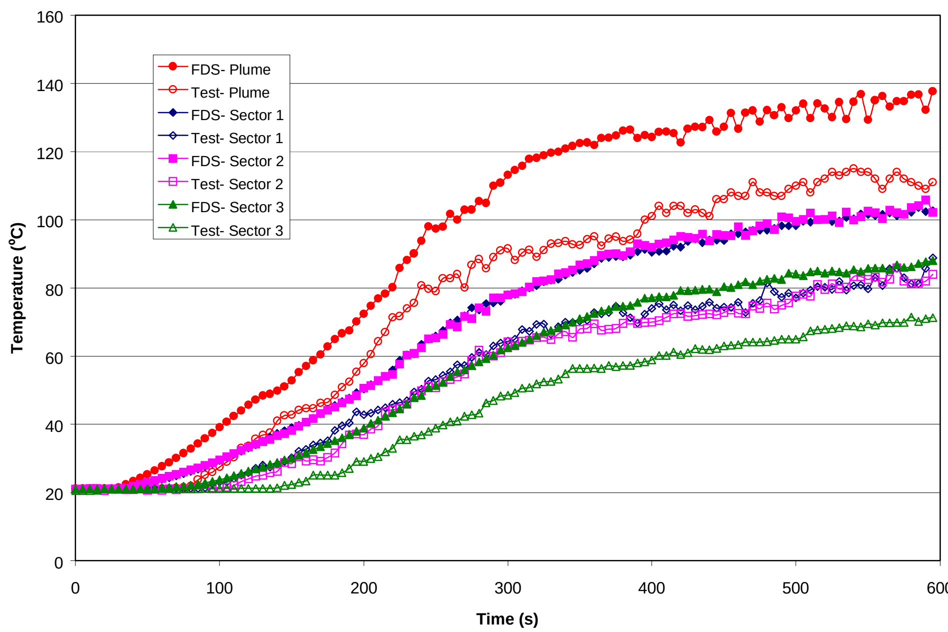

Figure A35. Test 5- 2 ft. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

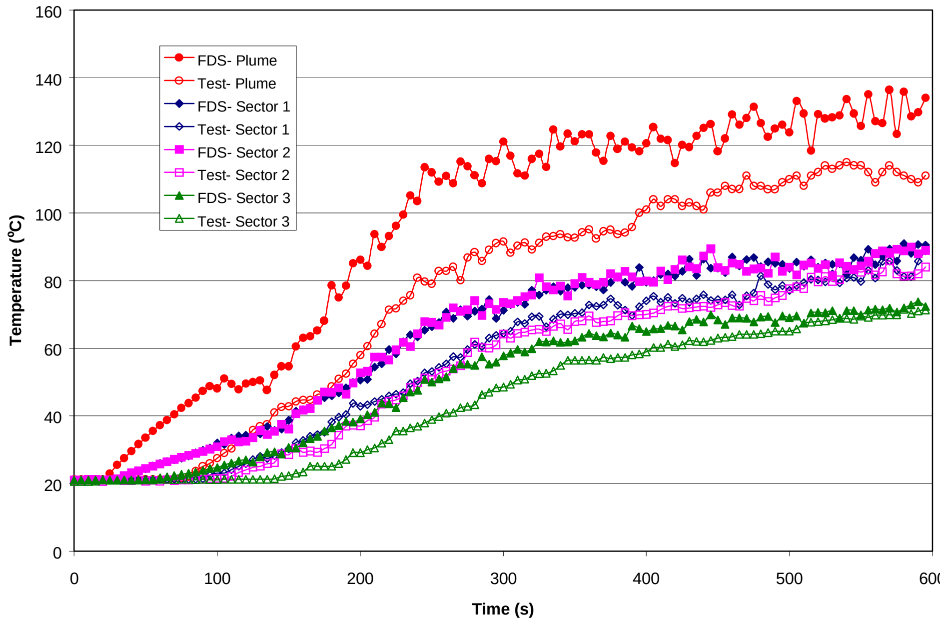

Figure A36. Test 5- 1 ft. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

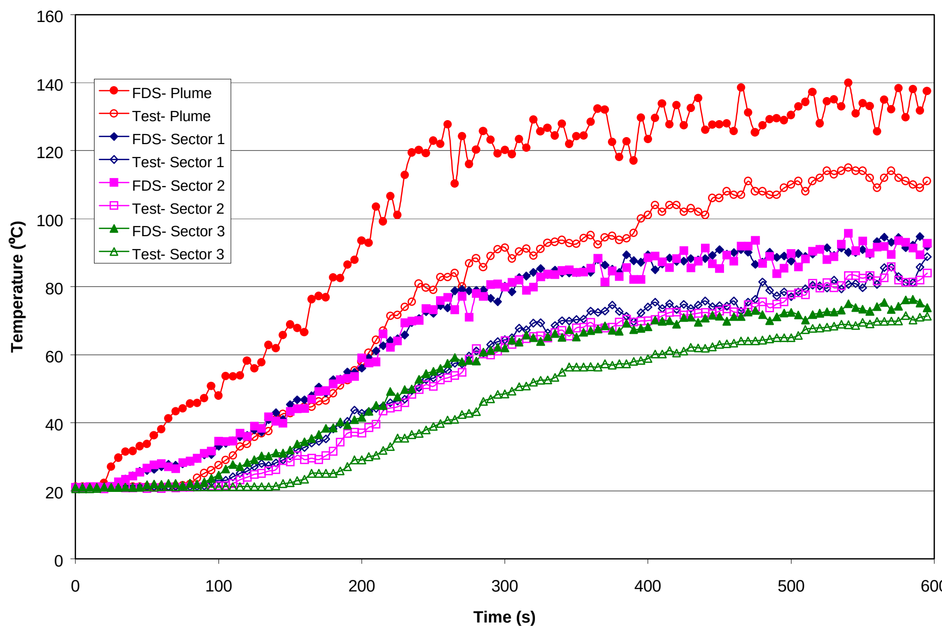

Figure A37. Test 5- 8 in. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

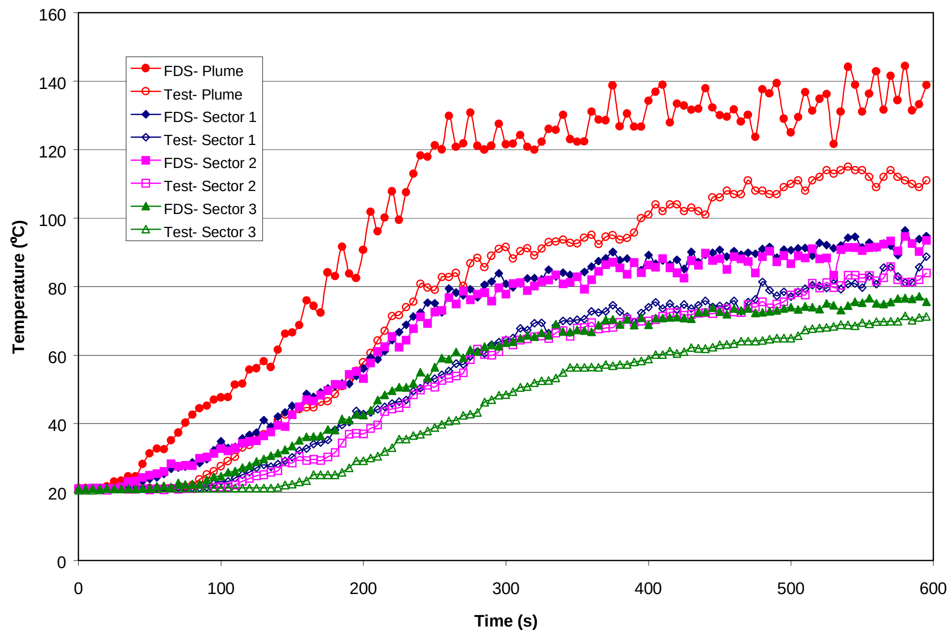

Figure A38. Test 5- 6 in. Grid Cells: Temperature Comparisons at 0.98H (Vertical Center Slice)

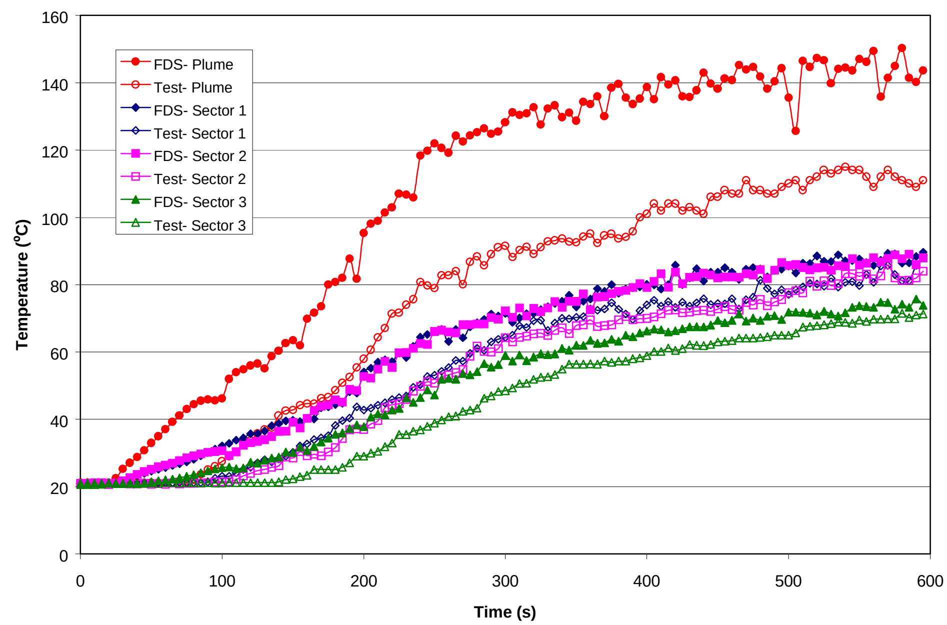

Figure A39. Test 5- 1 ft. Grid Cells (Grid Transformed to 6 in. Around Burner): Temperature Comparisons at 0.98H (Vertical Center Slice)

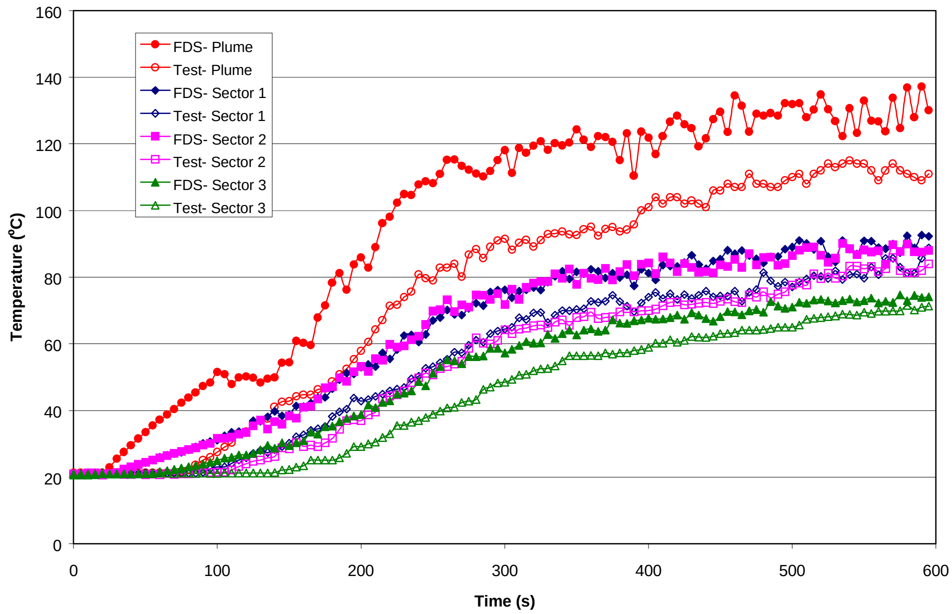

Figure A40. Test 5- 1 ft. Grid Cells (Radiation Calculation Enabled): Temperature Comparisons at 0.98H (Vertical Center Slice)

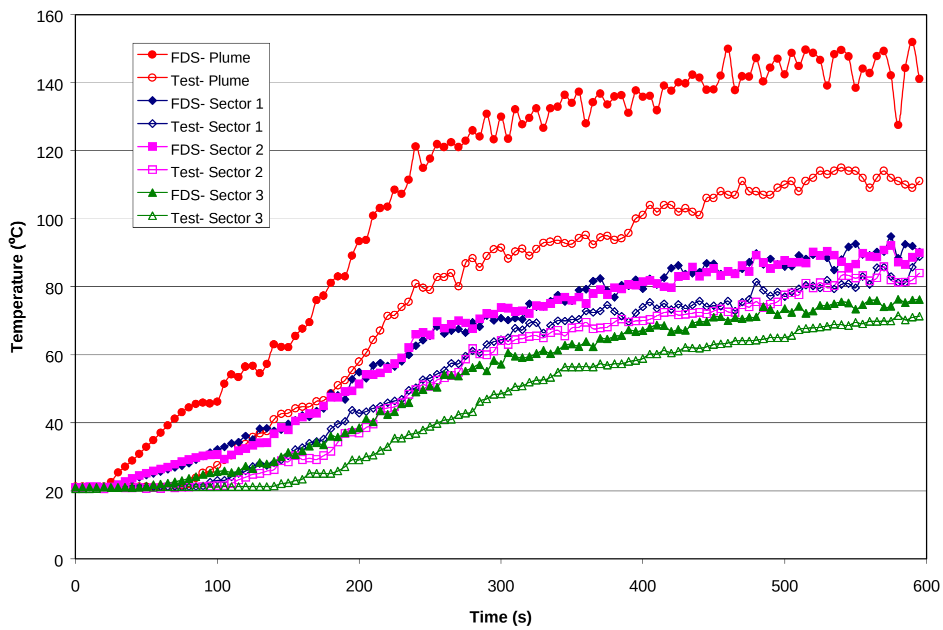

Figure A41. Test 5- 1ft. Grid Cells (Radiation Calculation Enabled & Grid Transformed to 6 in. Around the Burner): Temperature Comparisons at 0.98H (Vertical Center Slice)

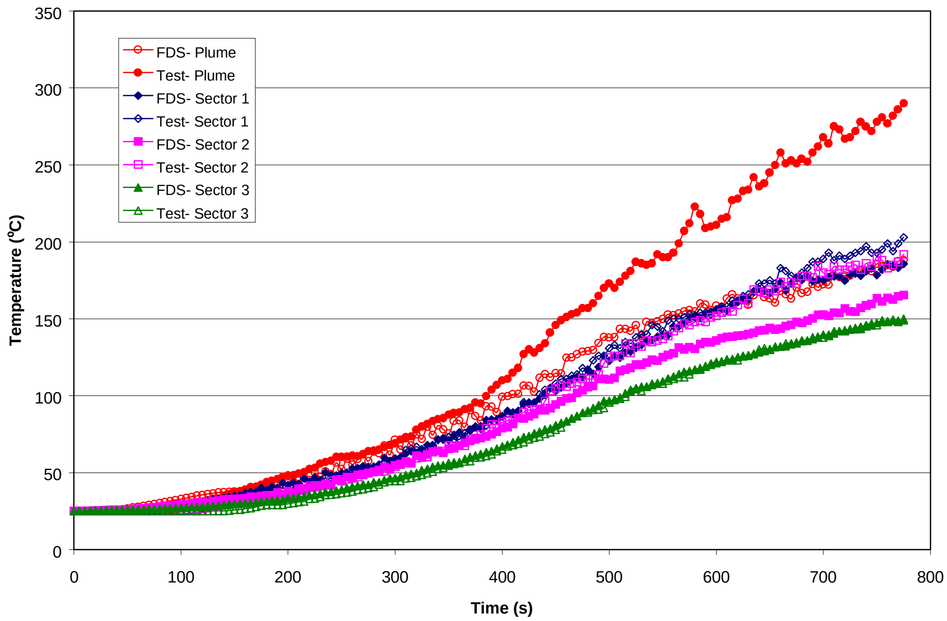

Figure A42. Test 8- 2 ft. Grid Cells: Upper Layer Temperature Comparisons (Vertical Center Slice)

Figure A43. Test 8- 1 ft. Grid Cells: Upper Layer Temperature Comparisons (Vertical Center Slice)

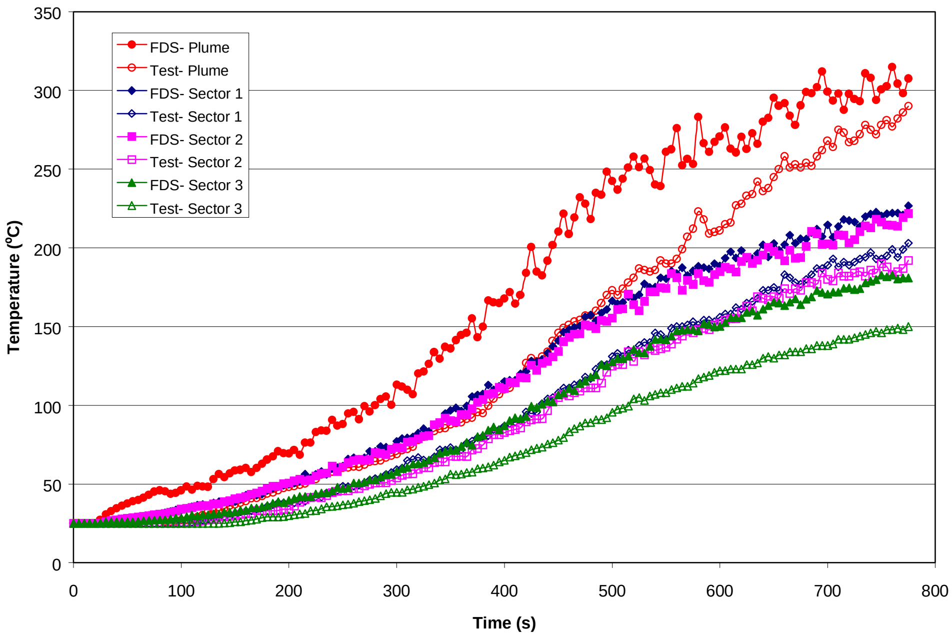

Figure A44. Test 8- 8 in. Grid Cells: Upper Layer Temperature Comparisons (Vertical Center Slice)

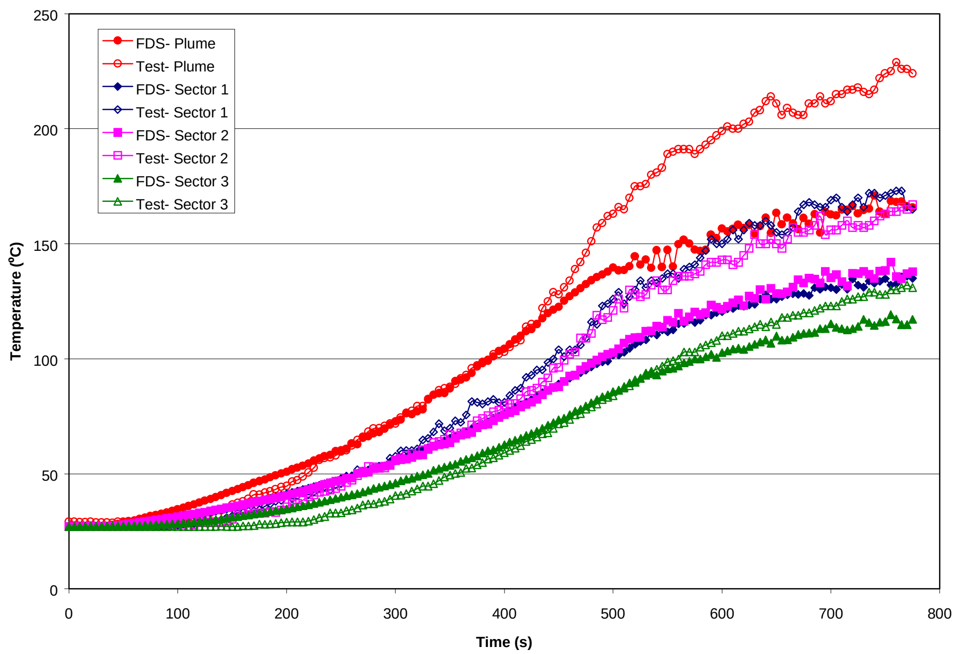

Figure A45. Test 9- 2 ft. Grid Cells: Upper Layer Temperature Comparisons (Vertical Center Slice)

Figure A46. Test 9- 1 ft. Grid Cells: Upper Layer Temperature Comparisons (Vertical Center Slice)

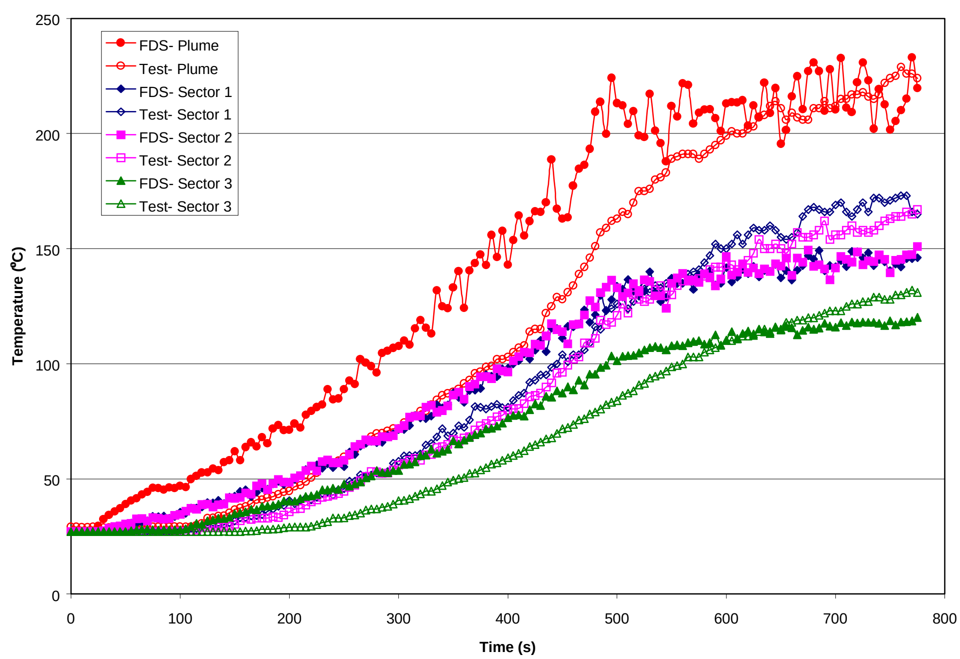

Figure A47. Test 9- 8 in. Grid Cells: Upper Layer Temperature Comparisons (Vertical Center Slice)

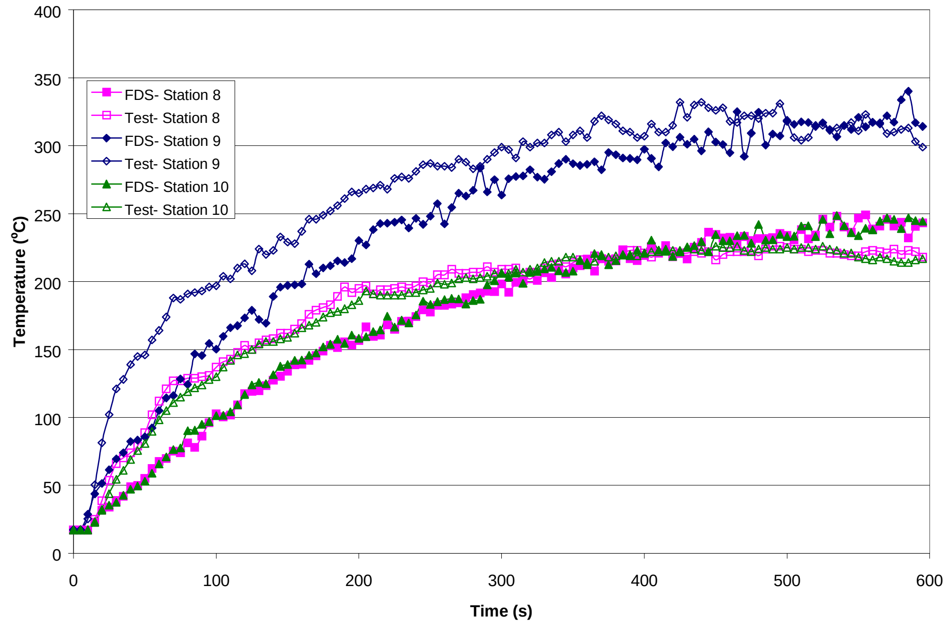

Figure A48. Test 12- 2ft Grid Cells: Upper Layer Ceiling Length Temperature Comparisons

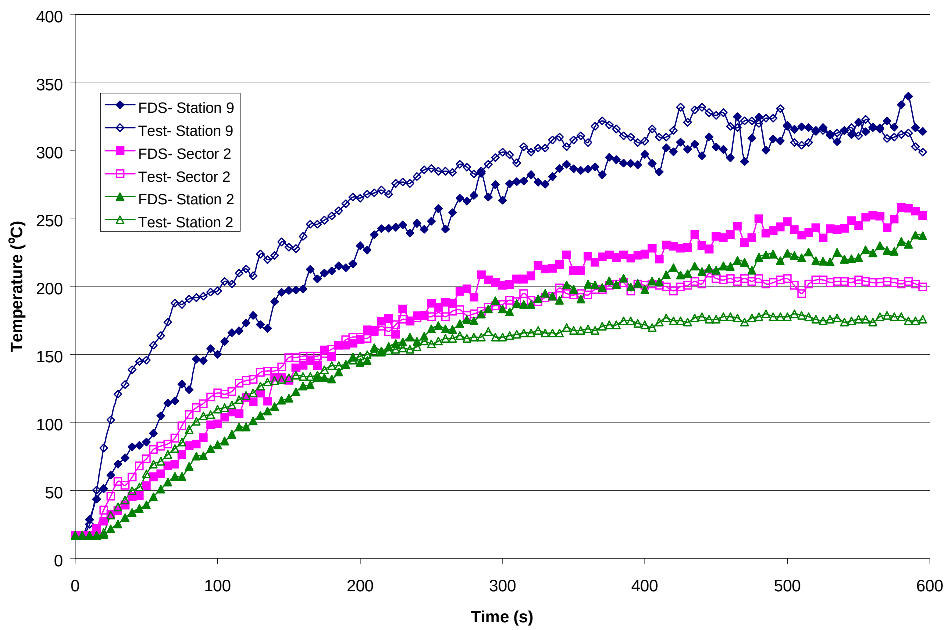

Figure A49. Test 12- 2ft. Grid Cells: Upper Layer Ceiling Width Temperature Comparisons

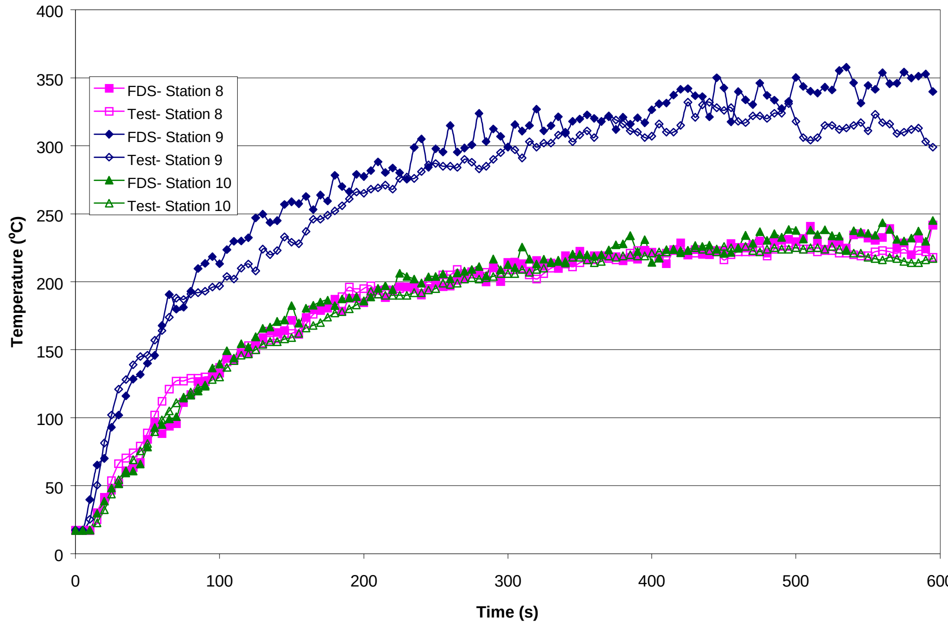

Figure A50. Test 12- 1ft Grid Cells: Upper Layer Ceiling Length Temperature Comparisons

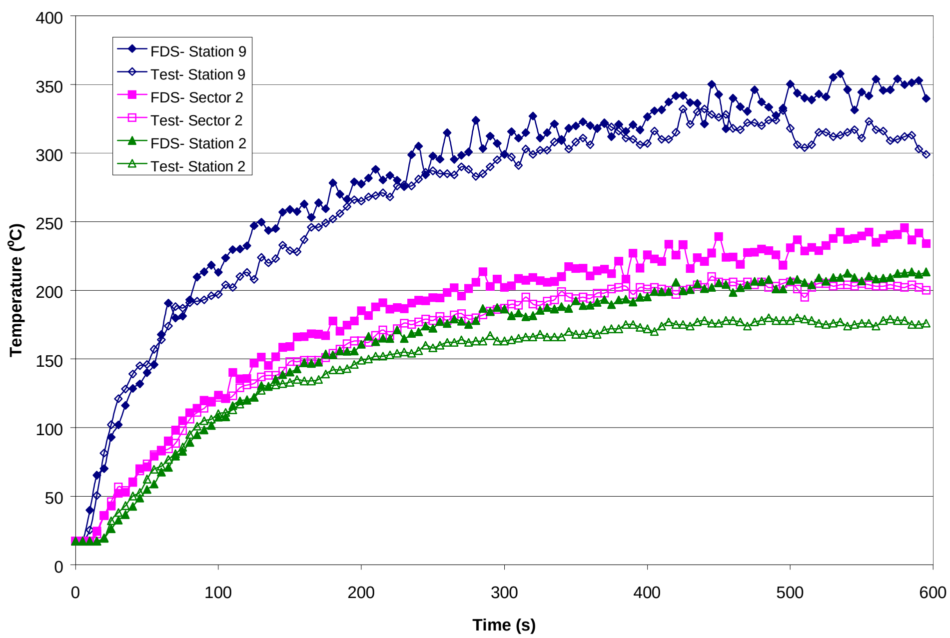

Figure A51. Test 12- 1ft. Grid Cells: Upper Layer Ceiling Width Temperature Comparisons

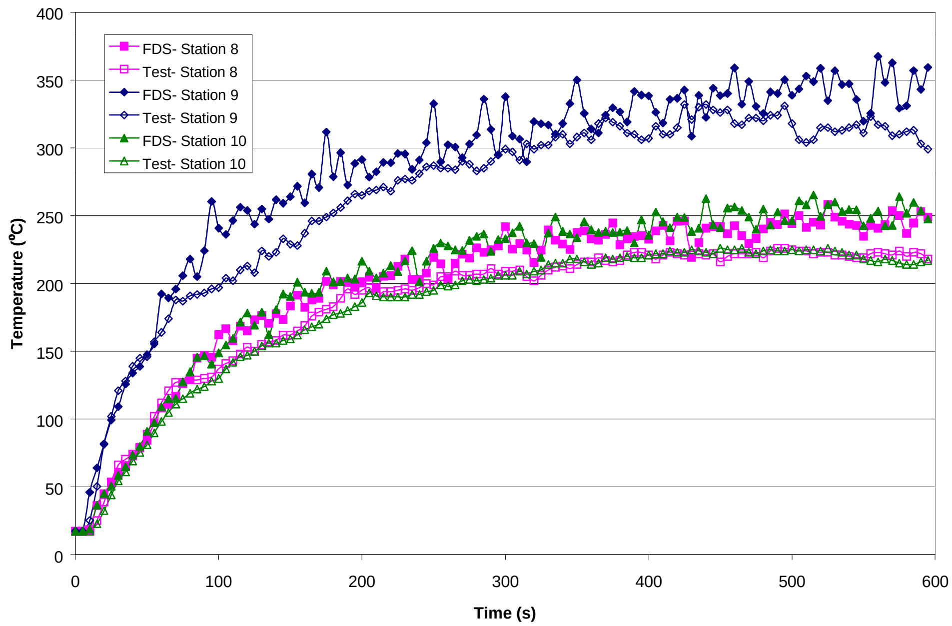

Figure A52. Test 12- 8 in. Grid Cells: Upper Layer Ceiling Length Temperature Comparisons

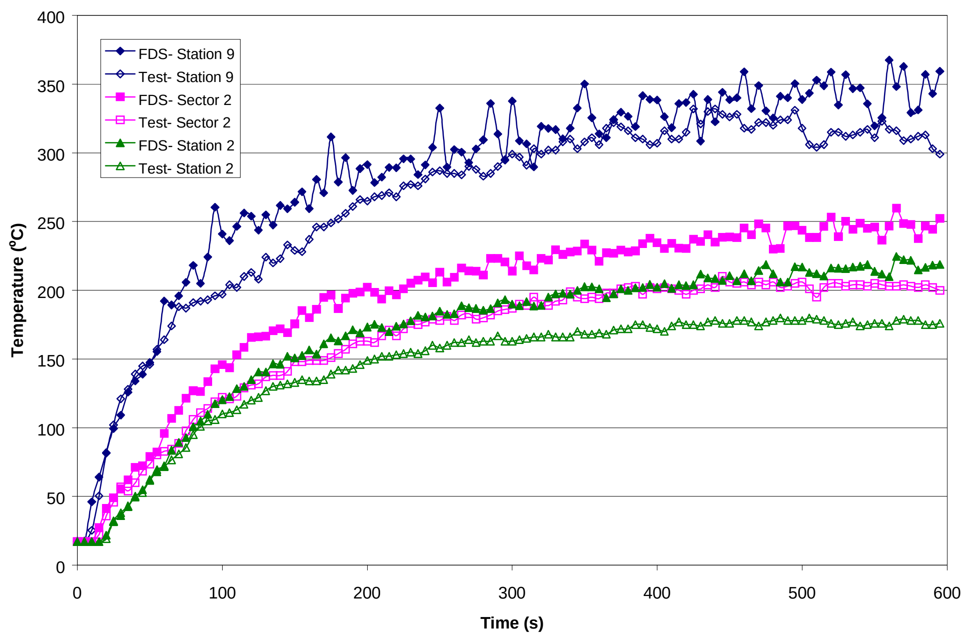

Figure A53. Test 12- 8 in. Grid Cells: Upper Layer Ceiling Width Temperature Comparisons

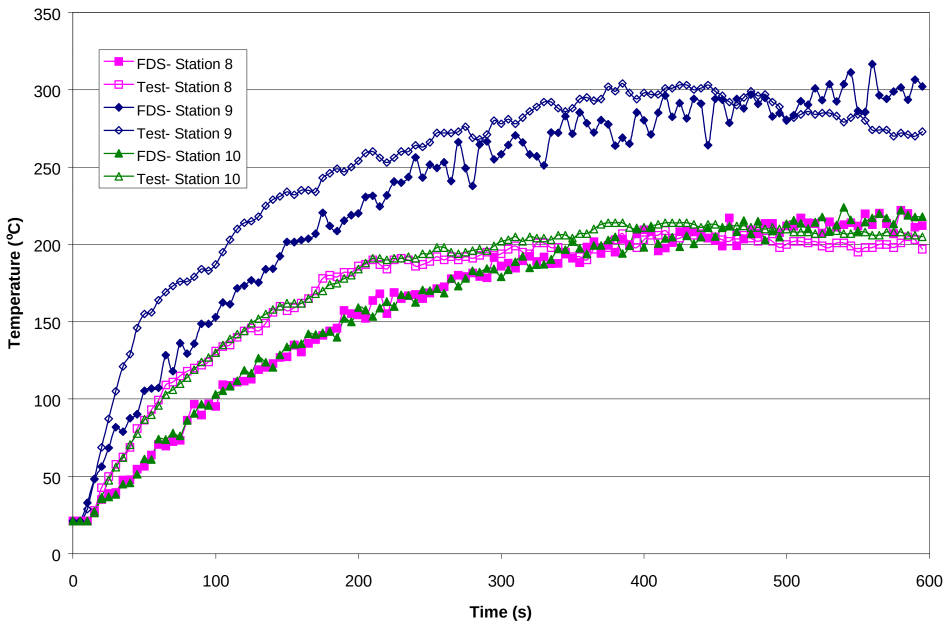

Figure A54. Test 13- 2 ft Grid Cells: Upper Layer Ceiling Length Temperature Comparisons

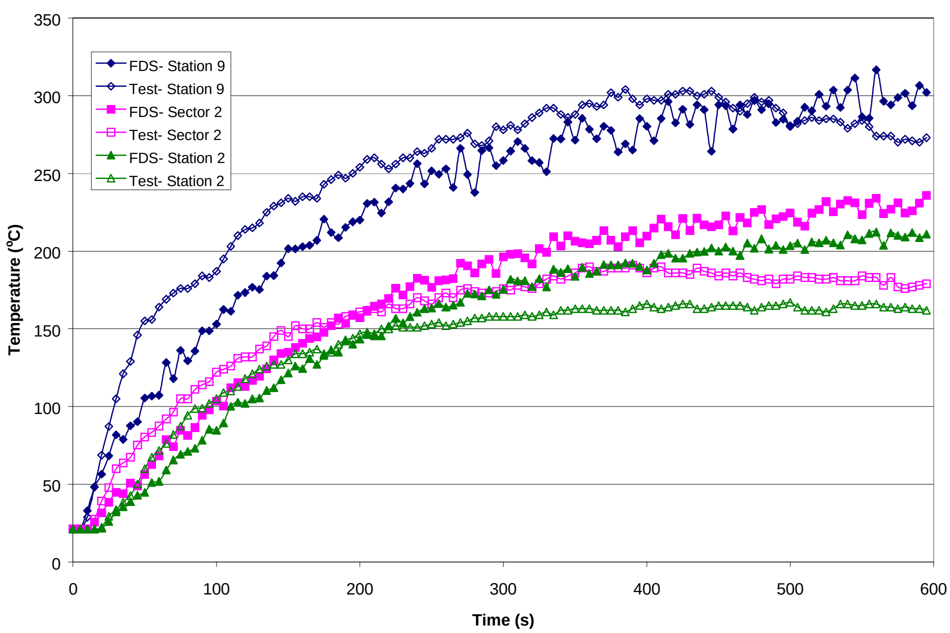

Figure A55. Test 13- 2 ft. Grid Cells: Upper Layer Ceiling Width Temperature Comparisons

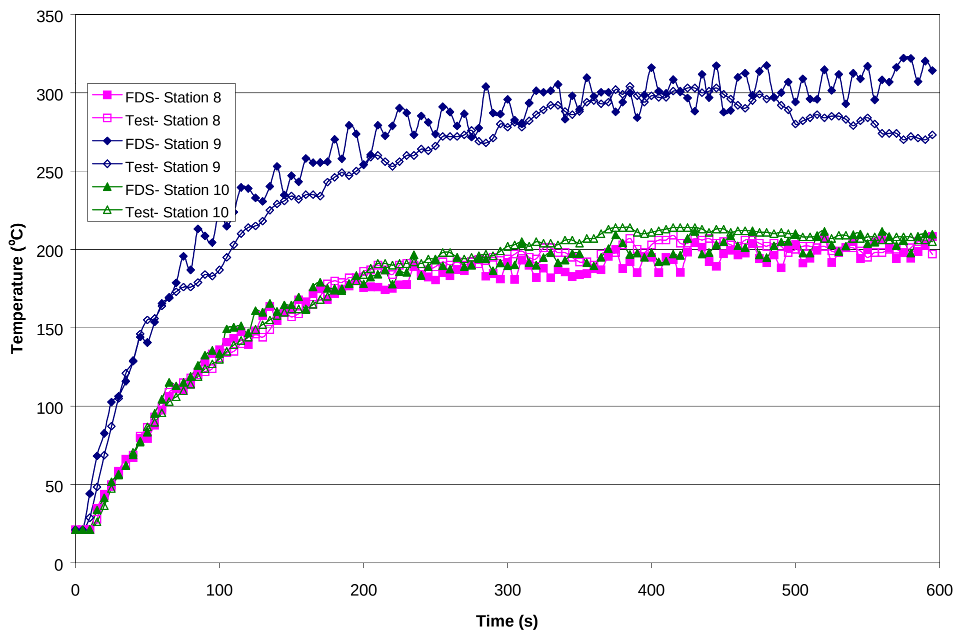

Figure A56. Test 13- 1ft Grid Cells: Upper Layer Ceiling Length Temperature Comparisons

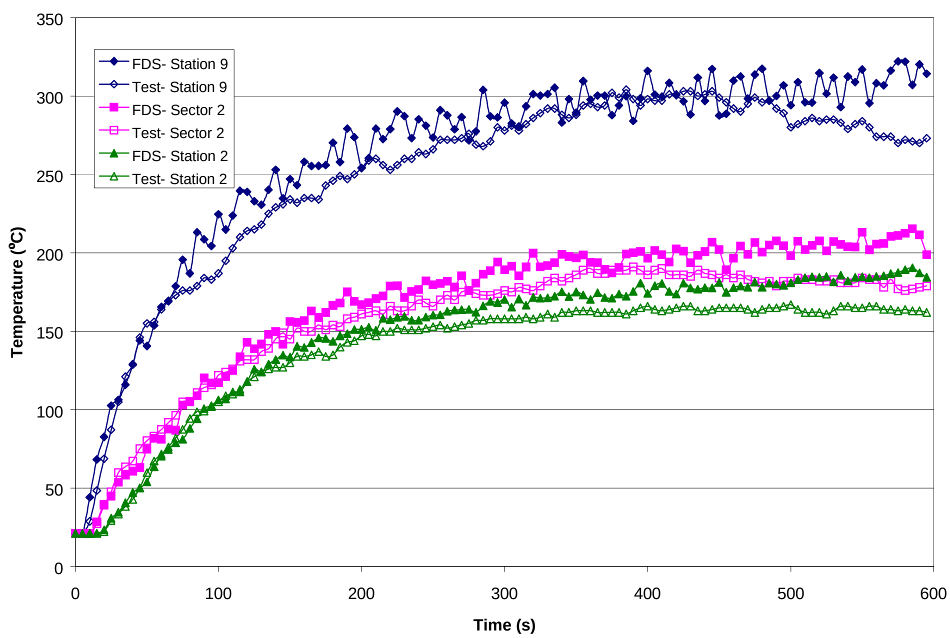

Figure A57. Test 13- 1ft. Grid Cells: Upper Layer Ceiling Width Temperature Comparisons

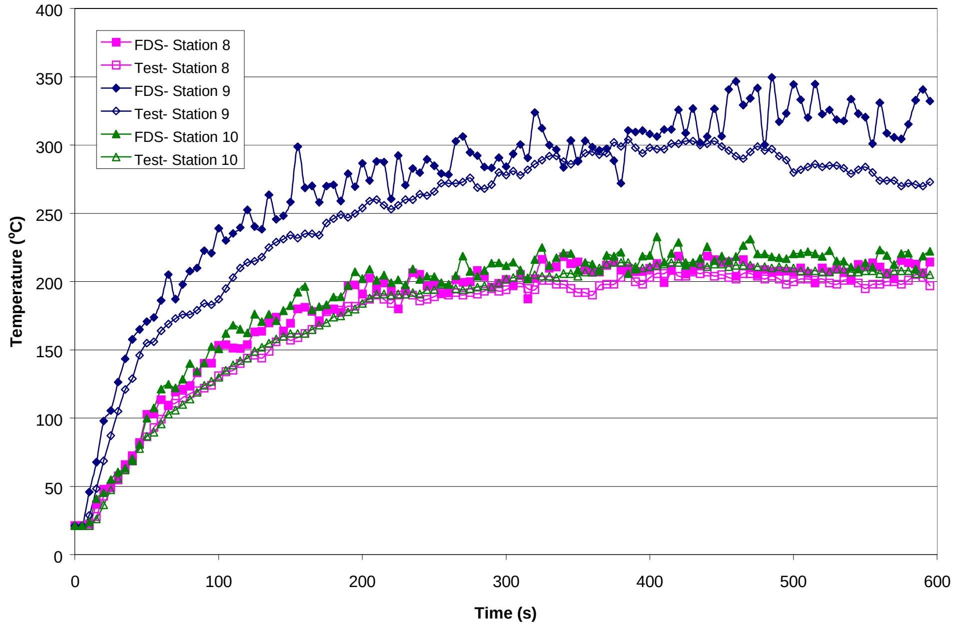

Figure A58. Test 13- 8 in. Grid Cells: Upper Layer Ceiling Length Temperature Comparisons

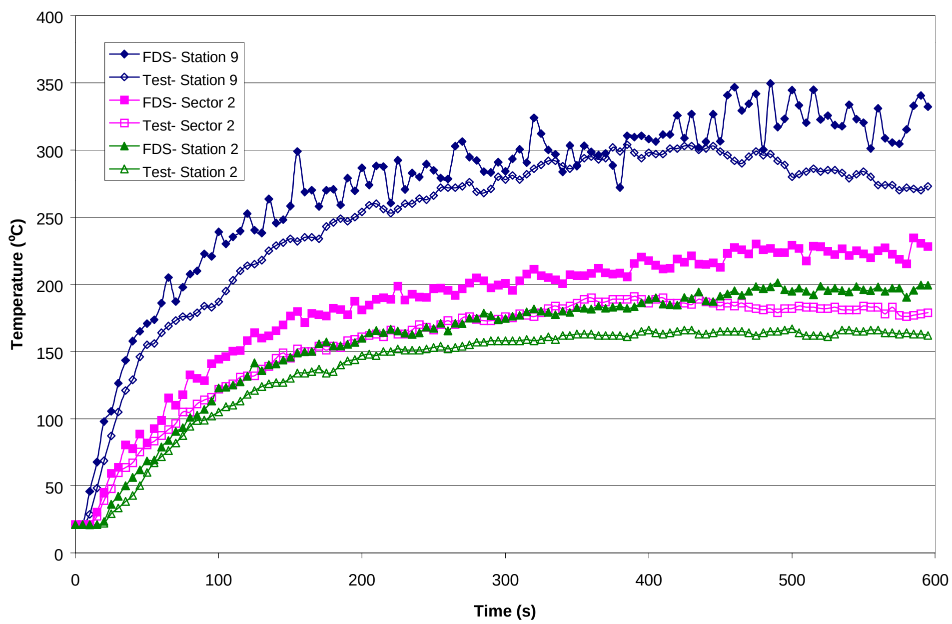

Figure A59. Test 13- 8 in. Grid Cells: Upper Layer Ceiling Width Temperature Comparisons

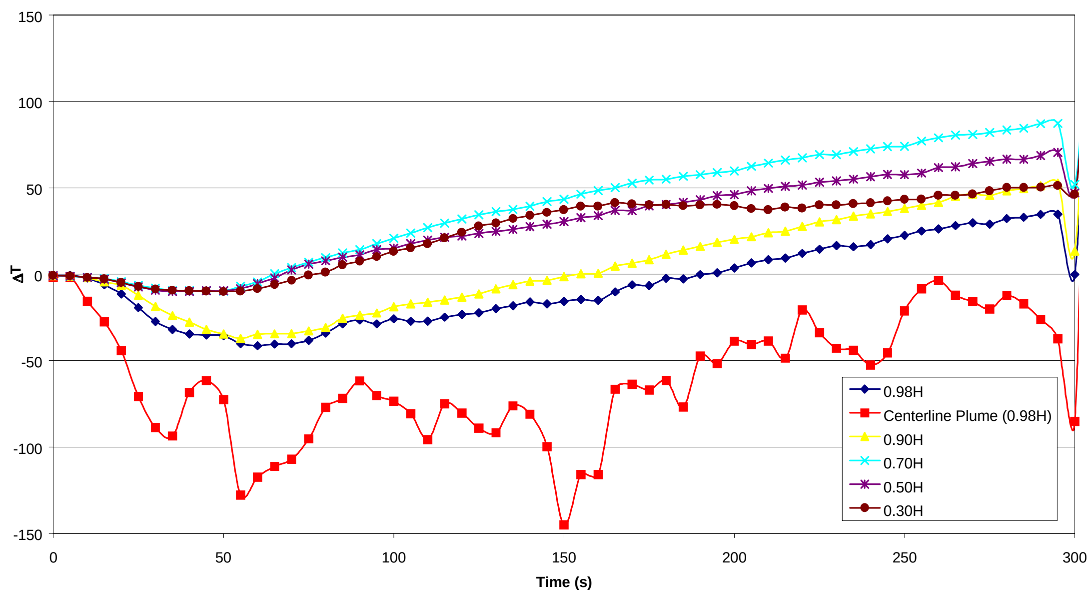

Figure A60. Average Temperature Differences Between FMSNL Test 3 and FDS with 2 ft Grid

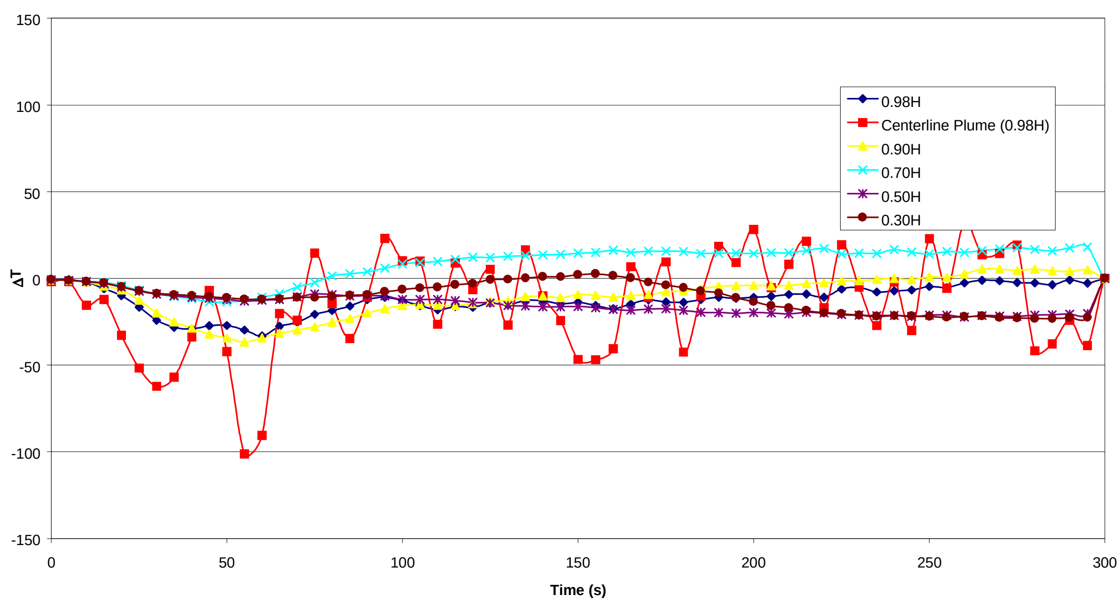

Figure A61. Average Temperature Differences Between FMSNL Test 3 and FDS with 1 ft Grid

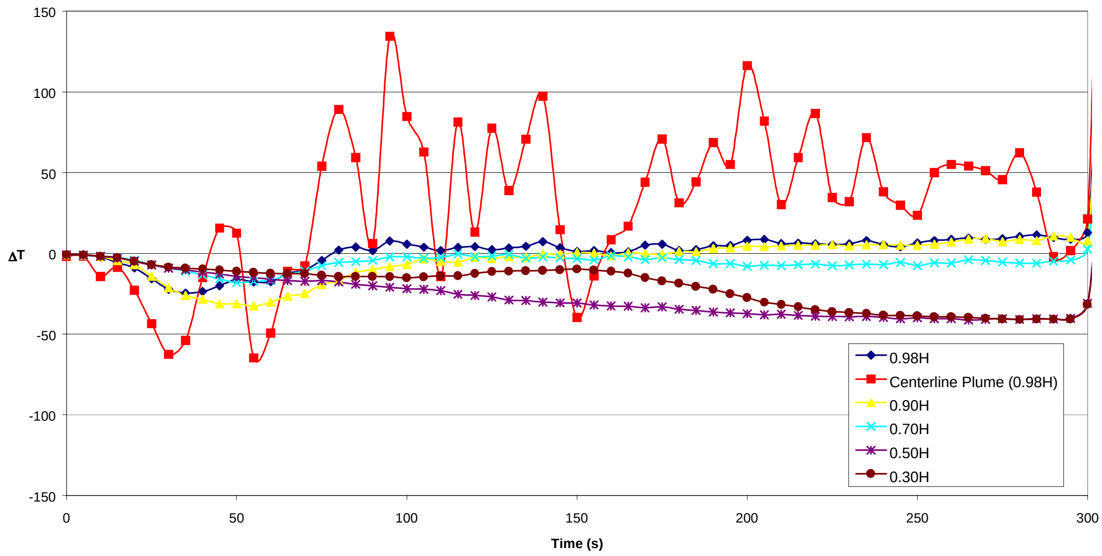

Figure A62. Average Temperature Differences Between FMSNL Test 3 and FDS with 8 in Grid

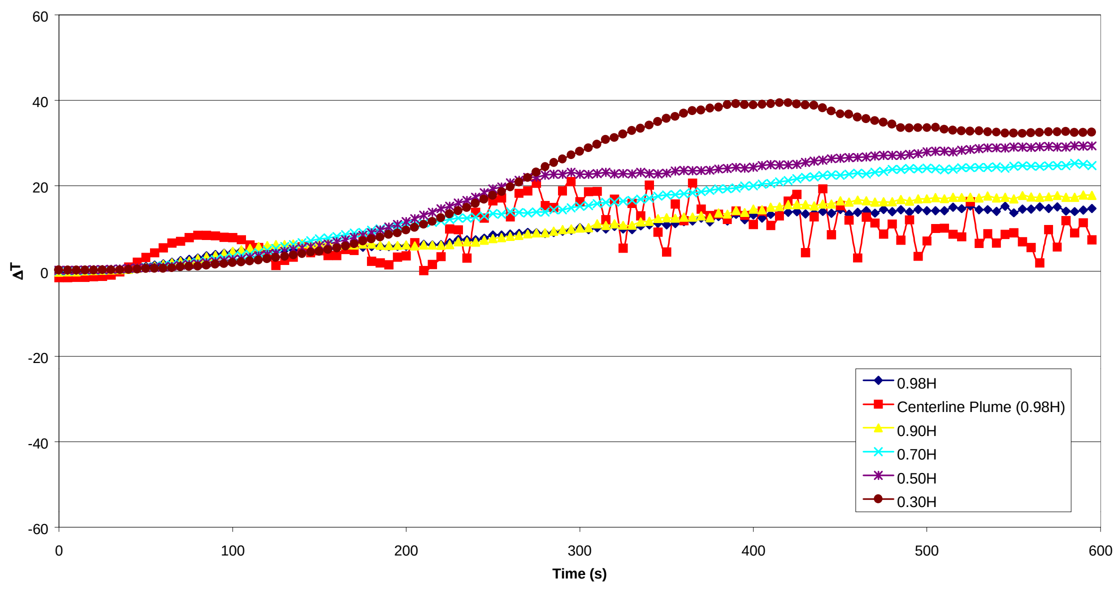

Figure A63. Average Temperature Differences Between FMSNL Test 4 and FDS with 2 ft Grid

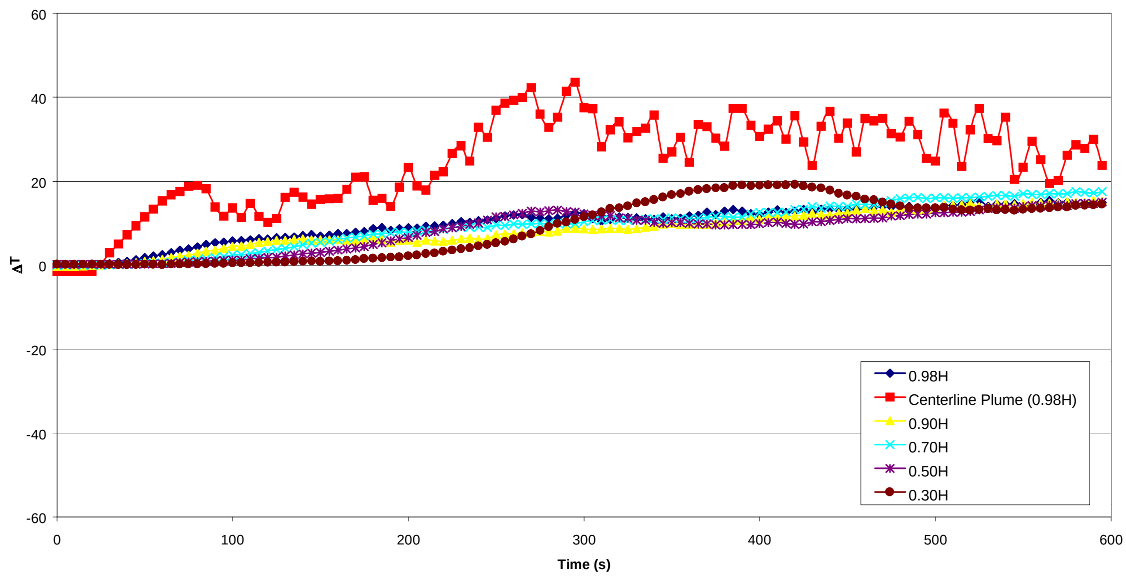

Figure A64. Average Temperature Differences between FMSNL Test 4 and FDS with 1 ft Grid

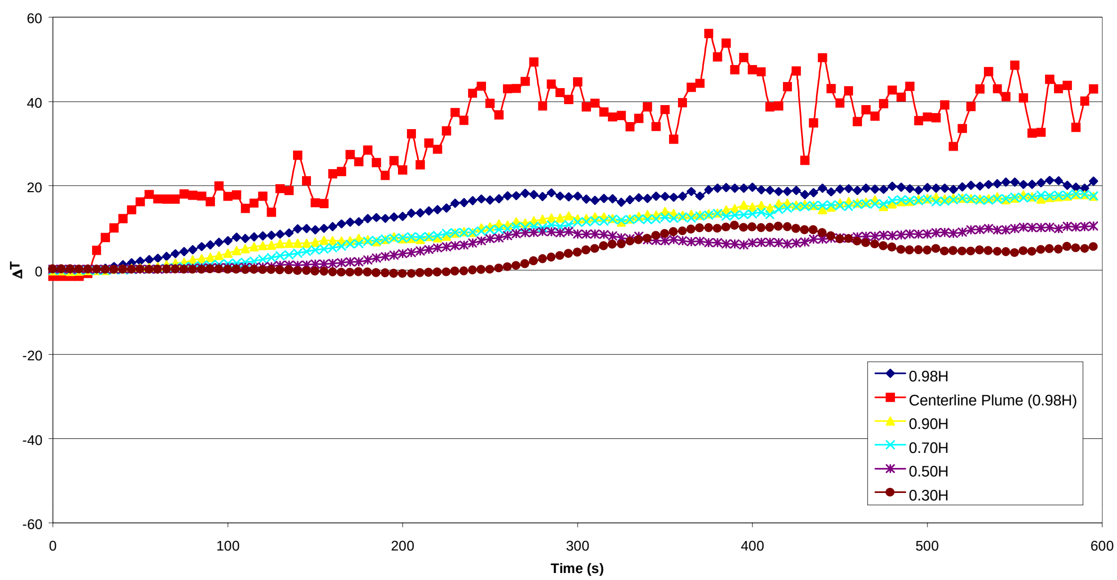

Figure A65. Average Temperature Differences between FMSNL Test 4 and FDS with 8 in Grid

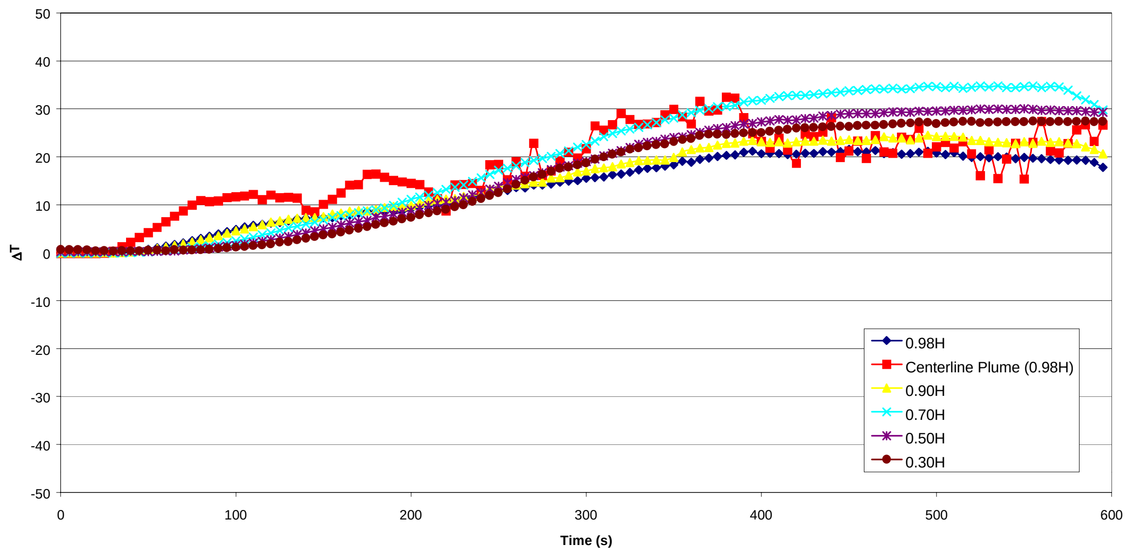

Figure A66. Average Temperature Differences between FMSNL Test 5 and FDS with 2 ft Grid

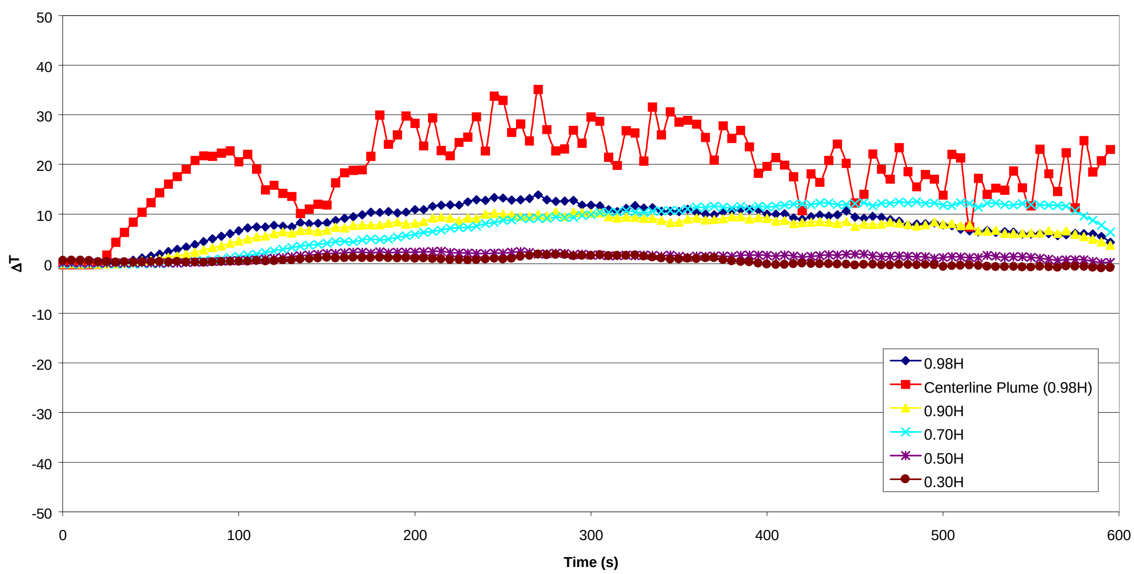

Figure A67. Average Temperature Differences between FMSNL Test 5 and FDS with 1 ft Grid

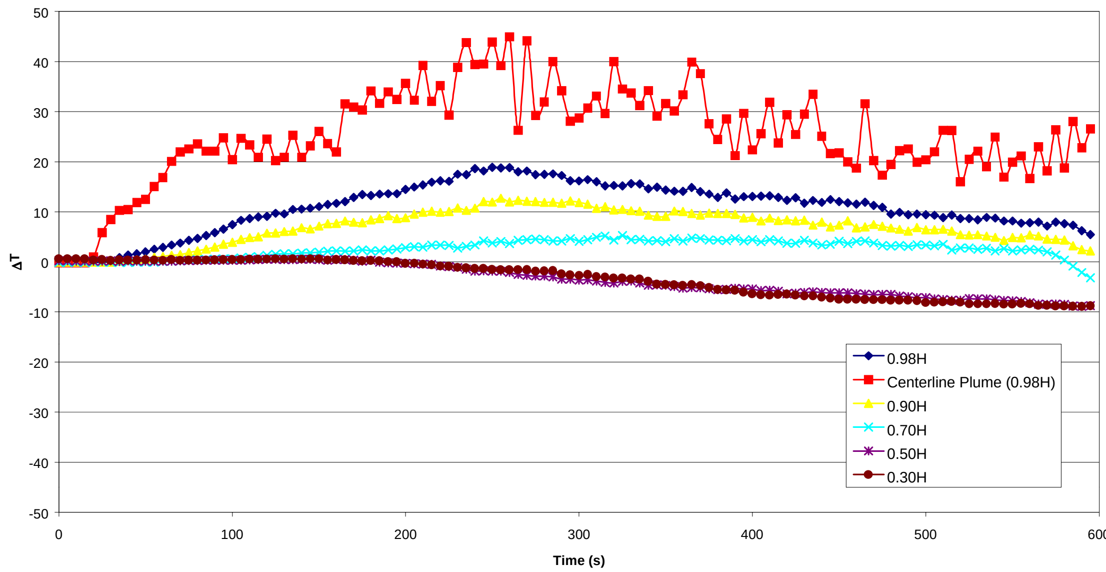

Figure A68. Average Temperature Differences Between FMSNL Test 5 and FDS with 8 in Grid

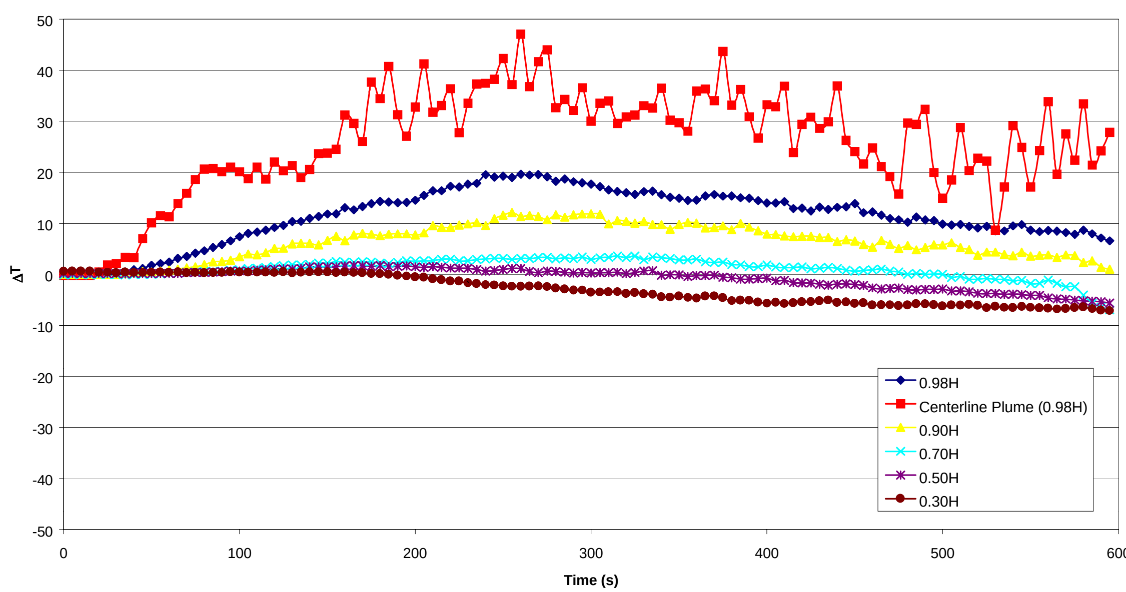

Figure A69. Average Temperature Differences Between FMSNL Test 5 and FDS with 6 in Grid

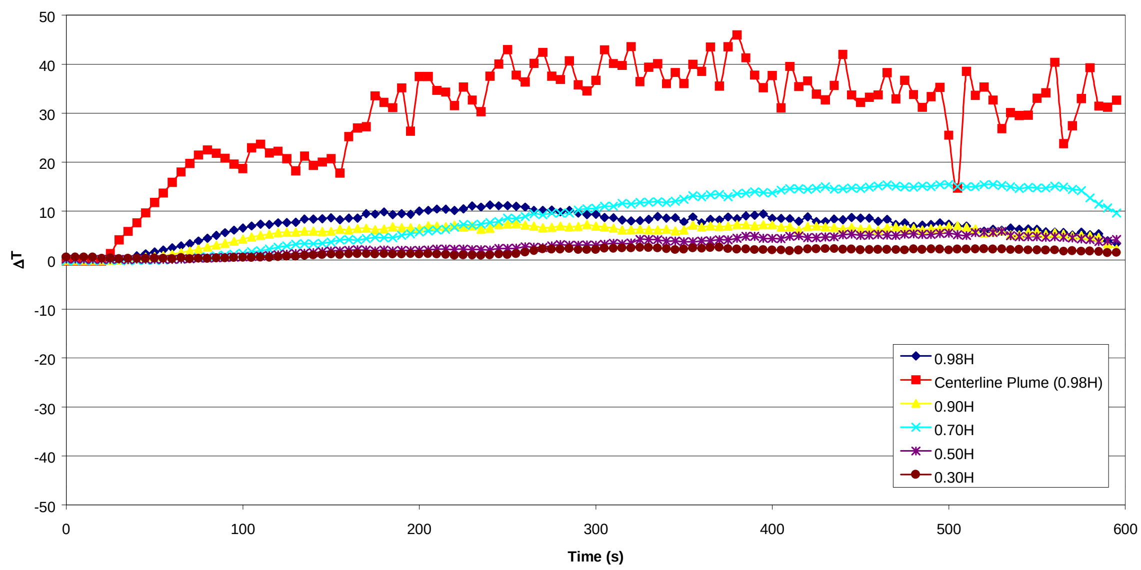

Figure A70. Average Temperature Differences Between FMSNL Test 5 and FDS with 1 ft Grid (Grid Transformed to 6 in. Around the Burner)

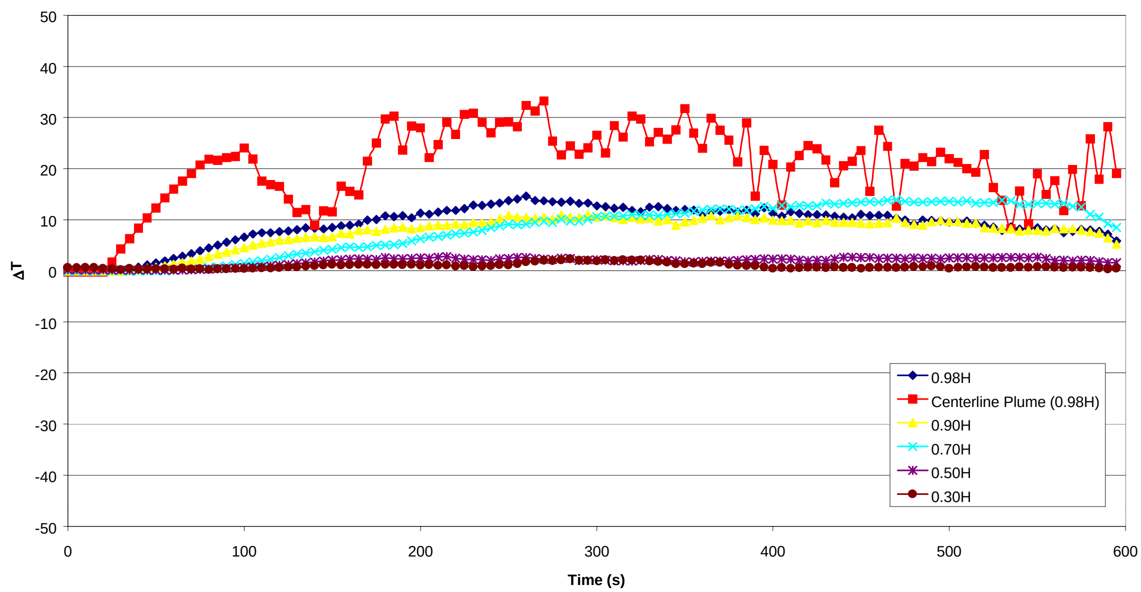

Figure A71. Average Temperature Differences Between FMSNL Test 5 and FDS with 1 ft Grid (Radiation Calculation Enabled)

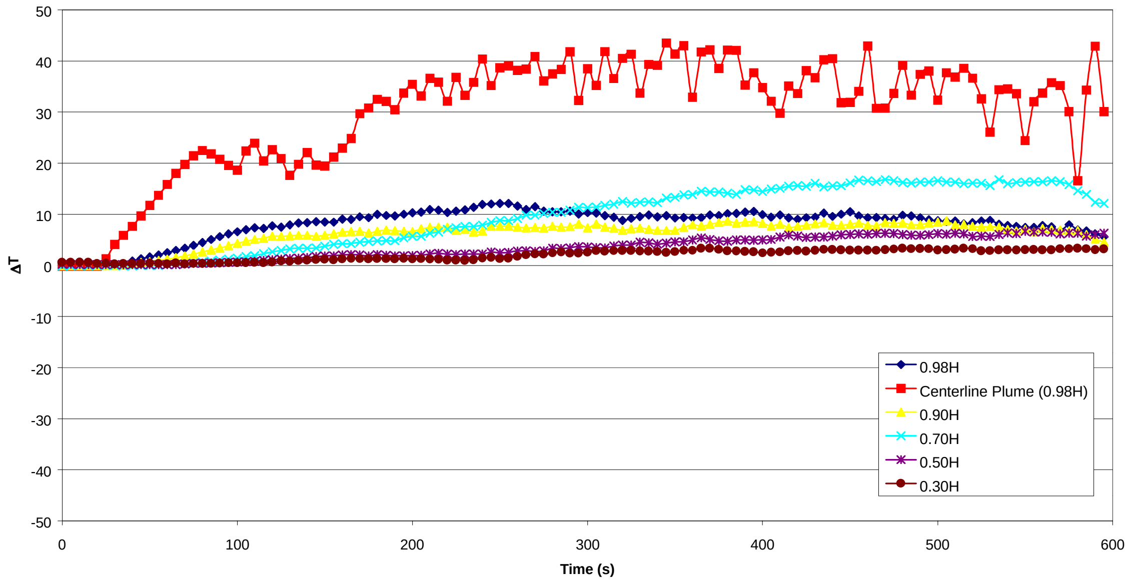

Figure A72. Average Temperature Differences Between FMSNL Test 5 and FDS w/ 1 ft Grid (Grid Transformed to 6in. Around the Burner & Radiation Calculation Enabled)

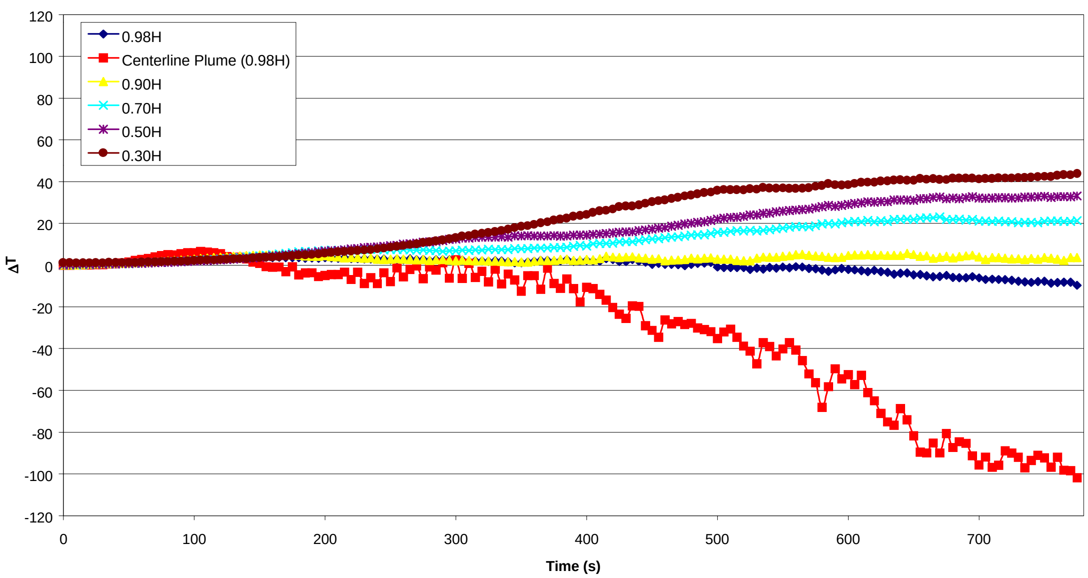

Figure A73. Average Temperature Differences Between FMSNL Test 8 and FDS with 2 ft Grid

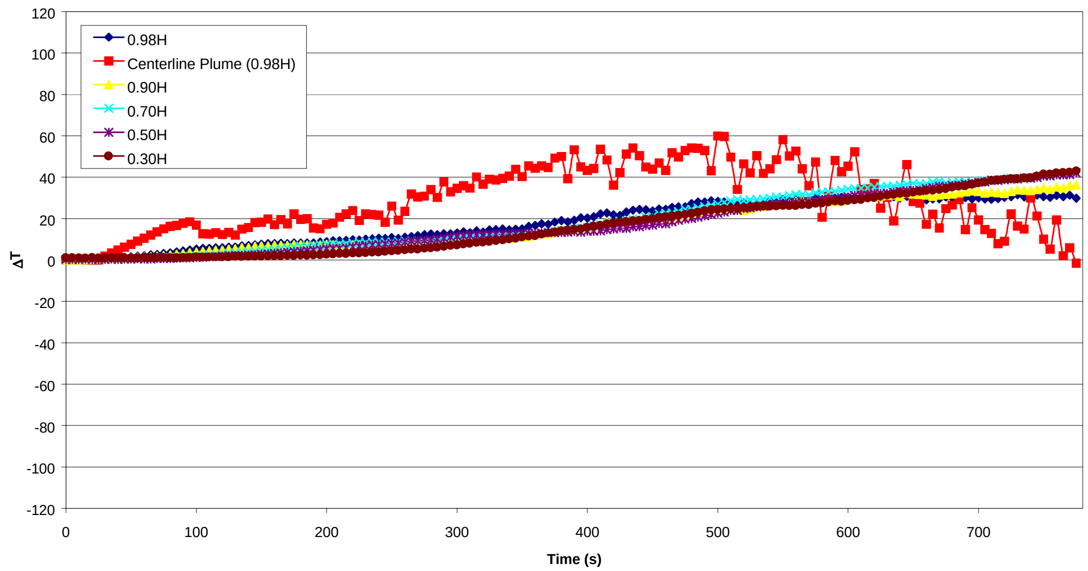

Figure A74. Average Temperature Differences Between FMSNL Test 8 and FDS with 1 ft Grid

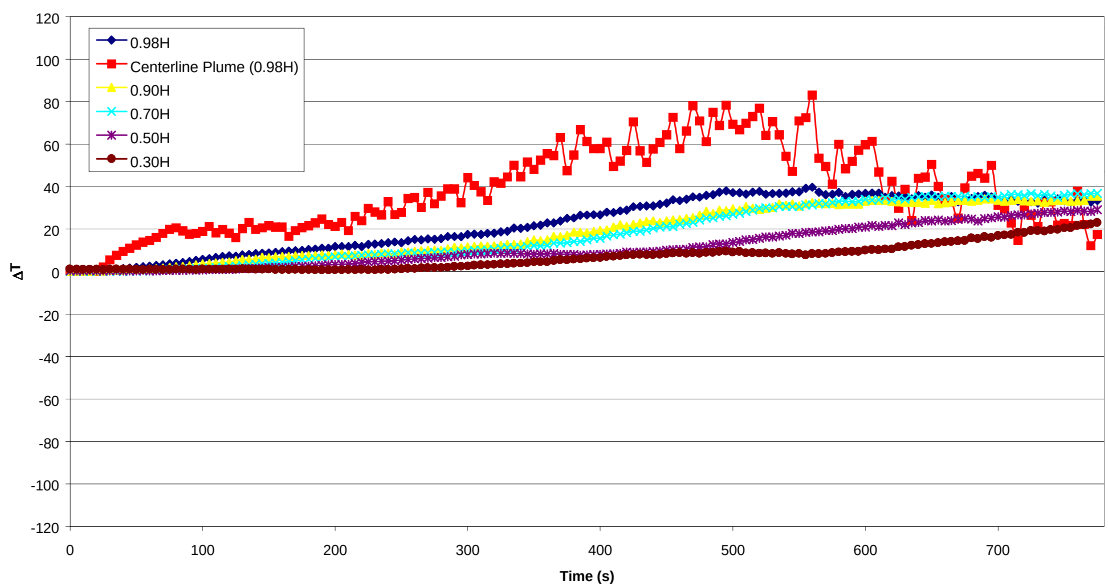

Figure A75. Average Temperature Differences Between FMSNL Test 8 and FDS with 8 in Grid

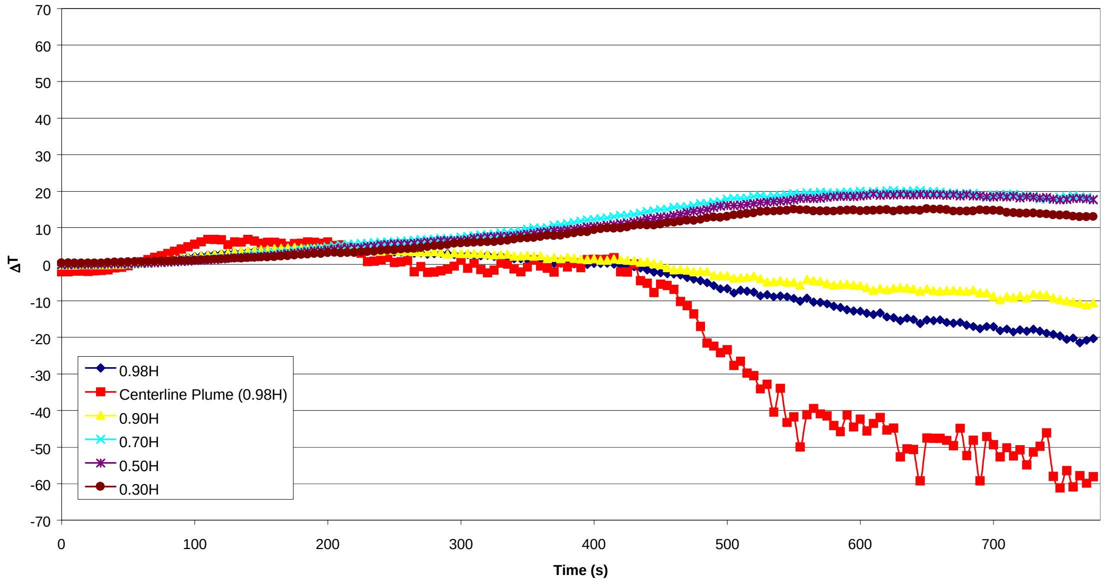

Figure A76. Average Temperature Differences Between FMSNL Test 9 and FDS with 2 ft Grid

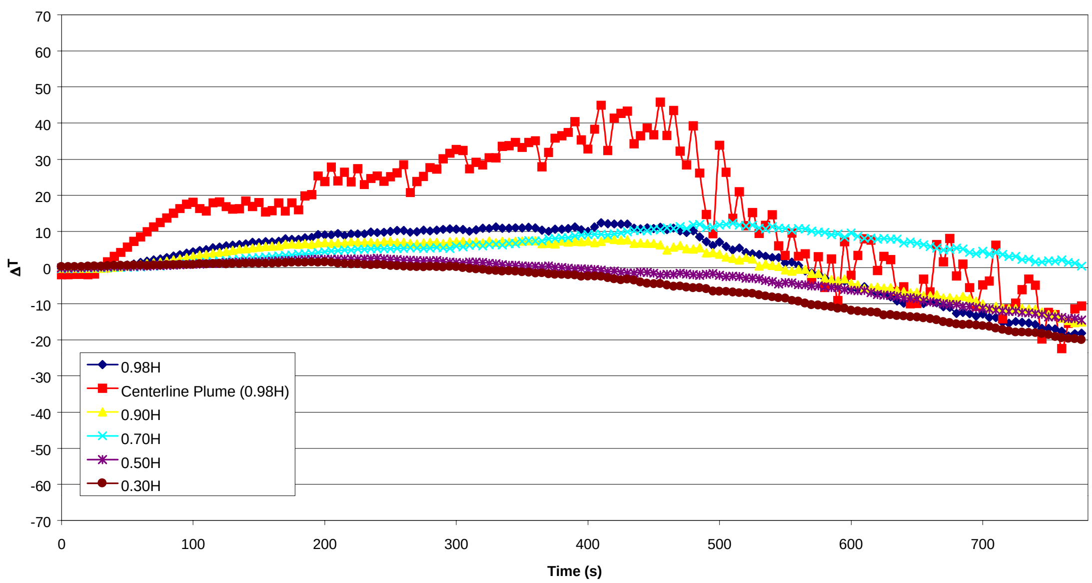

Figure A77. Average Temperature Differences between FMSNL Test 9 and FDS with 1 ft Grid

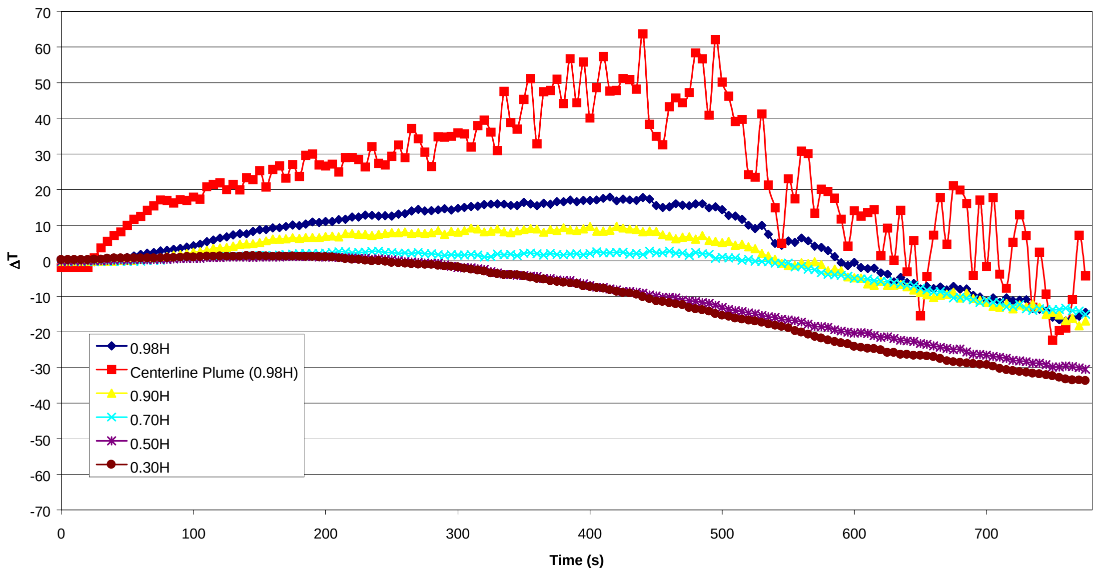

Figure A78. Average Temperature Differences Between FMSNL Test 9 and FDS with 8 in Grid

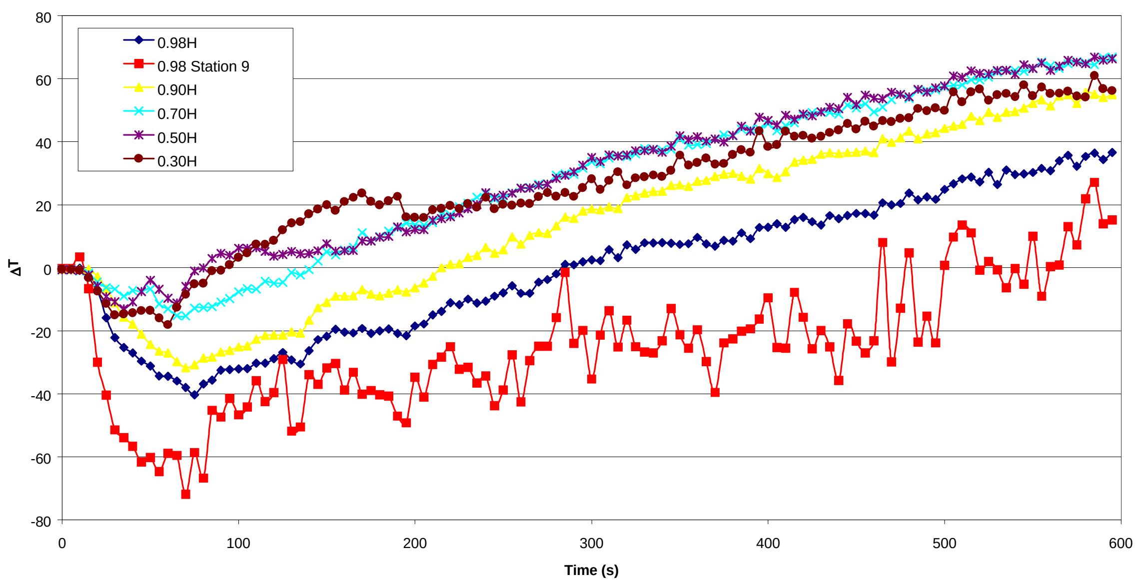

Figure A79. Average Temperature Differences between FMSNL Test 12 and FDS with 2 ft Grid

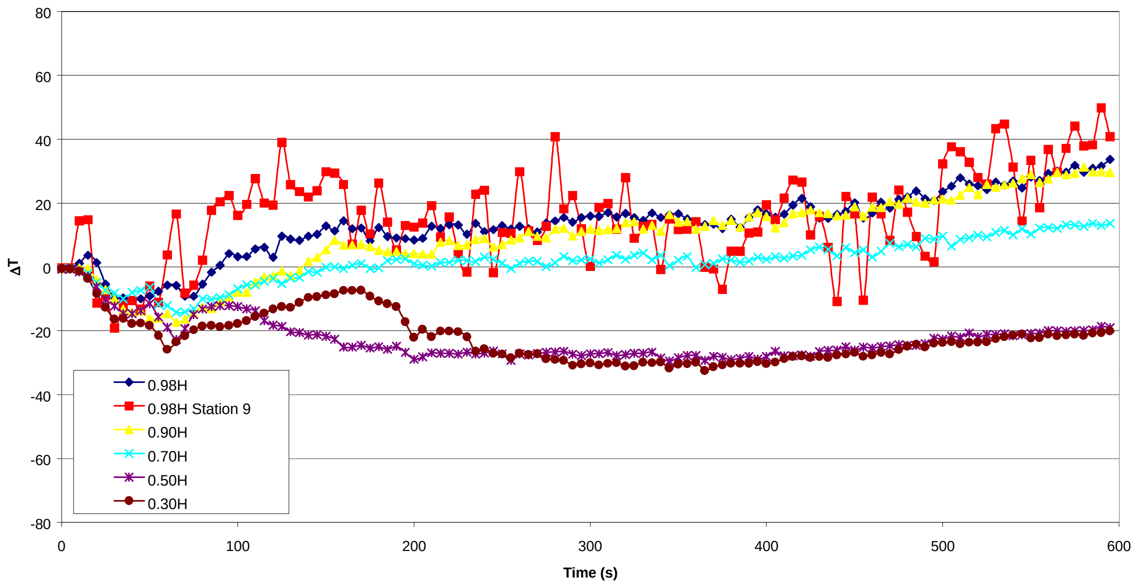

Figure A80. Average Temperature Differences between FMSNL Test 12 and FDS with 1 ft Grid

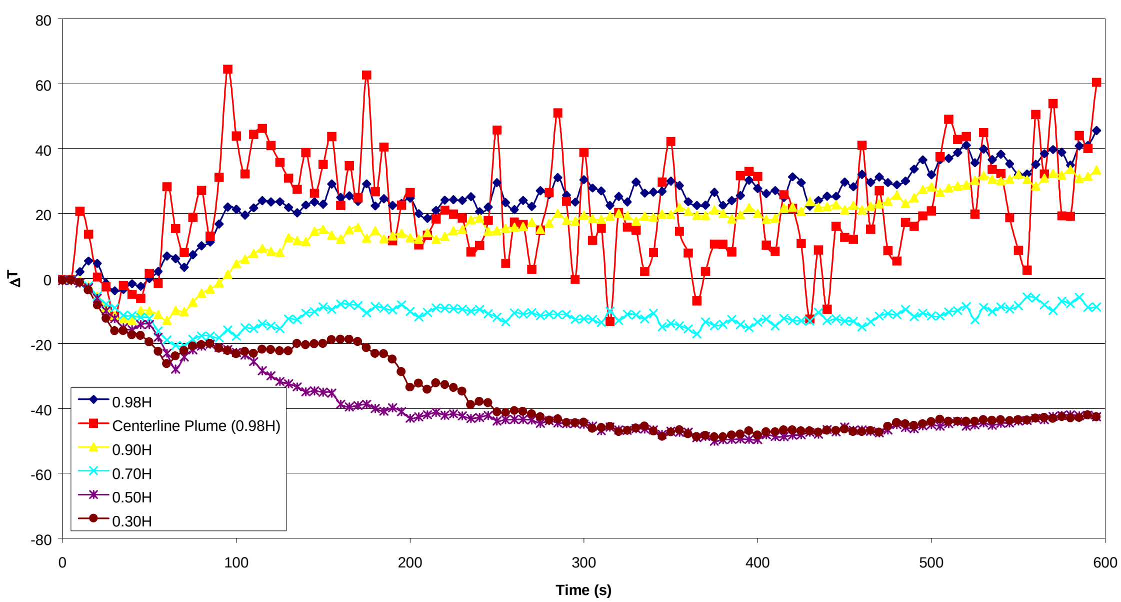

Figure A81. Average Temperature Differences between FMSNL Test 12 and FDS with 8 in Grid

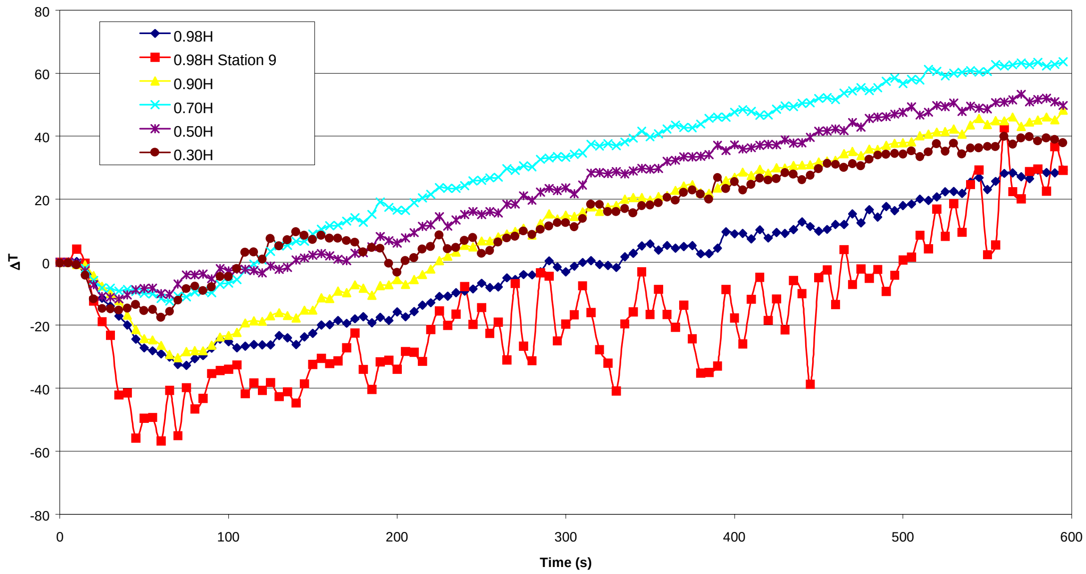

Figure A82. Average Temperature Differences between FMSNL Test 13 and FDS with 2 ft Grid

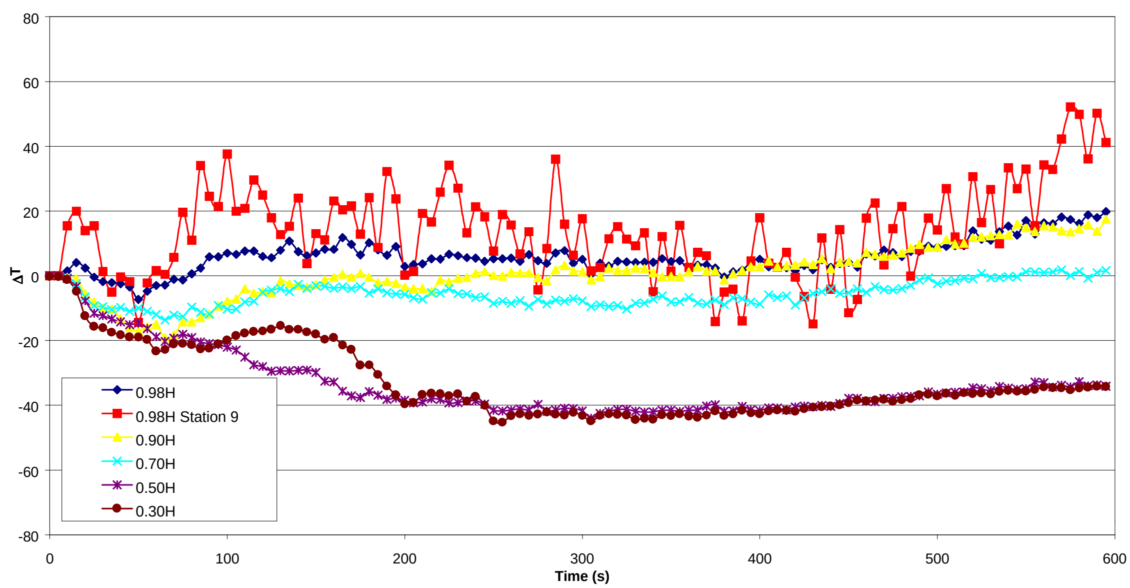

Figure A83. Average Temperature Differences between FMSNL Test 13 and FDS with 1 ft Grid

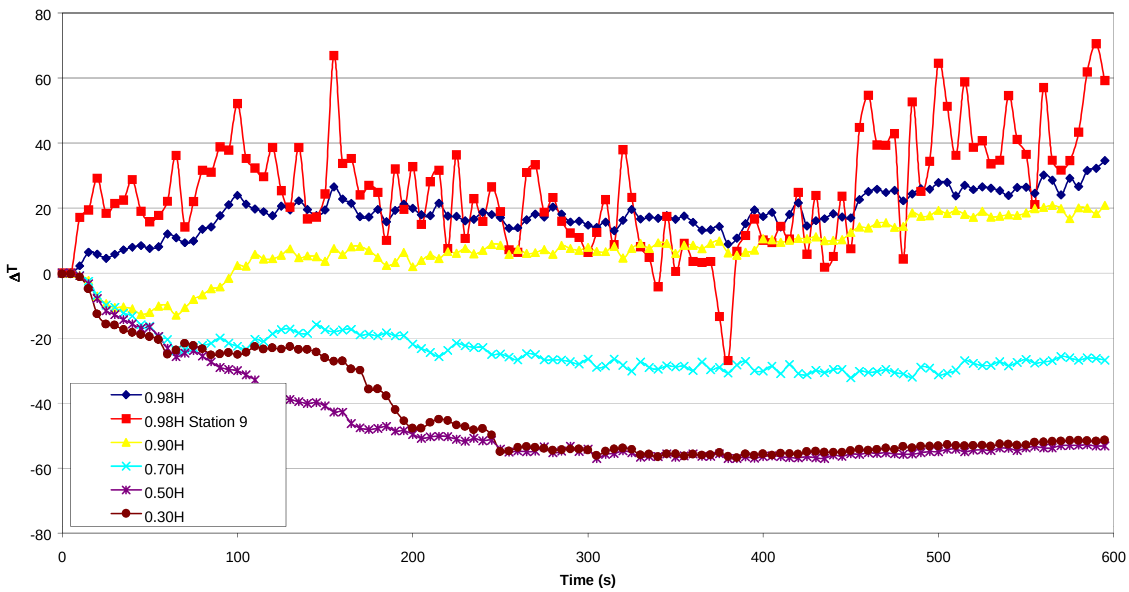

Figure A84. Average Temperature Differences between FMSNL Test 13 and FDS with 8 in Grid

APPENDIX B- Input Files

Test 3- 2 ft. Grid:

```
&HEAD CHID='test3(2ft)',TITLE='FMSNL Test #3- 2ft grid' /
&GRID IBAR=30,JBAR=20,KBAR=10 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=360. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=15.30 /
&SURF ID='burner',HRRPUA=3048.3,TBO=0.5,TAU_Q=-60 /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=17.20,VOLUME_FLUX=-0.685 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#1 injection
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#2 injection
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#3
injection
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#4 injection
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#5 injection
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#6
injection
&VENT XB=11.79,12.60,5.69,6.50,0.00,0.00,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
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/
&THCP XYZ=3.05,6.1,5.49,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch12' /
&THCP XYZ=3.05,6.1,4.27,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch13' /
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&THCP XYZ=16.76,4.57,5.98,QUANTITY='TEMPERATURE',LABEL='Station11 Ch26' /
&THCP XYZ=1.52,4.57,5.98,QUANTITY='TEMPERATURE',LABEL='Station12 Ch27' /
&THCP XYZ=12.19,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Station13 Ch28' /
(Centerline Plume)
&THCP XYZ=6.10,6.10,5.98,QUANTITY='TEMPERATURE',LABEL='Station14 Ch29' /
&THCP XYZ=16.76,7.62,5.98,QUANTITY='TEMPERATURE',LABEL='Station15 Ch30' /
&THCP XYZ=1.52,7.62,5.98,QUANTITY='TEMPERATURE',LABEL='Station16 Ch31' /
```

Test 3- 1 ft. Grid:

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&HEAD CHID='test3(1ft)',TITLE='FMSNL Test #3- 1ft grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=300. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=15.30 /
&SURF ID='burner',HRRPUA=3048.3,TBO=0.5,TAU_Q=-60 /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=17.20,VOLUME_FLUX=-0.685 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.16,SURF_ID='burner' / propylene
burner
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #6
&VENT XB=11.79,12.60,5.69,6.50,0.16,0.16,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
.
.
.
```

Test 3- 8 in. Grid:

```
&HEAD CHID='test3(8in)',TITLE='FMSNL Test #3- 8in grid' /
&GRID IBAR=90,JBAR=60,KBAR=30 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=360. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=15.30 /
&SURF ID='burner',HRRPUA=3048.3,TBO=0.5,TAU_Q=-60 /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=17.20,VOLUME_FLUX=-0.685 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #6
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
.
.
.
```

Test 4- 2 ft. Grid:

```
&HEAD CHID='test4(2ft)',TITLE='FMSNL Test#4- 2ft. grid' /
&GRID IBAR=30,JBAR=20,KBAR=10 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=15.7,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21.2,VOLUME_FLUX=-0.107 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#1 injection
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#2 injection
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#3 injection
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#4 injection
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#5 injection
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#6 injection
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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```

Test 4- 1 ft. Grid:

```
&HEAD CHID='test4(1ft)',TITLE='FMSNL Test #4- 1ft. grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=15.7,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=2.0E-7,KS=0.23,DELTA=0.0254 /
&SURF TMPWAL=21.2,VOLUME_FLUX=-0.107 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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```

Test 4- 8 in. Grid:

```
&HEAD CHID='test4(8in)',TITLE='FMSNL Test #4- 8in grid' /
&GRID IBAR=90,JBAR=60,KBAR=30 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=15.7,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=2.0E-7,KS=0.23,DELTA=0.0254 /
&SURF TMPWAL=21.2,VOLUME_FLUX=-0.107 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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.
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```

Test 5- 2 ft. Grid:

```
&HEAD CHID='test5(2ft)',TITLE='FMSNL Test #5- 2ft. grid' /
&GRID IBAR=30,JBAR=20,KBAR=10 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#1 injection
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#2 injection
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#3 injection
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#4 injection
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#5 injection
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#6 injection
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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```

Test 5- 1 ft. Grid:

```
&HEAD CHID='test5(1ft)',TITLE='FMSNL Test #5- 1ft. grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
.
.
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Test 5- 8 in. Grid:

```
&HEAD CHID='test5(8in)',TITLE='FMSNL Test #5- 8in. grid' /
&GRID IBAR=90,JBAR=60,KBAR=30 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 5- 6 in. Grid:

```
&HEAD CHID='test5d2',TITLE='FMSNL Test #5- 6in. grid' /
&GRID IBAR=120,JBAR=80,KBAR=40 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 5- 1 ft. Grid (transformation to 6 in. around burner):

```
&HEAD CHID='test5(1ft_tran)',TITLE='FMSNL Test #5- 1ft. with grid trans' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TRNX CC=9.14,PC=10.67 /
&TRNX CC=15.24,PC=13.72 /
&TRNY CC=3.05,PC=4.57 /
&TRNY CC=9.15,PC=7.62 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21,RADIATION=.FALSE. /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 5- 1 ft. Grid (radiation calculated):

```
&HEAD CHID='test5(1ft_rad)',TITLE='FMSNL Test #5- radiation' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21 /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.25E-7,KS=0.1032,DELTA=0.0254 / thermal properties for
Marinite
&SURF TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 5- 1 ft. Grid (transformation to 6 in. around burner and radiation calculated):

```
&HEAD CHID='test5(1ft_t_r)',TITLE='FMSNL Test #5- 1ft. trans and radiation'
/
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TRNX CC=9.14,PC=10.67 /
&TRNX CC=15.24,PC=13.72 /
&TRNY CC=3.05,PC=4.57 /
&TRNY CC=9.15,PC=7.62 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21 /
&SURF HRRPUA=787.,TBO=0.5,TAU_Q=-240. /
&SURF ALPHA=1.25E-7,KS=0.1032,DELTA=0.0254 / thermal properties for
Marinite
&SURF TMPWAL=21,VOLUME_FLUX=-0.63 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,ISURF=1 / propylene burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 8- 2 ft. Grid:

```
&HEAD CHID='test8(2ft)',TITLE='FMSNL Test #8- 2ft grid' /
&GRID IBAR=30,JBAR=20,KBAR=10 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=780. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=25.10 /
&SURF ID='burner',HRRPUA=1524.,TBO=0.5,TAU_Q=-480. /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=32.50,VOLUME_FLUX=-0.089 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#1 injection
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#2 injection
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#3
injection
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#4 injection
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#5 injection
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#6
injection
&VENT XB=11.79,12.60,5.69,6.50,0.00,0.00,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 8- 1 ft. Grid:

```
&HEAD CHID='test8(1ft)',TITLE='FMSNL Test #1- 1ft grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=780. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=25.10 /
&SURF ID='burner',HRRPUA=1524.,TBO=0.5,TAU_Q=-480. /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=32.50,VOLUME_FLUX=-0.089 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.305 /sand burner
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #6
&VENT XB=11.79,12.60,5.69,6.50,0.305,0.305,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 8- 8 in. Grid:

```
&HEAD CHID='test8(8in)',TITLE='FMSNL Test #1- 8in grid' /
&GRID IBAR=90,JBAR=60,KBAR=30 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=780. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=25.10 /
&SURF ID='burner',HRRPUA=1524.,TBO=0.5,TAU_Q=-480. /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=32.50,VOLUME_FLUX=-0.089 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #6
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 9- 2 ft. Grid:

```
&HEAD CHID='test9(2ft)',TITLE='FMSNL Test #9- 2ft grid' /
&GRID IBAR=30,JBAR=20,KBAR=10 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=780. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=27.10 /
&SURF ID='burner',HRRPUA=1524.,TBO=0.5,TAU_Q=-480. /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=29.10,VOLUME_FLUX=-0.663 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#1 injection
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#2 injection
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,SURF_ID='port',IOR=-3 /#3
injection
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#4 injection
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#5 injection
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port',IOR=-3 /#6
injection
&VENT XB=11.79,12.60,5.69,6.50,0.00,0.00,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 9- 1 ft. Grid:

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&HEAD CHID='test9(1ft)',TITLE='FMSNL Test #9- 1ft grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=780. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=27.10 /
&SURF ID='burner',HRRPUA=1524.,TBO=0.5,TAU_Q=-480. /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=29.10,VOLUME_FLUX=-0.663 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.305 /sand burner
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #6
&VENT XB=11.79,12.60,5.69,6.50,0.305,0.305,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 9- 8 in. Grid:

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&HEAD CHID='test9(8in)',TITLE='FMSNL Test #9- 8in grid' /
&GRID IBAR=90,JBAR=60,KBAR=30 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=780. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=27.10 /
&SURF ID='burner',HRRPUA=1524.,TBO=0.5,TAU_Q=-480. /
&SURF ID='wall',ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254,RADIATION=.FALSE. /
&SURF ID='port',TMPWAL=29.10,VOLUME_FLUX=-0.663 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=11.79,12.60,5.69,6.50,0.00,0.15 /sand burner
&VENT CB='EAST',SURF_ID='wall' /
&VENT CB='WEST',SURF_ID='wall' /
&VENT CB='NORTH',SURF_ID='wall' /
&VENT CB='SOUTH',SURF_ID='wall' /
&VENT CB='TOP',SURF_ID='wall' /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,SURF_ID='port' /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,SURF_ID='port' /vent on port #6
&VENT XB=11.79,12.60,5.69,6.50,0.15,0.15,SURF_ID='burner' / propylene
burner
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,SURF_ID='OPEN' / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 12- 2 ft. Grid:

```
&HEAD CHID='test12(2ft)',TITLE='FMSNL Test #12-2ft grid' /
&GRID IBAR=30,JBAR=20,KBAR=10 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=17.2,RADIATION=.FALSE. /
&SURF HRRPUA=2632.,TBO=0.5,TAU_Q=60 /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=19.6,VOLUME_FLUX=-0.504 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=8.69,9.61,11.19,12.10,0.00,0.15 /heptane pan (3x3ft)
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#1 injection
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#2 injection
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#3 injection
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#4 injection
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#5 injection
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#6 injection
&VENT XB=8.69,9.61,11.19,12.10,0.15,0.15,ISURF=1 / heptane pan
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 12- 1 ft. Grid:

```
&HEAD CHID='test12(1ft)',TITLE='FMSNL Test #12- 1 ft. grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=17.2,RADIATION=.FALSE. /
&SURF HRRPUA=2632.,TBO=0.5,TAU_Q=60 /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=19.6,VOLUME_FLUX=-0.504 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.69,9.61,11.19,12.10,0.00,0.15 /heptane pan (3x3ft)
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #6
&VENT XB=8.69,9.61,11.19,12.10,0.15,0.15,ISURF=1 / heptane pan
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
```

Test 12- 8 in. Grid:

```
&HEAD CHID='test12(8in)',TITLE='FMSNL Test #12- 8in grid' /
&GRID IBAR=90,JBAR=60,KBAR=30 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=17.2,RADIATION=.FALSE. /
&SURF HRRPUA=2632.,TBO=0.5,TAU_Q=60 /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=19.6,VOLUME_FLUX=-0.504 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.69,9.61,11.19,12.10,0.00,0.15 /heptane pan (3x3ft)
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #6
&VENT XB=8.69,9.61,11.19,12.10,0.15,0.15,ISURF=1 / heptane pan
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
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Test 13- 2 ft. Grid:

```
&HEAD CHID='test13(2ft)',TITLE='FMSNL Test #13-2ft grid' /
&GRID IBAR=30,JBAR=20,KBAR=10 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21.2,RADIATION=.FALSE. /
&SURF HRRPUA=2632.,TBO=0.5,TAU_Q=60 /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21.2,VOLUME_FLUX=-0.697 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=8.69,9.61,11.19,12.10,0.00,0.15 /heptane pan (3x3ft)
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.28,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#1 injection
&VENT XB=8.91,9.37,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#2 injection
&VENT XB=15.01,15.47,2.82,3.28,4.88,4.88,ISURF=3,IOR=-3 /#3 injection
&VENT XB=2.82,3.28,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#4 injection
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#5 injection
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3,IOR=-3 /#6 injection
&VENT XB=8.69,9.61,11.19,12.10,0.15,0.15,ISURF=1 / heptane pan
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
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Test 13- 1 ft. Grid:

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&HEAD CHID='test13(1ft)',TITLE='FMSNL Test #13-1ft grid' /
&GRID IBAR=60,JBAR=40,KBAR=20 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21.2,RADIATION=.FALSE. /
&SURF HRRPUA=2632.,TBO=0.5,TAU_Q=60 /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21.2,VOLUME_FLUX=-0.697 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.69,9.61,11.19,12.10,0.00,0.15 /heptane pan (3x3ft)
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #6
&VENT XB=8.69,9.61,11.19,12.10,0.15,0.15,ISURF=1 / heptane pan
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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Test 13- 8 in. Grid:

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&HEAD CHID='test13(8in)',TITLE='FMSNL Test #13-8in grid' /
&GRID IBAR=90,JBAR=60,KBAR=30 /
&PDIM XBAR=18.29,YBAR=12.19,ZBAR=6.10 /
&TIME DT=0.2,TWFIN=600. /
&PART QUANTITY='TEMPERATURE',DTPAR=0.05 /
&MISC TMPA=21.2,RADIATION=.FALSE. /
&SURF HRRPUA=2632.,TBO=0.5,TAU_Q=60 /
&SURF ALPHA=1.55E-7,KS=0.1035,DELTA=0.0254 /
&SURF TMPWAL=21.2,VOLUME_FLUX=-0.697 /
&OBST XB=2.82,3.28,2.82,3.28,4.88,6.10 /#1 injection port
&OBST XB=2.82,3.28,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,2.82,3.28,4.88,6.10 /#2 injection port
&OBST XB=8.91,9.37,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,2.82,3.28,4.88,6.10 /#3 injection port
&OBST XB=15.01,15.47,2.82,3.28,4.57,4.57 /deflector plate
&OBST XB=2.82,3.28,8.91,9.37,4.88,6.10 /#4 injection port
&OBST XB=2.82,3.28,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.91,9.37,8.91,9.37,4.88,6.10 /#5 injection port
&OBST XB=8.91,9.37,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=15.01,15.47,8.91,9.37,4.88,6.10 /#6 injection port
&OBST XB=15.01,15.47,8.91,9.37,4.57,4.57 /deflector plate
&OBST XB=8.69,9.61,11.19,12.10,0.00,0.15 /heptane pan (3x3ft)
&VENT CB='EAST',ISURF=2 /
&VENT CB='WEST',ISURF=2 /
&VENT CB='NORTH',ISURF=2 /
&VENT CB='SOUTH',ISURF=2 /
&VENT CB='TOP',ISURF=2 /
&VENT XB=2.82,3.27,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #1
&VENT XB=8.91,9.37,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #2
&VENT XB=15.01,15.47,2.82,3.27,4.88,4.88,ISURF=3 /vent on port #3
&VENT XB=2.82,3.27,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #4
&VENT XB=8.91,9.37,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #5
&VENT XB=15.01,15.47,8.91,9.37,4.88,4.88,ISURF=3 /vent on port #6
&VENT XB=8.69,9.61,11.19,12.10,0.15,0.15,ISURF=1 / heptane pan
&VENT XB=0.10,0.61,5.18,7.01,6.10,6.10,ISURF=-2 / exhaust vent
&THCP XYZ=3.05,6.1,5.98,QUANTITY='TEMPERATURE',LABEL='Sector3 Ch11',DTSAM=5
/
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The Fire Dynamics Simulator (FDS), a recently developed field fire model based on large eddy simulation (LES), is used to simulate seven full-scale fire tests. The fire tests were conducted in a large mechanically ventilated enclosure with dimensions of 18.3 m x 12.2 m x 6.1 m high, with air injection rates ranging from 1 to 12 air changes per hour (ACH), and fire heat release rates ranging from 0 to 2 MW. Test measurements and simulation predictions are compared. Comparison methods are presented and discussed. Simulations are run with 6,000, 48,000, and 162,000 grid cells to evaluate the influence of grid resolution on prediction accuracy. One test series was run on six different personal computers to explore the effects of different hardware configurations on simulation times. A grid dependent plume study was performed to investigate the relationship of grid resolution and plume temperature predictions. Increasing the number of grid cells in the plume region does not improve temperature predictions significantly, but does result in more accurate simulation of plume turbulent structures.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)
Fire models; fire tests; field models; heat release rate; simulation; plumes; large scale fire tests; temperature measurements

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