NISTIR 6923

Simulation of the Dynamics of a Fire in a One-Story Restaurant -- Texas, February 14, 2000

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National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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U.S. Department of Commerce
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Technology Administration
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1. Abstract

This report describes the results of computer model calculations using the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS) that were performed to provide insight on the thermal conditions that may have occurred during a fire in a one-story restaurant on February 14, 2000, in Texas.

A FDS model scenario was developed that represented the building geometry, material thermal properties, and fire behavior based on information and photographs from investigations by the National Institute for Occupational Safety and Health (NIOSH), the City of Houston Fire and Arson Bureau, the City of Houston Fire Department, and the Bureau of Alcohol Tobacco and Firearms (ATF). The results from this model scenario are provided in this report.

The FDS (version 2.0) calculations that best represent the reported fire conditions indicate that a fire originating in the office area of the restaurant spread into and throughout the attic space between the ceiling and roof. Upon the arrival of the fire department, the model results show this space had become a high temperature, oxygen depleted environment. Temperatures in this area ranged from 400 °C to 1000 °C (750 °F to 1800 °F) with an oxygen concentration of approximately 2 %. The FDS model also indicates that the use of positive pressure ventilation, as illustrated in this scenario, did not have a marked effect on the intensity of the fire.

Additional simulations were performed to provide insight as to whether or not lifting a ceiling tile just inside the entry door used by the initial firefighting crew could have given them an indication that there were flames within the attic area. In this simulation the FDS model predicted that this would have indicated the presence of fire in the attic area.

Key Words: cfd models; fire dynamics; fire fatalities; fire fighters; fire investigations; fire models; fire simulations; wood trusses

2. Introduction

Part of the mission of the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) is to conduct basic and applied fire research, including fire investigations, for the purposes of understanding fundamental fire behavior and to reduce losses from fire.

On February 14, 2000, a fire in a one story restaurant in Texas claimed the lives of two firefighters. The fire started in the office area of the restaurant, spread to the attic space between the ceiling and roof, causing the roof of the restaurant to collapse.

The National Institute for Occupational Safety and Health (NIOSH) investigates all line-of-duty firefighter deaths and publishes reports on those investigations. At the request and under the sponsorship of NIOSH, NIST has examined the fire dynamics of this incident to supplement the NISOH investigation. NIST has performed computer simulations of the fire using the newly developed NIST Fire Dynamics Simulator (FDS) and Smokeview, a visualization tool, to provide insight on the fire development and thermal conditions that may have existed in the restaurant during the fire. NIST has previously used FDS to predict the fire growth in other multiple-fatality fires [1,2]. This report describes the inputs and the results of the NIST FDS (Version 2.0) calculations.

Three areas of interest that NIOSH requested to be investigated were:

1. What were the conditions in the attic space upon arrival of the fire department?

2. Did the positive pressure ventilation (PPV) used by the fire department have an effect on the intensity of the fire?

3. Would lifting a ceiling tile just inside the entry door used by the initial firefighting crew have indicated the presence of fire in the attic space?

3. Fire Incident Summary

NIOSH, the City of Houston Fire and Arson Bureau, the City of Houston Fire Department, and the Bureau of Alcohol Tobacco and Firearms (ATF) provided this information to NIST on the construction of the restaurant and the events that took place during the fire. A summary of the events relevant to developing the FDS predictions of the fire follows.

On the morning of February 14, 2000, a fire started in the office area of a fast food restaurant. Figure 1 and Figure 2 show the office area of a similar restaurant. At 4:30 AM the fire department received a call from a civilian who reported that fire was emanating from the roof of the restaurant. At 4:37 AM the first fire department apparatus arrived on the scene and confirmed that fire was visible from the roof, Figure 3. Shortly after arrival, two fire fighters from the first arriving fire apparatus, entered the structure using a door located on the west side in an effort to locate and extinguish the fire. Other firefighters vented a door and window on the east side directly opposite the door where the two firefighters originally entered the structure. A positive pressure ventilation fan was placed and started at the door used by the initial two fire fighters. Within 10 min of the arrival of the first fire department apparatus a section of the roof located near the kitchen collapsed. Due to the collapse, the two firefighters became trapped within the structure. One of the firefighters was located near the kitchen area and removed from the building at 5:32 AM. The second firefighter was located near the rear door at 7:13 AM. A timeline of events is given in Table 1.

The post fire investigation determined that the fire had started in the office area of the restaurant approximately 25 min prior to the arrival of the fire department.

4. NIST Fire Dynamics Simulator (FDS)

NIST has developed a computational fluid dynamics (CFD) fire model using large eddy simulation (LES) techniques [3]. This model, called the NIST Fire Dynamics Simulator (FDS), has been demonstrated to predict the thermal conditions resulting from a compartment fire [4,5]. A CFD model requires that the room or building of interest be divided into small three-dimensional rectangular control volumes or computational cells. The CFD model computes the density, velocity, temperature, pressure and species concentration of the gas in each cell. Based on the laws of conservation of mass, momentum, species, and energy the model tracks the generation and movement of fire gases. FDS utilizes material properties of the furnishings, walls, floors, and ceilings to compute fire growth and spread. A complete description of the FDS model is given in reference [3].

4.1. Model Uncertainty

FDS can provide valuable insight into how a fire may have developed. However the model is only a simulation. The model output is dependent on a variety of input values such as material properties, time lines, geometry, and ventilation openings. Since complete knowledge of every detail of the fire site, fuel load or fire timeline is never available; estimations are incorporated into the model. For example, the estimation of the energy release rate of an initial "source fire" as a starting point for fire development and spread throughout the structure is a necessary part of re-creating this fire scenario. These estimations and others used in this simulation are further described in Section 6 of this report.

The ability of the FDS model to predict accurately the temperature and velocity of fire gases has been previously evaluated by conducting experiments, both lab-scale and full-scale, and measuring quantities of interest. For relatively simple fire driven flows, such as buoyant plumes and flows through doorways, FDS predictions are within the experimental uncertainty of the values measured in the experiments [4]. For example, if a gas flow velocity is measured at 0.5 m/s (1.6 ft/s) with an experimental uncertainty of ± 0.05 m/s

(± 0.2 ft/s), the FDS model gas flow velocity predictions were also in the range between 0.45 m/s and 0.55 m/s (1.5 ft/s and 1.8 ft/s).

In large scale fire tests reported in [5], FDS temperature predictions were found to be within 15 % of the measured temperatures and the FDS heat release rates were predicted to within 20 % of the measured values. Therefore the results are presented as ranges to address these uncertainties.

5. Smokeview

Smokeview is a scientific visualization program that was developed to display the results of a FDS model computation. Smokeview produces animations or snapshots of FDS results [6].

A new feature of Smokeview allows the viewing of FDS output in 3-dimensional animations. An iso-surface is a three dimensional version of a contour elevation often found on topographic maps. In this report, Smokeview was used to generate animated iso-surfaces to visualize the movement and spread of the fire within the attic space.

6. FDS Input

Inputs required by FDS include the geometry of the structure, the computational cell size, the location of the ignition source, the energy release of the ignition source, thermal properties of walls, ceilings, floors, furnishings, and the size, location, and timing of door and window openings to the outside which critically influence fire growth and spread. The timings of the door and window openings used in the simulation are given in Table 2. The timings of these events are based on the approximate timeline of the fire events from Table 1. These are based on information obtained from The City of Houston Fire and Arson Bureau, the Houston Fire Department and NIOSH. The size and location of ventilation openings are based on architectural drawings and field measurements by ATF. The size of the initial collapse zone is based on the approximate size of the air conditioning units that were located on the roof of the structure.

6.1. Geometry

The floor plan of the restaurant is shown in Figure 4. The restaurant was approximately 32.3 m x 12.5 m x 4.9 m (106.0 ft x 41.0 ft x 16.1 ft). For computational purposes the restaurant was enclosed within a 35.0 m x 13.5 m x 5.0 m (114.8 ft x 44.3 ft x 16.4 ft) rectangular volume. For the FDS simulation this volume was divided into 734,000 computational cells. The focus of the simulation was the attic space filled with trusses, Figure 5. In order to match the truss locations, the size of the cells in the north-south direction varied as shown in Figure 6. The computational cells between trusses were 125 mm x 255 mm x 125 mm (5.0 in x 10.0 in x 5.0 in) and cells located within the plane of a truss were 64 mm x 255 mm x 125 mm (2.5 in x 10.0 in x 5.0 in). The size and location of the walls, doorways, and windows are adjusted by FDS to correspond to the nearest computational cell location. The result is walls and ceilings, used in the model, that appear thicker than they are in the actual structure.

6.2. Initial Fire and Fuel Package

Information from arson investigators indicated that the fire started in the office area of the restaurant approximately 25 min prior to the arrival of the fire department. The heat release rate for the initial fire, which served as an ignition source for the rest of the structure was based on a fire in an office workstation [7].

This ignition source covered an area of 2.8 m^2 (30 ft^2) and was located 0.50 m (20 in) above the floor. The peak heat release rate for this ignition source was 6.0 MW. The heat release rate of this ignition source is assumed to grow linearly and reach its peak of 6.0 MW after 300 s. This peak heat release rate is maintained until 400 s into the simulation at which time it decreases in several stages to 1.6 MW. This final heat release rate is maintained for the duration of the simulation. Figure 7 is a graph of the heat release rate for this fuel package versus time.

6.3. Vents

For the purpose of this simulation, a vent is considered an opening in the building that will allow fire gases to exit the structure and/or ambient air from the outside to enter. Some vents were open to the outside at the beginning of the simulation. Others were opened at specific times in the simulation. The first three sets of vents described below were open at the start of the simulation and remained open during the entire simulation.

The first vents were four 0.75 m x 0.75 m (30 in x 30 in) vents located on the roof of the structure. These vents extended down to the kitchen area and the size and location of these vents were taken from architectural drawings of a similar restaurant.

The soffit vents, which formed the second set of vents, were simulated in FDS as vents along each exterior wall to the attic. The vents were 20.5 m x 0.125 m (67 ft x 5 in) on the east wall, 8 m x 0.125 m (26 ft x 5 in) on the front wall, 20.5 m x 0.25 m (67 ft x 10 in) on the west wall, and 10 m x 0.25 m (33 ft x 10 in) on the rear wall.

The third vent was for the drive-through window and was located on the west side of the structure. This vent had dimensions of 1.75 m x 1.00 m (69 in x 39 in) with a sill height of 1.25 m (49 in).

The remainder of the vents was closed at the beginning of the simulation. These vents were opened at specific times during the simulation as shown in Table 2. Once opened, these vents remained open.

The west side door was 0.75 m x 1.25 m (30 in x 49 in) and opened at 1620 s. This opening represented the removal of the bottom half of the glass door which was subsequently used by firefighting personnel to enter the structure.

The two vents on the east side of the structure were a 2.0 m x 2.25 m (78 in x 89 in) double door and a window with dimensions of 1 m x 1.4 m (39 in x 55 in) with a sill height of 0.60 m (24 in). The door was opened at 1680 s and the window at 1710 s into the simulation.

At 1740 s the impact of a positive pressure ventilation (PPV) fan was simulated. This was accomplished within the FDS model by placing a 0.75 m x 0.75 m (30 in x 30 in) vent 1.5 m (60 in) outside the west side door. At 1740 s a velocity was applied to the vent corresponding to the average fan velocity. The actual velocity for the fan used was unknown and would not be uniform over the face of the fan. An average velocity of 13 m/s (43 ft/s) was chosen based on typical manufacturer's fan ratings.

The final vent from the structure to the outside was caused by the roof collapse at 1860 s. This 2.5 m x 2.5 m (98 in x 98 in) opening was based on the size of an air conditioning unit on the roof.

At the time of the fire there was no wind, therefore for these simulations the heat from the fire and/or the fan used by the fire department generated all of the flows between the building and the exterior.

6.4. Openings Within the Structure

There were three events that occurred within the structure that affected the flow of fire gases. The first was the collapse of the office ceiling. Information from fire investigators indicated that there were several openings in the ceiling of the office area at the start of the fire. These openings lead directly to the attic area. These openings were modeled as a single 0.25m x 0.25m (10 in x 10 in) opening. The remainder of the office ceiling is estimated to have collapsed 900 s after the start of the fire based on previous fire experiments [8]. This report indicated that gypsum ceilings would start to collapse after 7 min of fire exposure with up to 50 % of the ceiling collapsing in a particular room after 8 min of exposure. The use of 15 min after the start of the fire to the collapse of the ceiling in these simulations was considered conservative.

The second event within the structure was the removal of an area from the ceiling just inside the door used for entry by the initial firefighting team. The size of this opening was 0.50 m x 1.25 m (20 in x 49 in) to simulate a firefighter entering the structure and using a tool to lift up one of the ceiling tiles. This event was assumed to take place at 1640 s into the simulation, 20 s after the door was opened. This event was modeled at the request of NIOSH to see if the FDS model could demonstrate what firefighters would have observed if they performed this action.

The third event within the structure was the collapse of the ceiling directly beneath the portion of the roof that collapsed. This took place at 1860 s, the same time as the roof collapse.

It should be noted that the FDS model does not predict the collapse of the building components. The approximate size, location, and time of the roof and ceiling collapses in these simulations were determined from information provided by the City of Houston Fire and Arson Bureau, The Houston Fire Department, and NIOSH. The collapse of the roof section in the FDS simulation was accomplished by removing a portion of the roof. This created an opening in the roof that allowed the products of combustion to escape. Likewise, the ceiling area below the roof was removed which allowed fire to spread into the attic. The model does not predict the burning of materials that fell into the restaurant so estimates of their contribution to the total heat release were added to the fire in the office area.

6.5. Material Properties

When a wall, ceiling, truss, piece of furniture, or any other structural item or piece of furniture is defined for use in the FDS model it is given a set of physical and thermal properties that are used by the model. A list of the materials used in these simulations along with the physical and thermal properties required by FDS are given in Table 3 [3]. The roof trusses used in this structure were made of wood. In the simulation these trusses were given the thermal characteristics of pine with a thickness of 0.038 m (1.5 in). The under side of the roof and the interior portion of the outer walls located above the level of the ceiling were also given the thermal characteristics of pine. In this case the thickness was 0.013m (0.5 in). This represented the plywood sheathing that was used as a substrate for the roof. Depending on the area of the restaurant, the ceiling was gypsum board, textured vinyl tiles, or fire retardant tiles. All interior walls of the restaurant were gypsum board. All exterior walls from the ground to the ceiling were considered to be inert. The thermal properties of the materials were used by FDS to calculate heat transfer and determine when these materials ignite and their contribution to the heat release rate of the fire.

7. Model results

Figure 8 shows the restaurant representation from the Smokeview computer program. The view is from the west side of the structure. The door used by the initial entry team can be seen in blue. The positive pressure ventilation fan is in green and is positioned outside the entry door. The initial collapse zone used in this simulation is shown as a blue square on the roof of the structure. The light blue structure toward the left of the figure is the drive through window. Figure 9 shows the model viewed from the south. The south and east walls have been removed to show the interior. To the left of the figure is the door used by the initial entry team. The red area to the rear of Figure 9 represents material from the roof and ceiling that has fallen to the floor. Figure 10 is a view of the restaurant from above. The roof and ceiling have been removed to view how the trusses are modeled. Additionally, some of the trusses have been removed in order to see the structures below them. The larger of the two red areas located in the interior of the restaurant represents the roof and ceiling materials that fell to the floor. The smaller red area in the small room to the right and down from the collapse zone is the office where the fire started.

7.1. Fire Simulation – Attic Temperature and Oxygen Concentration Predictions

Figure 11 shows a horizontal slice of the temperatures within the attic space at 300 s into the simulation. A slice contains the data within a rectangular array of grid points. In this case the data of interest are the gas temperatures. The color bar to the right represents the corresponding numerical values. This figure shows that the temperature of the gases in the area of the attic just above the office is approximately 400 °C (750 °F). These hot gases appear to be spreading more toward the east and west sides (the short sides) of the structure rather than the north and south sides (the long sides). Figure 12 shows the same slice of the attic area after 1500 s of simulation, the approximate arrival time of the fire department. The majority of the attic space is in the range of 400 °C to 500 °C (750 °F to 930 °F). The area of the ceiling collapse in the office can be seen as a definite red square. This corresponds to a temperature of approximately 1000 °C (1800 °F).

Figure 13 and 14 show the oxygen concentration within the attic at the same simulation times as Figures 11 and 12. Figure 12 and Figure 14 depict high temperature and low oxygen concentration within the attic area of the restaurant at approximately the time the fire department arrived. This would indicate there is little actual burning within the attic, except where the flames from the office area enter the attic and along the edges of the structure where the hot gases mix with fresh air and ignite. Even though there may not have been flames within a large part of the attic area, the gases themselves were hot enough to allow the wood trusses to pyrolize.

7.2. Positive Pressure Ventilation

Figure 15 shows the gas velocity in a vertical plane that passes through the doors on the east and west side of the restaurant. The blue squares on the right and left of the figure represent the doors. The color bar on the right shows the magnitude of the gas velocity parallel to the plane. At 1615 s into the simulation the doors are closed and there is no appreciable flow of gases from one door to the other. Figure 16 shows the gas velocities at 1630 s, after the lower half of the west side door was opened. The red color shows air flowing into the structure from left to right at approximately 1.0 m/s to 1.5 m/s (3.0 ft/s to 5 ft/s). Gas velocities that are positive move from left to right in the figure. Figure 17 shows the gas velocities at 1705 s when the double door on the east side had been opened. The blue color shows air entering the restaurant from the right. Figure 18 shows the gas velocity at 1745 s into the simulation, which was 5 s after the start of the PPV fan. By that time the window on the east side had also been opened. It appears that much of the flow caused by the fan results in flow out of the restaurant through the double doors in the opposite wall Figure 19.

A measure of the intensity of a fire is the amount of heat that is being generated or released by the fire. Figure 20 is a graph of the heat release rate of the fire. From this graph it appears that the ceiling collapse in the office at 900 s and the roof/ceiling collapse at 1860 s into the simulation had a much greater and sustained impact on the heat release rate than the use of positive pressure ventilation.

7.3. Removal of ceiling tile

At the request of NIOSH, the removal of a small portion of the ceiling just inside the entry door used by the initial firefighting crew was simulated to determine if the fire in the attic would be visible at the time they entered the building. Figure 21 is a view from inside the structure looking toward the door used by the initial firefighting crew at 1620 s into the simulation. At that time the lower half of the door was opened and the green square on the ceiling is the portion of the ceiling that is to be removed. Figure 22 shows the same view at 1640 s into the simulation, with the portion of the ceiling removed. The red area shown is an iso-surface, which provides a three dimensional approximation of the flame surface area where fuel, heat and oxygen are present such that flames may exist. Although the flame is visible in the simulation it might have been obscured by smoke during the fire.

Figure 23 shows the flame iso-surface at 1685 s into the simulation after the east side door had been opened. On the right side of the figure, the fire is entering the attic area from the office area and on the left the flame emerging from the area of the ceiling that was removed. Flame is not visible in the attic since the oxygen concentration is in the range of 0 % to 2 % (Figure 14); even though flames had previously spread through the attic. Pyrolysis of the combustibles in the attic would, however, continue.

8. Summary

The NIST FDS fire simulator program provided investigators with insight into the fire environment that existed in the restaurant at the time of the Fire Department arrival. The model simulation was based on a fire that started in the office area of the restaurant and spread up into and throughout the attic space. The model predicted that the attic space would have been a high temperature low oxygen concentration environment. In addition, the hottest area in the attic was in the area estimated to have been part of the initial collapse zone. The simulation also gives some indication of whether actions taken may have increased the intensity of the fire or if a certain action had been taken whether the firefighters may have been able to discern that there was a fire condition throughout the attic space. The use of a PPV fan at the door used by the initial firefighting crew did not have a significant effect on the intensity of the fire. If firefighters had lifted a ceiling tile inside the entry door they would likely have been aware that there was fire in the attic.

9. Acknowledgements

The authors would like to thank Ms. Dawn Castillo, Mr. Richard Braddee and Mr. Frank Washnitz of the NIOSH Fire Fighter Fatality Investigation and Prevention Program for their support of this research. The authors extend their appreciation to The City of Houston Fire & Arson Bureau, the City of Houston Fire Department, and the Bureau of Alcohol Tobacco and Firearms (ATF) for their documentation of the structure involved in this fire incident. Finally we would like to thank Dr. Kevin McGrattan for his continued development of the NIST Fire Dynamics Simulator Model, and Dr. Glenn Forney for his continued development of SmokeView.

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Table 1. Approximate Incident Timeline

Approximate Incident Time (h:min:s)	Event	Simulation Time (s)
04:13:00	Fire started	0
04:28:00	Office ceiling collapse	900
04:30:00	Fire Department notified of fire by 911 call	1020
04:33:00	Fire Department dispatched	1200
04:38:00	First Fire Department units arrive	1500
04:40:00	West door forced and vented	1620
04:41:00	East double doors vents	1680
04:41:30	Window next to east side double doors vented	1710
04:42:00	Positive pressure fan started at west door	1740
04:44:00	Roof and Ceiling collapse	1860

Table 2. Time of Ventilation Events for FDS Simulation

	Time of event (s)							
Vent	Initial Conditions	900	1620	1640	1680	1710	1740	1860
Drive-through window, roof and soffit vents	Open	Open	Open	Open	Open	Open	Open	Open
Office Ceiling Collapse	Closed	Open	Open	Open	Open	Open	Open	Open
West side door	Closed	Closed	Open	Open	Open	Open	Open	Open
Ceiling tile lifted*	Closed	Closed	Closed	Open	Open	Open	Open	Open
East side door	Closed	Closed	Closed	Closed	Open	Open	Open	Open
East side window	Closed	Closed	Closed	Closed	Closed	Open	Open	Open
Positive press ventilation started*	Off	Off	Off	Off	Off	Off	On	On
Roof and ceiling collapse	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Open

* Not performed in all simulations.

Table 3. Thermal Properties Data

Material	Thickness (m)	Ignition Temperature (°C)	Heat Release Rate per unit Area (kW/m^2)	Thermal Conductivity (W/m K)	Thermal Diffusivity (m^2/s)
Gypsum board	0.013	400	100	0.48	4.1E-7
Pine	0.013	390	200	0.14	8.3E-8
Pine trusses	0.038	390	200	0.14	8.3E-8
Textured vinyl ceiling tile	0.013	400	130	0.48	4.1E-7
Fire retardant ceiling tile	0.020	400	10	0.04	8.6E-8


Figure 1. Office area in a similar restaurant.


Figure 2. Office area in a similar restaurant.

Figure 3. Early stages of the fire.

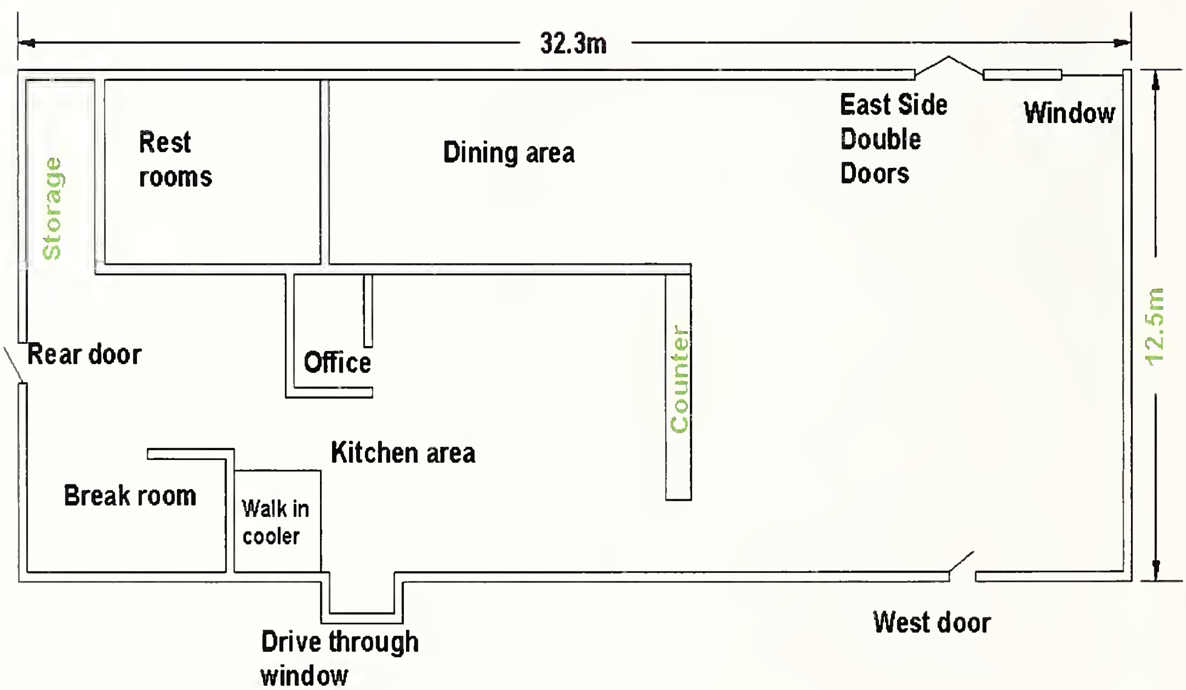

Figure 4. Floor plan of restaurant.

Figure 5. Attic area in a similar restaurant showing the trusses.

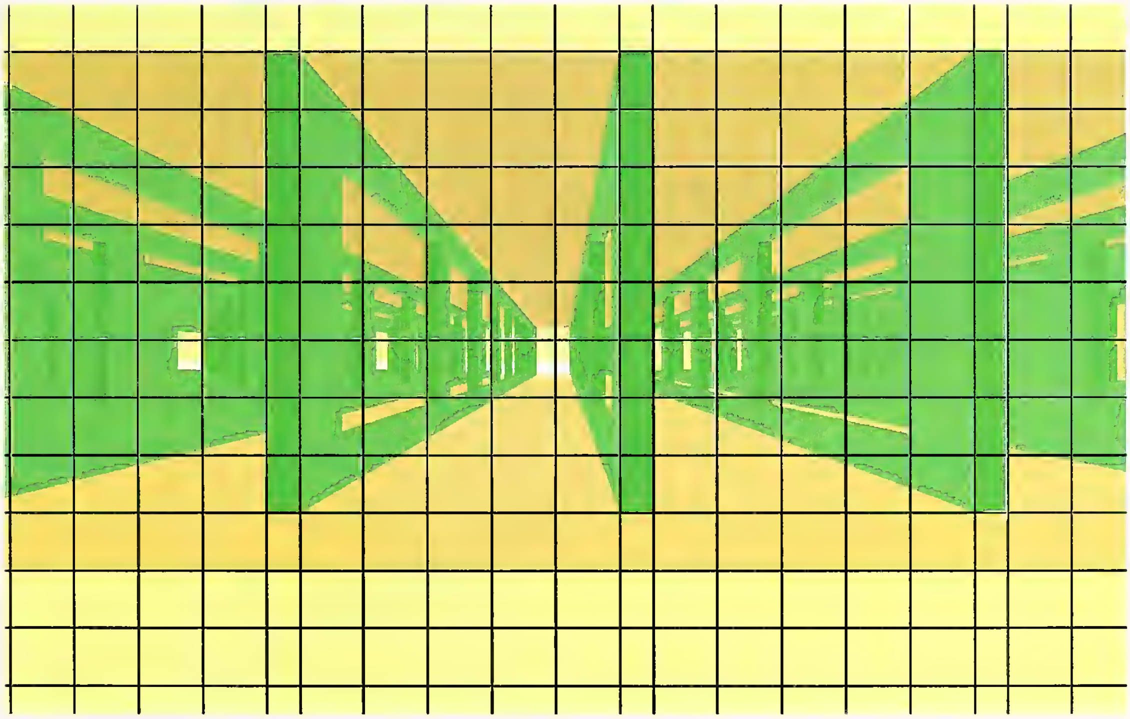

Figure 6. Attic computational cells in the north-south direction.

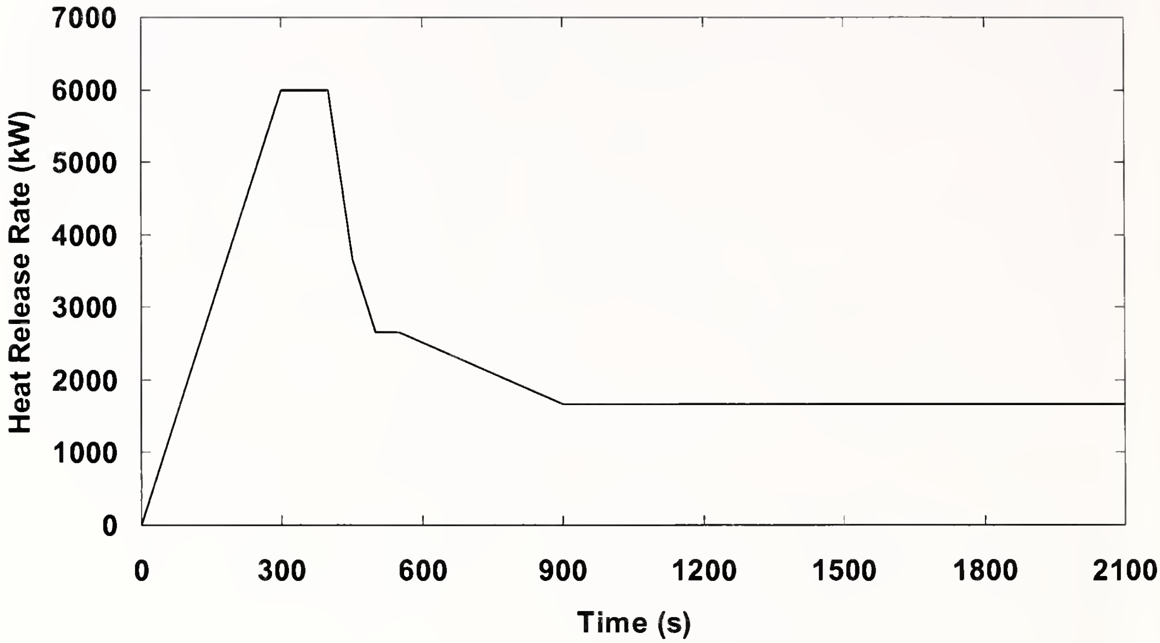

Figure 7. Heat release rate for the ignition source.

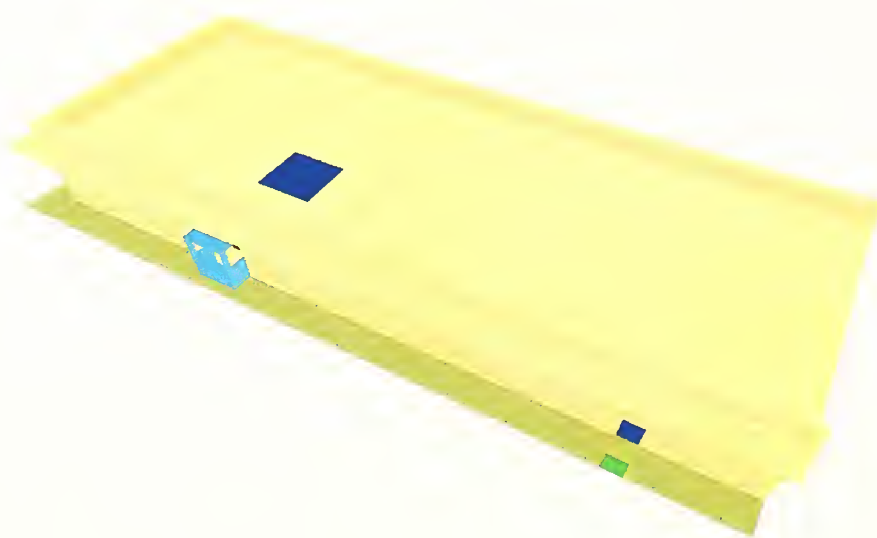

Figure 8. Smokeview representation of the restaurant from the west side.

Figure 9. View from the south side with the south and east walls removed.

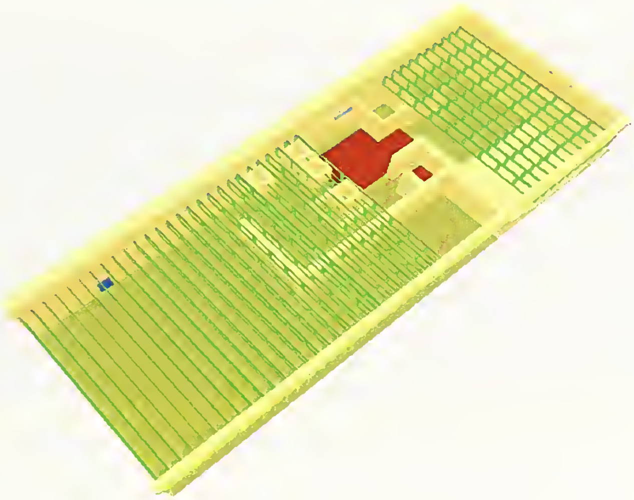

Figure 10. View from the top with the roof and ceiling removed to show trusses and interior walls. Some of the trusses have been removed.

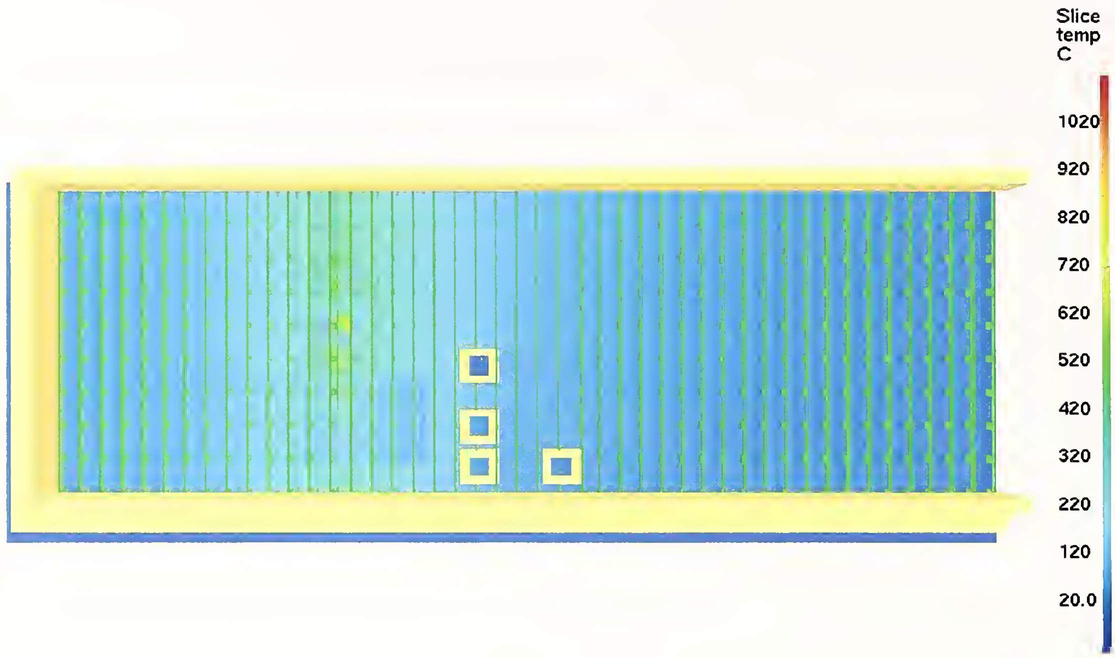

Figure 11. Temperatures in the attic area at 300 s into simulation.

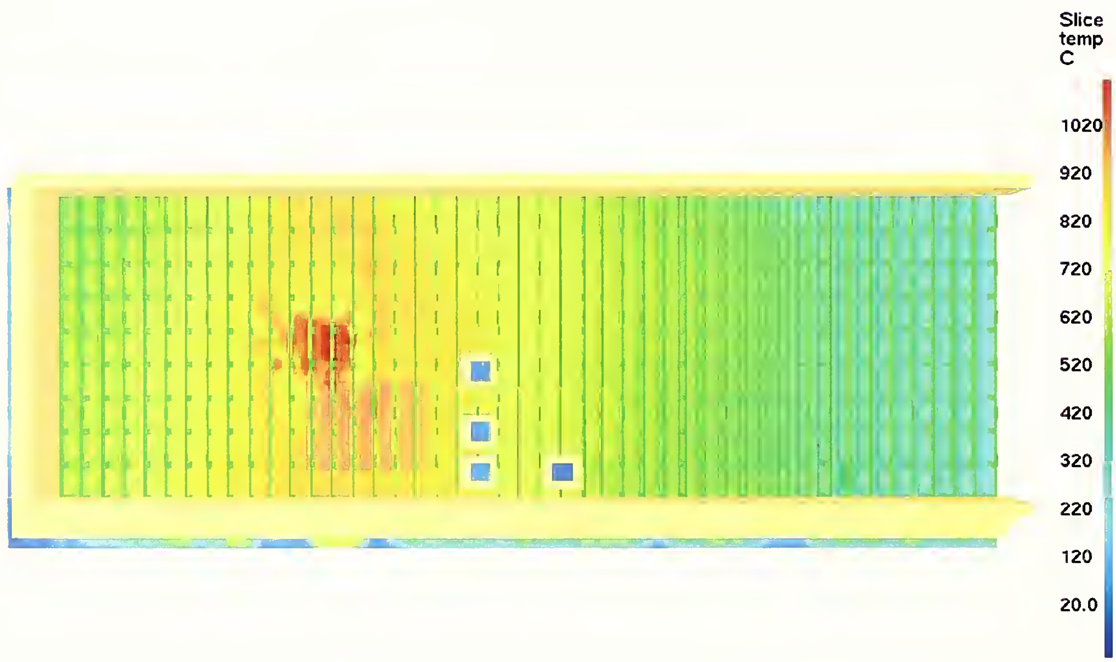

Figure 12. Temperatures in the attic area at 1500 s into simulation, the approximate time of arrival of the first fire department apparatus.

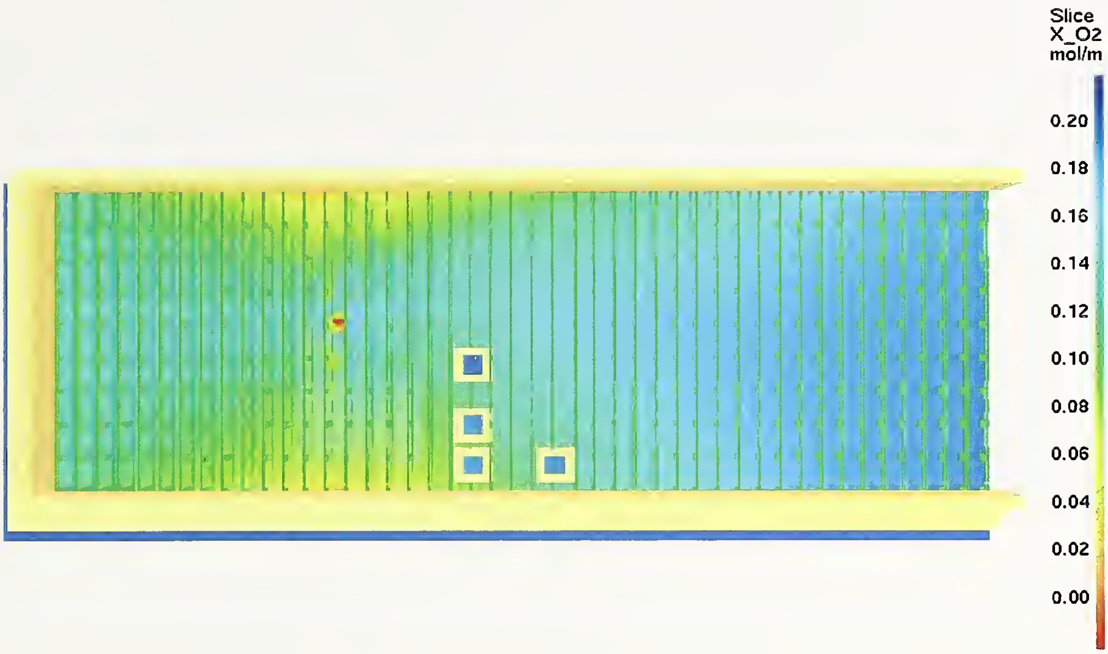

Figure 13. Oxygen concentrations in the attic area at 300 s into simulation.

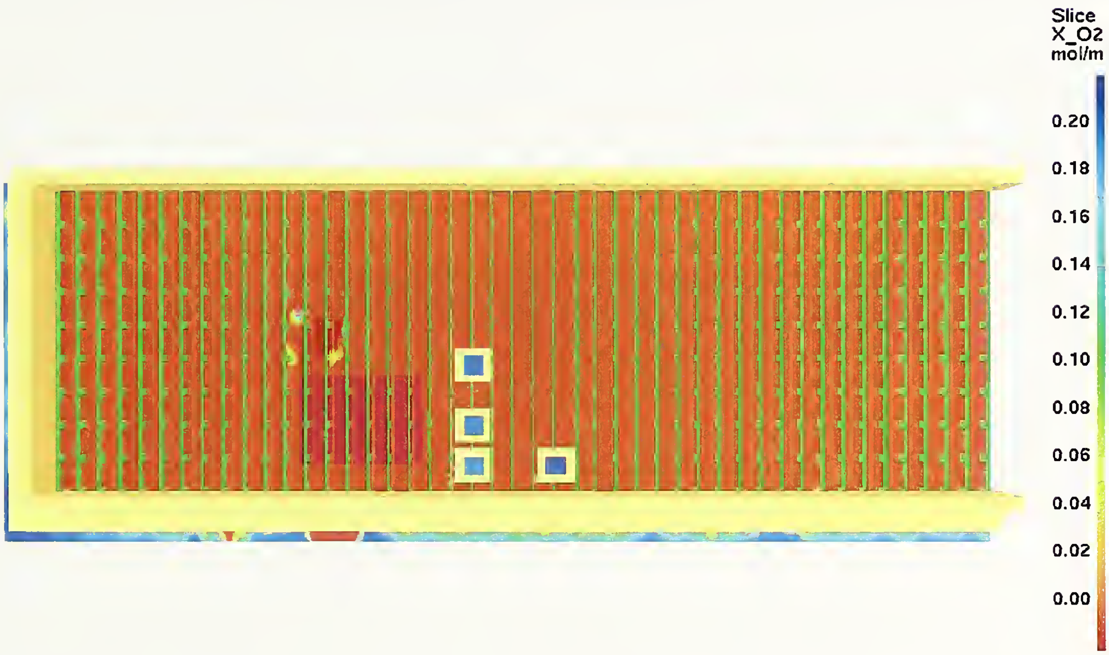

Figure 14. Oxygen concentrations in the attic area at 1500 s into simulation, the approximate time of arrival of the first fire department apparatus.

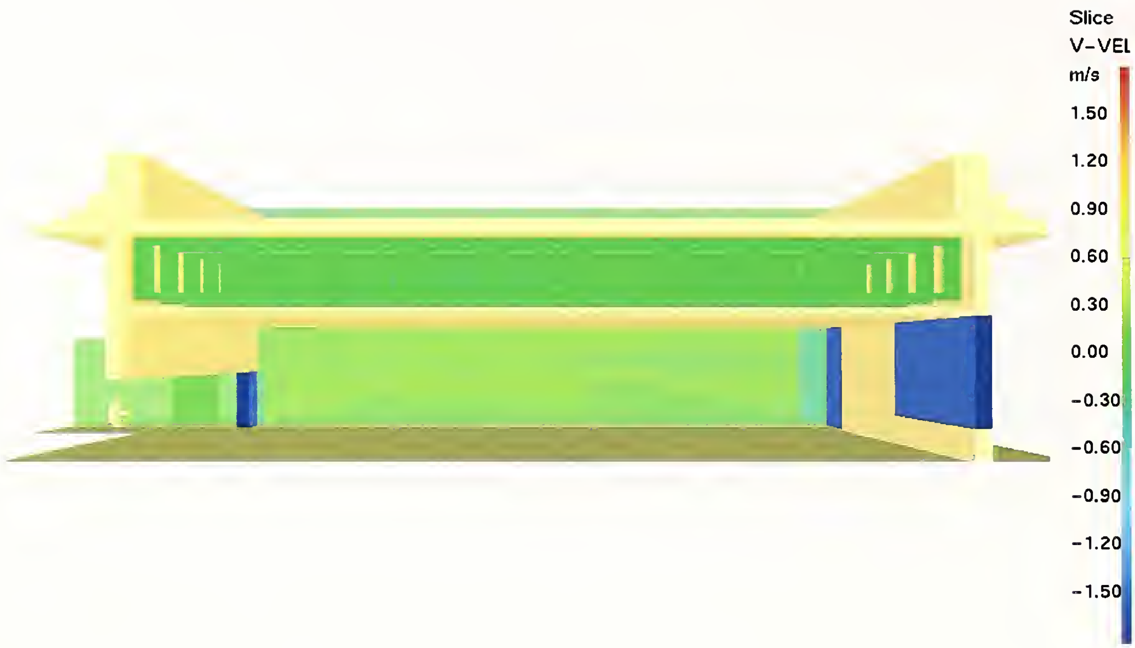

Figure 15. Gas velocities at 1615 s into the simulation, before the west or east side doors were opened. Gas velocities within the plane are essentially zero.

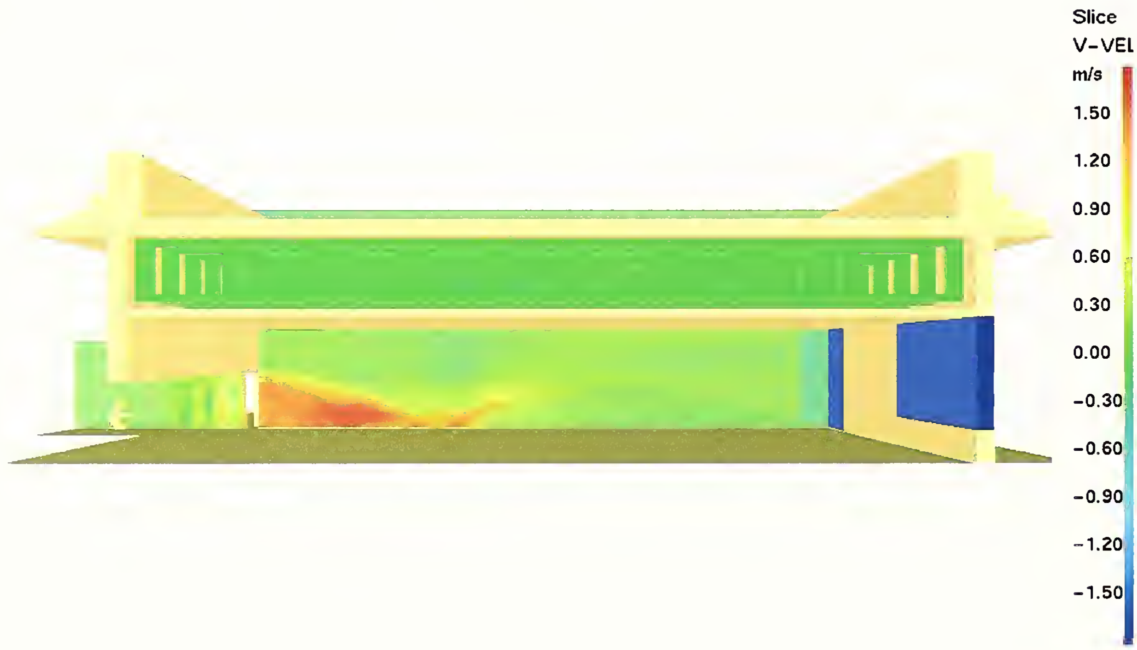

Figure 16. Gas velocities within a vertical plane at 1630 s, after the lower half of the west side door is opened. The red shows air flowing into the structure from left to right.

Figure 17. Gas velocities within a vertical plane at 1705 s into the simulation. The double door has been opened on the east side. The blue indicates air moving right to left into the structure.

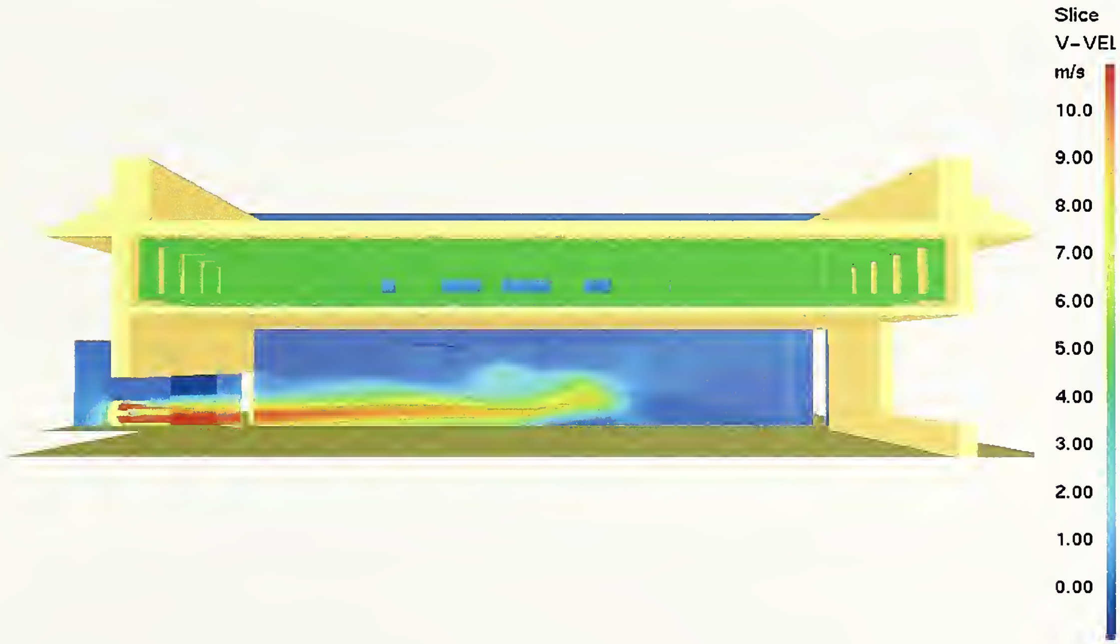

Figure 18. Gas velocities within a vertical plane at 1745 s into the simulation. PPV fan was activated at 1740 s into the simulation. Note the scale difference between this figure and Figure 15 through Figure 17.

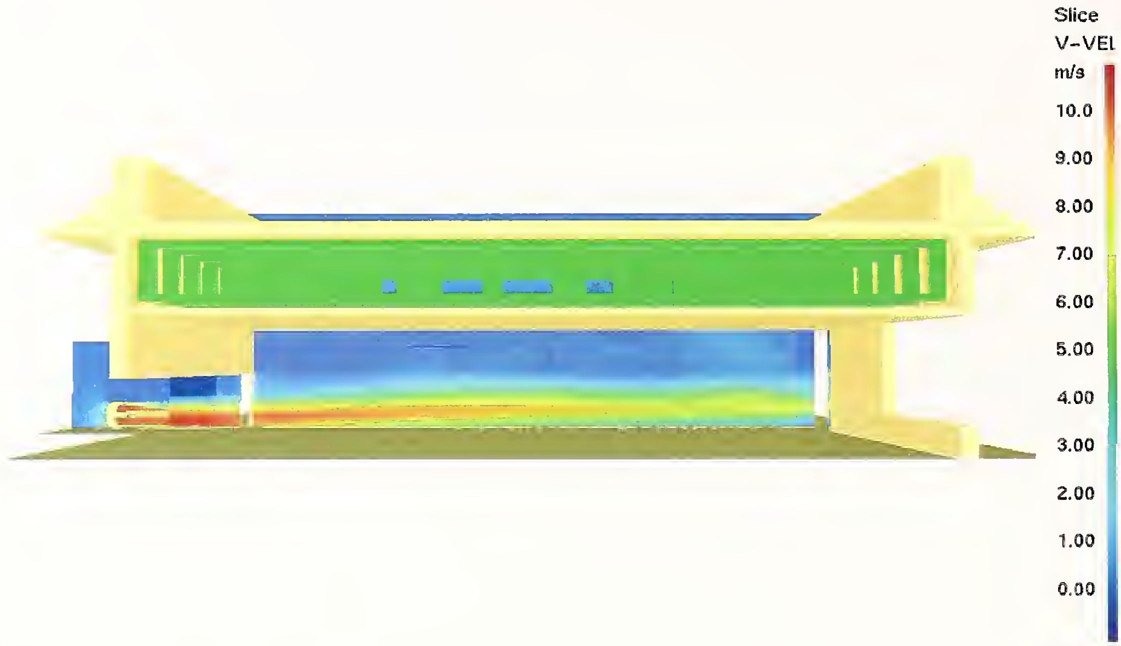

Figure 19. Gas velocities within a vertical plane at 1750 s into the simulation. Note the scale difference between this figure and Figure 15 through Figure 17.

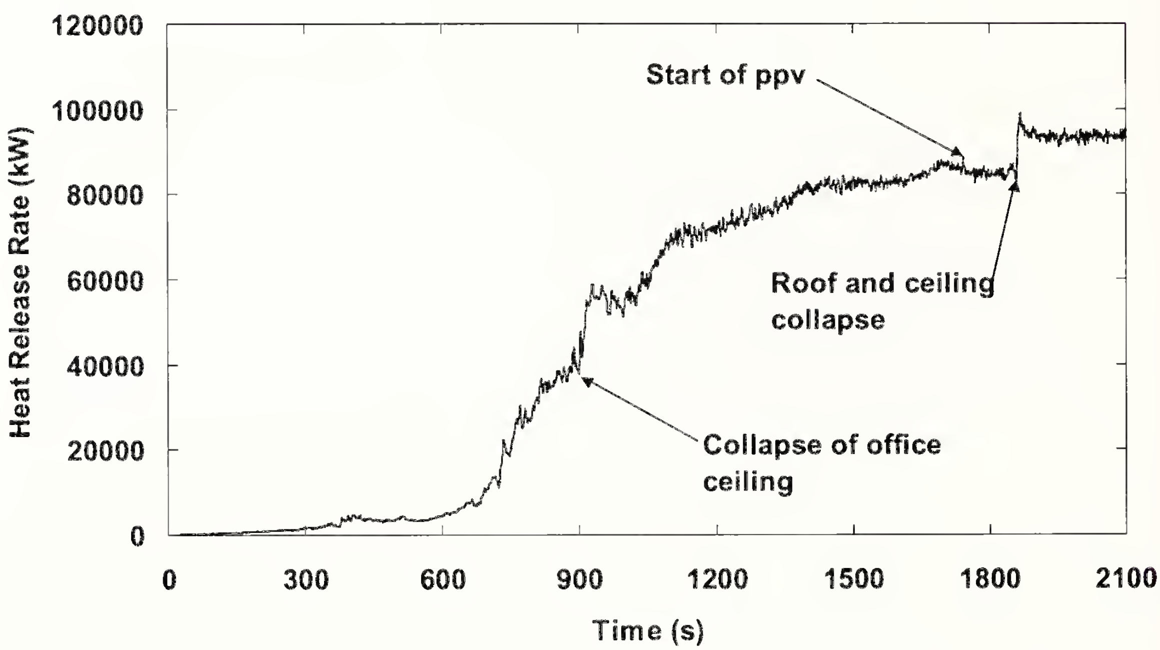

Figure 20. Heat release rate for simulation.

Figure 21. View from inside the restaurant looking toward the entry door used by the initial firefighting crew.

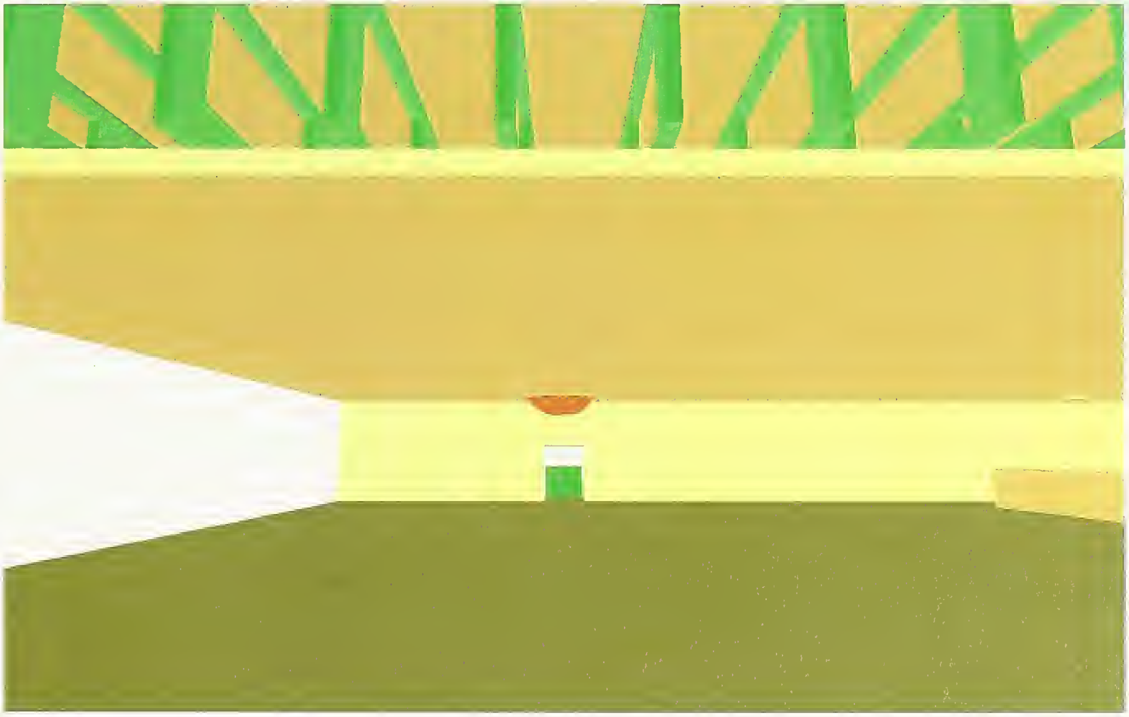

Figure 22. Same view as Figure 21 at 1640 s into the simulation. The red area indicates fire coming out opening in the ceiling near the entry door.

Figure 23. Attic space showing fire going into attic from office area and coming out opening in the ceiling near the entry door.