U. S. Department of Justice
Bureau of Alcohol, Tobacco, Firearms and Explosives
Fire Research Laboratory
6000 Ammendale Road
Ammendale, Maryland 20705-1250

ATF Fire Research Laboratory

December 27, 2011

MEMORANDUM TO: Matthew Varisco, ATF Senior Special Agent/CFI
Baltimore Field Division

CC: Christopher Gauss, Captain
Baltimore County Fire Investigation Division

THRU: Brian Grove P.E., Engineering Section Chief
ATF Fire Research Laboratory

FROM: Adam St. John P.E., Fire Protection Engineer
ATF Fire Research Laboratory

SUBJECT: FDS Modeling Analysis
30 Dowling Circle

INTRODUCTION:
Assistance from the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) Fire Research Laboratory (FRL) was requested for a fire at 30 Dowling Circle by the Baltimore County Fire Investigation Division (FID) through the ATF Baltimore Field Division on the night of January 19, 2011. ATF Fire Protection Engineers were asked to utilize engineering analysis methods, including computer fire modeling, to assist with determining the route of fire spread and the events that led to the firefighter MAYDAY and subsequent Line of Duty Death.

BACKGROUND:
Working closely with the Post Incident Analysis Team, the ATF Fire Research Laboratory created a computer simulation of the garden apartment building using Fire Dynamics Simulator (FDS). FDS is a computational fluid dynamics (CFD) modeling program developed by the National Institute of Standards and Technology (NIST). FDS utilizes mathematical calculations to predict the flow of heat, smoke and other products of fire. Smokeview, a post-processer computer program also produced by NIST, was then used to visualize the mathematical output from FDS. The most current available versions of both programs were used: FDS 5.5.3 and Smokeview 5.6. Below are photographs of the front and rear of the fire building next to an image of the same building constructed in FDS.

Figure 1. A front view of 30 Dowling Circle.

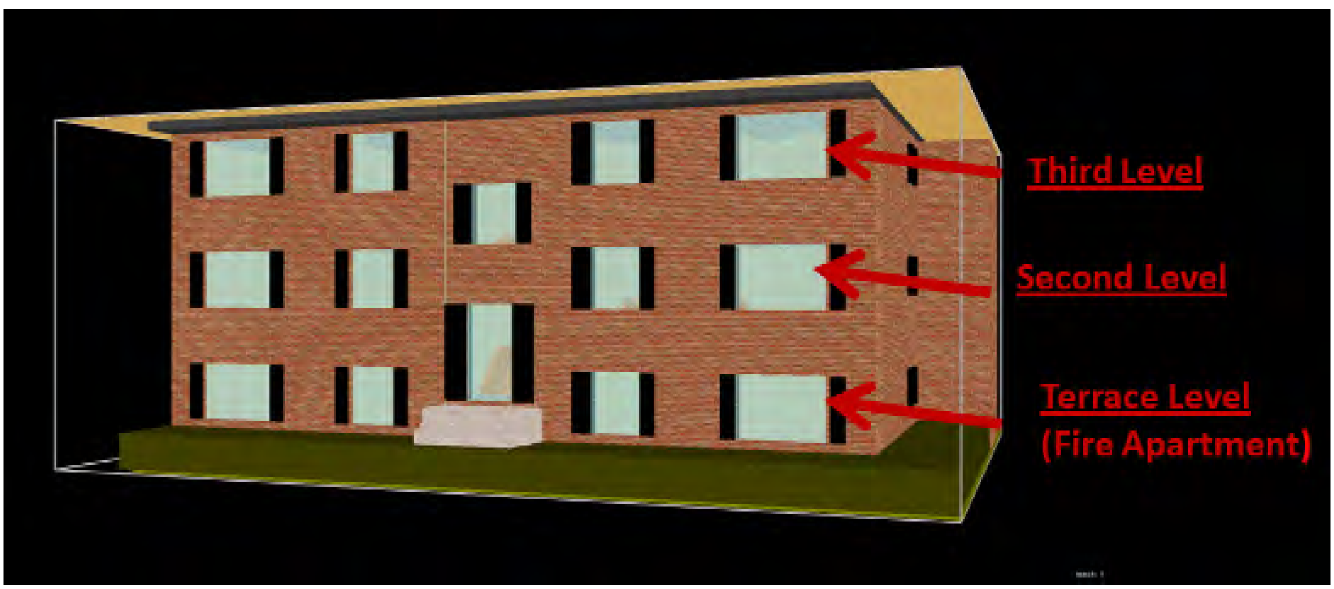

Figure 2. FDS representation of the front of 30 Dowling Circle showing the terrace (T), second (A) and third (B) levels.

Figure 3. A rear view of 30 Dowling Circle.

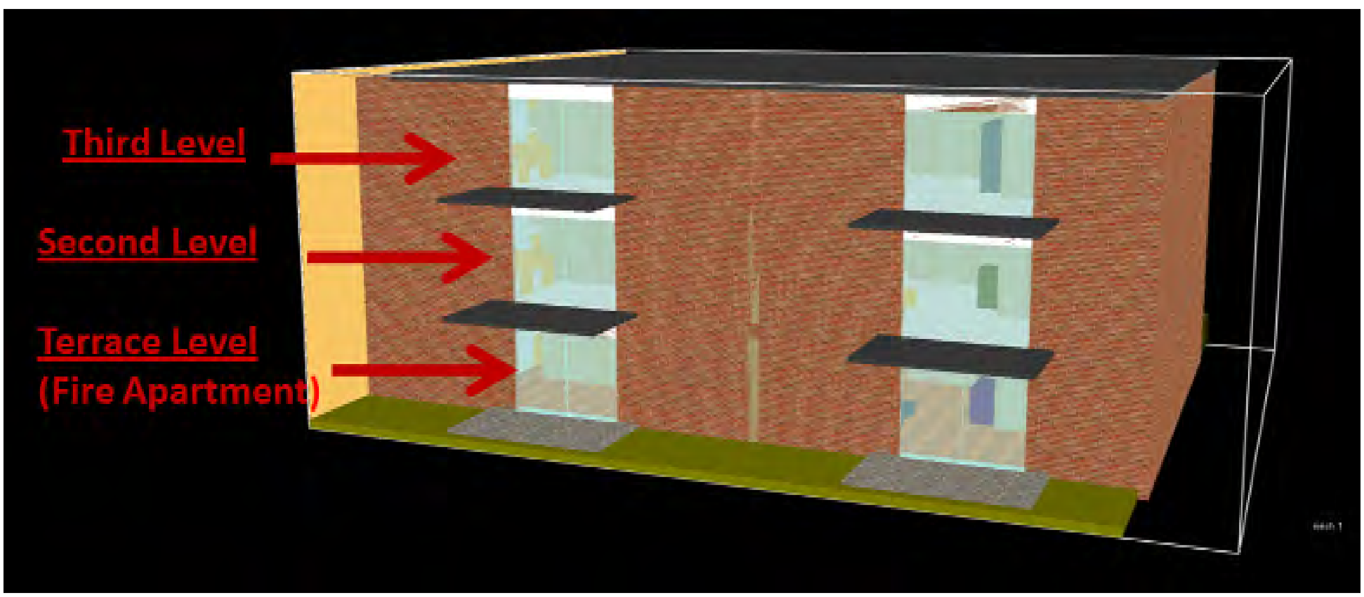

Figure 4. FDS representation of the rear side of 30 Dowling Circle showing the terrace (T), second (A) and third (B) levels.

The garden apartment building at 30 Dowling Circle was attached to two similar garden apartment buildings, one on each side. The fire damage was isolated to 30 Dowling Circle, so the exposure buildings were not included in the computer fire model. The entire six unit garden apartment building was modeled in FDS, including the patio and balconies on the rear of the building. FDS works by dividing a space into cubical "grid cells" for calculation purposes. FDS then computes various CFD calculations for each grid cell to predict the movement of mass, energy, momentum and species throughout a three-dimensional space. The Dowling Circle model consisted of 2,560,000 total grid cells that were each 3.9 inch (10 cm) cubes. The model was used to simulate a total elapsed real time of 27.5 minutes, beginning before the 911 call and ending just after flashover of the third floor and the firefighter MAYDAY. The model was synchronized in real time with the fireground audio throughout the duration of the fire.

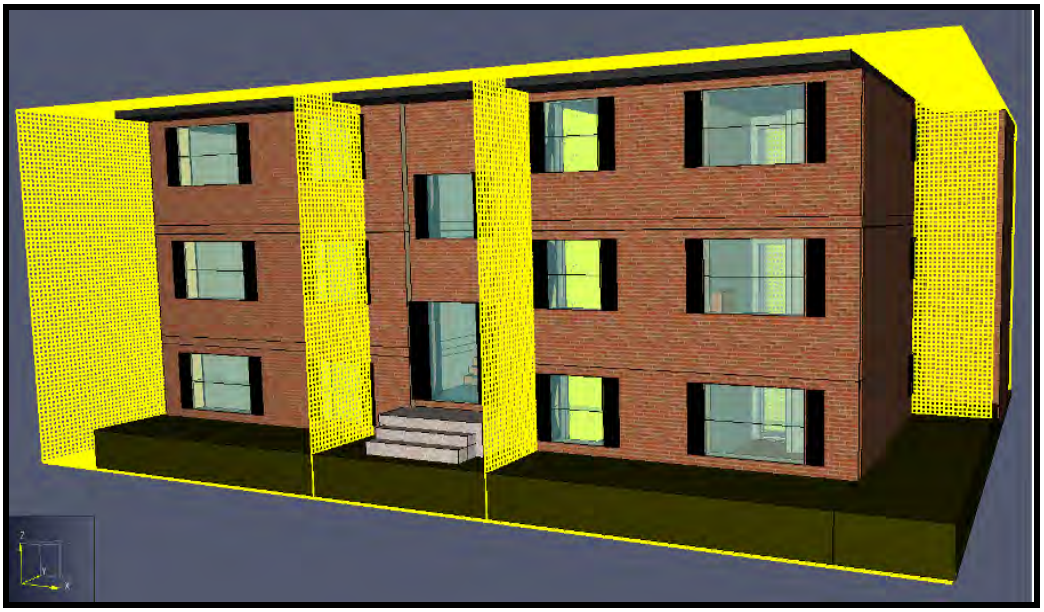

Figure 5. FDS representation of building with cubical grid cells highlighted.

FDS has been validated to predict the movement of heat and smoke throughout a compartment, however the accuracy of fire modeling depends on it being used appropriately by a trained user that is aware of its limitations. Due to lack of knowledge about the exact material properties for the various furnishings and other available fuels, a user-specified fire progression was used for this application. For flame and fire gas movement after consumption of the original burning fuel packages, the fire model calculated smoke and ventilation flow paths through the building and was used to gain a better understanding of the rapid fire growth leading to flashover of the stairwell and third floor. In addition, FDS was utilized to illustrate the complex route of fire spread through the building as verified by witness statements, firefighter interviews, photographs and burn patterns.

Input data for the computer model included heat release rate data and video from previous testing conducted by the ATF FRL and NIST. Ambient weather data was also input into the model, including temperature, as well as wind direction and magnitude at the time of the fire. In addition, several alternative compartmentation scenarios were modeled to explore the possible effects of closed stairway apartment entrance doors on the spread of smoke and flames in the stairwell.

The statements of each firefighter were reviewed and their individual actions (breaking windows, opening doors, etc.) and observations (fire size, smoke conditions, etc.) were recorded on floor diagrams. The actions and observations of the firefighters were then associated with specific times in the fireground audio to generate an overall event timeline. All events in the model are based on this master timeline of events. In addition, all photographs were time stamped and synchronized with the model. The Post Incident Analysis Team was consulted throughout the development of the event timeline and the computer fire model to ensure accuracy.

MODELING ANALYSIS:

1. Analysis of Fire Development in the Terrace Level

The fire originated on the stovetop of an occupied apartment on the right (south) side of the terrace level (apartment T2). Flames from a grease fire ignited kitchen cabinets, eventually causing the kitchen to flashover into the attached living room. Upon fire department arrival, a fully developed fire existed in the living room and kitchen of apartment T2. Prior to exiting the apartment, the occupant opened both the rear sliding door and the apartment entrance door in an attempt to ventilate smoke from the apartment. These openings provided sufficient ventilation and supported rapid fire growth within the apartment.

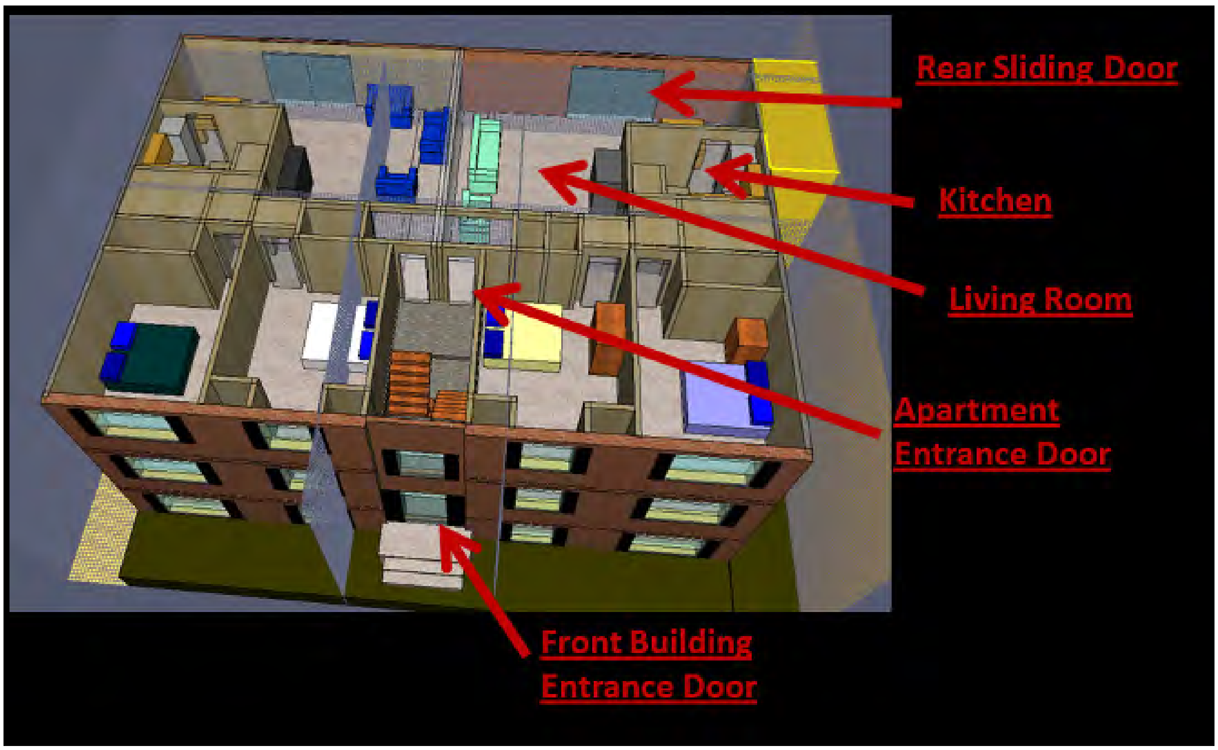

Figure 6. A typical floor plan of the right side apartments at 30 Dowling Circle.

Figure 7. Smokeview frame of the rear of the building indicating the fire origin and smoke spread within the T2 apartment.

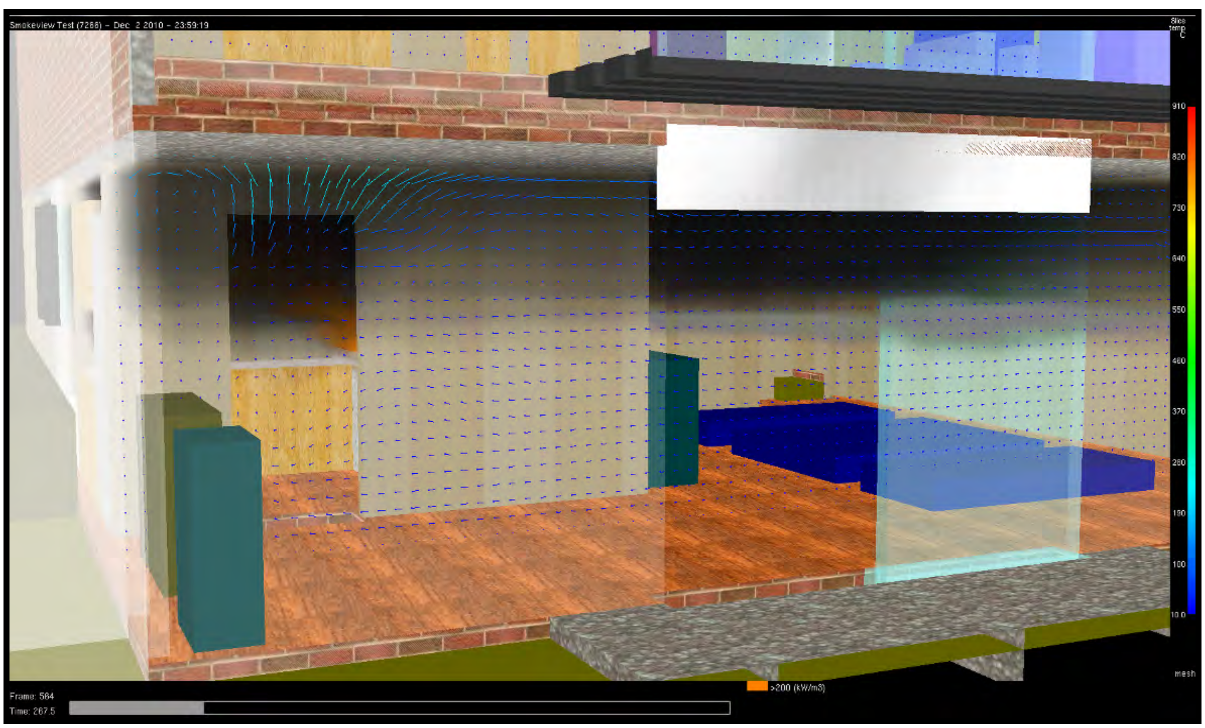

Figure 8. View of smoke flow out of kitchen and open sliding glass door (center of photo) in the rear of apartment T2.

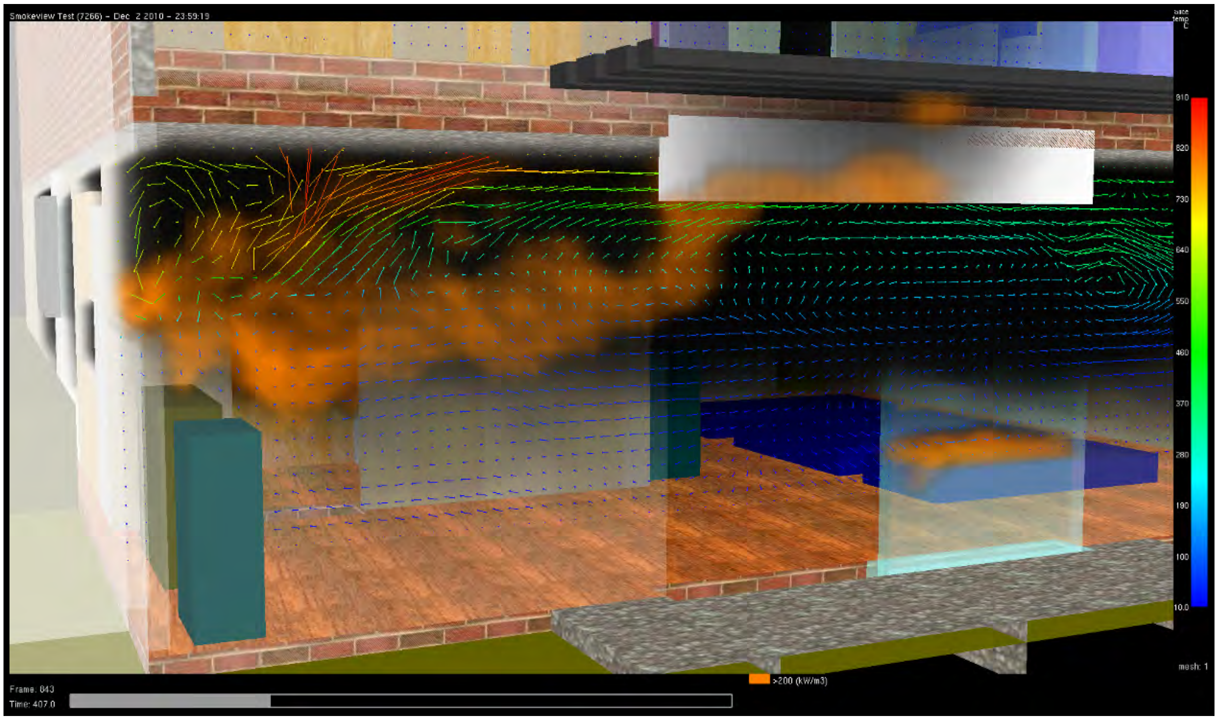

Figure 9. Smokeview frame of flashover of the kitchen with flames extending into the living room. Flames also begin to extend out of the rear sliding door and impact the balcony above.

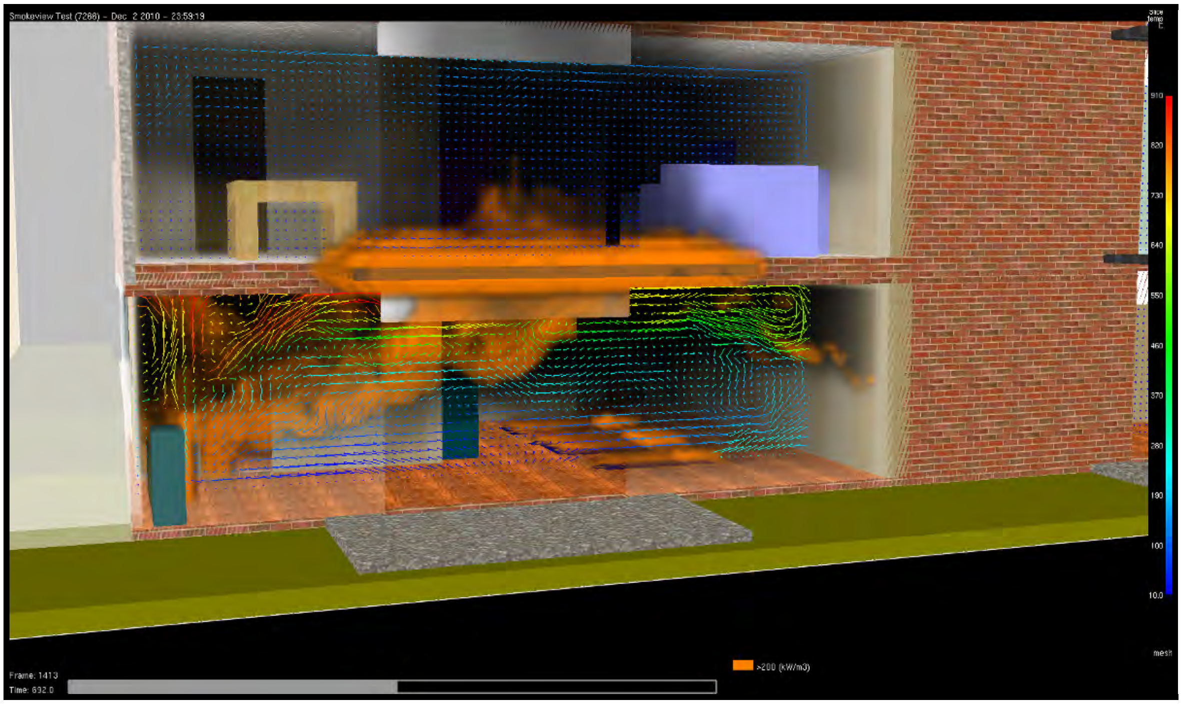

Figure 10. Ignition of second level balcony resulting from flame extension from living room.

An analysis of the ventilation flow path through the apartment with FDS indicated that a significant unidirectional flow path existed up the stairs with an inlet at the rear terrace sliding door and outlet at the front apartment entrance door leading to the stairwell.

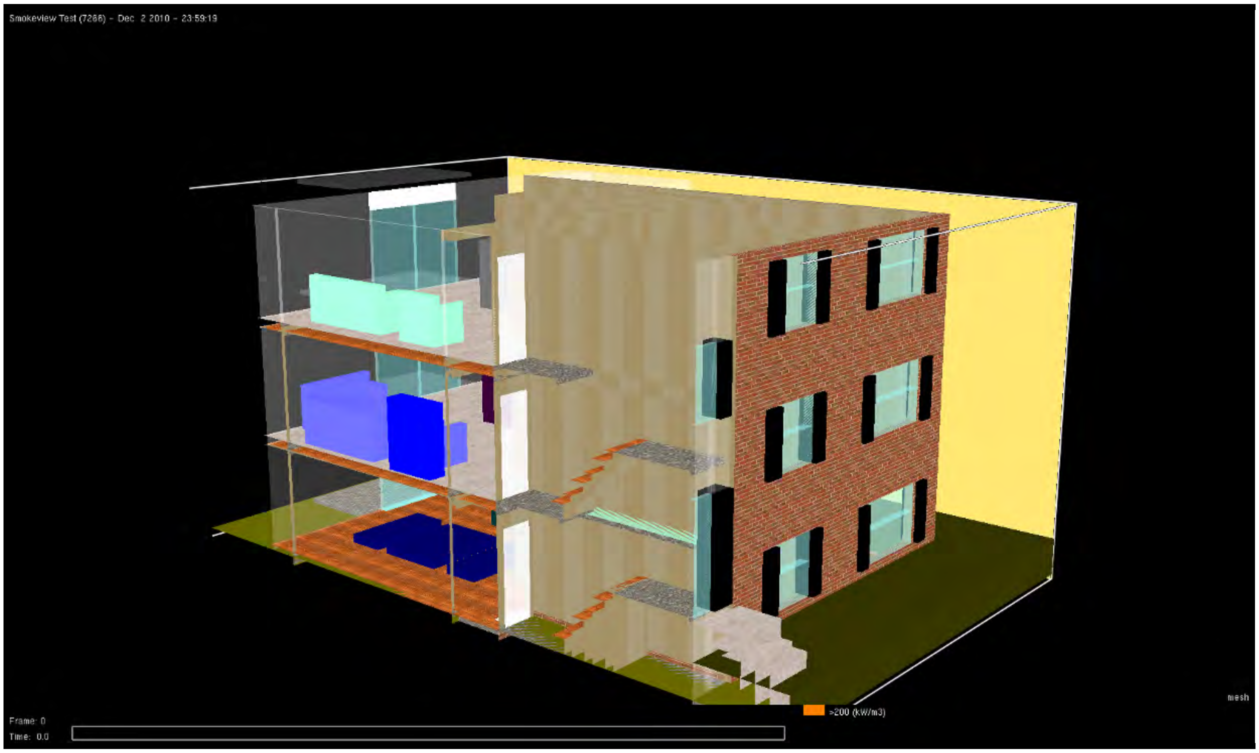

Figure 11. Smokeview frame showing section view of stairwell and living room area of all three south side apartments.

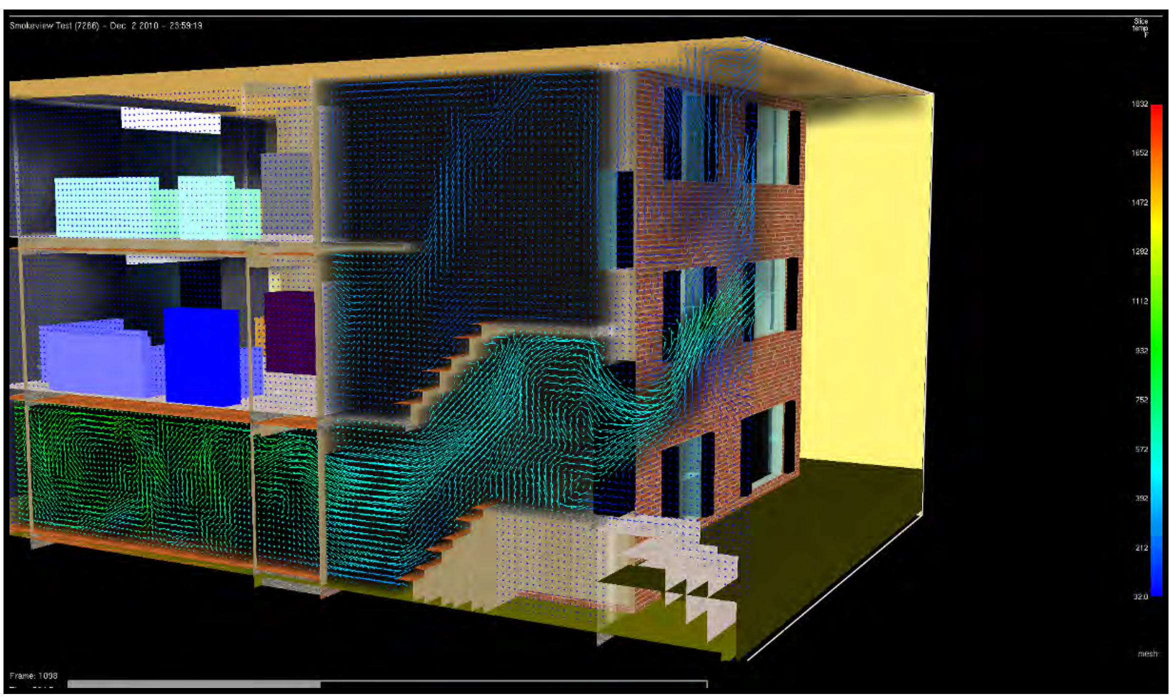

Figure 12. Smokeview section frame showing unidirectional flow of approximately 600 Fahrenheit (315 Celsius) gases out of the stairwell entrance door.

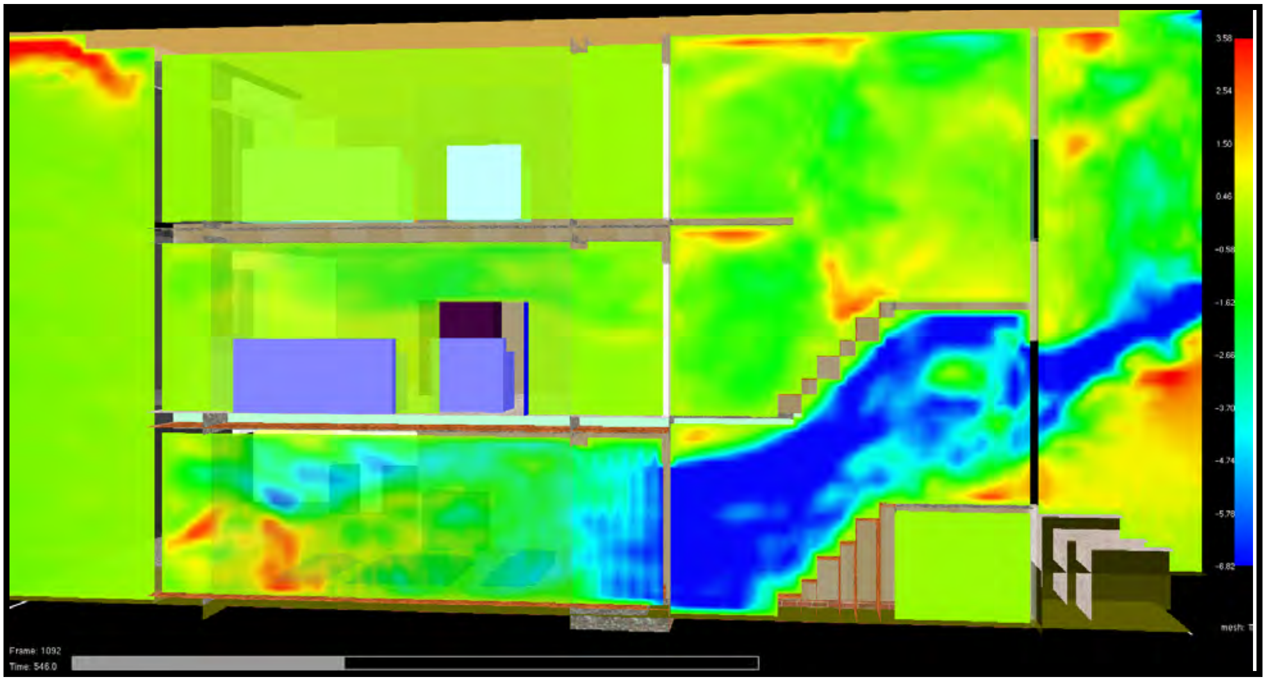

Figure 13. Smokeview frame indicating gas velocity up the stairs of approximately 6 mph (2.7 m/s) from floor to ceiling.

Figure 14. Front photo of unidirectional flow of smoke up stairwell from apartment T2. Note the high volume of smoke from floor to ceiling as the stairwell door serves as the flow path outlet. The

ground ladder in the foreground was used to rescue an occupant on the third floor trapped by heavy smoke in the stairwell.

Figure 15. Photo from rear of flames in apartment T2 and extension to the balcony above. Note the relative minimal volume of smoke as the sliding door serves as the inlet for ventilation into the apartment. The smoke and heat is flowing in from the rear, through the apartment and up the stairs.

This unidirectional flow path up the stairs is difficult to combat and is often experienced during basement fires as crews attempt to descend interior stairs. The model indicates sustained air temperatures in the stairwell of approximately 600 Fahrenheit (315 Celsius) at velocities of approximately 6 mph (2.7 m/s) from floor to ceiling as crews attempted to descend the stairs. This is consistent with statements from firefighting crews, who experienced extremely high heat conditions and indicated periodically seeing flames in the smoke layer flowing up the stairs. The elevated air velocity of the stairwell flow path resulted in a high rate of convective energy transfer to the structural firefighting gear and high perceived temperatures as the firefighters attempted to descend the stairs.

Firefighting crews flowed a hoseline down the stairs to combat the high temperatures; however no significant cooling was noticed by firefighters because the hose stream could not reach the seat of the fully developed fire in the kitchen area. The crews were simply cooling the ventilation flow path without cooling the source of the energy in the apartment. It was not until a hose stream was directed through an exterior window and a portion of the fire was extinguished that gas temperatures and velocities began to decrease, allowing firefighters to make entry to the terrace apartment via the stairs.

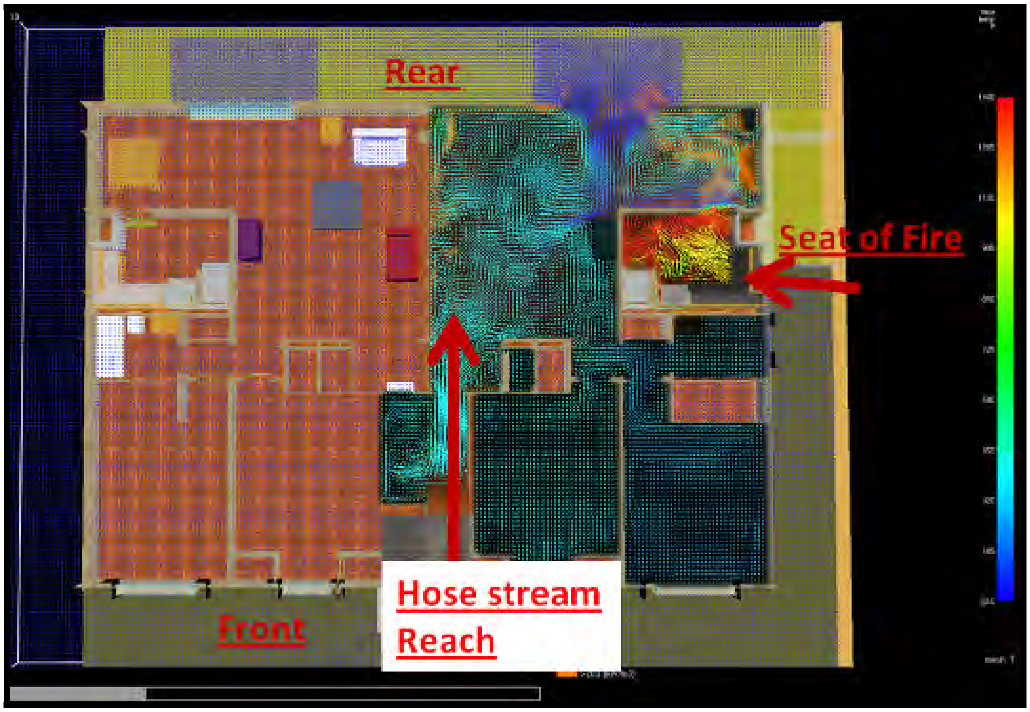

Figure 16. Plan view of flow path and temperatures within the apartment. Note the location of the seat of the fire and the location of initial hose stream application down the stairs.

Figure 17. Photograph of hoselines being positioned at the stairwell entrance door and front window. Note the heavy smoke venting from all front openings in apartment T2.

2. Rapid Fire Progression Leading to Flashover of the Third Level

Flames extended upwards from the T2 apartment sliding door and ignited the rear balconies of the second and third level apartments above. Fire on the second floor balcony extended into apartment A2 by failing the sliding glass door and igniting vertical plastic slat curtains that were suspended above. As crews searched within the second floor apartment, they noted seeing the burning curtains on the floor with flames extending to a nearby couch (containing polyurethane foam padding) adjacent to the sliding doorway. The fire continued to grow unsuppressed and spread to a second couch as interior firefighting crews were engaged in rescuing two victims from the living room in the second floor apartment.

Figure 18. Smokeview frame of the rear of the building with flames extending from T2 and involving both balconies above.

Figure 19. Photo of flame extension and suppression efforts at the rear of the structure. Flames caused the second level glass slider to fail and ignite plastic curtains in the doorway located at the top of the photo.

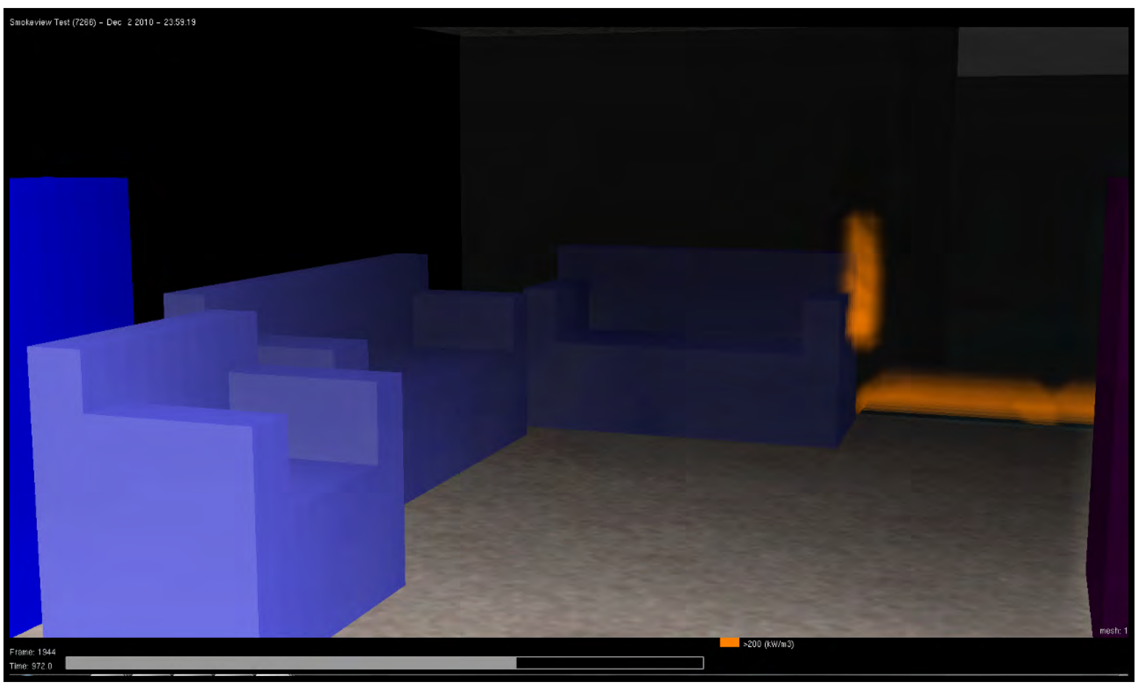

Figure 20. Flames extend from plastic curtains in apartment A2 to corner of couch as witnessed by firefighters conducting a search of the second level apartment. Two victims were rescued from the living room.

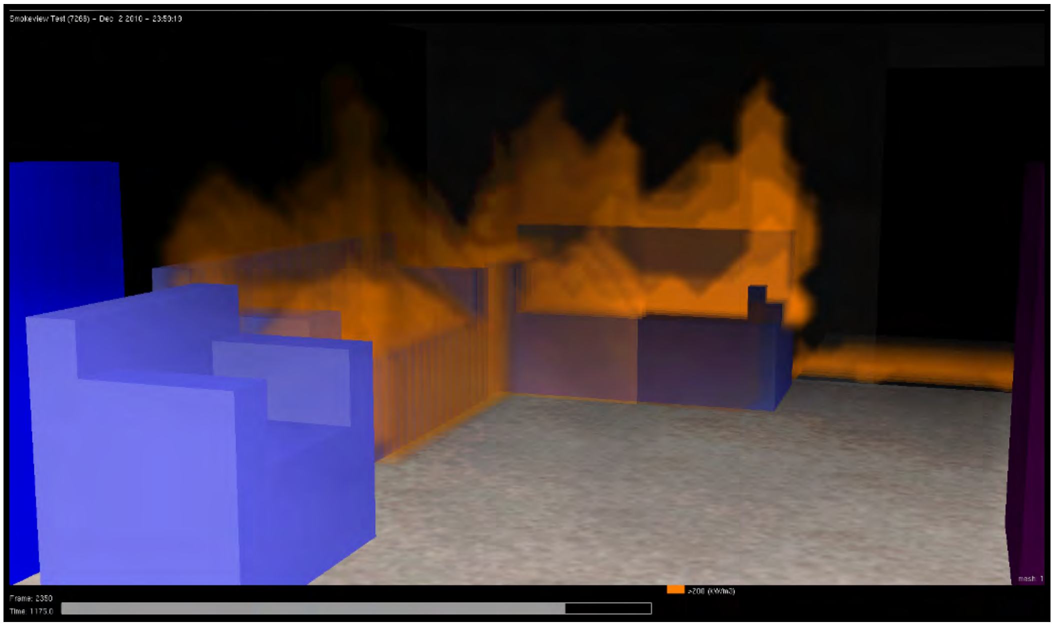

Figure 21. As the second victim was located, flames continued to spread across the couches in the living room of A2. The apartment entrance door was opened by additional search crews, allowing sufficient oxygen to support fire growth within the apartment.

The middle level apartment (A2) entrance door was opened by a second search crew around the same time as the second couch ignited, creating a ventilation flow path from the second floor balcony, through the apartment, and upwards into the stairwell (third floor). This flow path follows the same general route through the apartment and into the stairwell as was seen in the terrace level apartment below.

Squad 303's crew arrived on scene after the bulk of the fire in the terrace level apartment had been suppressed and appeared to be under control. The crew entered the front stairwell, which had minimal smoke up to the second level and the crew began to systematically search the building.

Figure 22. Photo depicting building smoke and fire conditions around the arrival of Squad 303. Note the lack of heavy smoke or fire in the stairwell or terrace level. There is also no indication of the growing fire in the second (middle) level apartment.

Squad 303's crew proceeded to search two apartments before entering the third floor right side apartment to conduct a search, leaving the entrance door open. It should also be noted that carpeting impacted the bottom of the door and prevented the apartment entrance doors on the second and third levels from closing automatically. The entry doors had to be actively pushed closed to overcome the friction of the carpet.

Figure 23. Exemplar apartment showing apartment entrance door.

Figure 24. Close view of base of the door impacting the carpet, preventing the door from self closing.

When Squad 303's crew of two firefighters entered the third level apartment (B2), smoke was banked about halfway down the walls with moderate visibility. The crew could clearly see the floor of the apartment without the need to crawl below the smoke layer to search. Squad 303's crew was unaware of the flames spreading across the two couches in the second floor apartment below them. The crew split in order to search the apartment faster, with one firefighter searching the front bedrooms and the officer searching the kitchen and living room.

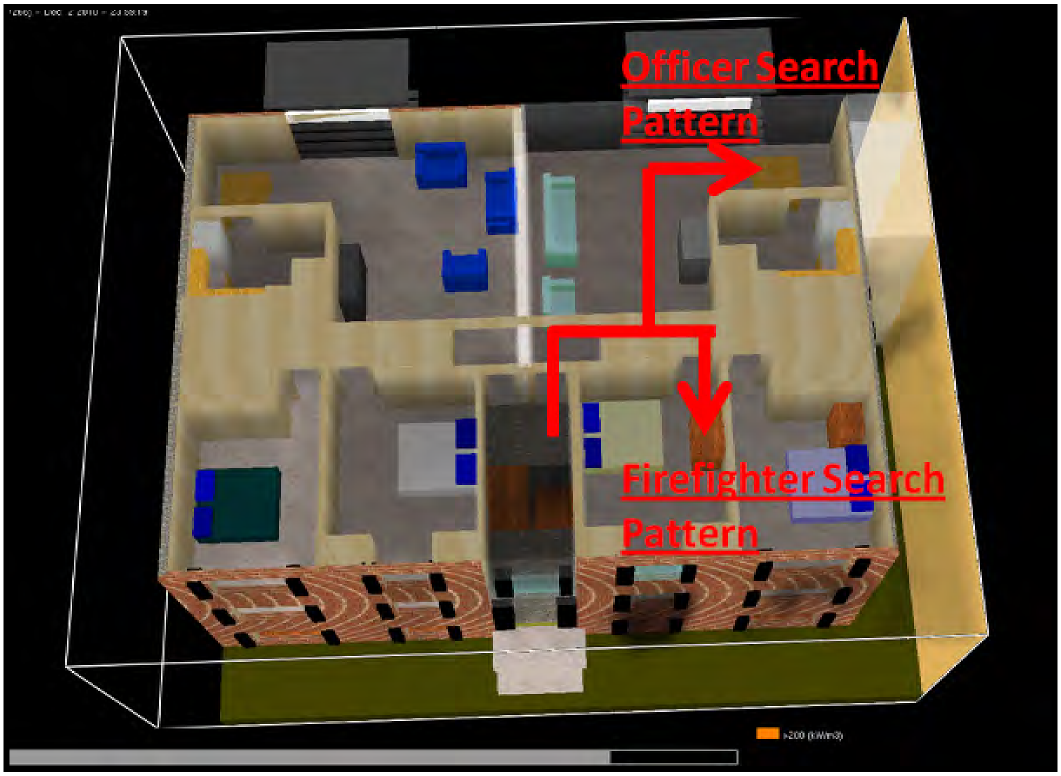

Figure 25. Search pattern of Squad 303's officer and firefighter after they split to conduct a search of the third floor apartment. The officer searched the rear of the apartment while the firefighter searched the bedroom.

As flames in the second level began to rollover into the apartment entranceway, the smoke layer in the third level quickly dropped to the floor with a rapid increase in temperature. With Squad 303's crew searching above, flames began to extend into the stairwell, supplied by sufficient ventilation flowing through the apartment. This combination of fuel, heat and oxygen rich fresh air resulted in a rapid increase in heat release rate and flashover of the second level apartment followed by full room involvement. The open entrance doors on the second and third levels created a ventilation flow path through the second floor apartment, into the sealed stairwell and up through the third floor apartment directly above. The flames followed this flow path and extended from the second floor, through the stairwell and into the living room area of the third floor apartment. Flashover of the third floor occurred approximately 30 seconds after the second floor experienced flashover.

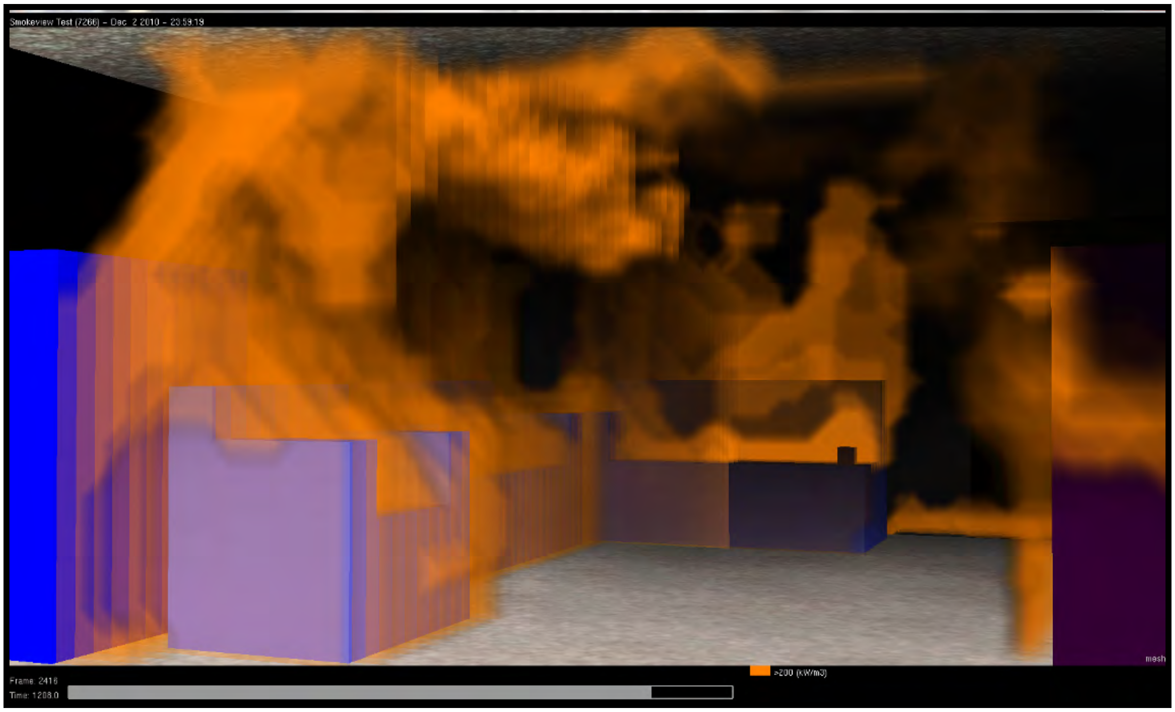

Figure 26. Involvement of the furniture items in the second level apartment that leads to flashover.

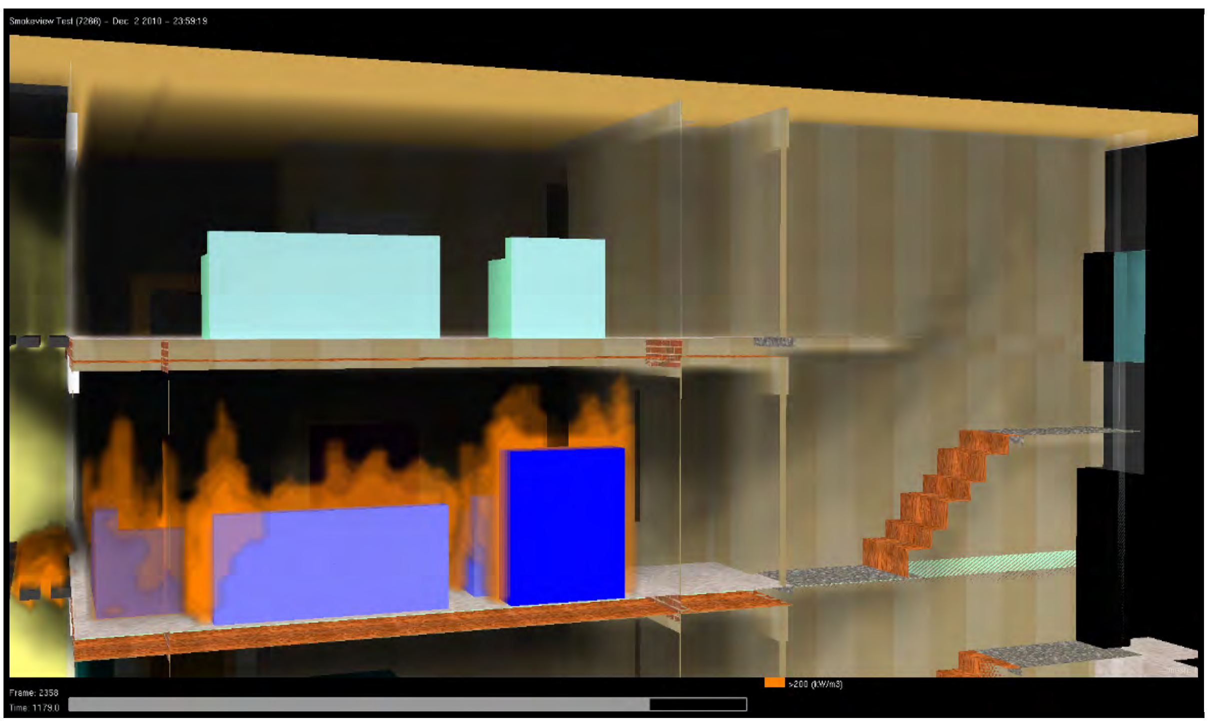

Figure 27. Section view of couches and furniture involved in flame just prior to flashover.

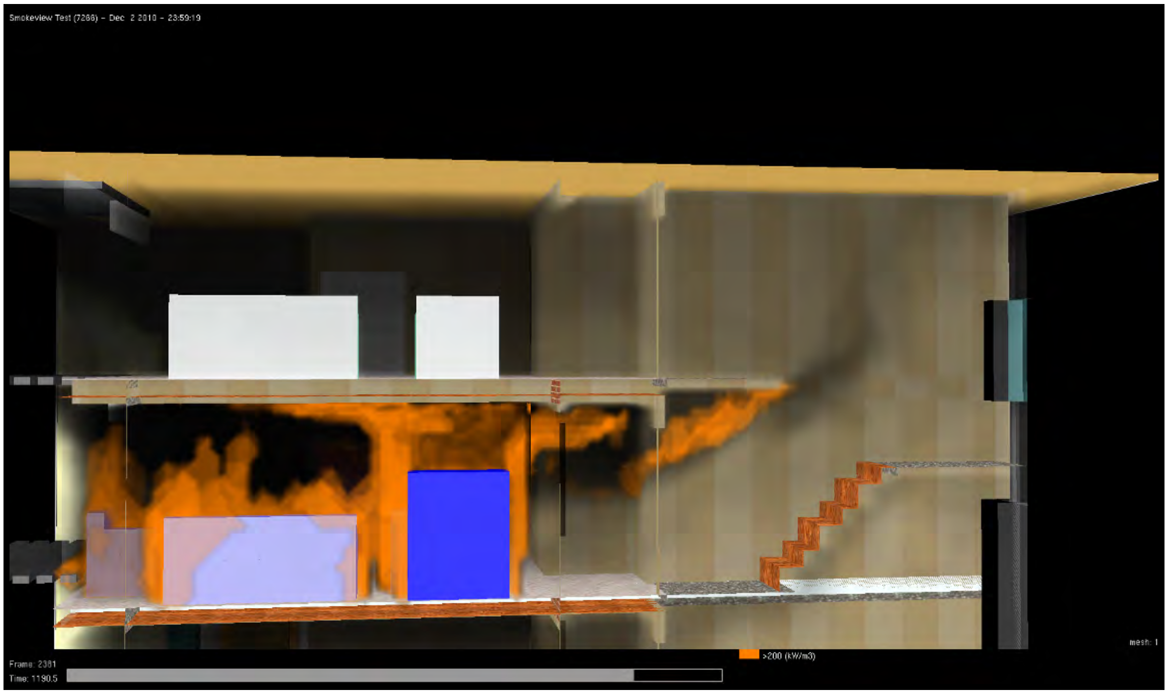

Figure 28. Rollover from the second level apartment into the stairwell. The second victim was removed from the apartment just as flames began to extend out of the door. Firefighters covered the victim to protect her from the flames, sustaining damage to their gear.

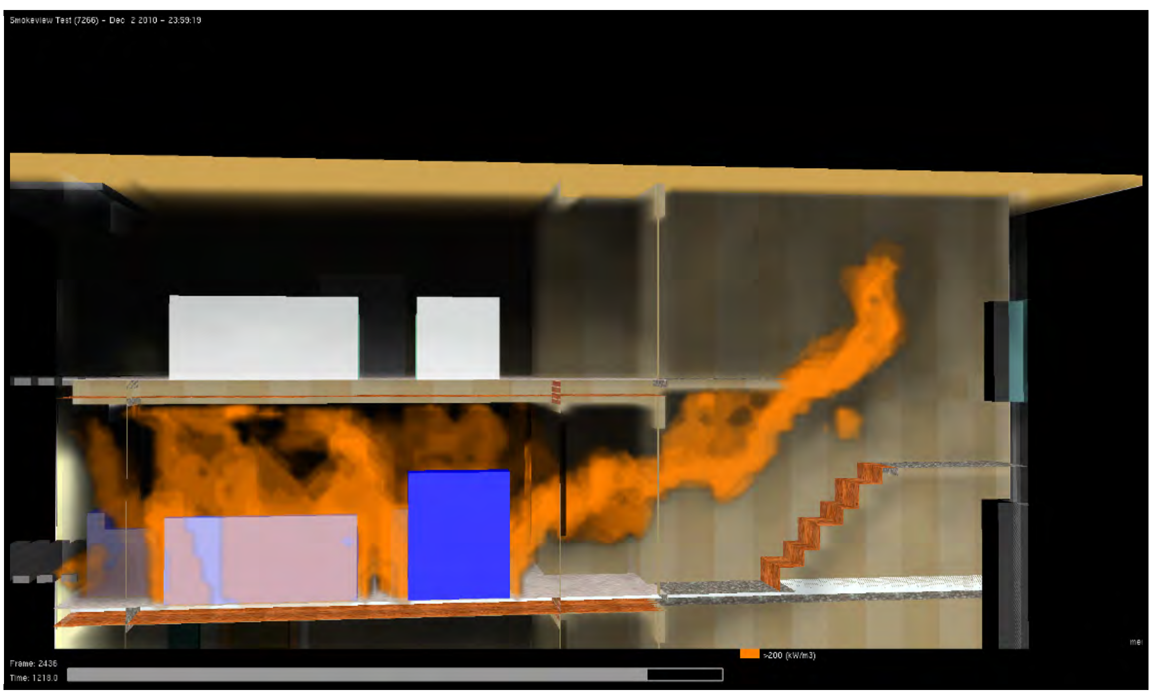

Figure 29. Flashover of the second level with flames extending upwards into the sealed stairwell.

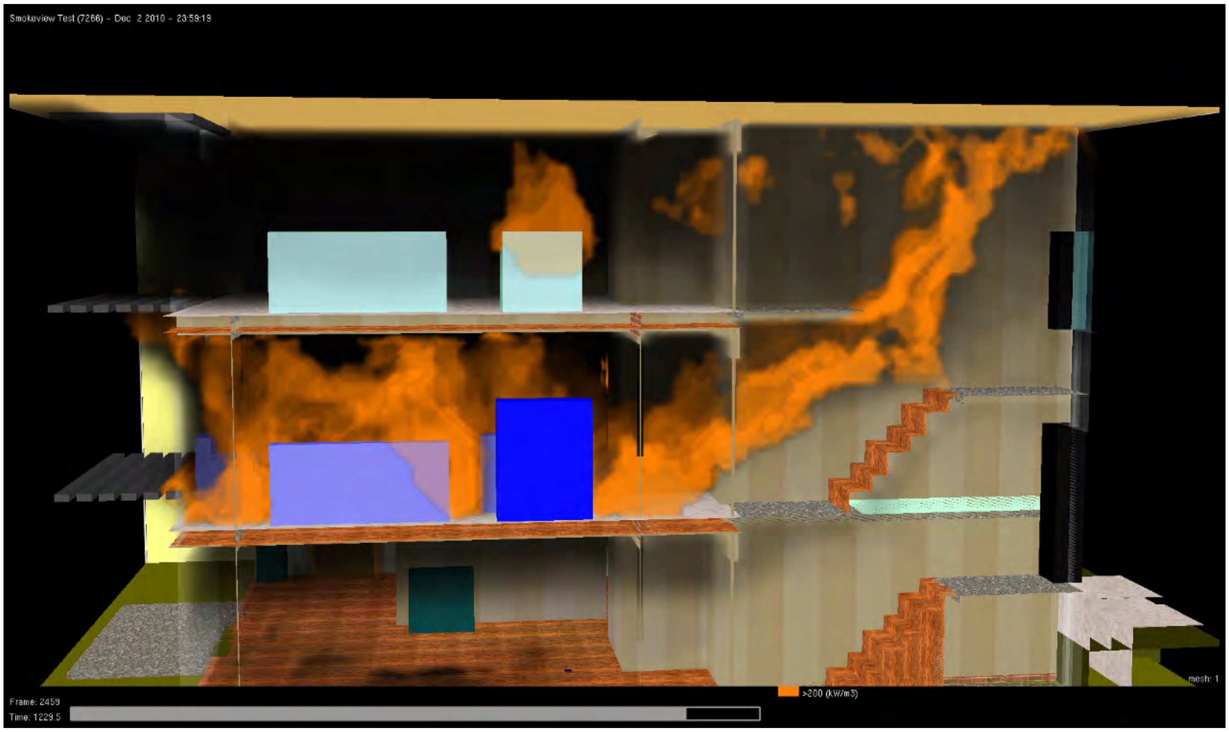

Figure 30. Flames followed the ventilation flow path and extend into the third floor apartment, resulting in ignition of the couches just inside the doorway.

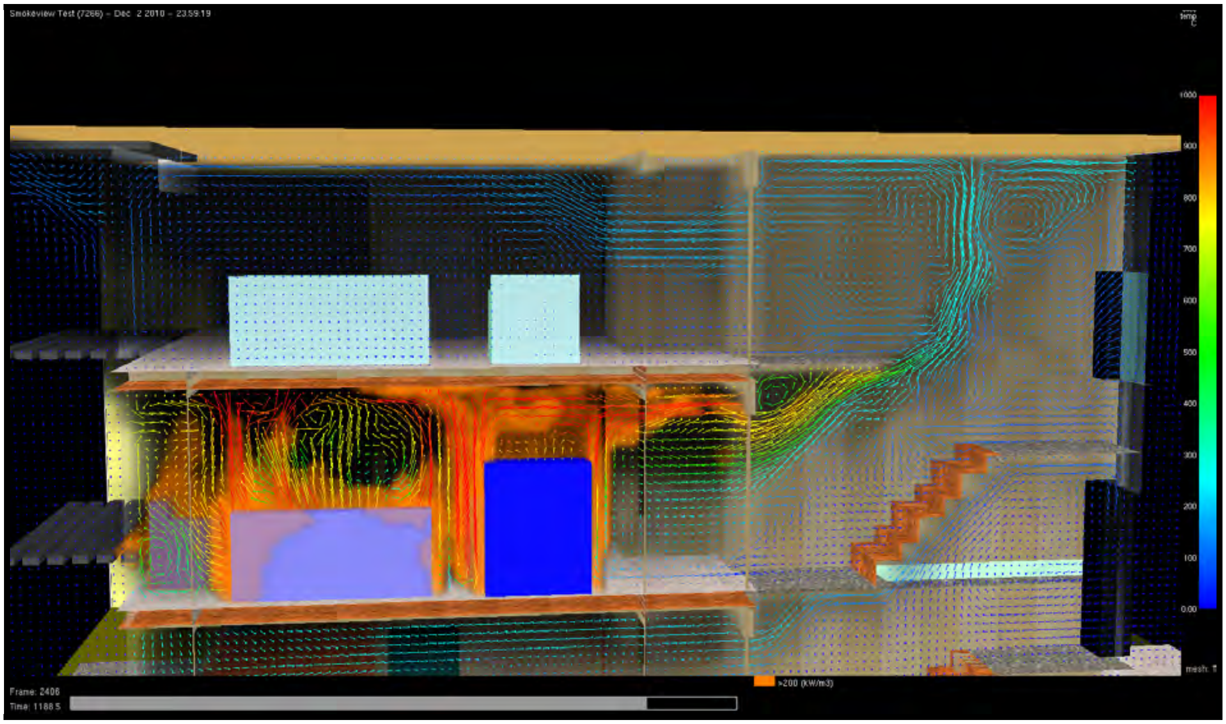

Figure 31. Smokeview frame showing temperature, direction and magnitude of ventilation flow path through stairwell at the time of rollover. Note the flow of heat out of the apartment into the stairwell.

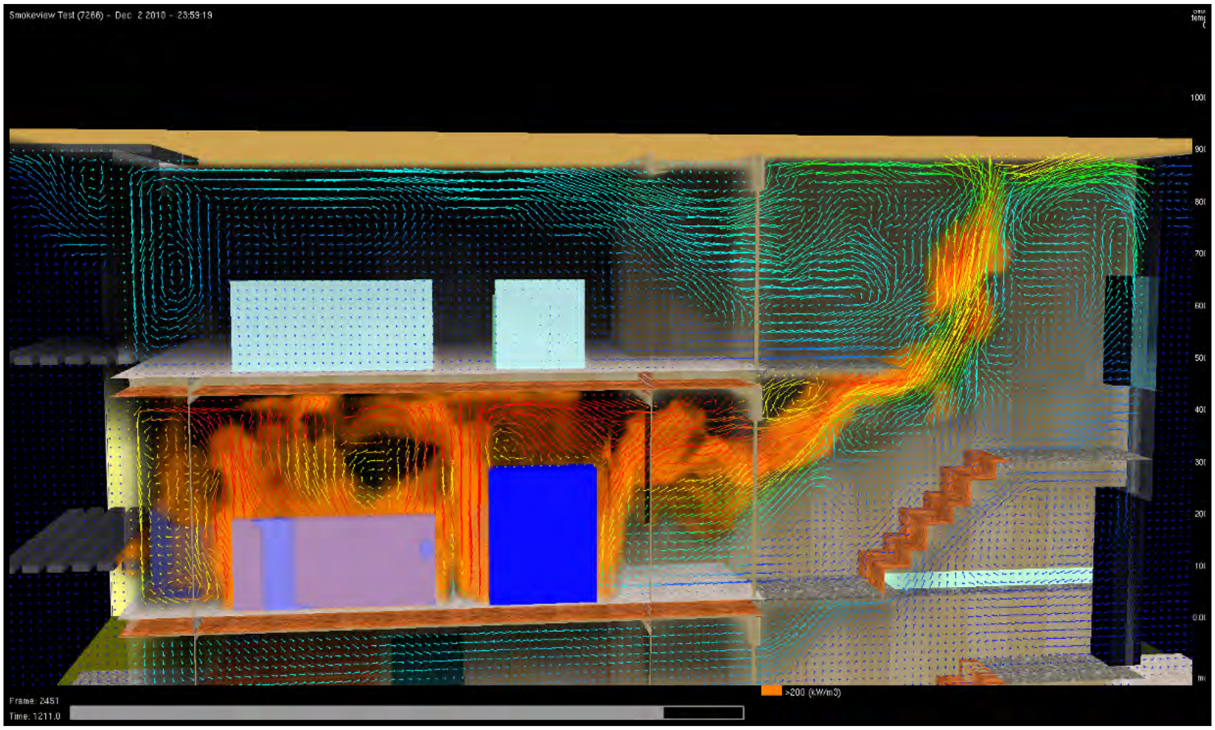

Figure 32. Smokeview frame showing smoke and heat filling the sealed stairwell and flowing into the third level above. Note the flow path from the stairwell into the third floor apartment.

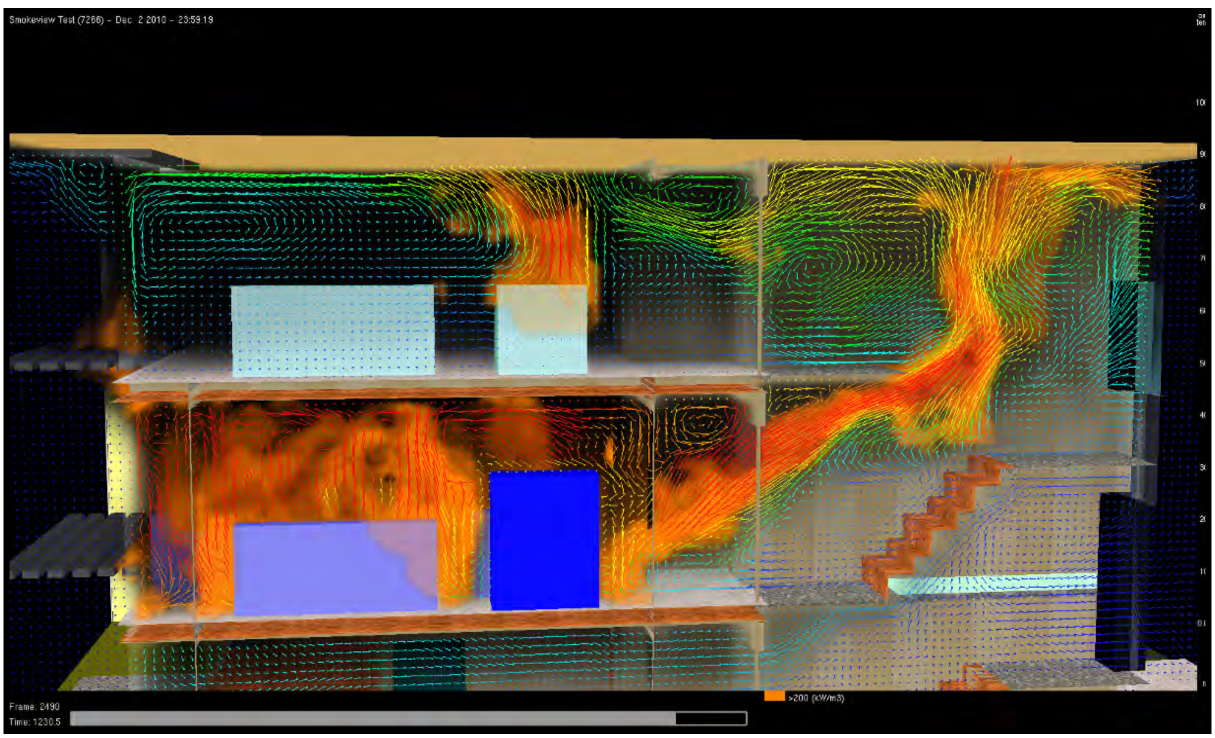

Figure 33. Smokeview frame showing ignition of the couches just inside the third level doorway. The energy from the fully involved second floor apartment flows through the sealed stairwell, directly into the apartment above.

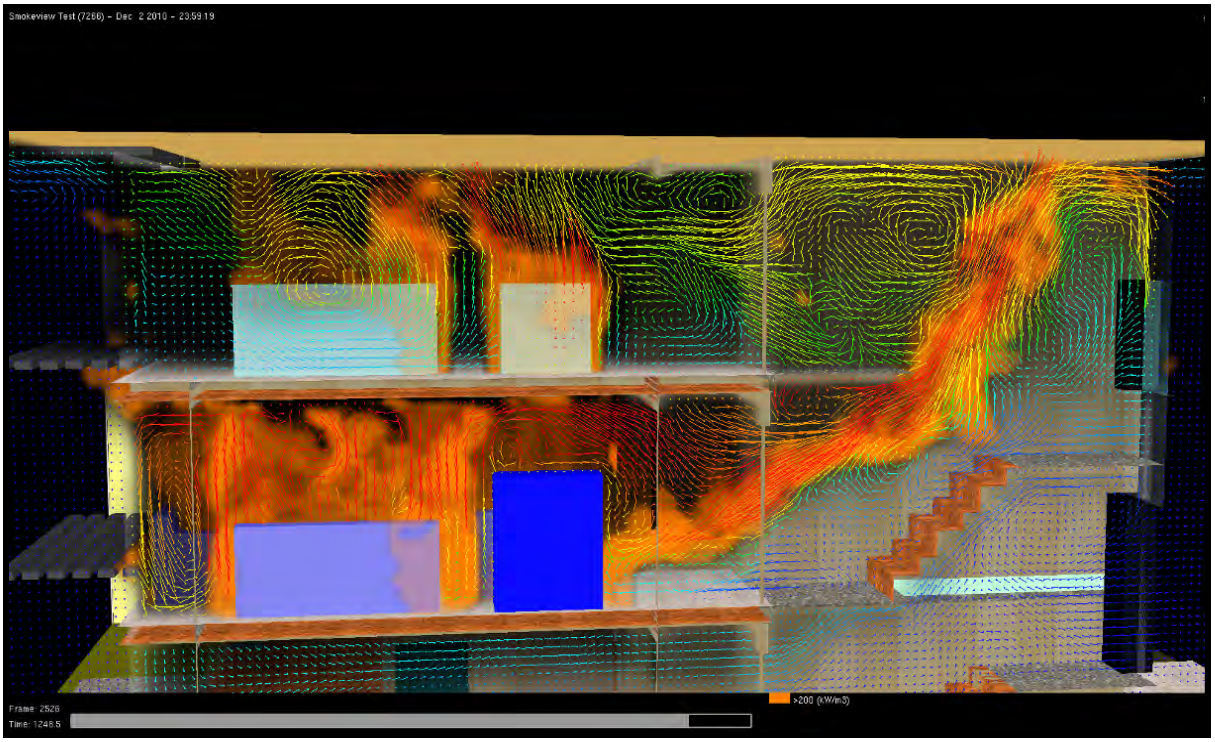

Figure 34. Smokeview frame showing fully developed fire on the second level resulting in flashover of the third floor.

Figure 35. A front view of the apartment building from Smokeview of flames extending through the stairwell into the third floor (front stair wall is hidden to show flame extension).

Figure 36. Photo showing flame extension into hallway as the second floor apartment reaches flashover. Note the heavy smoke and fire conditions that now exist in the stairwell as compared to when Squad 303 originally made entry.

Figure 37. Photo showing flame extension through the stairwell to the third level. The stairwell window is broken by a ladder just after flames extend to the third floor. Evacuation tones are sounded just before this photo.

Command sounded the building evacuation tones as flames extended into the hallway and up to the third level apartment. Two couches just inside the entrance door on the third level ignited, blocking the primary means of egress for both firefighters from Squad 303.

Upon hearing the evacuation horns from the trucks, the second firefighter from Squad 303 (searching the front bedrooms) attempted to exit the apartment via the apartment entrance door, however he was blocked by flames in the living room and stairwell. Trapped in the bedroom, the firefighter bailed out headfirst down a ground ladder on the front side from the third floor.

Squad 303 officer's means of egress through the apartment entrance door was also blocked by the flames in the living room and stairwell. There were no windows located in the rear of the apartment. The only means of escape was the balcony slider, however the entire balcony was engulfed in flames from the fully involved apartment below.

With both escape routes blocked by flames and experiencing extremely high heat conditions, Squad 303's officer requested assistance and declared a MAYDAY from the rear of the third floor apartment. Firefighters re-entered the structure to combat the fire and locate the trapped firefighter. The downed firefighter was eventually located on the third level just inside the sliding glass door and was removed to the rear balcony. The firefighter was then extricated in a stokes rescue basket down the aerial ladder of a truck located in the rear, where he was subsequently transported to the hospital.

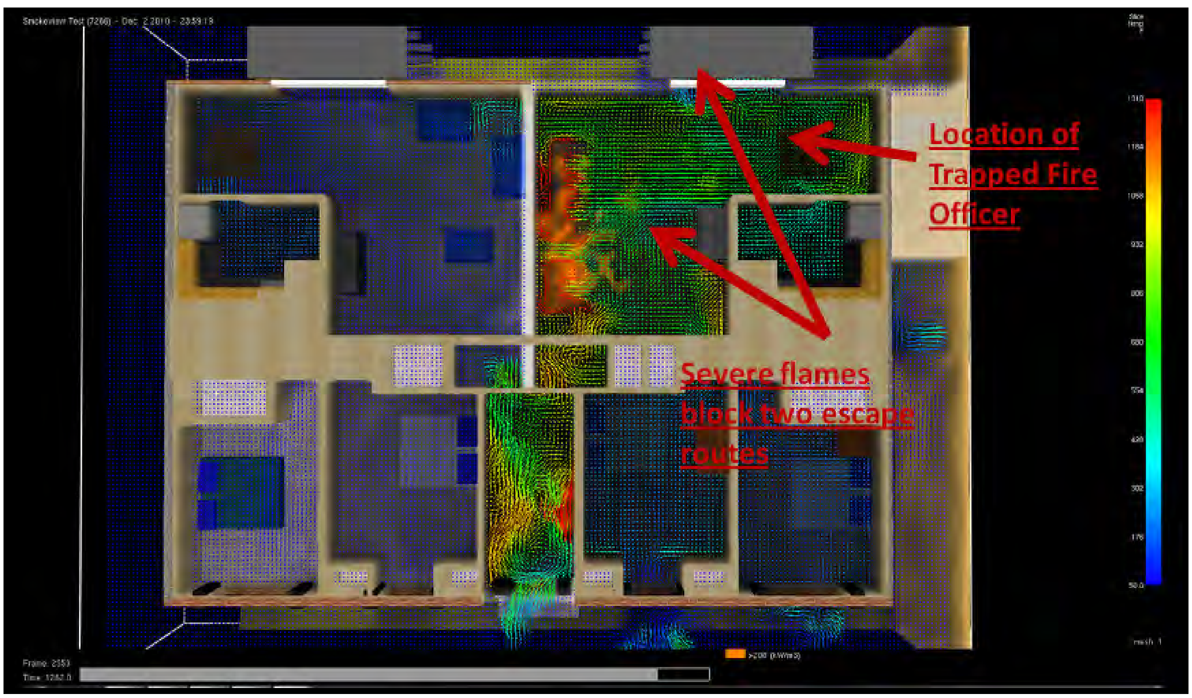

Figure 38. Plan view showing location of trapped fire officer and potential escape routes through structure, both of which are block by flames.

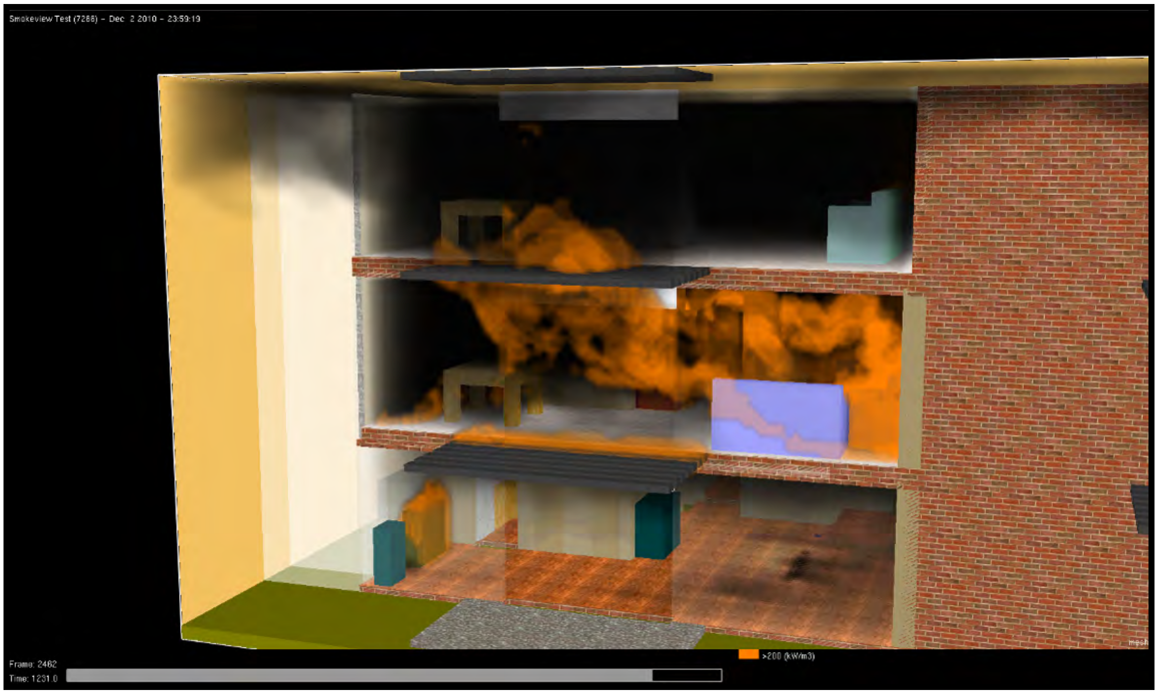

Figure 39. Smokeview frame showing flames blocking potential egress through the third floor balcony as seen from the rear of the building.

3. Effects of Compartmentation on Fire Spread

The Post Incident Analysis Team requested that alternate modeling scenarios be conducted to explore the effects of compartmentation on fire spread throughout the building. The team specifically wanted to know how the ventilation flow paths through the stairwell would differ if the second or third level apartment entry doors were shut after entering/leaving the apartments. Two alternate computer fire modeling scenarios were conducted.

The first alternative modeling run featured the exact same fire scenario, except the second (middle) level apartment door was closed after the last victim was removed from that apartment. The apartment entry doors from the stairwell were fire-rated doors constructed of solid wood. As soon as the door is shut, the ventilation flow path through the apartment and up the stairwell is blocked.

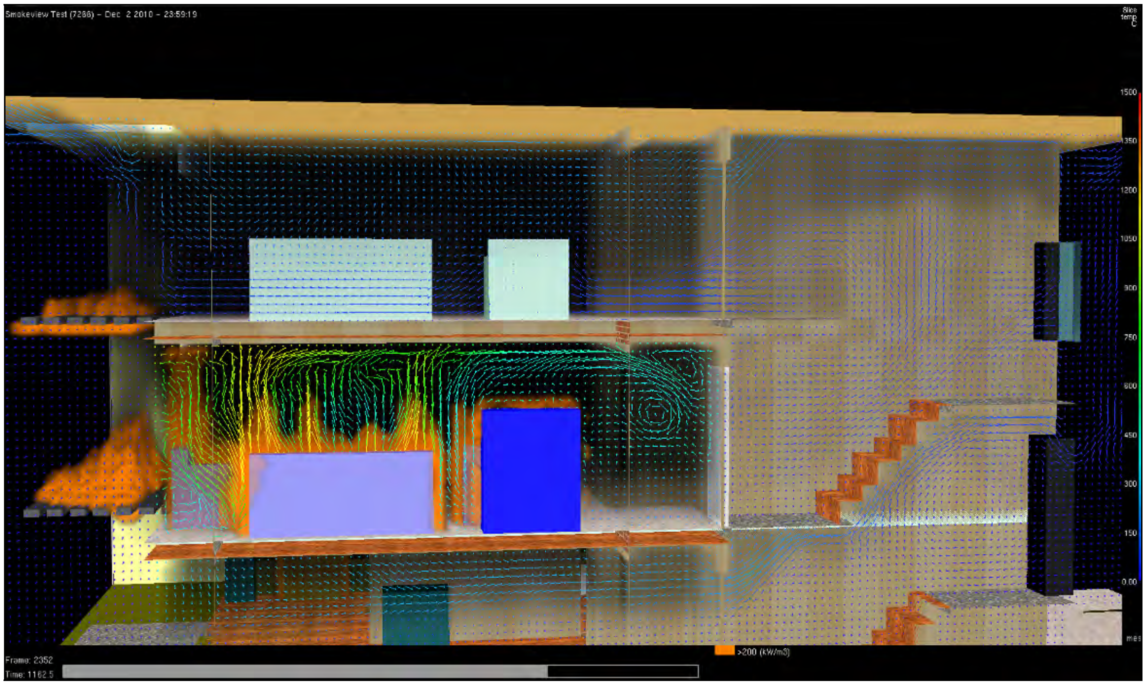

Figure 40. Shutting the second level apartment door blocks the flow path and flame extension into the stairwell.

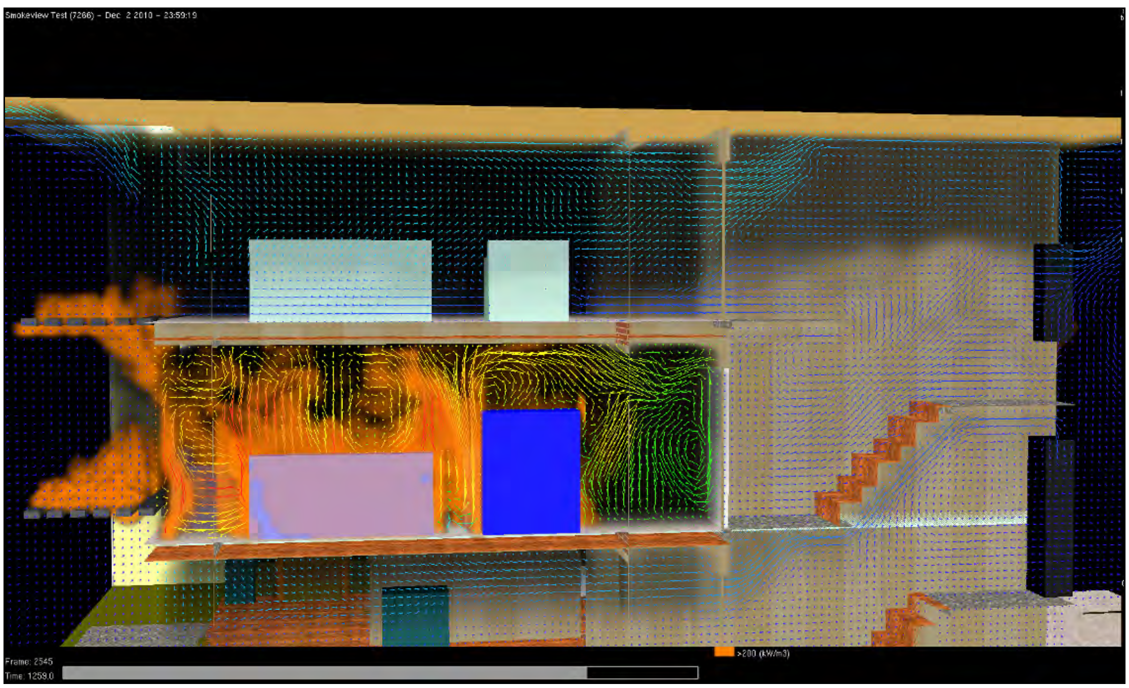

Figure 41. Even with the third floor apartment door left open, the model indicates that the stairwell and third floor remain tenable for firefighters. Flames eventually extend from the third floor balcony into the apartment, however the escape routes through the stairwell and the front apartment windows are accessible.

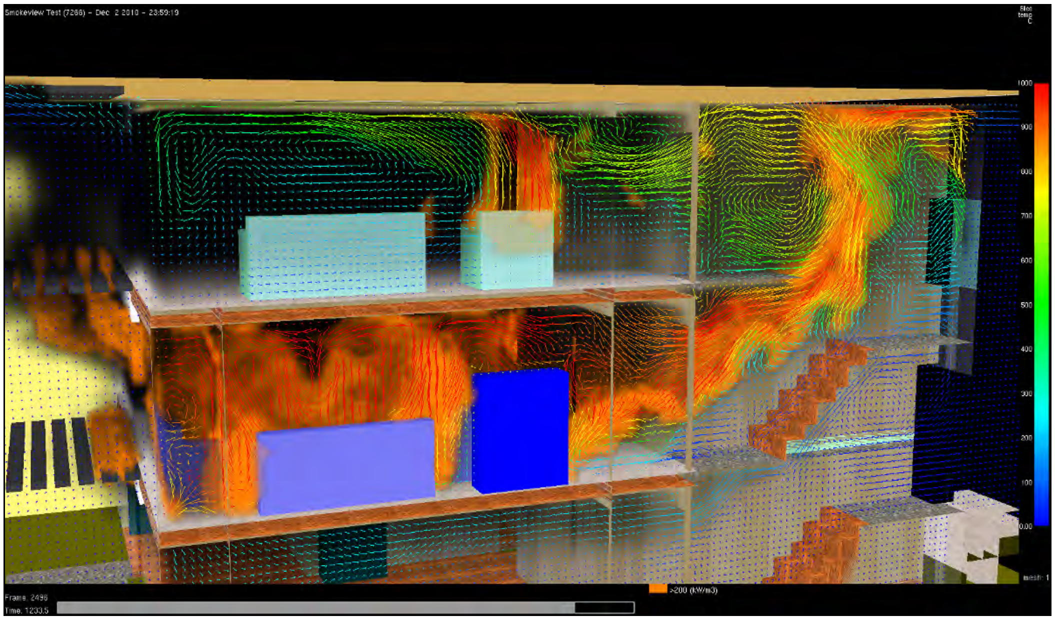

Figure 42. Smokeview frame from the actual model with both apartment doors open for comparison purposes. The ventilation flow through the apartments results in an increased burning rate within both the second and third levels, as well as the stairwell.

The model indicates that closing the second level apartment door prevents the flow of smoke, heat and other products of combustion from entering the stairwell, thus preventing flashover of the stairwell and the third level. As long as the second floor entry door remains shut, the model indicated that the conditions within the stairwell and third floor remain tenable for firefighters, even with the third floor apartment door open.

A second alternative modeling scenario was conducted where the third level entrance door was closed after crews made entry to search the apartment. The same fire conditions from the actual model were used. When the door remained closed, the outlet of the ventilation flow path was blocked at the top of the stairs. Without a complete flow path, there wasn't sufficient oxygen flowing through the second floor apartment to support extended burning in the stairwell. Consequently after flashover of the second floor, the flames in the stairwell only exist momentarily before consuming all available oxygen and becoming ventilation limited. The fire model indicated that temperatures within the third floor apartment stayed tenable for firefighters, even with a fully developed fire on the second floor and flames in the stairwell. Flames would eventually extend up the rear balcony to the third level, however they would not block egress through the living room and front windows of the apartment. By closing the apartment door on the third floor and blocking the outlet for fire gases emanating from the second floor apartment, the third floor apartment remains tenable for firefighting crews and the temperatures only briefly spike in the stairwell before the fire becomes ventilation limited.

Table 1. Results of each modeling scenario describing extent of flame spread.

FDS Model Run	**Flashover of 2nd Level**	**Flashover of Stairwell between 2nd and 3rd level**	**Flashover of 3rd Level**
Actual Modeling Run	YES	YES	YES
2nd Floor Apt. Door Closed	YES	NO	NO
3rd Floor Apt. Door Closed	YES	YES	NO

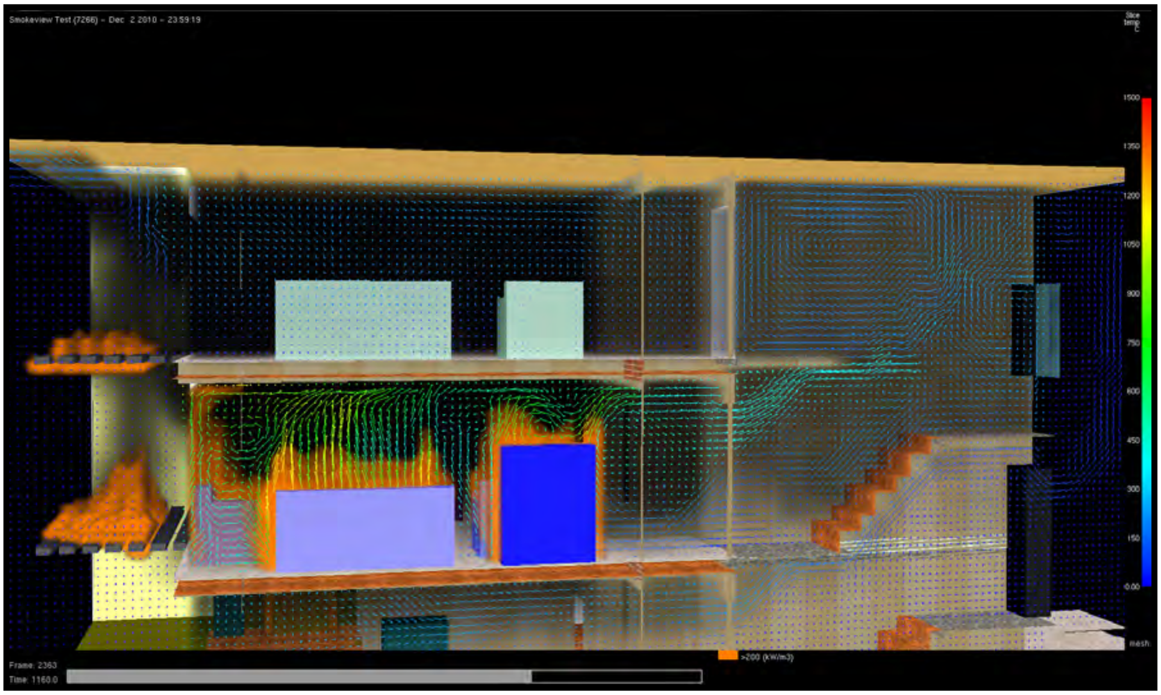

Figure 43. Smokeview frame showing closed third floor apartment door preventing fire gases from entering the apartment.

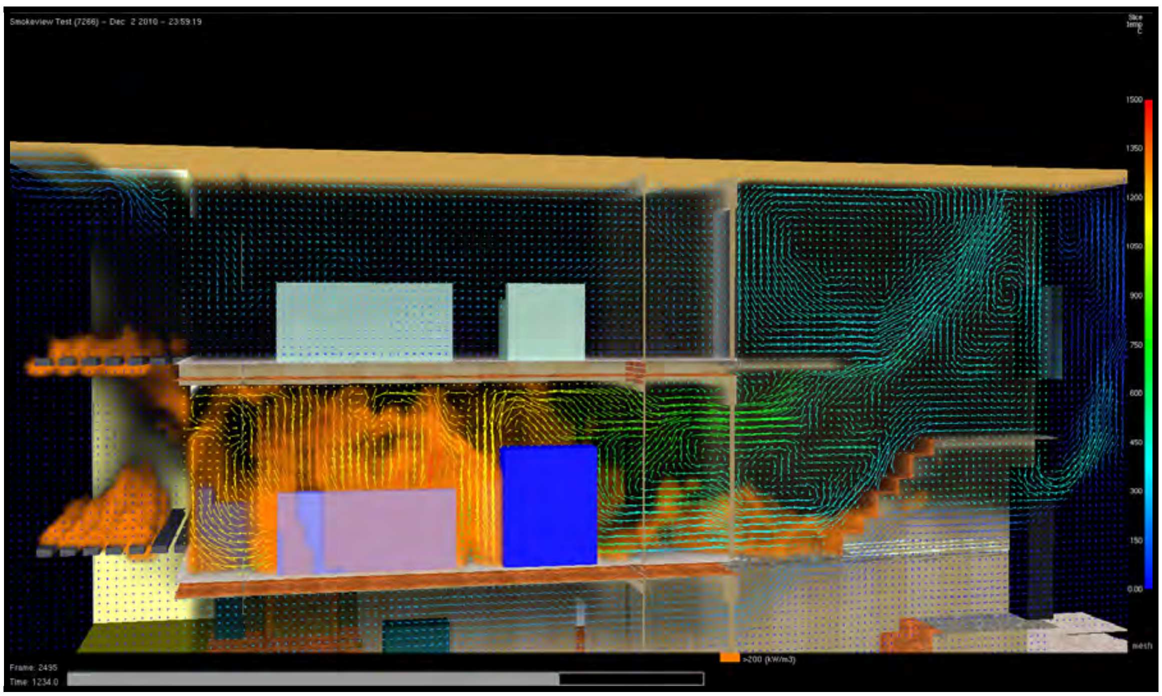

Figure 44. Blocking the outlet of the flow path decreases the burning rate within the second floor apartment and stairwell. The stairwell becomes oxygen limited and doesn't support sustained flaming combustion by the third floor apartment door at the top of the stairs.

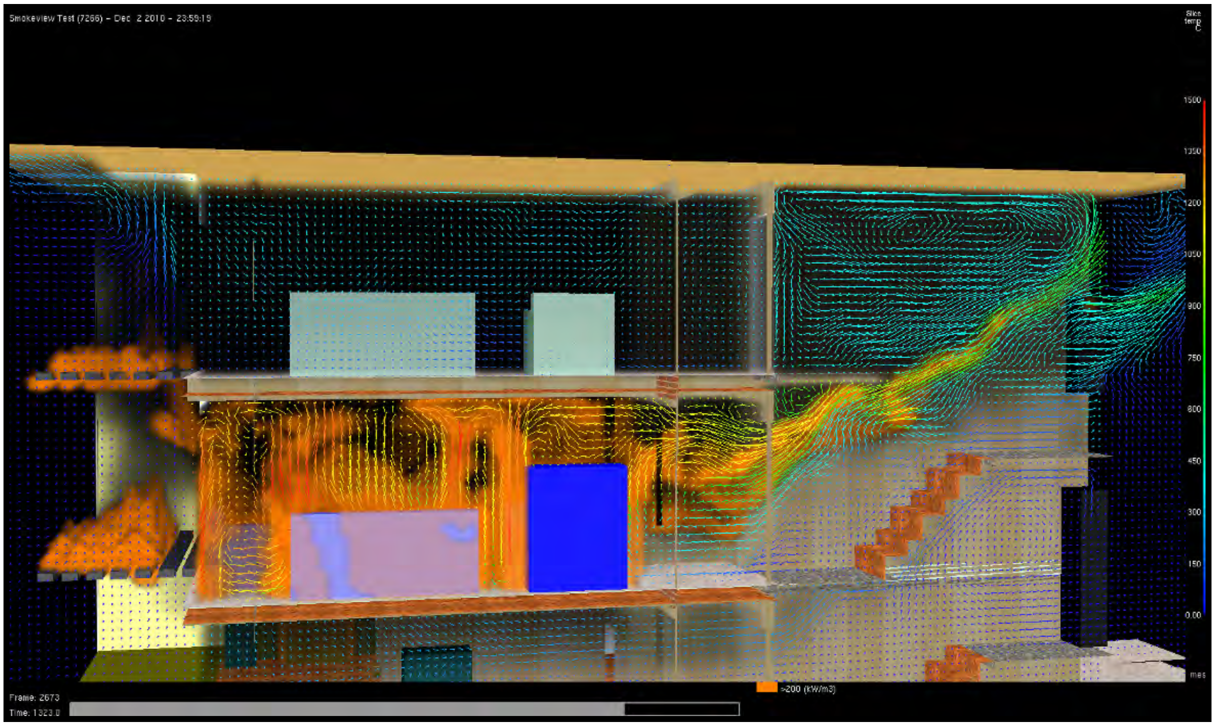

Figure 45. Even with the front stairwell window vented, the upper volume of the stairwell near the third level apartment entry doors remains oxygen limited and flames do not extend to the third level apartments via the stairs.

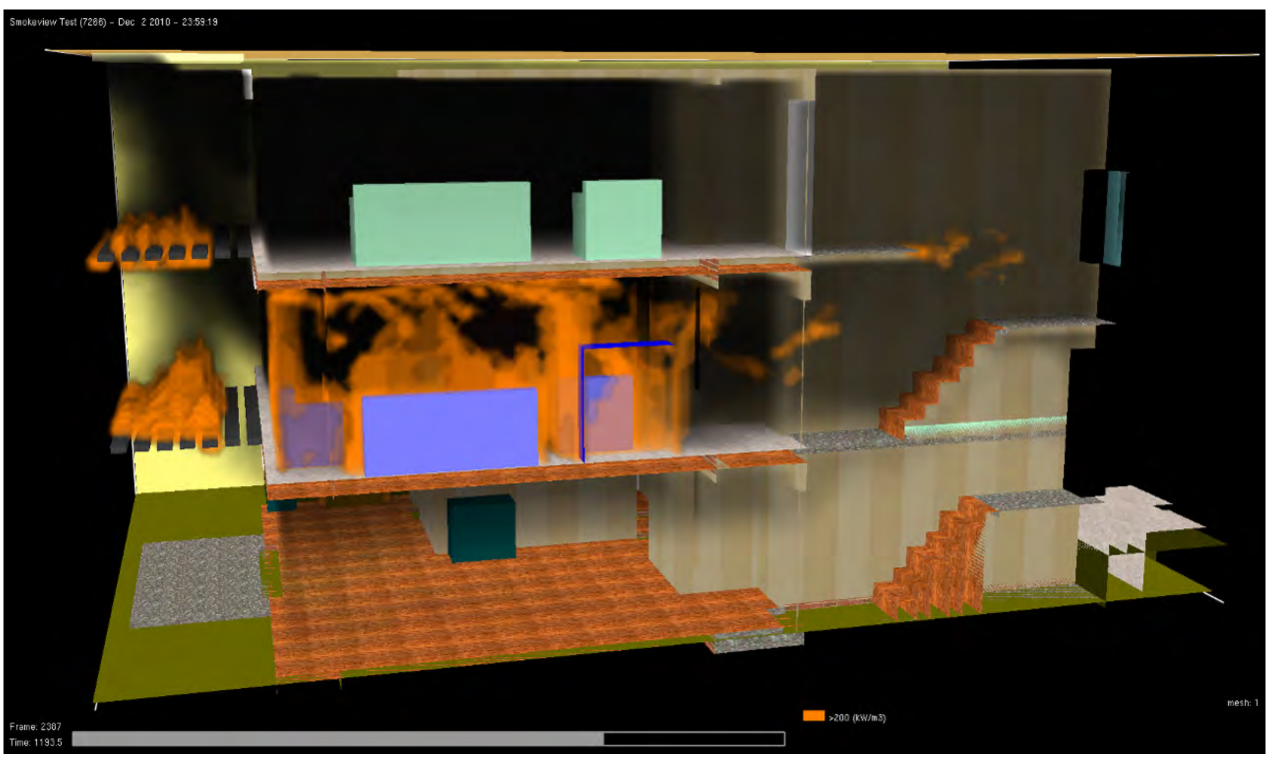

Figure 46. Smokeview frame showing oxygen limited conditions within the stairwell and relatively little flaming combustion as compared to the actual modeling scenario with both doors open.

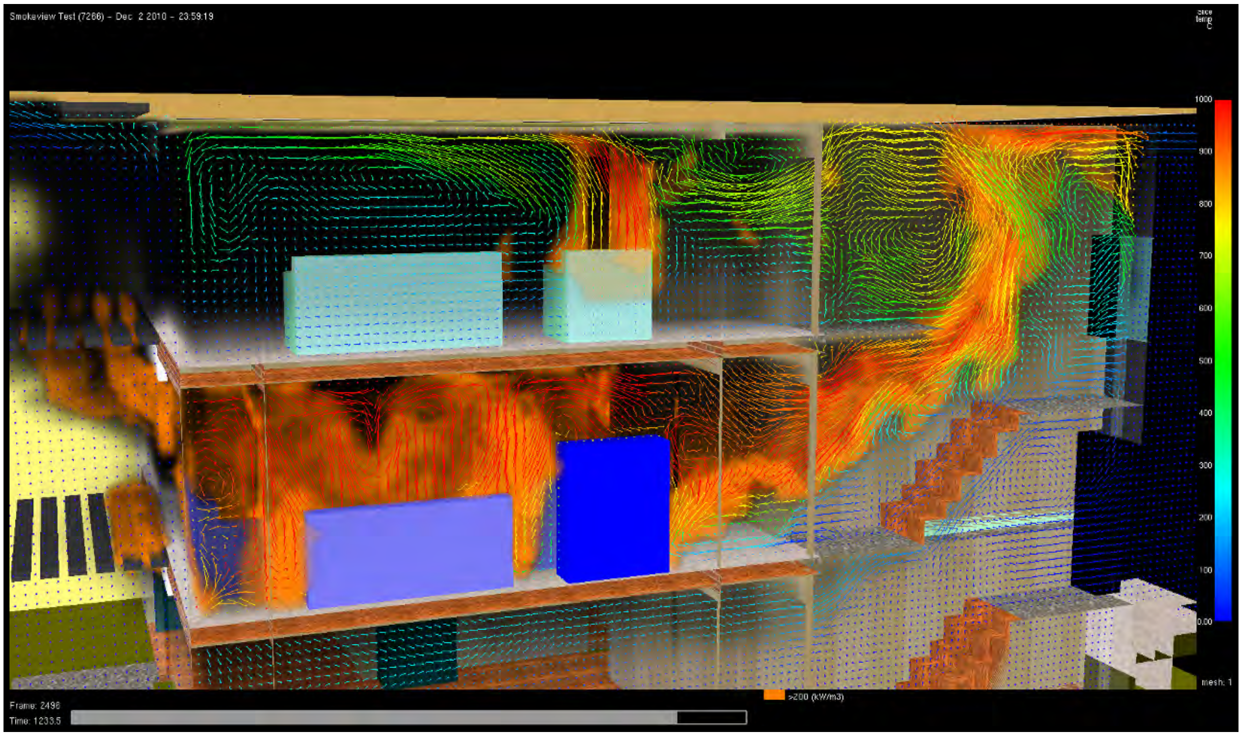

Figure 47. Smokeview frame of actual modeling scenario for comparison purposes. Note the increased burning rate as compared to the ventilation limited conditions within the stairwell with the third floor apartment door shut.

4. The Effects of Compartmentation on Fire Damage to the Structure

The impact of compartmentation on fire and smoke spread is evident by examining the post-fire damage throughout the structure. While other factors contributed to the relative fire damage, including fire department overhaul and relative apartment configuration, analyzing the damage to the building and the position of the apartment entry doors provides insight on the benefits of compartmentation. By closing apartment unit entrance doors and interior hollow core doors, one can slow or even block the ventilation flow path through the structure, thus significantly reducing the rate of fire spread. The photos below represent the post-fire damage in all six apartments within the fire building. Four of the six apartment entry doors were open for the majority of the fire and the relative difference in damage is clearly evident.

Figure 48. Terrace level stairwell landing looking into T1 (left) and T2 (right) apartments.

Figure 49. Damage to apartment T1. Door was closed for majority of the fire.

Figure 50. Damage to apartment T2 (post overhaul). Door was opened by occupant after discovering the fire.

Figure 51. Photo of second floor stairwell landing and apartments A1 (left) and A2 (right).

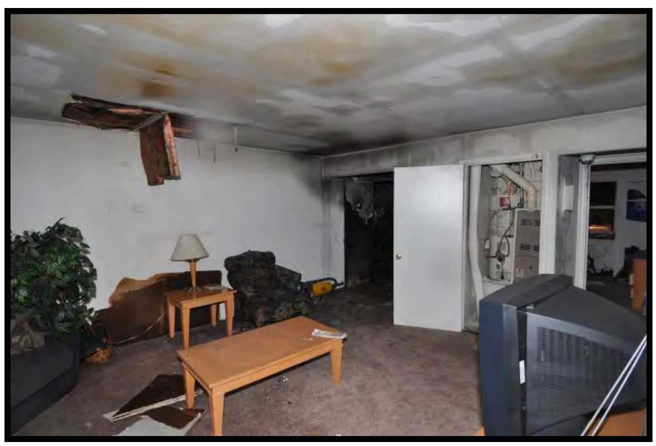

Figure 52. Photo of damage to apartment A1. Door was closed for majority of fire.

Figure 53. Photo of damage to apartment A2. Door was left opened by search crews.

Figure 54. View of the third floor landing looking in at apartments B1 (left) and B2 (right).

Figure 55. Damage to apartment B1 (post overhaul). Door was left opened by search crews.

Figure 56. Damage to apartment B2 (post overhaul). Door was left opened by search crews.

Using doors to compartmentalize and limit fire and smoke spread in a structure is not limited to fire-rated entrance doors. Interior hollow core doors also offer considerable protection for compartmentation purposes. A search crew utilizing the Vent, Enter and Search (VES) technique through a front window used a hollow core bedroom door to isolate themselves from the developing fire in the living room of apartment A2. As the crews removed the second victim from the living room to the bedroom, they shut the bedroom hollow core door behind them. The living room soon experienced flashover followed by full room involvement, however the bedroom remained isolated from the heat and smoke for the duration of the fire. The photos below illustrate this effective use of compartmentation to protect firefighters during a search.

Figure 57. The left side hollow core door in this photo was shut by search crews after removing a victim from the living room to the bedroom. The living room reached flashover a short time later.

Figure 58. Photo of the bedroom on the other side of the hollow core where the victim was removed. Note the lack of smoke and fire damage, despite a fully developed fire on the other side of the door.

Figure 59. A second photo of same bedroom showing the VES window where the search crew entered and exited the apartment. Taking the time to shut the hollow core door blocked the ventilation flow path through the front window, thus isolating the crew and victim from the severe smoke and fire conditions in the hallway and living room.

Figure 60. Photo of living room that experienced flashover in apartment A2. The hollow core bedroom door is located in the small hallway at the upper left of this photo.

SUMMARY:

While no fire model will exactly replicate a fire, this model provided insight on the route of fire spread, the rapid fire growth leading to flashover of the second and third level, and the benefits of compartmentation on slowing fire and smoke spread. The unidirectional flow path up the stairs from the terrace level apartment resulted in a high rate of convective heat transfer to the firefighters initially attempting to descend the stairs, making attacking the seat of the fire very difficult. The model then supported the fact that the main stairwell acted as an open channel for fire and smoke spread between the second and third levels, resulting in flashover of the third level in approximately 30 seconds after the second level. This rapid fire growth leading to flashover is supported by photographs, witness statements and fireground audio. The model was then utilized to explore the effects of compartmentation using apartment entrance doors. The FDS model supported the scene observations and indicated that shutting the entrance doors blocked the flow of buoyancy driven fire gases through the structure, ultimately preventing fire extension to the third floor apartment via the stairwell.

The FDS model was utilized as part of the overall engineering analysis of this tragic fire and allowed for a better understanding of the events that led to the firefighter MAYDAY and subsequent Line of Duty Death. The model was also used as an educational tool providing insight on potential methods of preventing similar tragedies in the future. The results of this engineering analysis are intended to be reviewed by the Post Incident Analysis Team to assist in the creation of recommendations to mitigate the danger associated with future fire incidents.

POINT OF CONTACT:

Adam St. John

Adam St. John P.E.,
Fire Protection Engineer
ATF Fire Research Laboratory
Adam.St.John@atf.gov