Adam St. John: Ventilation Flow Paths and Fire Growth

6.17.15

By Adam St. John

Ventilation-limited fires and ventilation flow paths are often misunderstood by many firefighters. Understanding these concepts is critical for effective and safe firefighting operations. This article examines several recent U. S. Department of Justice Bureau of Alcohol, Tobacco, Firearms (ATF) case studies as well as field fire tests conducted by the ATF Fire Research Laboratory that focus on ventilation-limited fires and ventilation flow paths and how these scenarios affect fire dynamics.

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 flash over into the attached living room. On 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.

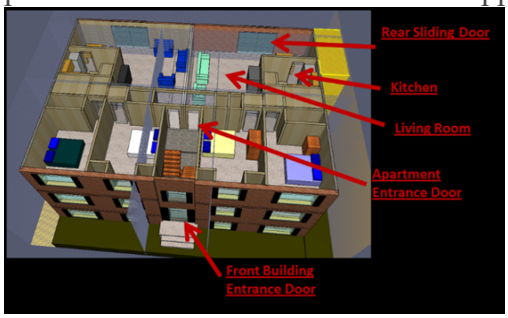

Figure 1. A typical floor plan of the right-side apartments at 30 Dowling Circle.

Figure 2. A Smokeview frame of the rear of the building indicating the fire origin and smoke spread within the T2 apartment.

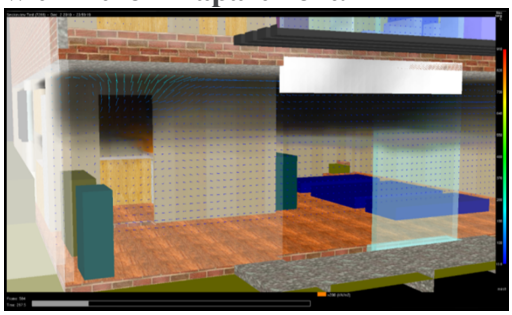

Figure 3. A view of smoke flow out of the kitchen and the open sliding glass door (center of photo) in the rear of apartment T2.

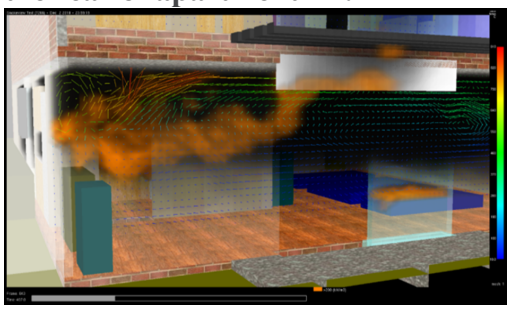

Figure 4. A Smokeview frame of the flashover of the kitchen with flames extending into the living room. Flames also begin to extend out of the rear sliding door and impact the balcony above.

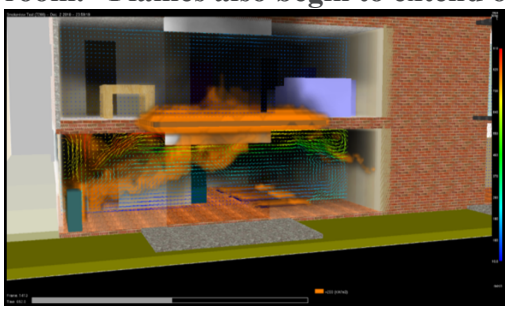

Figure 5. Ignition of the second-level balcony resulting from flame extension from the living room.

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

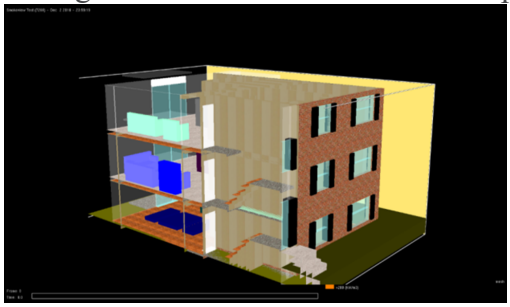

Figure 6. A Smokeview frame showing a section view of the stairwell and the living room area of all three south side apartments.

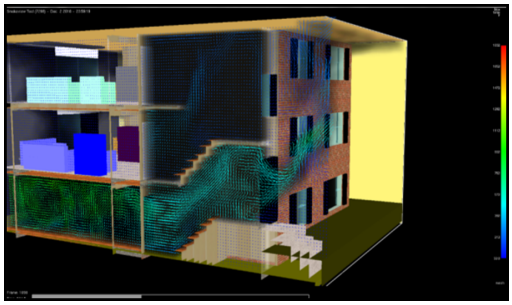

Figure 7. A Smokeview section frame showing unidirectional flow of approximately 600˚F (315˚C) gases out of the stairwell entrance door.

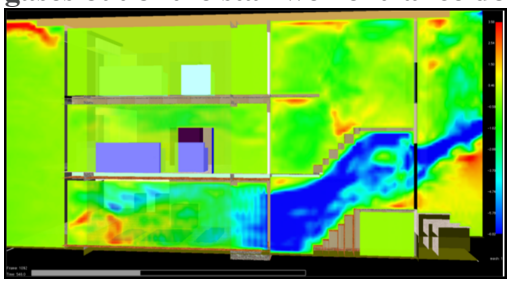

Figure 8. A Smokeview frame indicating gas velocity up the stairs of approximately 6 miles per hour (mph) (2.7 m/s) from floor to ceiling.

Photo 1. The front of the structure shows the unidirectional flow of smoke up the 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 who was trapped by heavy smoke in the stairwell.

Photo 2. The rear of the structure showing 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 are 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˚0 (315˚C) at velocities of approximately 6 miles per hour (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.

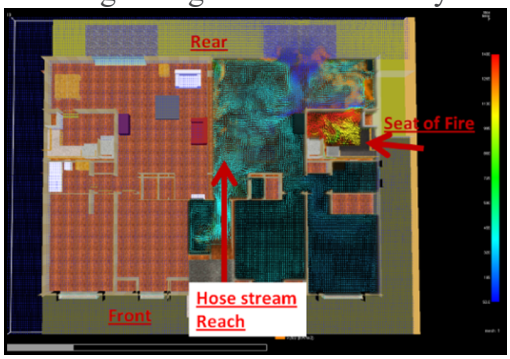

Figure 9. A plan view of the flow path and temperatures within the apartment. Note the location of the seat of the fire and the location of the initial hose stream application down the stairs.


Photo 3. Hoselines are being positioned at the stairwell entrance door and the 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 upward from the T2 apartment sliding door and ignited the rear balconies of the second- and third-level apartments. Fire on the second-floor balcony extended into apartment A2 by failing the sliding glass door and igniting the vertical plastic slat curtains that 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 10. A Smokeview frame of the rear of the building with flames extending from T2 and involving both balconies above.

Photo 4. 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 (top of the photo).

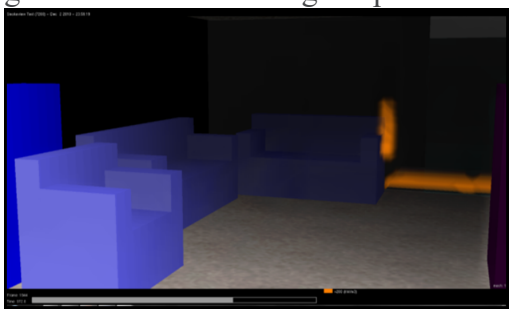

Figure 11. Flames extend from plastic curtains in apartment A2 to corner of couch as witnessed by firefighters conducting a search of the second-level apartment. Two victims were rescued from the living room.

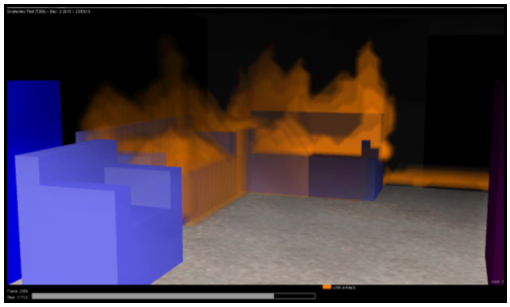

Figure 12. As the second victim was located, flames continued to spread across the couches in the living room of A2. The apartment entrance door was opened by additional search crews, allowing sufficient oxygen to support fire growth within the apartment.

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 upward 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.

Photo 5. Building smoke and fire conditions around the arrival of Squad 303. Note the lack of heavy smoke or fire in the stairwell or on the 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 13. Exemplar apartment showing the apartment entrance door.

Figure 14. A close view of the 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 to search the apartment faster, with one firefighter searching the front bedrooms and the officer searching the kitchen and the living room.

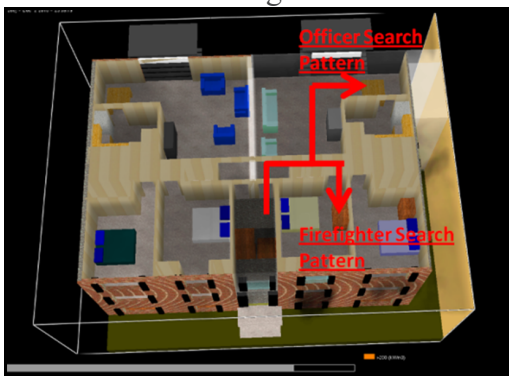

Figure 15. Search pattern of Squad 303's officer and firefighter after they split to conduct a search of the third floor apartment. The officer searched the rear of the apartment while the firefighter searched the bedroom.

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 16. Involvement of the furniture items in the second-level apartment led to flashover.

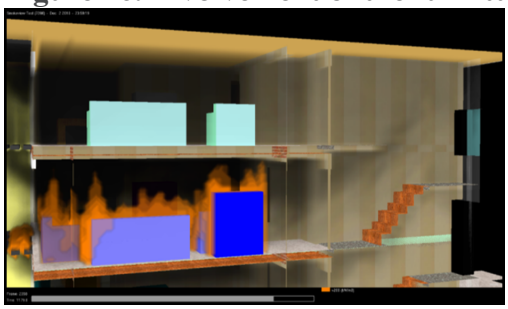

Figure 17. A section view of couches and furniture involved in flame just prior to flashover.

Figure 18. 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; they sustained damage to their gear.

Figure 19. Flashover of the second level with flames extending upward into the sealed stairwell.

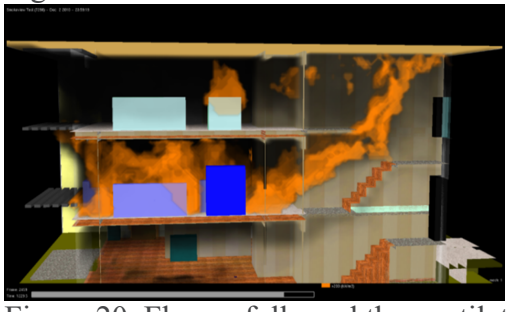

Figure 20. Flames followed the ventilation flow path and extended into the third-floor apartment, resulting in ignition of the couches just inside the doorway.

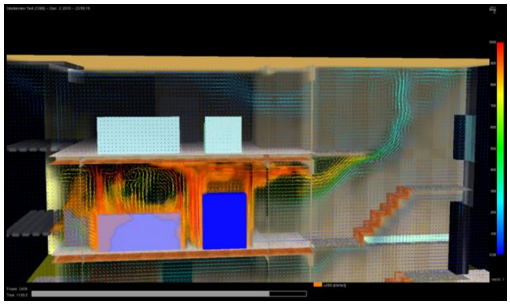

Figure 21. A Smokeview frame showing the temperature, direction and magnitude of the ventilation flow path through the stairwell at the time of the rollover. Note the flow of heat out of the apartment into the stairwell.

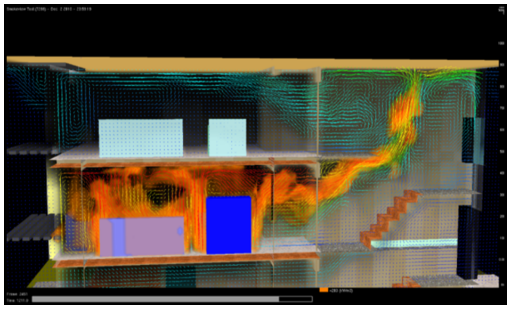

Figure 22. A Smokeview frame showing smoke and heat filling the sealed stairwell and flowing into the third level above. Note the flow path from the stairwell into the third-floor apartment.

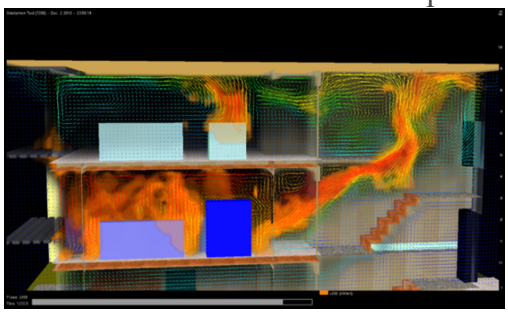

Figure 23. A Smokeview frame showing ignition of the couches just inside the third-level doorway. The energy from the fully involved second-floor apartment flows through the sealed stairwell, directly into the apartment above.

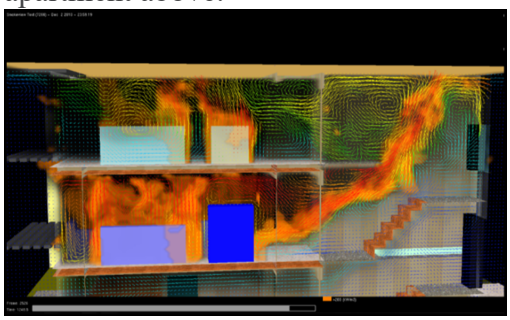

Figure 24. A Smokeview frame showing fully developed fire on the second level that resulted in the flashover of the third floor.

Figure 25. 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).

Photo 6. Flame extension into the 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.

Photo 7. 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 were 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 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 reentered 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 in the rear, where he was subsequently transported to the hospital.

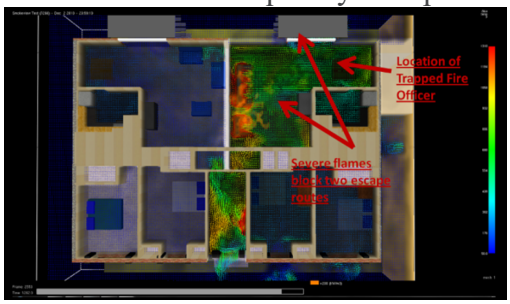

Figure 26. The location of the trapped fire officer and potential escape routes through the structure, both of which are blocked by flames.

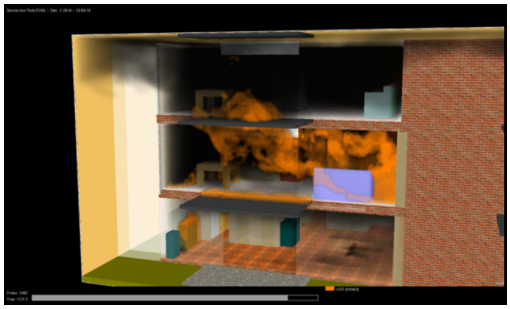

Figure 27. A Smokeview frame showing flames blocking potential egress through the third-floor balcony, as seen from the rear of the building.

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.

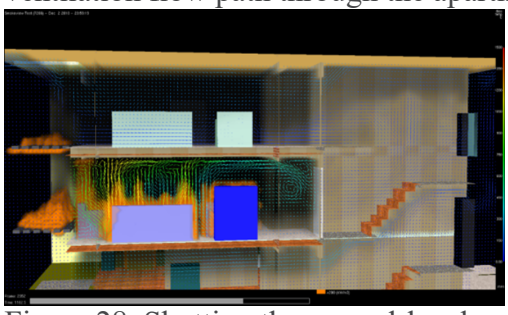

Figure 28. Shutting the second-level apartment door blocks the flow path and flame extension into the stairwell.

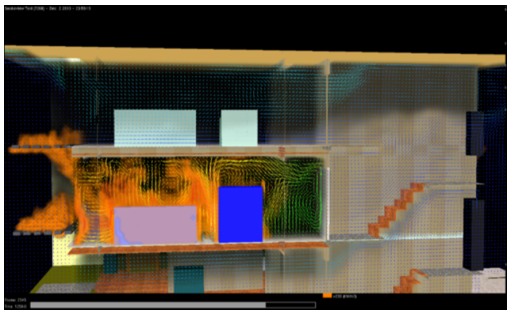

Figure 29. Even with the third-floor apartment door left open, the model indicates that the stairwell and the third floor remain tenable for firefighters. Flames eventually extend from the third-floor balcony into the apartment; however, the escape routes through the stairwell and the front apartment windows are accessible.

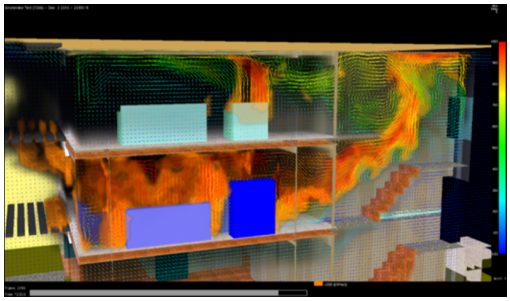

Figure 30. A Smokeview frame from the actual model with both apartment doors open, for comparison purposes. The ventilation flow through the apartments results in an increased burning rate within both the second and third levels, as well as the stairwell.

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 indicates 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

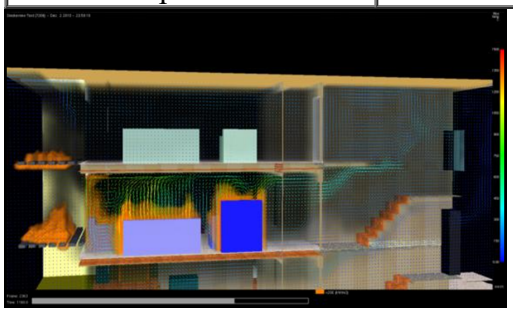

Figure 31. A Smokeview frame showing the closed third-floor apartment door preventing fire gases from entering the apartment.

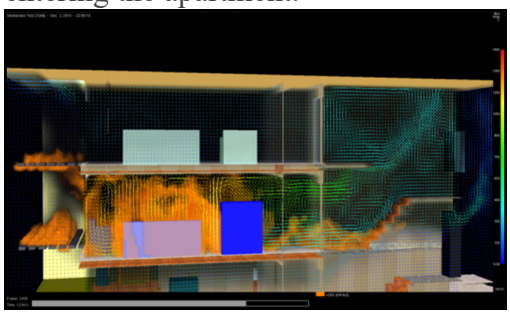

Figure 32. Blocking the outlet of the flow path decreases the burning rate within the second-floor apartment and stairwell. The stairwell becomes oxygen limited and doesn't support sustained flaming combustion by the third-floor apartment door at the top of the stairs.

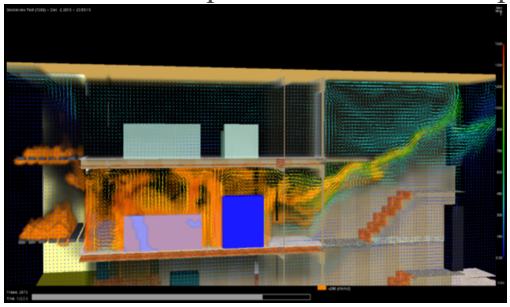

Figure 33.. Even with the front stairwell window vented, the upper volume of the stairwell near the third-level apartment entry doors remains oxygen limited and flames do not extend to the third-level apartments via the stairs.

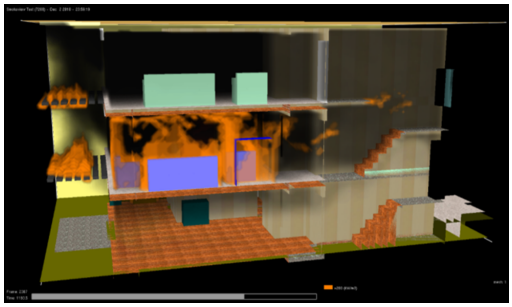

Figure 34. A Smokeview frame showing oxygen-limited conditions within the stairwell and relatively little flaming combustion as compared to the actual modeling scenario with both doors open.

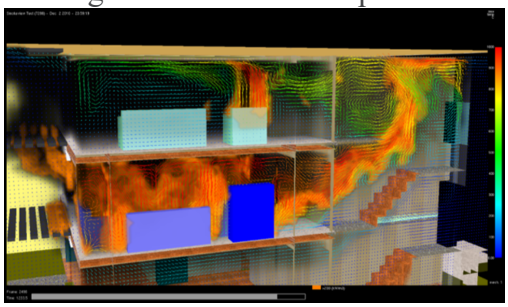

Figure 35. A Smokeview frame of the actual modeling scenario for comparison purposes. Note the increased burning rate as compared to the ventilation-limited conditions within the stairwell with the third-floor apartment door shut.

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, you 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.

Photo 8. The terrace-level stairwell landing looking into T1 (left) and T2 (right) apartments.

Photo 9. Damage to apartment T1. The door was closed for the majority of the fire.

Photo 10. Damage to apartment T2 (post overhaul). The door was opened by the occupant after discovering the fire.

Photo 11. The second-floor stairwell landing and apartments A1 (left) and A2 (right).

Photo 12. The damage to apartment A1. The door was closed for the majority of the fire.

Photo 13. The damage to apartment A2. The door was left open by search crews.

Photo 14. A view of the third-floor landing looking in at apartments B1 (left) and B2 (right).


Photo 15. Damage to apartment B1 (post overhaul). The door was left open by search crews.


Photo 16. The damage to apartment B2 (post overhaul). The door was left open 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 used the Vent-Enter-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.


Photo 17. 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.

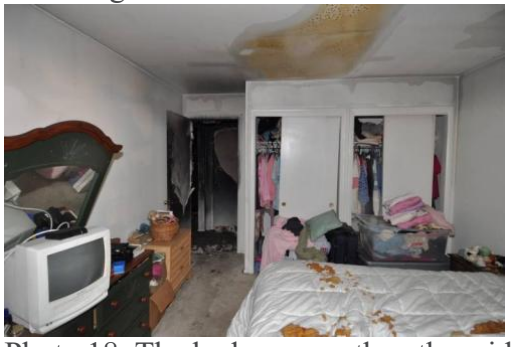
Photo 18. The bedroom on the other side of the hollow core door from which the victim was removed. Note the lack of smoke and fire damage despite a fully developed fire on the other side of the door.

Photo 19. The same bedroom above 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.

Photo 20. The living room that experienced flashover in apartment A2. The hollow core bedroom door is l in the small hallway at the upper left of this photo.

BIO

ADAM ST. JOHN is a licensed fire protection engineer employed by the ATF Fire Research Laboratory for the past five years. He is on the ATF National Response Team and conducts full-scale fire tests. He has been in the fire service for 12 years and is a captain in Montgomery County, Maryland.