Fire Behavior Case Study

CFBT-US
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Introduction

Developing mastery of the craft of firefighting requires experience. However, it is unlikely that we will develop the base of knowledge required simply by responding to incidents. Case studies provide an effective means to build our knowledge base using incidents experienced by others.

The deaths of Captain John Drennan (Ladder 5), Firefighter James Young (Engine 24), and Firefighter Christopher Seidenburg (Engine 24) in an apartment fire were the result of a complex web of circumstances, actions, and events. This case study focuses on the fire behavior and related tactical operations involved in this incident.

Aim

Firefighters and fire officers recognize and respond appropriately to the hazards presented by ventilation controlled compartment fires.

References

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Learning Activity
Review the incident information and discuss the questions provided. Focus your efforts on understanding the interrelated factors influencing the outcome of the incident including building construction, fire behavior, and tactical operations. Even more important than understanding what happened in this incident is the ability to apply this knowledge in your own tactical decision-making.

The Case
This case study was developed using a paper written by Richard Bukowski (1996) of the National Institute for Standards and Technology (NIST) Building and Fire Research Laboratory (BFRL). The Fire Department of the City of New York (FDNY) requested the NIST assistance in modeling this incident to develop an understanding of the extreme fire behavior phenomena that took the lives of Captain Drennan and Firefighters Young and Seidenburg.

At 1936 hours on March 28, 1994, FDNY responded to a report of heavy smoke and sparks from a chimney of a three-story apartment building at 62 Watts Street (see Figure 1) in Manhattan. On arrival companies observed smoke from the chimney, but no other evidence of fire. The first due engine and truck companies stretched a hoseline to the first floor unit and vertically ventilated over the stairwell.

Figure 1. 62 Watts Street-Side A

Working as the inside team of the second due truck company, Captain John Drennan (Ladder 5), Firefighter James Young, and Firefighter Christopher Seidenburg (both detailed from Engine 24 to Ladder 5) went to the second floor to begin primary search of the upper floors. At the doorway to the second floor apartment unit, they were trapped by an explosion and rapid fire progression from the first floor apartment up the common stairwell. Both firefighters died within 24 hours because of thermal injuries. Captain Drennan survived for 40 days in the burn unit before succumbing to his injuries.

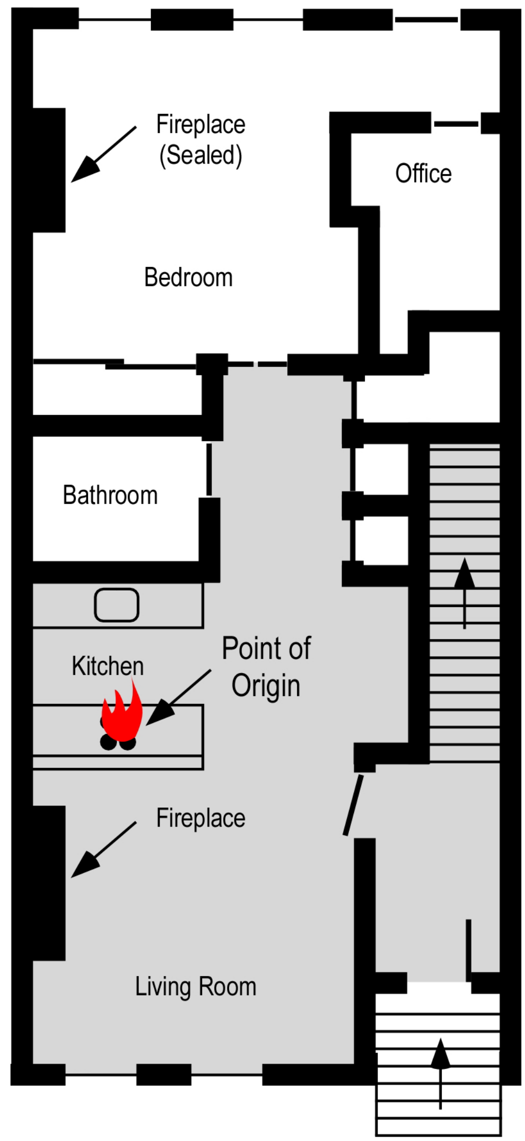
Building Information

The fire occurred in a 6.1 m (20') x 14 m (46'), 3 ½ story apartment building of ordinary (Type III) construction, containing four dwelling units (the basement apartment was half below grade). Each unit had a floor area of slightly less than 81.7 m^2 (880 ft^2). The basement unit had its own entrance and the units on Floors 1-3 were served by a common stairwell on Side D of the building (see Figure 1). Exposure B was an attached building identical to the fire structure. Exposure D was a similar structure. Neither exposure was involved.

The building was originally built in the late 1800s and had undergone numerous renovations. Recent renovations involved replacement of plaster and lath compartment linings with drywall over wood studs and lowering of the ceiling height from 2.8 m (9'3") to 2.5 m (8'4"). All apartments had heavy wood plank flooring. During the latest renovation, windows and doors were replaced and extensive thermal insulation added to increase energy efficiency. The building was originally heated with the use of multiple fireplaces in each apartment. However, most of these had been sealed shut. However, the fireplace in the living room of the first floor apartment (unit of origin) was operable and had a 0.209 m^2 (2.25 ft^2) flue.

All apartments had similar floor plans (differences resulting from location of the stairwell). The floor plan of the first floor apartment (unit of origin) is illustrated in Figure 2. Each apartment consisted of a living room, kitchen, bathroom, and bedroom. The first floor unit had an office constructed within the bedroom.

Figure 2. Floor Plan-First Floor Apartment



Note: Adapted from *Modeling a Backdraft Incident: The 62 Watts St. (NY) Fire*.

The structure had a flat roof with a scuttle[1] and skylight over the stairwell.

The Fire

The occupant left the first floor apartment at 1825 hours, leaving a plastic trash bag on top of the gas fired kitchen range (see Figure 2). Investigators deduced that the bag was ignited by heat from the pilot light. Fire extended from the bag of trash to several bottles of high alcohol content liquor located on the counter adjacent to the stove. The fire progressed into the growth stage, involving other fuel packages within the apartment. The apartment was tightly sealed with the only sources of ventilation being the open fireplace flue and minimal normal building ventilation.

Weather Conditions

The weather was 10° C (50 ° F) with no appreciable wind.

Conditions on Arrival

On arrival companies observed smoke from the chimney of the apartment building, but no other signs of fire.

Firefighting Operations

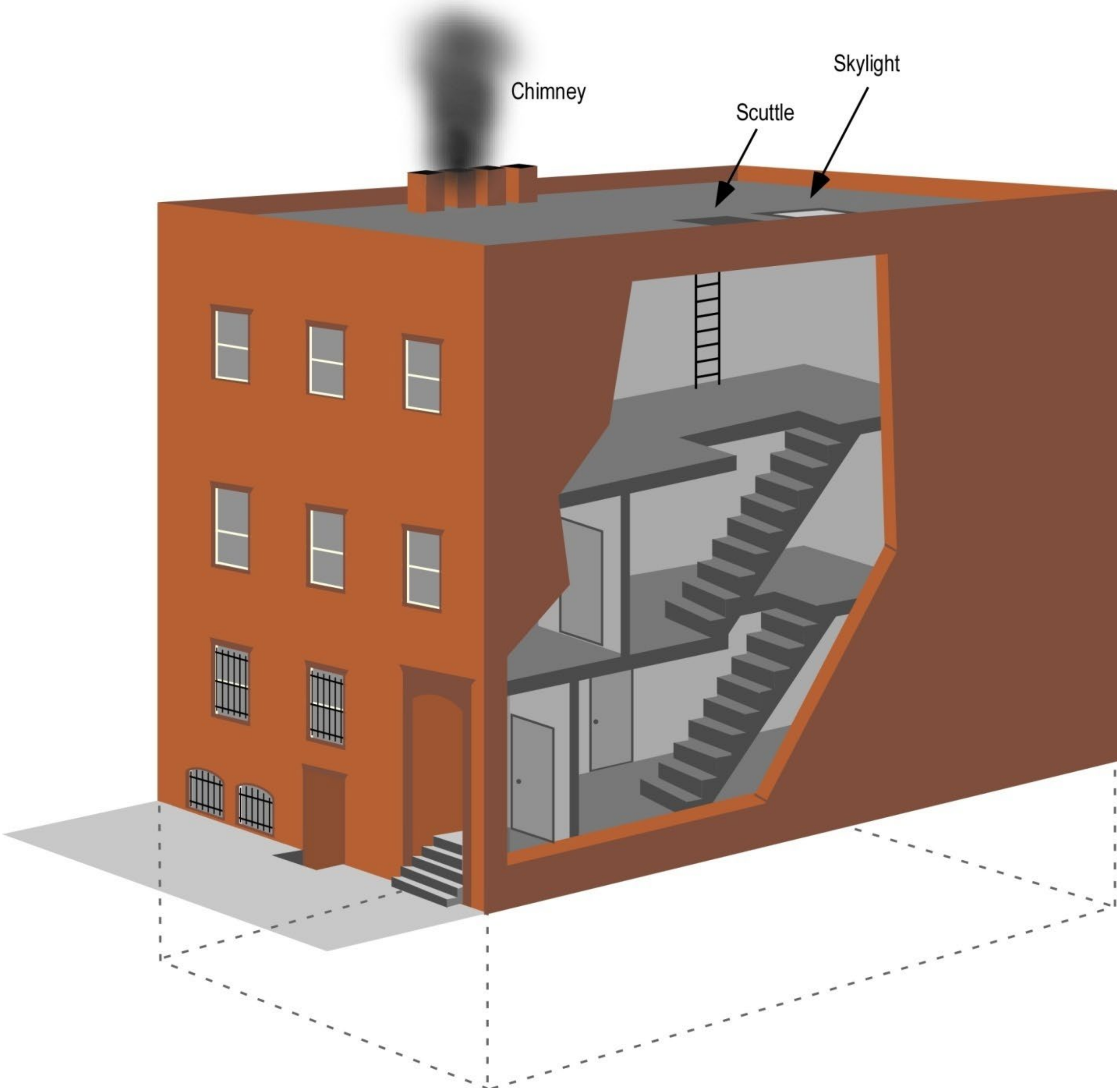
The outside team from the first due truck went to the roof and opened the scuttle over the stairwell while the first arriving engine company stretched a hoseline to the interior and prepared to make entry into the first floor apartment along with the inside team from the ladder company. Ladder 5 was the second due truck. The inside team from Ladder 5, Captain Drennan, Firefighter Young, and Firefighter Seidenburg, went to the second floor to begin primary search.

> FDNY standard operating procedures define company responsibilities based on resource type and order of arrival. The first ladder company is responsible for truck company operations on the fire floor and ventilation (vertical and horizontal). The second ladder company is responsible for searching above the fire floor and assisting with ventilation operations as needed.
>
> Ladder company personnel are split into two teams (inside and outside). The inside team consists of the company officer and two firefighters (one assigned to forcible entry and the other with a water extinguisher). The Outside team consists of the apparatus operator and firefighters assigned to the roof and outside ventilation operations. The company officer can vary these standard assignments based on incident conditions.
>
> FDNY doctrine calls for ventilation of skylights and scuttles above common stairwells during initial operations to create a vertical draft, removing hot smoke and fire gases from the stairwell to provide a more tenable environment. (FDNY, 2000)

[1] A scuttle is an opening in the roof fitted with a cover. Scuttles provide access to the roof from the attic or upper floor.

When the first due engine and truck forced the door to the first floor apartment, they observed a pulsing air track consisting of an inward rush of air followed by an outward flow of warm (not hot) smoke. This single pulsation was followed by a large volume of flame from the upper part of the door and extending up the stairwell.

Figure 3. 3D Cutaway View of 62 Watts Street



Note: Adapted from *Modeling a Backdraft: The 62 Watts Street Incident.*

The crews working on Floor 1 were able to escape the rapid fire progression, but Ladder 5's inside team was engulfed in flames which filled the stairwell. Flames extended from the doorway of the first floor apartment through the stairwell and vented out the scuttle opening and skylight. This flaming combustion continued more than 6 minutes 30 seconds[2]. The intense fire in the stairwell severely damaged the stairs and melted the wired glass in the skylight.

Analysis and Computer Modeling

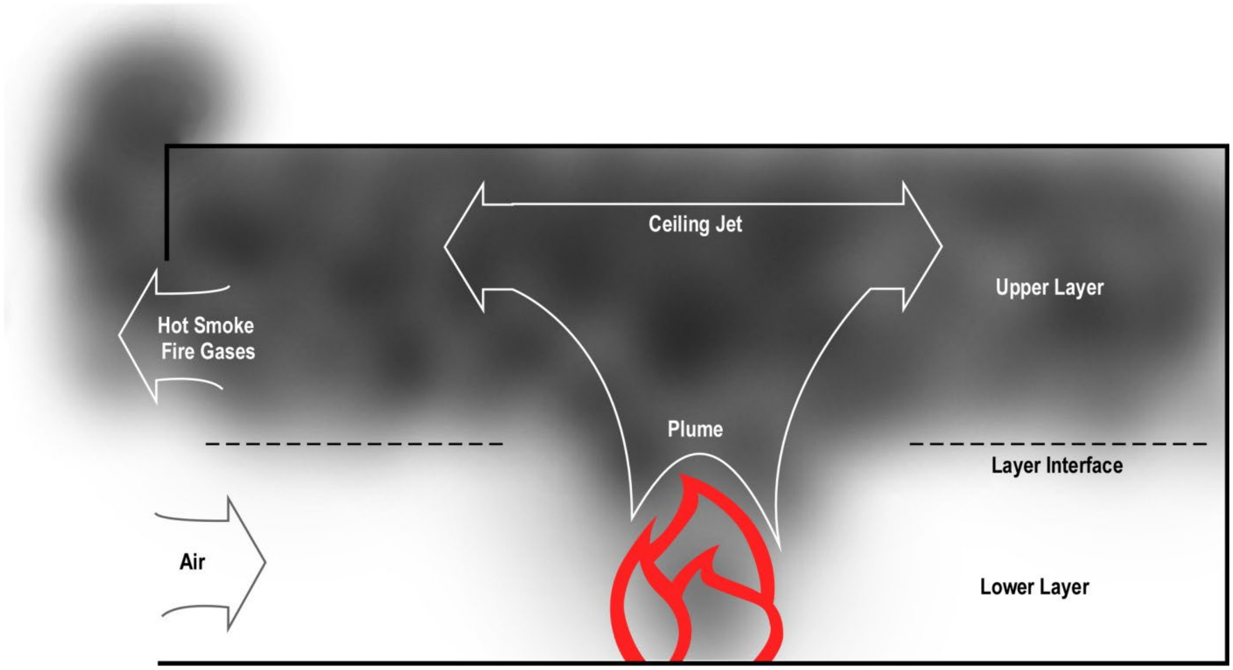
FDNY asked NIST to assist in developing a computerized model to aid developing an understanding of the fire behavior phenomena that occurred during this incident.

Hypothesis: The fire burned for over an hour under severely ventilation controlled conditions resulting in production of a large quantity of unburned pyrolizates and products of incomplete combustion. Opening the apartment door allowed exhaust of warm fire gases and inflow of cooler ambient air, resulting in a combustible fuel/air mixture. Bukowski (1995) does not identify a source of ignition. However, it is likely that the combustible fuel/air mixture underwent piloted ignition as flaming combustion resumed in the apartment. Once the gas phase fuel was ignited, flaming combustion extended from the door through the stairwell to the ventilation opening at the roof.

Richard Bukowski of the NIST Building and Fire Research Laboratory modeled the fire using CFAST to determine if a sufficient mass of gas phase fuel could have accumulated in the apartment to account for the severity and duration of flaming combustion that occurred. CFAST is a two-zone fire model used to predict the distribution of smoke and fire gases and temperature over time in a multi-compartment structure subjected to a fire. A two-zone model is based on calculations that describe conditions in the upper and lower layers (see Figure 3). While there are obvious differences in conditions within each of these zones, these differences are relatively small in comparison to the differences between the two zones (Jones, Peacock, Forney, & Reneke, 2005).

[2] An amateur photographer was shooting video of the incident when this extreme fire behavior phenomena occurred. The tape showed 6 minutes and 30 seconds of flaming combustion in the stairwell and venting from the roof. However, there were several pauses of unknown duration in the tape.

Figure 4. Upper and Lower Layers in Two Zone Models

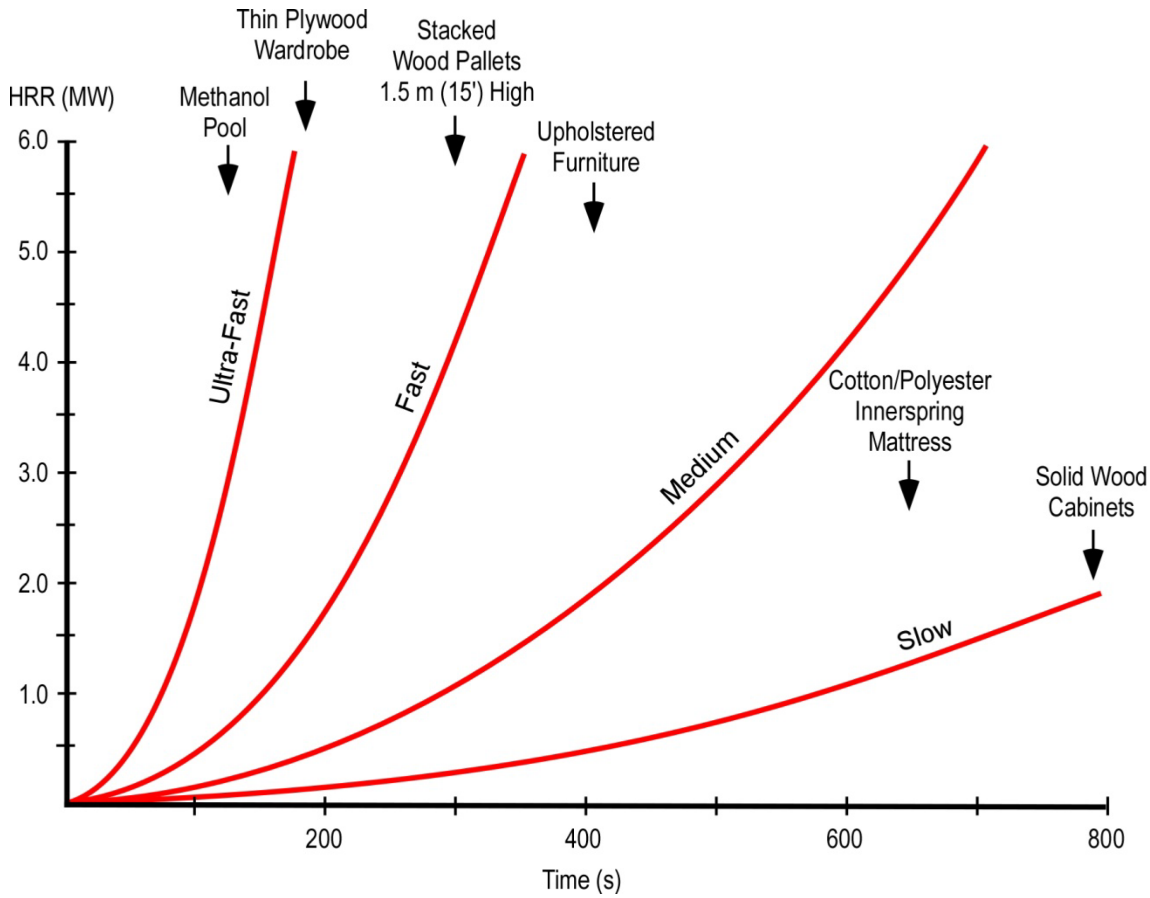


Bukowski's (1995) model of the Watts Street fire divided the involved area of the structure into three compartments. The apartment was defined as a single 6.1 m (20') x 14 m (46') x 2.5 m (8'3") compartment. The stairwell was defined as a second 1.2 m (4') x 3 m (10') x 9.1 m (30') compartment connected to the apartment by a closed door and having a roof vent with a cross sectional area of 0.84 m^2 (9 ft^2). The fireplace flue was defined as a vertical duct with a cross section of 0.14 m (1.5 ft2) x 10 m (33').

The heat release rate in the initial growth phase of a compartment fire is nearly always accelerating with energy release as the square of time (t^2). Multiplying t2 by a factor α various growth rates (e.g., ultra-fast, fast, medium, slow) can be simulated (Karlsson & Quintiere, 2000).

Based on experimental data from burning trash bags, Bukowski (1995) estimated the initial heat release rate at 25 kW with the fire transitioning to a medium t^2 fire (typical of residential structure contents) which would have had a peak HRR of 1 MW, but did not reach this HRR due to limited ventilation.

Figure 5. Heat Release Rate of Growth Phase t^2 Fires.

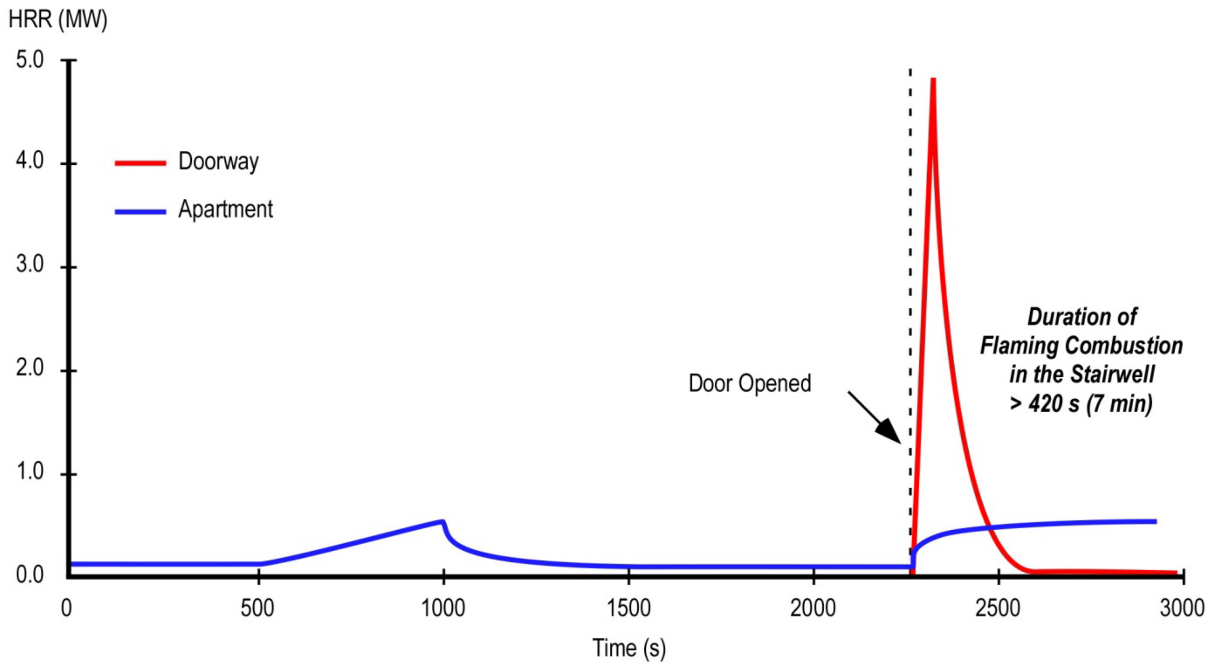


Note: Adapted from *CFAST – Consolidated model of fire growth and smoke transport (Version 6).*

Results of the computer model indicated that the HRR of the fire in the apartment grew to a heat release rate of 0.5 MW (see Figure 5) and then HRR decreased rapidly as oxygen concentration dropped below 10% (see Figure 6).

As the fire continued to burn under extremely ventilation controlled conditions, the concentration of unburned pyrolizates and flammable products of incomplete combustion in the apartment continued to increase.

Figure 6. Heat Release Rate

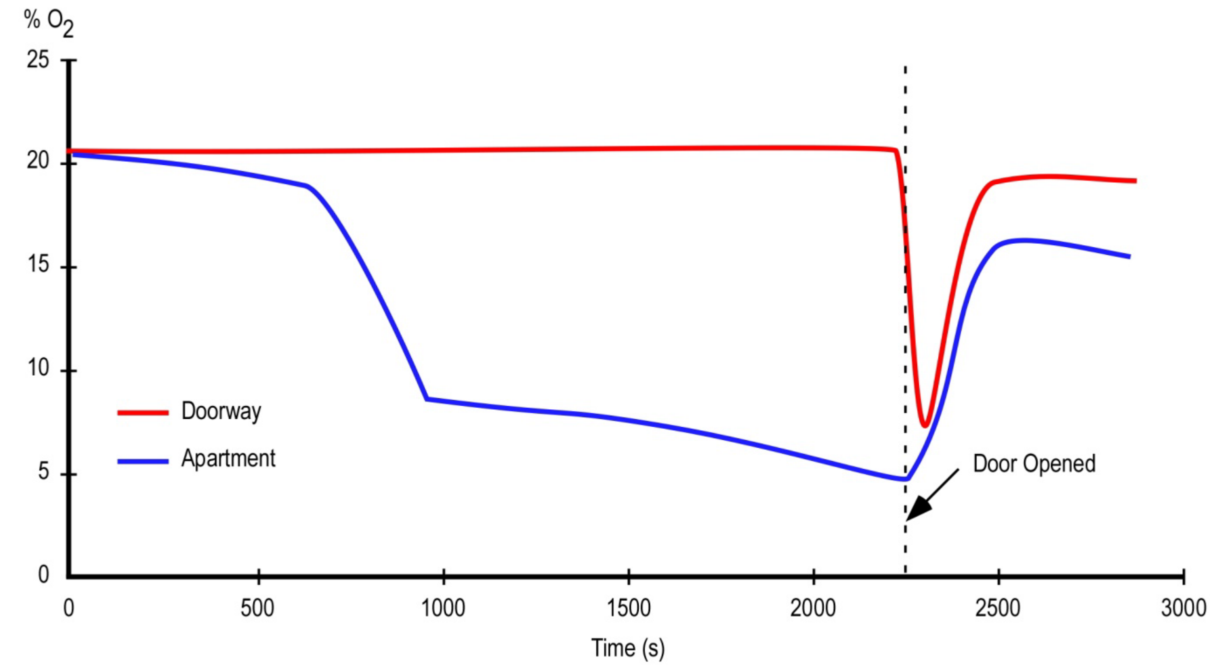


Note: Adapted from *Modeling a Backdraft: The 62 Watts Street Incident.*

Research indicates that the concentration of gas phase fuel (e.g., total hydrocarbons, carbon monoxide) is a critical determinant in the likelihood of backdraft occurrence. In small scale, methane fueled compartment fire experiments, Fleischmann, Pagni, & Williamson (1994) found that a total hydrocarbon concentration >10% was necessary for occurrence of a backdraft. At lower concentrations, flame travel is slow, and compartment overpressure is lower. As total hydrocarbon concentration increased, the overpressure resulting from backdraft increased. Similarly, Weng & Fan (2003) found mass fraction (concentration by mass) of unburned fuel to be the critical determinant in the occurrence and severity of backdraft. In their small scale, methane fueled experiments, increases in mass fraction of unburned fuel resulted in increased overpressure and more severe backdraft explosions.

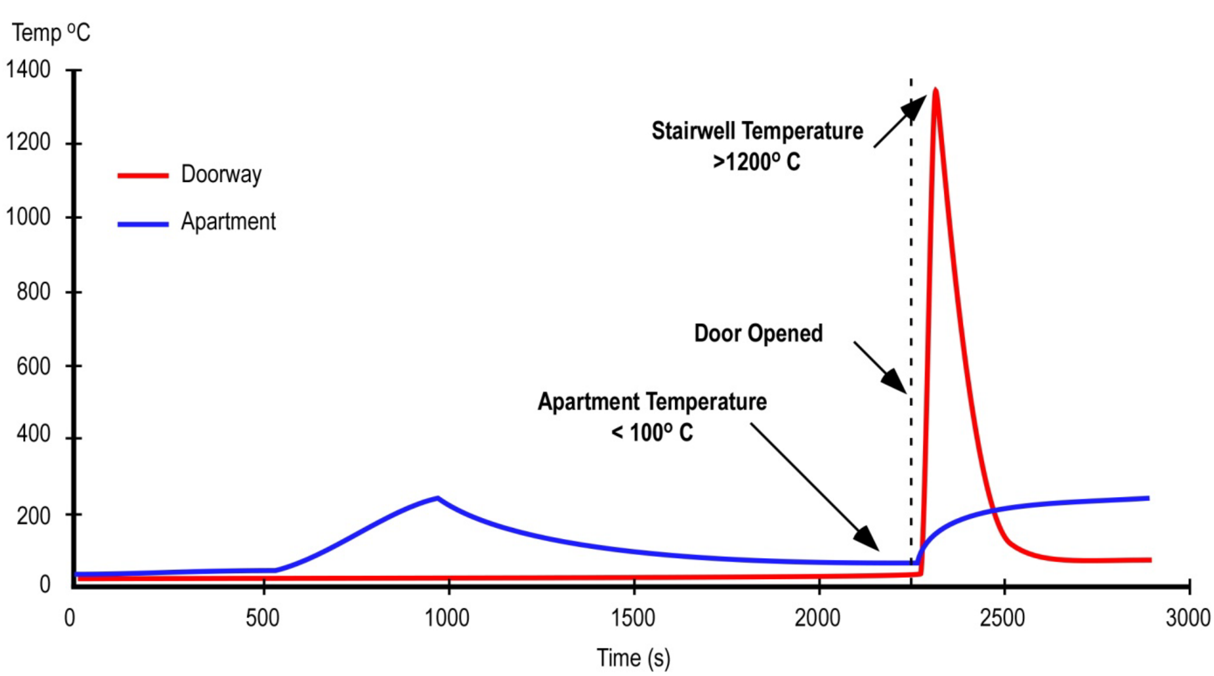
Both research projects involved the use of a methane burner in a compartment and the researchers identified the need for ongoing research using realistic, full scale compartment configurations and fuel loads.

Figure 7. Oxygen Concentration



Note: Adapted from *Modeling a Backdraft: The 62 Watts Street Incident.*

Figure 8. Temperature



Note: Adapted from *Modeling a Backdraft: The 62 Watts Street Incident.*

Estimating the time that fire companies forced the door to the apartment, the front door in the simulation was opened at 2250 seconds. As in the actual incident, there was an outflow of warm air from the upper part of the doorway, followed by inward movement of ambient air in the lower part of the doorway. Almost immediately after this air track pulsation, the heat release rate in the stairwell increased to nearly 5.0 MW (see Figure 5), and raised temperature in the stairwell to more than 1200^o C (2200^o F).

Theory and Practice

Output from the CFAST model was consistent with the observation and conditions encountered by the companies operating at 62 Watts Street on March 28, 1994. The model showed that sufficient fuel could have accumulated under the ventilation controlled conditions that existed in the tightly sealed apartment to result in the extended duration and severity of flaming combustion that occurred in the stairwell.

Following this investigation, FDNY identified several similar incidents that had occurred previously, but which had gone unreported because no one had been injured. Remember that it is important to examine near miss incidents as well as those which result in injuries and fatalities.

Questions

The following questions focus on fire behavior, the influence of tactical operations, and related factors involved in this incident.

1. Other than smoke and sparks from the chimney, what B-SAHF indicators might have been present and visible from the exterior or at the doorway that would have provided an indication of conditions inside the apartment?

2. What do you make of the observations of the company making entry to the first floor apartment for fire attack? Is this consistent with your understanding of backdraft indicators? Why or why not?

3. Examine the oxygen concentration and temperature curves (Figures 6 & 7) up to the time that the door of the apartment was opened (2250 seconds). How does this data fit with the observations of the company making entry into the first floor apartment and your conception of conditions required for a backdraft?

4. How might the temperature in the apartment have influenced B-SAHF indicators visible from the exterior and when performing door entry during this incident?

In *Modeling a Backdraft Incident: The 62 Watts St (NY) Fire*, Bukowski states "as buildings become better insulated and sealed for energy efficiency such hazards [e.g., ventilation controlled fires, increased concentration of gas phase fuel, backdraft] may become increasingly common. Thus, new operational procedures need to be developed to reduce the likelihood of exposure to flames of this duration" (p. 5).

5. What operational procedures and practices would be effective in reducing risk and mitigating the hazards presented by ventilation controlled fires in energy efficient buildings? Consider size-up and dynamic risk assessment as well as strategies and tactics.

6. The often oversimplified tactical approach to dealing with potential backdraft conditions is to ventilate vertically. In this case, existing roof openings were used to ventilate the stairwell, but this had no impact on conditions in the apartment. How can tactical ventilation be used effectively (or can it) when faced with potential backdraft conditions on a lower floor or in a basement?

7. Another, less common approach to dealing with potential backdraft conditions is to cool the atmosphere and inert the space with steam to reduce the potential for ignition. Examine the temperature curve prior to opening the door (2250 seconds) and determine if this was a viable option?

8. Bukowski's (1995) paper did not speak to the door entry procedures used by the companies at the apartment door. How might good door entry procedures have reduced risk in this incident?