Wind, Fire, and High-Rise Buildings

Firefighters and engineers conduct research to combat a lethal threat

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In December 1998, three New York City firefighters were making their way along a corridor to reach a burning apartment on the top floor of a Brooklyn building. The occupant had fled and left the door open. The firemen were trying to reach the apartment to close the door. That would give them a measure of control over the situation. It would reduce heat in the corridor, and let them and their colleagues get into position to fight the fire as they had been trained to do.

As the three men headed toward the open door, the exterior windows of the burning apartment failed, exposing the fire to the wind. About the same time, the occupant of an apartment at the far end of the hall, about 50 feet away and behind the firefighters, opened the door to the corridor. The windows of that apartment, which was on the lee side of the building, were open.

The heat of the fire traveled down the hallway toward the far apartment and overwhelmed the three firemen in its path. The official cause of death was termed "thermal shock."

The heat in the corridor had grown so intense that their bodies had shut down. They had no time to escape.

The firefighters were following the procedures they had been taught. In the words of Jerry Tracy, a New York Fire Department battalion chief who would describe the incident years later, "They were doing their job."

But no one expected the wind to drive the fire the way it did. There was little fuel in the hallway but paint. There was also little understanding of the influence of wind on a high-rise fire.

It is to avoid tragedies like this one that the Building and Fire Research Laboratory of the National Institute of Standards and Technology is working with the fire departments of Chicago and New York City and with the Polytechnic Institute of New York University to study the dynamics of wind-driven fires. A better understanding of these types of fires will improve safety for firefighters and building occupants, and will guide the development of new training techniques and methods to combat wind-driven fires.

That can make the world safer in human and economic terms.

Wind can add to the hazard of fire anywhere, but it is frequently in play around the upper floors of tall buildings. And high-rise fires create unique safety challenges for occupants and firefighters, even without the influence of wind.

Smoke and heat spreading through corridors and stairwells, for instance, can inhibit occupants' ability to escape and can limit firefighters' ability to rescue them.

Changes in ventilation, such as the opening of doors or windows, can intensify the fire, and allow flames and combustion gases to spread beyond the room of origin. When a window in the fire apartment fails, the influx of wind can create significant and rapid increases in the heat production of a fire.

According to the National Fire Protection Association, there were 7,300 reported fires in high-rise structures (buildings of seven stories or more) in 2002. The majority of these high-rise fires occurred in residential occupancies, such as apartment buildings. In fires that originated in apartments, 92 percent of the civilian fatalities occurred in incidents where the fire spread beyond the room of origin.

Testing New Tactics

Having witnessed firsthand the devastation that a wind-driven fire can cause, firefighters in New York began experimenting with a variety of methods to limit the wind's impact on a fire and to apply water to a fire from a location other than from downwind inside the building.

The fire department proposed using a wind control device, deployed from the floor above the fire, to limit the impact of the wind. The wind control device is essentially a curtain of fire-resistant material that can be unrolled over a window opening to halt the momentum of the wind and limit the oxygen available to the fire.

Another concept, developed by firefighters in New York and Chicago, is the high-rise nozzle. Deployed from the floor below the fire, the nozzle can be used to introduce water from the upwind side of the building directly through a window opening into the fire apartment. Chicago firefighters also had begun to test the use of large portable fans to pressurize stairwells in order to keep them free of smoke and combustion gases.

While their ideas were promising, the firefighters had no means of testing or measuring the impact that each method might have on reducing the fire hazard.

In 2007, NIST and the Polytechnic Institute began collaborating with the New York Fire Department to study wind-driven fires in high-rise buildings. The study received funding from the Department of Homeland Security through the Assistance to Firefighters Research and Development Grant Program of the Federal Emergency Management Agency and through the United States Fire Administration.

As a starting point, NIST conducted a series of eight full-scale experiments in its laboratory in Gaithersburg, Md. The experiments were designed to simulate a public corridor exposed to a wind-driven post-flashover apartment fire. Conditions in a corridor are of critical importance because it is the route that firefighters use to approach a fire and that occupants use to exit a building.

The principal measurements used to assess the hazards generated by a wind-driven fire were temperature, heat flux, velocity, pressure, and concentrations of oxygen, carbon dioxide, carbon monoxide, and total unburned hydrocarbons. Each test was recorded with video and thermal imaging cameras. Conducting the experiments in a laboratory provided the researchers with the highest levels of control, as well as the ability to determine heat release rates and gas concentrations, tasks which would have been difficult and very costly to perform in a structure in the field.

The controlled “wind” was generated with an air boat from Maryland’s Montgomery County Fire Department. The door from the apartment to the corridor was open for each of the experiments.

The fires were started in the furnished bedroom of the simulated apartment. Prior to the failure or venting of the bedroom window, which was on the upwind side of the experimental apartment, the heat release rate from the fire was on the order of 1 MW. After window failure, but prior to implementing either of the mitigating tactics, the heat release rates from the post-flashover structure fire were typically between 15 MW and 20 MW. When the door from the apartment to the corridor was open, temperatures in the corridor near the open doorway, 1.52 meters (5 feet) below the ceiling, were in excess of 600 °C (1,112 °F) in each of the experiments. The heat fluxes measured in the same location during the same experiments were in excess of 70 kW/m<super>^{2}. These extreme thermal conditions, which were attained within 30 seconds of the window failure, are not tenable, even for a firefighter in full protective gear.

After quantifying the level of hazard, the focus of the experiments turned to measuring the impact of the wind control devices and exterior water application. In these experiments, covering the window reduced the temperatures in the corridor outside the doorway by more than 50 percent within 60 seconds. Heat fluxes were reduced by at least

70 percent during the same minute. The wind control devices also mitigated any gas velocity due to the external wind.

The externally applied water streams were implemented in three different ways: a fog stream across the face of the window opening; a fog stream into the window opening; and a solid water stream into the window opening. The fog stream across the window was not effective at reducing the thermal conditions in the corridor. The fog stream in the window decreased the corridor temperature by at least 20 percent and the corresponding heat flux measures by at least 30 percent. The solid stream experiments resulted in corridor temperature and heat flux reductions of at least 40 percent within 60 seconds.

None of the water applications had a significant impact on reducing the gas velocities in the structure. These experiments demonstrated that wind control devices and high-rise nozzle deployment were effective in reducing the thermal hazard in the corridor. However, firefighters do not fight fires in laboratories; thus the next step was to have firefighters employ the new tactics in live-burn experiments.

Governors Island Experiments

Governors Island, located just south of Manhattan, is home to a national monument and an abandoned military base which includes several high-rise buildings. One of the seven-story buildings became our test site. It was instrumented to measure temperature, pressure, and velocity in the fire apartments, public corridors, and stairwells.

The experiments on Governors Island were necessary to examine the effects of natural ventilation (door control) and positive pressure ventilation on a fire. The experiments would also allow researchers to study the means of egress in the building, and how conditions were affected by the use of wind control devices and high-rise nozzles. These studies provided real-scale data to guide the development of appropriate tactical operations for use under wind-driven conditions.

While many new high-rise buildings may incorporate safety systems which could provide stairwell protection and an automatic sprinkler system for fire suppression, the majority of residential high-rises in cities such as New York and Chicago are not equipped with any of these fixed systems.

NIST, the Polytechnic Institute, and the New York Fire Department conducted 14 burn experiments on the seventh, fifth, and third floors of Building No. 844 on Governors Island. The results of the week-long series of burn experiments were witnessed by representatives from major fire departments across North America, and demonstrated the capabilities of each of the tools and how they worked in tandem.

The experiments also established the importance of controlling the air flow through the building. For example, traditional fire-fighting tactics call for the stairwell doors on the first floor, on the fire floor, and on the roof to be opened. Unfortunately, this places the firefighters entering the fire floor from the stairwell in the flow path of the hot fire gases.

The experiments demonstrated that pressurizing the stairwell with the portable positive pressure ventilation fans and coordinating the door openings so that the roof door (at the top of the stairs) is opened to vent smoke and subsequently closed before the fire floor door is opened provides a much safer working environment for firefighters.

Blocking the wind with a control device or suppressing the fire with a high-rise nozzle mitigates the wind-driven effect and enables the fans to maintain a higher pressure in the stairwell than on the fire floor to hold back smoke and heat. This tactic kept the vertical egress paths in the building tenable for both building occupants and firefighters.

Computerized Fire Simulations

While the experiments proved that the tools and tactics were effective, firefighters needed to understand how to implement the tactics in buildings and under conditions outside the test parameters before the fire department would fully implement the new tactics as standard operating procedure. Given the high cost and limited opportunities for full-scale experiments, modeling was used to address this requirement.

By simulating various fire scenarios with the use of commercially available software such as Fluent 6.3 and NIST’s Fire Dynamics Simulator, researchers at the Polytechnic Institute are providing the scientific basis for the phenomena observed during the live-burn experiments. The simulation studies have proven the ability of positive pressure ventilation to mitigate the smoke and heat, thereby increasing the visibility and safety of firefighters in rescue operations. They have also demonstrated that deployment of wind control devices reduces the wind-driven effect on a fire and increases the effectiveness of positive pressure ventilation, even in the presence of high winds. Current studies are focused on perfecting the design of high-rise firefighting tools such as positive pressure ventilation fans, wind control devices, and high-rise nozzles.

After proving the effectiveness of these new tactics, researchers and New York firefighting officials are optimizing the tactics to address various important parameters of wind-driven high-rise fires (e.g., wind speed, building and stairwell structures, heat release rate, bulkhead door openings, vents, placement of fans, multiple fan deployment, etc.) using computerized simulation.

In addition to validating the results and observations for regular pre-experiment and post-experiment purposes, the fire department officials are also using simulations to train and educate the firefighters in understanding the unique characteristics of wind-driven high-rise fires and the tactics and tools top fight them. This study has fostered the blending of scientific lexicon into fire service culture.

Web Based Training

In addition to the development of wind-driven high-rise firefighting procedures, the objective of this study is also to train and educate firefighters in these strategies so that fire services will be able to implement the tactics in real life situations. The Polytechnic Institute developed a Web-based, interactive multimedia general methodology, as well as a specific tool called ALIVE (Advanced Learning in Integrated Visual Environments).

The prototype divides specific, evidenced-based firefighting strategies into a series of steps. At each step, information is presented in various forms—text, images, video of a real scenario, audio of a real communication, etc.— and several options are presented which are similar to those firefighters consider in a real situation. Each option routes the participant down a different path, which dynamically alters the scenario and logically leads to changes in conditions and to new choices in which further decisions are required.

Once an identifiable, multi-step sub-task has been completed, the user is presented with the result of his or her decision, as well as an explanation of why the choice was correct or incorrect. The system is also designed to allow the user to loop recursively through the scenario to see where errors were made, while providing relevant information necessary for making appropriate decisions at different points.

Training session records can be automatically saved to a database, thereby making it practical to track training material usage levels, and, over time, to reliably assess the need for a particular type of training at the level of a single firefighter, a region, or nationwide.

Thus, in addition to providing training and engendering diffusion, ALIVE also provides feedback to learners and their supervisors about the ways in which firefighters discern, comprehend and respond to the situations presented.

As a result of this research, New York has changed procedures for fighting fires in high-rise buildings. The city's fire department continues to collaborate with researchers from NIST and the Polytechnic Institute to train firefighters in the use of the new tools and tactics for fighting wind-driven fires.

With additional support from the FEMA program, the Fire Department of New York has purchased positive pressure ventilation fans, wind control devices, and high-rise nozzles to outfit fire companies throughout the city. Fire departments from around the world are reviewing the data and observing New York's use of the new tools with great interest.

Future fire fighters may not be aware of the experiments or the computational fluid dynamics models that were used to support this fundamental change in tactics, but it is clear that the synergy between the practical experience of fire departments and cutting-edge engineering practice has led to significant improvements in firefighting and firefighter safety.

To Follow Up

A DVD set which includes videos of the experiments and a presentation of findings can be requested at www.fire.gov. The presentation, which was made before an audience of firefighters, includes comments by Peter Van Dorpe, battalion chief of the Chicago Fire Department, and Jerry Tracy, battalion chief of the Fire Department of New York.

More information, including additional videos of experiments are available at the Polytechnic Institute's Web site at www.poly.edu/fire.

Publications related to the research program and to wind-driven high-rise fires in general include:

"High-Rise Building Fires," John R. Hall, National Fire Protection Association, Fire Analysis and Research Division, Quincy, Mass., August 2005.

"Three Firefighters Die in a 10-Story High-Rise Apartment Building – New York," NIOSH F99-01, National Institute for Occupational Safety and Health, Fire Fighter Fatality Investigation and Prevention Program, Morgantown, W.Va., August 1999.

"High-Rise Apartment Fire Claims the Life of One Career Fire Fighter (Captain) and Injures Another Career Fire Fighter (Captain) – Texas," NIOSH F2001-33, NIOSH Fire Fighter Fatality Investigation and Prevention Program, Morgantown, W. Va., October 2002.

"Extreme Wind-Driven Fireproof Multiple Dwelling Fires," John Norman, <ital>With New York Firefighters<endital>, New York, NY, 1st/2007.

Tracy, Gerald, "1 Lincoln Plaza, Operations of the First-Arriving Units at a High-Rise Multiple Dwelling Fire", <ital>With New York Firefighters<endital>, New York, 2nd/1997.

"Wind-Driven Queens Fire Provokes Several Maydays," James, D. Daly and George Healy, <ital>With New York Firefighters<endital>, New York, 3rd/2006.

"Fire Fighting Tactics Under Wind-Driven Conditions: Laboratory Experiments," D. Madrzykowski and S. Kerber, National Institute of Standards and Technology, Gaithersburg, Md., NIST TN 1618, January 2009.

"Fire Fighting Tactics Under Wind-Driven Conditions: 7 – Story Building Experiments," S. Kerber and D. Madrzykowski, National Institute of Standards and Technology, Gaithersburg, Md., NIST TN 1629, April 2009.