Firefighting Technology Research at NIST

BY DAN MADRZYKOWSKI AND STEVE KERBER

During the past year, the National Institute of Standards and Technology (NIST) has continued work on many projects and started a few new efforts to improve firefighter safety. In addition to the research projects listed below, the Fire Fighting Technology Group continues to improve the way that information is transferred to the fire service. The biggest change in information transfer this year is a redesigned Web site, www.fire.gov. The new site has a list of subjects of interest to firefighters such as flashover, thermal imaging, structural collapse, and positive-pressure ventilation (PPV). Relevant NIST reports and downloadable videos can be found under each subject.

Thermal Imaging Cameras

NIST is continuing to work closely with the National Fire Protection Association (NFPA) Technical Committee on Electronic Safety Equipment and the U.S. Army's Night Vision Laboratory to develop test methods to support and enable thermal imaging camera (TIC) performance standards. Given that a TIC is composed of a number of components that affect what a firefighter "sees," this effort has gone beyond the NIST Fire Research Division and has tapped the expertise of the NIST Physics Laboratory as well as the NIST Electronics and Electrical Engineering Laboratory. NFPA plans to present the standard for public vote at its 2009 annual meeting.

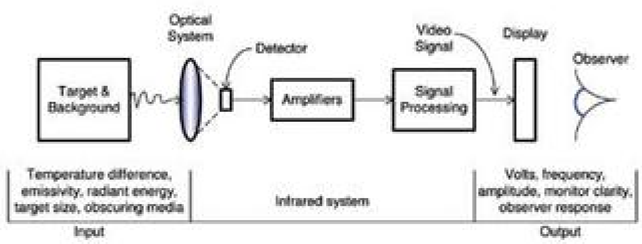

Figure 1. Components of a Thermal Imaging System
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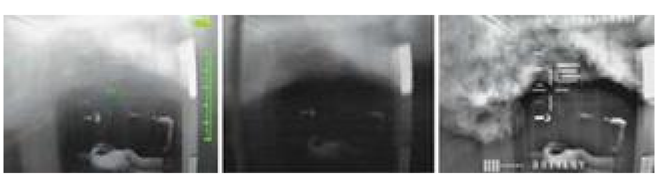
Integrated PASS Device

In 2005 and 2006, NIST published reports on the performance of thermal exposure sensors in personal alert safety system (PASS) devices and on the thermal environment considerations for electronic equipment used by the fire service. The thermal exposure research in concert with field observations by the NIOSH Fire Fighter Fatality Investigation and Prevention Program identified issues with the decrease in alarm signal volume at high temperatures. This led to the revision of the thermal test requirements of NFPA 1982, Standard on Personal Alert Safety Systems, which went into effect in July 2007.



(1) Comparison of three thermal imaging camera detector technologies of the same fire environment at the same time: (left to right) vanadium oxide (VOx), amorphous silicon (ASi), and barium strontium titanate (BST). (Photos courtesy of NIST.)
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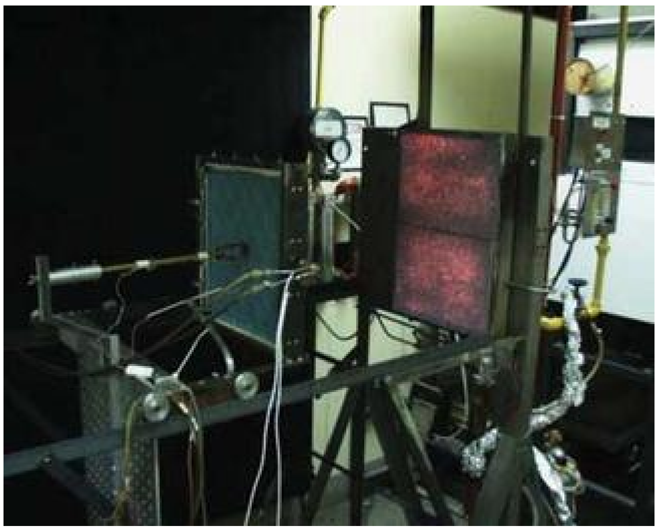
NIST is continuing the thermal exposure research and is developing a new thermal test loop that can be used to test a range of personal protective equipment, including integrated PASS devices. The apparatus is designed to accommodate the entire SCBA and is expected to be operational by July 2008.

The Thermal Capability of Firefighter Protective Clothing

Every year, approximately 100 firefighters die in the line of duty, and more than 80,000 firefighters are injured. Although not the leading cause of fatalities, reports on firefighter deaths and injuries indicate that burns accounted for approximately 7 percent of firefighter fatalities and 8.5 percent of firefighter injuries. Firefighter personal protective clothing (PPE) is designed to provide the wearer with a limited amount of protection from burn injury. Burn injuries can occur from exposure to the heat produced by a fire through contact with flames, hot combustion gases, steam, burning items, or any combination of these conditions. Firefighters can also receive burn injuries when their protective garments become compressed as a result of contact with hot objects or when movement compresses clothing material against the skin.



(2) The bench scale thermal exposure test apparatus with a PPE sample exposed to a gas-fired radiant panel.
Click here to enlarge image

Two thermal performance test methods found in NFPA 1971, Ensembles for Structural Firefighting and Proximity Fire Fighting, have had a significant impact on improving the performance of firefighters' protective clothing. The Fabric Flammability Test (FFT) has resulted in the development of protective garments that resist flaming ignition. The second test, the Thermal Protective Performance (TPP) method, has helped in the design of protective garments that reduce the rate of heat flow from a firefighting environment through the protective clothing. The TPP test measures heat flow through a garment while exposed to a heat flux of approximately 83 kW/m2, intended to simulate exposure to a flashover fire. A single copper calorimeter is used to measure heat transfer through a protective clothing assembly. Work by Krasny et al. at NIST suggests that firefighters will likely receive serious burn injuries in less than 10 seconds when exposed to a heat flux of 83 kW/m2. Fortunately, very few firefighters are exposed to flashover conditions. Most firefighter burn injuries appear to result from thermal exposures much less severe than the flashover conditions used by the TPP test. In addition, many of these burn injuries appear to result from relatively long-duration exposures to low or moderate heat fluxes.

As part of a project funded by the United States Fire Administration (USFA), the Building and Fire Research Laboratory (BFRL) at NIST is exploring the feasibility of developing new apparatus for evaluating the thermal performance of firefighter protective clothing. This test apparatus would be capable of measuring the thermal performance of firefighters' protective clothing over a wide range of thermal environmental conditions and over extended time periods.

NIST developed a bench scale test apparatus, using combinations of protective clothing material approximately 0.38 m (1.3 ft) square. A full-scale apparatus that uses the full ensemble of protective clothing mounted on a mannequin to more effectively examine the complex geometric interactions of the protective clothing and the potential for various burn injuries is under development. The report (see below) presents the results of tests conducted using turnout gear mock-ups in the bench scale apparatus and the full-scale test apparatus. In addition, data obtained from the mock-up tests are evaluated against results from tests of complete firefighter ensembles in the full-scale test apparatus. Finally, the experimental data are compared with calculations from a mathematical computer model of heat transfer through firefighter protective clothing systems.

The complete report, NISTIR 7467, Full Ensemble and Bench Scale Testing of Fire Fighter Protective Clothing, by David Stroup, Roy McLane, and William Twilley, can be downloaded from http://fire.nist.gov/bfrlpubs/fire07/PDF/f07083.pdf.

Figure 2 shows the data from five repeat full-scale experiments for the four locations through the turnout coat (shell surface, inside of shell, body side of thermal liner, and outer surface of workstation shirt). This graph provides a visual representation of the variation in the thermal profile through the garment.

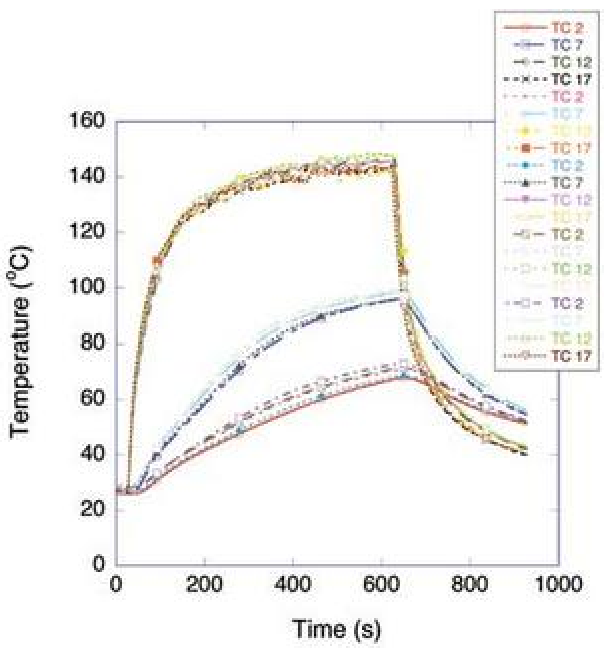


Figure 2. Results of Repeat Experiments
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Building on knowledge gained from this work, NIST is continuing the research on stored energy in PPE, working with North Carolina State University and the Fire Protection Research Foundation on investigating a new test method for measuring the energy retention capacity of the protective clothing. This new test apparatus is being considered for inclusion in NFPA 1971.


(3) An instrumented mannequin in front of electric radiant panels.

Longer-term research is being conducted on reactive cooling systems and nanocomposite fabrics for use in PPE. The reactive cooling systems are proposed to work by adding a layer of phase-change materials (changes from solid to liquid as it absorbs heat) to the lining of the turnout gear. As heat is added to the PPE from a fire environment, the phase-change materials would absorb energy to delay the thermal penetration. Once the phase-change material has absorbed enough energy to change the state, the heat wave would continue to the person inside the PPE. As an example of phase change, consider a piece of wax. When the wax is heated (absorbs thermal energy), it changes from a solid to a liquid. When the wax cools (loses thermal energy), it changes back to a solid.

PPV in High-Rise Buildings

During the past year, NIST issued two reports, NISTIR 7412, Evaluating Positive Pressure Ventilation in Large Structures: High-Rise Pressure Experiments, and NISTIR 7468, Evaluating Positive Pressure Ventilation in Large Structures: High-Rise Fire Experiments (available for download from www.fire.gov). Working in cooperation with the Chicago (IL) Fire Department, the Toledo (OH) Department of Fire and Rescue, and the Fire Department of New York, NIST conducted PPV fan studies in a 30-story and a 16-story high-rise. The Department of Homeland Security, Office of Science and Technology funded part of these efforts. The studies address the use of PPV for pressurizing stairwells to prevent heat and smoke infiltration and improving conditions for firefighters entering the building and building occupants trying to exit. Many configurations of fans were tested, such as the number of fans, the sizes of fans, positions, locations, and so on.

(4) The Chicago Fire Department's truck-mounted fan pressurizes the first floor and the stairwell and forces the fire back through the fire apartment and out the window.
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The experiments showed that the portable fans (24 to 27 inches) and the mounted fans (46 to 50 inches) generated pressures sufficient to remove the smoke from and keep the target stairwell free of smoke under a range of conditions. The pressures measured during these experiments agreed with the correlation provided in NFPA 92A, Standard for Smoke-Control Systems Utilizing Barriers and Pressure Differences, for using a pressure differential as a smoke barrier.

(5) A wide variety of portable fans were used during the Toledo and Chicago high-rise experiments.
Click here to enlarge image

The large mounted fans positioned at the front of the structure were able to clear the stairwell quickly when vented and were able to keep smoke out of the entire stairwell with the fire floor door open. The mounted fans were also able to clear the smoke all the way back out of the fire apartment, past the fire, and through an open rear window. Even when a second stairwell was opened, the mounted fans were able to keep that second stairwell free of smoke as well.

(6) Flames being forced out of a classroom window by a PPV fan located at a remote exterior doorway.
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The portable fans were also effective at ventilating the 16-story stairwell and keeping it free of smoke while pressurizing. In most cases, the single portable fan at the base of the stairwell resulted in significantly improved conditions in the stairwell. The increased pressures greatly reduced the amount of smoke that was able to flow into the stairwell under natural ventilation conditions. When a second fan was added two floors below the fire floor, smoke was kept completely out of the stairwell, even with the fire floor door open or with an additional door open.

(7) A post-flashover experiment in the school gymnasium.
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The bottom line is that PPV fans used correctly can increase the effectiveness of firefighters and the survivability of occupants in high-rise buildings. In a high-rise building, it is possible to increase the pressure of a stairwell to prevent the infiltration of smoke if fire crews configure the fans properly. When configured properly, PPV fans can meet or exceed previously established performance guidelines for fixed smoke-control systems. Proper configuration requires the user to consider a range of variables, including fan size, setback, and angle; fan position inside or outside of the building; and number and alignment of multiple fans. The portable fans were most effective when a single fan was positioned outside the stairwell on the first floor and another portable fan was positioned two floors below the fire floor, pressurizing from outside of the stairwell.

(8) A wind-driven fire spreading from the bedroom through the apartment and venting out of the living room.
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A compilation of the PPV reports to date and videos documenting the fire experiments are available from NIST at no cost. Send your PPV DVD requests to skerber@nist.gov.

School Tests in Toledo

Last summer, another building of opportunity brought the NIST Fire Technology Group to Toledo, Ohio, to further examine PPV with the Toledo Department of Fire and Rescue. A series of experiments was run in an abandoned high school to examine the ability of PPV fans to limit smoke spread or to remove smoke from desired areas. The two main scenarios included a long hallway with classrooms and a gymnasium. Both scenarios included fires that produce a large amount of smoke and hot gases. Instrumentation was placed to assess tenability criteria and how PPV tactics can increase or decrease survivability. Measurements included temperature, oxygen concentration, CO concentration, pressure, and numerous video views. The report is scheduled for release in summer 2008; watch the Web site www.fire.gov for further details.

Wind-Driven Fires in Structures

One of the last experiments in the 16-story building in Chicago was the simulation of a wind-driven fire. Conditions in the public corridor went from tenable (in PPE) to untenable within 30 seconds of the onset of the wind. Flames were forced from a bedroom on the upwind side of the structure, down a hallway, through the living room, and into the public corridor. In response to the results of that experiment and the loss of firefighters and civilians in wind-driven fires in New York City; Houston, Texas; and Prince William County, Virginia, NIST initiated a new research project this year to examine wind-driven fires.

NIST, in partnership with the Fire Department of New York; the Fire Protection Research Foundation; and Polytechnic University, New York—and under the sponsorship of the DHS's Assistance to Firefighters Grant Program—is conducting experiments to develop an improved understanding of wind-driven fires and examine a variety of tactics to mitigate the hazards of firefighting under wind-driven conditions.

Wind-control devices, PPV fans, and fire suppression nozzles that can be operated from the floor below the fire floor will be among the tactics examined. The research program begins with full-scale experiments in a three-room structure built at the NIST large-fire facility in Gaithersburg, Maryland. The research program will leave the lab and continue in a seven-story building on

Governors Island in New York Harbor. Results from the laboratory study and the New York experiments will be available later this year on www.fire.gov.

DAN MADRZYKOWSKI is a fire protection engineer with the National Institute of Standards and Technology.