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NIST Goes back to school

Just in time for Fall, NIST evaluates positive pressure ventilation tactics in a retired high school.

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By Steve Kerber

During the past six years, the National Institute of Standards and Technology (NIST) has conducted numerous experiments examining the effectiveness of positive pressure ventilation (PPV) for the fire service. As a tactic, fire departments frequently rely on PPV to ventilate a structure after extinguishing a fire, allowing them to complete salvage and overhaul operations in a less hazardous atmosphere. PPV has also been used during fire suppression operations to increase visibility and force heat away from the attack team as they locate the blaze. While PPV has been implemented with some success, however, using it also comes with some difficulties.

So how should PPV be used? What are some of the best practices for this tactic?

To answer these questions, NIST developed a series of experimental studies, with funding from the Fire Protection Research Foundation, that ranged in scale from a single room to a 30-story office building and identified tactical considerations for the most effective use of PPV fans. The results of these studies provide insight into questions such as where to place the fans, how much larger the fire could grow with added oxygen from the fans, and what size fans are needed to pressurize a stairwell in a high-rise building effectively.[1–7]

Experiments were also performed in a two-story, 300,000-square-foot (27,871-square-meter) retired high school in Toledo, Ohio, to examine the ability of PPV fans to limit smoke spread or to remove smoke from desired areas in an educational occupancy. Unfortunately, many fire departments don't have enough personnel to allow them to effect multiple rescues in a highly populated structure. The tactics NIST explored provide the fire service with

AUDIO CLIPS

NIST fire protection engineer Steve Kerber answers questions about the positive pressure ventilation test in Toledo, Ohio.

- What is positive pressure ventilation, and why is it valuable for fighting fires?
- Why did NIST chose this specific location for the PPV test?
- Does it require special equipment?
- The outcome of the test?
- More audio files

PHOTOS

ways to remove the hazard from the occupants, as opposed to removing the occupants from the hazard, which is much more time-consuming and labor-intensive.

The school was constructed of masonry bearing walls and steel column grids. The roof and floor systems were mostly steel deck on steel joists with reinforced concrete. Due to the complex floor plan, the condition of the structure, and the purpose of the experiments, engineers isolated a section of the building for the experiments. This section was to the right of the front entrance and includes long hallways, numerous classrooms, and a large gymnasium. Numerous ventilation points existed all the way around the structure, which allowed researchers to examine many configurations during the experiments.

An aerial view of the school prior to testing.

Each experiment included fires that produced a large amount of smoke and hot gases. Instrumentation was placed to assess tenability criteria and to examine the conditions firefighting crews could operate in and how PPV tactics would either increase or decrease the survivability of potential occupants. Measurements included temperature, pressure, thermal imaging, and video views.

A look at classroom fires

Each experiment began with all the ventilation points, doors, and windows closed, with the exception of the door from the fire room to the hallway. Engineers then ignited the fuel package of wood pallets, excelsior, and foam mats and allowed the fire to grow. As a first-order estimate, each stack of six pallets, without mats, produced a peak heat release rate of 2.5 megawatts, and a stack of 10 pallets produced 3.5 megawatts. This was calculated using the correlation from the chapter “Heat Release Rates” in The SFPE Handbook of Fire Protection Engineering, written by Vytenis Babrauskas, and is consistent with other NIST heat release rate experiments.3,8 At a minimum time of six minutes, the fires reached their peaks and became ventilation-limited.

Figure 1: NIST researchers photographing the fire ventilation.

Using the interior cameras and thermocouples, engineers determined when the smoke layer had lowered to the floor in the hallway and tenability was compromised. At this time, they ventilated the structure and opened either the fire room window or the doorway remote from the fire rooms (see Figures 1 and 2). They naturally ventilated the fire for two minutes, then turned on the fans and forced the ventilation. Researchers recorded data from the different fan configurations, then the fire was suppressed.

Figure 2: Ventilation through the fire room window.

Success with something as simple as a fan...

The pressure in any structure during a fire is important because it dictates the flow of smoke and heat throughout the structure. The fire creates its own pressure, and smoke and hot gases flow away from the fire to areas of lower pressure, which, in this scenario, are the hallways outside the fire room. The purpose of the PPV fan is to create pressures higher than that of the fire to manage where the smoke and hot gases flow.

Table 1 shows the peak pressure in the fire room ranged from 12 to 18 Pascals before natural ventilation or PPV was applied. This table also shows the pressure drop that occurred in the fire room after natural ventilation took place. Opening the window dropped the 7-foot (2-meter) pressure an average of 4 Pascals.

Figure 3: Experiment tested portable fans ...

The key to controlling the fire flow with fans is to create a pressure that is greater than that created by the fire. During testing, the ventilation doorway or the fire room window was always opened when the fans were activated, and in most of the experiments both configurations were used. The average pressure increases in the hallway created by the fans in the vicinity of the fire rooms during each of the experiments are in Table 2 . In most of the experiments, the fans created a pressure that exceeded the peak pressure created by the fire.

Temperature measurements taken throughout the structure allowed the engineers to analyze occupant tenability, operating conditions for firefighters, and potential fire and smoke spread.

In a building with long hallways, the lack of compartmentation increases the potential for exposure in areas farther away from the seat of the fire than might be the experience otherwise. Firefighters can use proper ventilation techniques to limit or control these temperature exposures both to occupants and themselves while they search for the occupants and extinguish the fire.

Engineers next analyzed the impact of several ventilation techniques on temperature, identifying the effects of natural ventilation and PPV using the fire room window, as well as the hallway door, as ventilation points.

Table 3 shows the average ceiling temperature change of the two closest thermocouple arrays to the fire room 90 seconds after ventilation for each experiment. This is an area of the hallway with the potential for highest temperature exposure for both occupants and firefighters. The temperatures in the fire rooms exceeded the tenability thresholds for both occupants and firefighters. Due to the large volume of the hallways, the temperature outside the fire room below 4 feet (1.2 meters) above the floor never exceeded 212°F (100°C).

The natural ventilation did not have a large impact on ceiling temperatures in the hallway adjacent to the fire room. In each case, the temperature changed very little. There was either a slight decrease in temperature because of heat escape or a slight increase in temperature because the fire grew due to the introduction of oxygen.

The PPV scenarios decreased the ceiling temperature in every experiment, regardless of ventilation location. Ventilating the fire room window usually had a greater benefit by lowering temperatures, but even when they were ventilated remote to the fire, the hallway temperatures either decreased or remained the same. The mounted fans had the maximum impact, yet even the single portable fan reduced temperatures.

As a result, the experiments established that the use of PPV can limit the spread of hot gases and decrease the temperature in the structure, allowing for increased survivability for potential victims and enhancing firefighter safety.

Gymnasium fire experiments

Other common areas found in educational buildings are large-volume spaces such as gymnasiums or auditoriums. A large-volume space can have enough oxygen to support larger fires as well as fires that can burn longer, can be very difficult for firefighters to search systematically, and can take hours to ventilate naturally. These experiments analyze fire growth, smoke filling, and smoke removal relating to firefighting activities.

Six experiments were conducted in the 340,080-cubic-foot (9,630-cubic-meter) gymnasium. Four different fan configurations were used with three different types of fans. Three of the experiments used portable fans, and three used mounted fans (see Figures 3

Figure 4: ...and mounted fans.

Figure 5: Engineers ignited the fuel package of pallets, excelsior, and mats and allowed the fire to grow for 9 to 14 minutes.

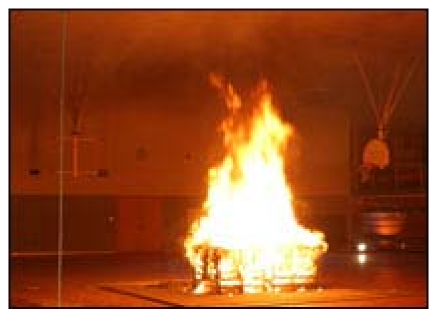
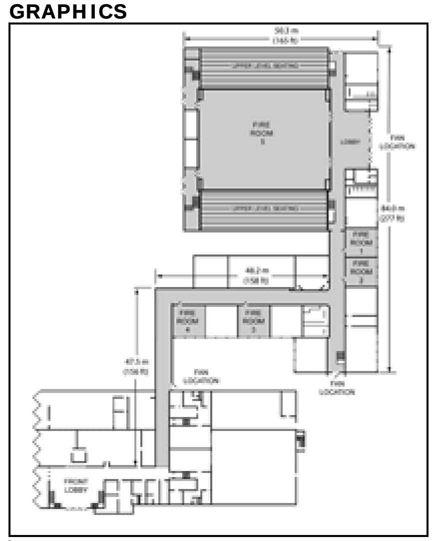


Figure 6: The scene inside the school gymnasium.

GRAPHICS



A floorplan of the school

and 4). The fans were all positioned outside the gymnasium lobby and were started after natural ventilation took place. During some of the experiments, the portable fans were moved inside to the doors between the lobby and the gymnasium. Two ventilation points were used at the rear of the gymnasium and at an opening in the roof. Each of the rear doors was 3 feet (1 meter) wide by 7 feet (2 meters) high, and the roof opening was approximately the same size as a single rear door.

Once again, each experiment began with all the ventilation points, doors, and windows closed, with the exception of the doors from the fan location to the lobby. Engineers then ignited the fuel package of pallets, excelsior, and mats and allowed the fire to grow for 9 to 14 minutes, depending on fuel load or smoke conditions (see Figure 5). This was approximately the time at which the smoke reached its maximum filling. The estimated heat release rates ranged from 2.5 megawatts to 56 megawatts.

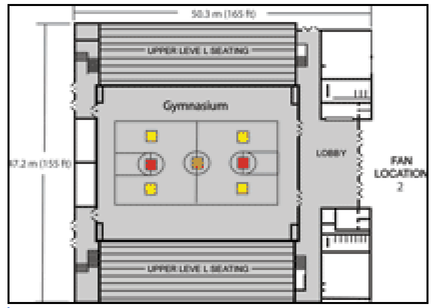
Using interior cameras and thermocouples, engineers determined when the smoke layer dropped to the point where tenability would be compromised at the floor level. At this time, the structure was ventilated through the rear doors of the gymnasium or the roof opening (see Figure 6). The fire was naturally ventilated or ventilated with positive pressure, depending on the scenario. Researchers recorded the effects of different fan configurations, then the fire was suppressed. After suppression, the smoke was ventilated.

Taming gym fires with PPV

In this limited series of experiments in the gymnasium, the use of PPV to increase pressure to reduce temperatures, limit smoke, and increase visibility was effective. The pressure, temperature, and video data suggest that each fan was able to create pressures that forced the products of combustion back through the lobby into the gymnasium, improving conditions in the lobby. This ability is very important in this type of structure, because the smoke is then limited to an area and the remainder of the building is protected from smoke, allowing more of the structure to remain tenable for occupants and making it easier and safer for firefighters to search it.

All the fans created higher pressures in the gymnasium, which increased the flow out of the ventilation points. The first five experiments created conditions consistent with a fire that is contained and in the decay stage. A single portable fan produced elevated pressures to increase ventilation for a volume of this magnitude, but it had limited effectiveness. Adding a second fan in parallel approximately doubled the pressure increase, and using a mounted fan approximately tripled the pressures created by the two portable fans. The purpose of elevating the pressure in the lobby is to prohibit the flow where it's not wanted, while the purpose of elevating the pressures in the gymnasium is to increase the flow out of the ventilation points. Using this technique, firefighters can accomplish either exposure protection or exposure protection and ventilation at the same time if there is an opening.

The single portable fans positioned outside reduced temperatures in the gymnasium at the rate of approximately 5°F to 11°F (3°C to 6°C) per minute. The mounted fans and the two portable fans in parallel cooled the gymnasium at the rate of 14°F to 27°F (8°C to 15°C) per minute. These rates are based on the ventilation of the gymnasium in the decay stage of the fire for five minutes after the peak output of the fire. Ventilation later in the fire had lower rates of cooling and ventilation after a larger fire had larger rates of cooling, but these numbers were reasonable expectations for a contained fire decaying in a large volume.



A floorplan of the gymnasium

TEST TABLES

TABLE 1. Peak Fire Room Pressures

Experiment	Peak Fire Room Pressure Before Ventilation (PA)	Pressure after Room Window Was Ventilated with No Fans (PA)
CF1	13	12 to 8
CF2	14	14 to 11
CF3	18	15 to 12
CF4	14	16 to 10
CF5	17	NA
CF6	12	NA

Table 1: Peak Fire Room Pressures

TABLE 2. Average Hallway Pressures with PPV

Experiment	Average Hallway Pressure in the Vicinity of the Fire room with Fans Operating (PA)	
	Ventilated Out Fire Room Window	Ventilated Out Hallway Door
CF1	18	NA
CF2	21	NA
CF3	16	12
CF4	8	6
CF5	35	25 (Both open)
CF6	32	28

Table 2: Average Hallway Pressures with PPV

TABLE 3. Impact of Ventilation on the Average Fire Room Temperatures at 2 meters

Experiment	Average Hallway Temperature Change in the Vicinity of the Fire Room 90 Seconds after Ventilation (°C)			
	Naturally Ventilated Out Fire Room Window	Naturally Ventilated Out Hallway Door	PPV Ventilated Out Fire Room Window	PPV Ventilated Out Hallway Door
CF1	-25	NA	-110	NA
CF2	+5	NA	-200	NA
CF3	+10	-25	-138	0
CF4	+50	+25	-88	-5
CF5	NA	+20	-140	-180
CF6	-10	-5	-135	-43

Table 3: Impact of Ventilation on the Average Fire Room Temperatures at 2 meters

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Of course, the fans should not be used in a way that will cause fire, smoke, or heated gases to be driven toward an evacuation route, an area of refuge, or trapped occupants.

Returning visibility to such a large-volume space was difficult, since removing all the smoke could require a very long time. However, the fans, independent of size, all decreased the amount of time for this process. In the hallways, the fans were able to push the smoke down the hallway, top to bottom, and out of the ventilation point. The flow path was the size of the total hallway, whereas that same flow path in the gymnasium was only a fraction of the total size. The use of the fans returned visibility in the lower portion of the gymnasium, which made searching the floor area easier. Using the fans to improve visibility higher up in the bleachers to allow for potential searches took much longer but still succeeded.

Waiting for a gymnasium of this volume to ventilate naturally could take many hours. When the roof was opened in Experiment GF9 (the data of which is in this article online), there was little improvement to visibility or heat levels after two minutes. The fan worked well with the roof vent to lift the smoke layer but was not significantly more effective than using the rear doors. The size of the roof ventilation opening, which was about the same size as the single rear door, would have had to be the size of four rear doors to take advantage of the flow from the trailer-mounted fans.

In the final experiment, the combination of PPV and vertical ventilation caused the ventilation-limited fire in the gymnasium to transition to flashover. While this was not desired, it was important to note that this entire space was untenable before ventilation. Once flashover occurred, the fan kept the combustion products in the gymnasium and protected the rest of the structure. It also improved conditions and visibility, so firefighters could walk through the lobby to the glow from the entrance of the gymnasium and extinguish the fire safely and rapidly.

The fire did not burn out of the gymnasium toward the fan because the pressure created by the fan was much greater than that of the fire. If firefighters had had to search for the fuel-rich, oxygen-limited fire, they might have found themselves between the fire and the ventilation point they opened to enter the structure. If the fire gained access to air by burning through the roof or by coming through additional doors opened by other crews, the firefighters inside searching for the seat of the fire could have found themselves in a rapidly transitioning fire.

Ventilation of oxygen-limited or fuel-rich fires, either naturally or mechanically, can cause rapid fire growth. Ventilation is not synonymous with cooling. Venting must be coordinated with all other operations on the fire ground.

In this limited series of experiments, the pressure was increased enough to reduce temperatures, giving potential occupants a more survivable environment and increasing firefighter safety; to limit smoke spread, keeping additional parts of the structure safe for occupants and undamaged, and reducing the scale of the emergency for the firefighters; and to increase visibility, allowing occupants a better chance to self-evacuate and providing firefighters with an easier atmosphere in which to operate. With appropriate knowledge and training, PPV is another tool firefighters can use to make their jobs safer and more efficient.

For a complete detailed analysis of these experiments, visit www.fire.gov.

Editor's Note — The NIST experiments provide a great deal of useful information on how particular PPV tactics will or will not affect the speed and course of development of fire and fire effects, for a variety of important fire scenarios. Interested fire officers and engineers and responsible authorities will need to do more to decide where to go from here. They will want to know whether there are any adverse developments—such as the onset of flashover in the last experiment—that could have made a critical difference in survivability in a different fire scenario. More generally, they will want to consider how best to translate the experimental results into detailed guidance on whether and how to use PPV, based on fire conditions the fire department can see when they arrive on the scene. They will want to consider whether issues not directly studied—such as fan pressure making it difficult for occupants or firefighters to move through doors—can be resolved based on further analysis of the existing experimental results or might require additional experiments or additional analysis more tailored to those issues. In so doing, they will be in a much better position to make good decisions.

Steven Kerber is a fire protection engineer for NIST. He is a member of the NFPA 921, Fire and Explosion Investigations, Technical Committee and is an executive member of the research section.

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