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FIRE DEPARTMENT APPLICATION OF POSITIVE PRESSURE VENTILATION

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ABSTRACT

This paper will address the difficulties that fire departments have in smoke removal from buildings and describe an innovation that has significantly improved the methodology of handling the problem. Common practice over the past 25 years or more has been to use negative pressure ventilation for smoke removal. Experiments and experience using positive pressure methodology have proved this to be the method of choice in most cases. A high-volume air movement system has been developed to facilitate replacement of the contaminated air with fresh air from outside the structure.

INTRODUCTION

Smoke removal from buildings during and following a fire is one of the most challenging aspects of modern firefighting. Numerous factors have contributed to the increased problems over the past 25 or 30 years. Three of the most significant contributors are the increased use of complex chemical-based furniture, fixtures, and equipment; the increased toxicity of modern smoke; and buildings with unopenable windows.

In modern society it is almost impossible to have a fire in an ordinary building where there are no plastics involved. The basic composition of these materials is of substances that release large volumes of smoke per pound of material when heated to extreme temperatures. The Btu output of these materials is on the order of two times that of ordinary combustibles, which further complicates the problem because of increased ambient temperature throughout the problem area.

Approximately 80% of all fire deaths in the United States result from inhalation of the toxic products of combustion. Carbon monoxide (CO) has long been considered the principal toxic gas in smoke that causes fatalities. Recent research following fires in which there was major loss of life has indicated that other products in the smoke may be major contributors to the deaths, since autopsies have revealed that some victims had less than lethal concentrations of CO in their blood. These victims were nonthermal deaths.

Buildings that do not have openable windows present an increased problem for fire departments attempting to remove smoke from a structure. Extremely limited access to outside air precludes natural ventilation from being a practical approach to the smoke removal process.

Frustration over the efficiency of our methods to remove the smoke from buildings in a timely manner was the root cause of the creation of the innovation to be described. The crowning blow was a high-rise fire that involved only one suite on the 20th floor of a 25-story building. While the fire did not extend beyond the suite of origin, the smoke permeated the 20th through the 25th stories of the building. The building was equipped with a modern smoke-removal system, which, unfortunately, failed to materially contribute to the smoke evacuation. The fire department, using conventional smoke ejectors, worked approximately three hours to clear the building of smoke. Fire control had only taken a few minutes. The bulk of the fire had been extinguished by the automatic sprinkler system.

Discussions with personnel who specialize in restoring furniture and buildings following a fire led to the discovery that smoke damage now frequently exceeds the total of fire and water damage in an incident. In some cases, 95% of the loss is reported to be smoke damage. These discussions revealed that if the smoke can be removed while it is still hot, a significant reduction in loss can be achieved, the basis of this being that when the smoke cools, the heavier particulates in the smoke settle out and become affixed to or imbedded in carpets, drapes, and furniture.

The most common smoke-removal equipment used by fire departments throughout the country is 16-in and 24-in fans. These fans are used for the most part in a negative ventilation mode. The fans are either set on the floor near a door blowing from the interior to the exterior of the building, hung by straps or brackets from the top of the door frame, or placed in a window blowing from the inside to the outside. This methodology has been common throughout the industry for more than 25 years.

PROPELLER-POWERED SYSTEM

A general belief that a greatly increased quantity of air movement was necessary to significantly improve the effectiveness of operations led to the idea that since propeller-driven airplanes have to move a lot of air to fly, an airplane propeller could be used for smoke removal.

Since funding for such an experiment was nonexistent, the author opted to develop a miniature system to ascertain the practicality of the approach, buying a model airplane engine and building a frame on which to mount the assembly. Semi-rigid duct was used to connect the apparatus to the area to be evacuated and both positive-

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and negative-pressure methods were used. The atmosphere used for these initial experiments was the interior of an automobile. Purely subjectively, it appeared that blowing fresh air into the interior and providing an exhaust vent for the smoke to escape was more efficient than mounting the system so that the smoke was being pulled through the propeller to the outside.

Convinced that possibilities existed for a significant improvement in methodology, the second-stage prototype was built. This prototype was developed using a more efficient fan than the little 4-in, two-blade propeller. The second-stage prototype consisted of a 24-in vane axial fan powered by a 10-hp gasoline engine with a belt drive. This unit weighed approximately 200 lb and had to be wheel-mounted for maneuverability.

An abandoned building, once used as a roadside bar, was obtained for experimentation. The building was loaded with smoke using a 500,000 ft^3 smoke bomb. Alternate placement techniques were used to attempt smoke removal. The fan was placed inside the building and forced smoke to the outside; then it was placed outside the structure and forced fresh air in to replace the smoke. The time taken to clear the building was determined to be faster using the technique of positive pressure inducement from the exterior. No scientific measurements were taken on air flow. This unit was capable of 15,000 cfm at maximum output.

The unit was considered to be a significant improvement over the conventional equipment carried on the fire apparatus and the decision was made for research staff to take it to some actual fires and test its practicality in real-life situations. The results were encouraging, but severe skepticism remained on the part of command officers, who feared that adding air would rekindle the fire that had been controlled but where smoldering remains existed. Conservative approaches on the timing of the use of the machine resulted in no unfortunate experiences and the critics became supporters of the concept.

An airplane propeller that had been damaged was obtained for the third-stage prototype. The propeller was shortened from 6 ft to 5 ft by an airframe and engine company to remove the damaged tips.

When a career change resulted in the author leaving the Dallas fire department after 24 years, it was decided that the third-stage prototype would be built in Austin. An operations research section was created within the Austin fire department, and the first major project for the group was to build the high-volume smoke-removal system.

With nothing but the propeller in hand, we began concept drawings of how the problem might be approached. Since funding was a major obstacle, salvage parts were used as much as possible. No one was anxious to spend large sums of money on something that might turn out to be useless.

Initial thoughts were to use a semi-rigid duct system that could be employed in a positive- or-negative-pressure mode. Expense of the material for a 6-ft-diameter, 100-ft-long chute made the semi-rigid concept unworkable. Since we were now locked in on positive pressure as the only option, we began to collect the pieces necessary to build the prototype.

A city wrecker that was about to be salvaged was bought to provide the transport vehicle. The propeller was mounted on a 2-in stainless steel shaft machined for this specific purpose. Stream straighteners made of 1/4-in aluminum served as a framework to hold the shaft in place. A sheet metal shroud was constructed to encase the assembly.

Since conditions are frequently crowded around the scene of a fire, it was decided that the entire assemblage should be mounted on a turntable so as to allow 90° rotation from the normal axis.

Because of limited access around buildings, the decision was made to construct a chute to bridge the distance between the unit and the point of access. A length of 100 ft was selected as the maximum practical length necessary to cover most situations. The search for lightweight but durable material resulted in a decision to use hot air balloon fabric. The material selected was a 1.5-oz ripstop nylon. A firm was selected to sew the material into a 6-ft-diameter, 100-ft-long tube that could be affixed to the vehicle on one end. The opposite end had a 3/4-in-diameter polyvinyl chloride (PVC) pipe sewn in to provide a means to hold the tube inside a door frame. Only the required amount is removed from the frame and the rest is cinched in place.

Initial testing at a local university resulted in a maximum flow of 70,928.1 cfm. Power for the propeller was provided by a 54-hp air-cooled engine with a 1:1 drive ratio. The maximum speed obtainable was 2200 rpm. A change in the ratio to effect a 25% reduction from engine speed to propeller speed resulted in an improvement in the engine's ability to achieve rpms in the 3800 to 4000 range with a propeller speed of 3000 rpm. This significantly improved the air flow. Other minor changes also added efficiencies. A local air balancing company assisted in recent tests, which concluded that the system will now deliver 112,177 cfm of free air movement.

DISCUSSION

The same type of skepticism was experienced in Austin as in Dallas. The high-volume smoke-removal system was placed in service in March 1985. The unit responds to all structural fires in the city. Detailed reports are filled out on each use.

Numerous experiments have been conducted in field applications since the unit has been operational. The first experiment used a 3800 ft^2 house as a subject. The house was loaded with smoke several times, with different techniques being used to clear the smoke. The fastest time for smoke clearance was 1.5 min and the worst time was 6 min. The experiment was repeated using conventional smoke ejectors. A total of six were used each time—four 16-in and two 24-in ejectors used in conjunction. The best time achieved was 13 min for smoke clearance.

Typical pressurization in buildings is .40 in of water using the system as measured by magnahelic gauges. It was discovered early in the experimental phase that the system functions much more efficiently when the exhaust port is smaller than the intake. When the exhaust port is equal to or greater than the 28.27 ft^2 of the chute opening, the time required to clear the area doubles.

Tests conducted at a nearby university in 1985 revealed several interesting observations. A building used for fire department training was used to conduct the experiments. A series of tests was devised where the most common fire service smoke-removal techniques could be fairly compared. Every possible variable was eliminated and every effort was made to ensure that subject ventilation techniques were done correctly.

Equipment sets were as follows:

1—Negative pressure with three 16-in AC smoke ejectors
2—Positive pressure with three 16-in AC smoke ejectors
3—Positive pressure with high-volume smoke remover
4—Natural ventilation (opening doors and windows)

Temperature varied from 70°F to 72°F and the wind was from the southeast to northwest at 9 to 17 knots. Relative humidity was 80% to 90% with intermittent light rain.

Each test fire was set in the same location using 9 lb of urethane foam (one 4-in-thick king-size mattress) and 3 lb of fabric (65% dacron and 35% rayon). This fuel load was intended to simulate an ordinary residence or light commercial interior fire load.

Temperature readings were taken every 15 seconds at three locations from the start of each set until completion of each ventilation. The instrument used was a digital temperature indicator with three 50-ft 16/2 copper wire leads, each tipped with 10 ft of heat-resistant flexible wire and a thermocouple. Locations were the fire room ceiling, the second floor ceiling adjacent to the fire, and the room above the fire ceiling.

A hand-held digital thermometer with a 3-ft thermocouple lead taped to a stiff wire also was used. This was for the outside crew to monitor the ceiling temperature over the fire and cool it down if necessary.

Smoke detectors used were PID ionization detector heads, rated between 1.3 and 1.5 obscuration rate (U.L.). These detectors were each powered by a pair of 6V dry cell batteries wired in series. Each detector set had a small fan mounted adjacent to it to prevent false readings from dead air in the detector head and a 50-ft 16/2 copper wire lead to a common control, consisting of one lead and one switch for each detector. The switches were manually thrown every 15 seconds to reset the detectors during each ventilation set. The detectors were suspended from ceilings with wire, and were as close to the ceilings as possible in the following locations:

1. Fire room ceiling
2. Stairwell adjacent to fire room between the first and second floors
3. Room above fire 6 ft off the floor
4. Attic

The four test fires exhibited surprising variations in maximum temperature. Heat production was much lower than expected. The maximum temperature reached during the series was 735°F at the fire room ceiling at the height of the burn. The temperatures were taken for each of three thermocouples every 15 seconds from the point when the fuel was entirely consumed until all smoke detectors had cleared. At no time did the fire room temperature return to ambient temperature, which was in the low 70s.

Temperature reductions were surprisingly similar using both negative and positive pressure methods when the 16-in fans were used. Both required five minutes to reduce the temperature to 100°F. The temperature reduction was much faster using the high-volume unit. Temperature was reduced to 100°F in 1.5 minutes and to near ambient in 2.25 minutes. Natural ventilation resulted in slightly quicker reductions to 100°F than occurred in either of the first two experiments.

Smoke obscuration results revealed that all detectors were registering more than 1.5% obscuration after three minutes using negative pressure ventilation. Two of the detectors cleared at the four-minute mark and one cleared at seven minutes. The last detection cleared at nine minutes.

The positive pressure experiment with 16-in fans had the same results at three minutes. One detector cleared at four minutes, one cleared at six minutes, one cleared at seven minutes, and one cleared at nine minutes.

Using the high-volume unit resulted in the first detector clearing at two minutes, two more clearing at three minutes, and the final detector clearing at four minutes.

Natural ventilation results were exactly the same as the 16-in positive pressure experiment, except that the last detector had not cleared when the experiment was terminated at 10 minutes.

Pressures were taken the day before the actual ventilation tests. Measurements were taken at several engine speeds with the building closed and with one door open. These are measurements of the pressure differential developed during positive pressure ventilation with the high-volume unit. All measurements were taken over approximately three-minute run times.

Fan Speed (rpm)	**Pressure (in of water)**	
	Building Closed	**One Door Open**
1125	.15	.05
1500	.40	.20
1875	.45	.20
2250	.35	.20

These pressures were measured on the ground floor of the building. Measurements taken on the second floor were .05 to .15 in of water lower for all cases.

Gas sample analysis was limited to carbon monoxide and oxygen level counts in parts per million (ppm). The oxygen levels did not vary more than 2% from ambient.

Carbon monoxide (CO) levels in the negative pressure tests revealed the following quantities in ppm for each succeeding minute beginning at zero: 112 ppm at the start, 125 ppm after one minute, 25 ppm after two minutes, 30 ppm after three minutes, 33 ppm after four minutes, and 30 ppm at five and six minutes.

Positive pressure results showed 240 ppm at the start; 85 ppm at one minute, 60 ppm at two minutes, 40 ppm at three minutes, 35 ppm at four minutes, 20 ppm at five minutes, and 10 ppm at six minutes.

The high-volume unit showed rapidly dropping CO levels from the start—220 ppm were recorded at the beginning. At one minute, the residual CO was 30 ppm, two minutes showed 15 ppm, and there were 8 ppm continuously after that.

The natural ventilation readings began at 192 ppm. After one minute, the level had dropped to 135 ppm, after two minutes the residual was 120 ppm, 55 ppm remained after three minutes, the level rose to 62 ppm after four minutes and fell to 47 ppm for the fifth and sixth minutes, at which time the tests were terminated.

During recent testing by a local firm, it was observed that fan performance begins to tail off rapidly at a motor rpm of 2500. Comparison of dynamics indicates that as static pressure (system resistance imposed by the chute) increases, velocity pressure (cfm) goes down. From a practical standpoint, this simply means that the shorter the chute, the higher the output and the longer the chute, the lower the output. Although we do not have a very practical way to test for a precise value, we know that a significant loss is attributed to the fact that the fan must inflate the chute. Were the chute self-supporting or of lighter fabric, performance would increase. However, the obvious trade-offs, such as set-up difficulty and fabric life vs. loss of performance, may not be worth the effort and expense.

During testing a great deal of turbulence was noted, attributable to the reinforcing rings around the inlet and discharge of the fan. Although it is virtually impossible to assess, we know from experience and from literature in the field that such turbulence may affect fan performance by as much as 30% or more. While it is also true that it could only be as little as 5%, reducing or eliminating turbulence will be well worth the effort.

The fact that the motor is in the airstream also affects performance. While we know this effect exists, we cannot assess an exact value and, given the design of the unit and engine application, it may not be practical or desirable to move it.

Eddy currents that result from poor directional stability impede laminar flow and therefore the actual rate at which smoke is removed. With improved directional stability, we would expect to see smoke removal appear more as a "wall" between clear and smoke-filled air rather than as a dilution of the smoke that occurs due to backwash.

As with any system, there are always opportunities for improvement. Many, however, will not result in enough improvement to justify the expense or effort. By any estimation, this tool has proved itself in practical applications. Whether or not the fan is the best design is really academic —it works.

CONCLUSION

The use of positive pressure ventilation as the method of choice in smoke removal has been proved beyond a doubt in our judgment. High-volume smoke-removal systems such as the one described result in a reduced amount of time for fire companies committed to this phase of post-fire activity.

No fire has gotten out of control from the premature use of the system. Fatigue levels of firefighters have decreased because of the speed with which the system clears the smoke and reduces the ambient temperature in the structure to that of the outside environment. Early critics are among the most ardent supporters and are lobbying for a second unit to be available in the event there are simultaneous fires or if the unit is out of service for mechanical problems.