SIMULATION OF POSITIVE PRESSURE VENTILATION (PPV) FOR FIRE FIGHTER TRAINING

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ABSTRACT

As new technologies and emergency management tactics are introduced into fire agencies, additional education and training become necessary. Due to the costs and hazards of live fire exercises, simulation is gaining acceptance for use in training programs for fire fighters.

PPV is a relatively new technique for attacking and combating structural fires which, when properly implemented, can reduce property damage and save lives. Proper use of the technique requires special training that can, in part, be realized through physical and computer simulation.

This paper reports advancements in PPV simulation for fire fighter training. Physical, scale model simulations are addressed and supported by live fire tests. Results from this research are being used to generate the data and experience base necessary for future computer simulation.

INTRODUCTION

Using simple fans, a structure (building, house, aircraft, etc.) can be slightly pressurized to provide rapid and effective removal of heat, smoke and toxic gases as conceptually illustrated in Figure 1. This fire fighting technique is known as Positive Pressure Ventilation (PPV) and has been shown to improve the environment inside the structure by lowering temperatures, improving air quality and increasing visibility [1,2,3]. The benefits of PPV include enhanced search and rescue operations, reduced property damage and minimized long-term adverse health effects for fire fighters. Although PPV use during post-fire salvage and overhaul operations has become popular within recent years, it is rarely used or taught as an initial fire attack technique where it's benefits may be more fully realized.

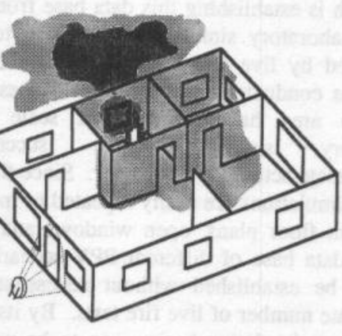

FIGURE 1 Conceptual Illustration of Positive Pressure Ventilation

Training and practice are required in order to use PPV techniques effectively. Unfortunately, the fire service is limited in its ability to safely and repeatedly expose personnel to various live fire emergency training scenarios while at the same time complying with a variety of state and federal mandates. Although training fires can be staged in condemned or donated structures and specially constructed burn buildings, the safety and health hazards to which personnel are exposed pose additional liability and concern for training program managers. Asbestos, heat and toxic combustion products produce an excessive hazard to personnel while in a training environment. Since training is vital to a fire fighter's well-being, accurate simulation of techniques such as PPV is desirable.

For the past 18 months, UCF and OCFRD have been conducting a research program to evaluate the merits of PPV and to develop the tools necessary for fire fighter training. The ultimate goal of these efforts is to develop a simple, user friendly, PC-based computer simulation package that can be incorporated into any comprehensive fire fighter training program.

In order to accurately simulate PPV and assess the validity of computer simulation, a large, reliable data base must be established for comparison. Research is establishing this data base from scale model laboratory simulations which in turn are supported by live fire tests. Live fire training exercises conducted in donated residences in the Orlando area have shown that scale model laboratory simulation can successfully approximate actual PPV behavior. Since the scale model simulations are easily repeated or modified (different floor plans, open windows and doors, etc.) a data base of different PPV scenarios can readily be established without necessitating an inordinate number of live fire tests. By itself, the laboratory simulation has proven to be useful in fire fighter training for both exercise planning and post fire evaluation.

The software for computer simulation is in the early stages of development and consequently results are not presented here. Unlike existing CFD or zone model codes which require extensive computer knowledge and expensive state-of-the-art computational hardware to use, the code being developed is more amenable for training. The real-time code is based in modeling momentum driven flows similar to the laboratory simulations.

SCALE MODEL SIMULATION

A novel underwater simulation technique for PPV has been under development at the UCF Two-Phase Flow and Heat Transfer Laboratories. Scale models of structures are constructed of thin, clear acrylic for easy viewing of hot and cool air masses simulation by colored water injection. The simulation is conducted either on a water table or in a deeper transparent tank built to accommodate taller multi-story models. Simulations have been conducted for a series of live fires that were fought with and without the PPV technique (1992-1993). Each fire was instrumented with thermal, chemical and video sensors to monitor the fire fighting environment and provide verification of the laboratory simulations. Results show that live fire testing supports the accuracy of the real-time simulations.

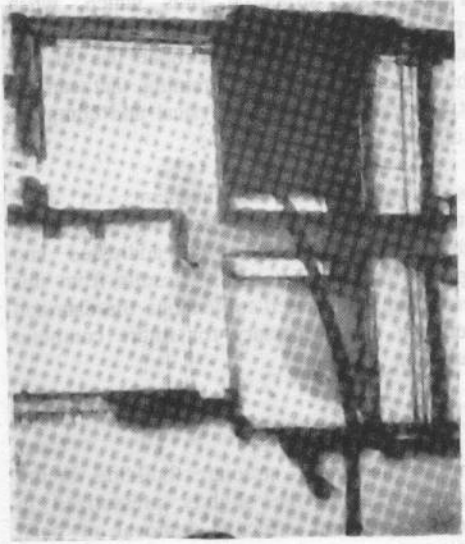

FIGURE 2 Underwater Scale Model Simulation of Heat Spread
(Dark areas show heated air as it moves through the house)

As shown in Figure 2 the simulations can be used to vividly illustrate the spread of heat from isolated fire sources and to identify "hot spots" within the structure. Laboratory simulation is a safe and cost effective (less time, manpower, equipment) alternative to live fire testing for demonstrating proper and improper PPV techniques and it permits a spectrum of training scenarios to be quickly evaluated. Visualization of the entire PPV process is possible with a laboratory simulation allowing all personnel to witness the effects of heat movement and ventilation that are not apparent during a real fire. Also, fire and ventilation scenarios are repeatable and lend themselves to easy variations within the laboratory and any errors in judgment regarding implementation of PPV present no hazard to fire fighters, civilians or property when executed in a laboratory environment.

The thermodynamics and fluid mechanics of the fire and PPV are simulated by injecting red colored water dyes at a rate determined from actual fire measurements. Buoyancy effects can be approximated by vertical water injection or by fresh water injection into a salt water filled model. A similar underwater technique was successfully used by Steckler et al. [4] for simulating the spread of heat during on-board ship fires.

The time history of the temperature changes in the fire room is important for simulating the expansion of heated air. Air expands when heated and a relationship exists that relates the change in air mass for a given temperature change. For a constant volume structure at constant pressure:

$$m_2 - m_1 = \left(\frac{PV}{R}\right)\frac{T_1 - T_2}{T_1 T_2} \qquad (1)$$

The left hand side of this equation is the change in air mass in a room over a specified period of time. Pressure (P), room volume (V) and the specific gas constant (R=287 N-m/kg-K for air) are essentially constant and do not change with temperature (T). T_1 and T_2 are the values of temperature at the beginning and the end of the specific time interval.

Time and temperature data from the live fire tests were used to verify the simulations. The temperature curve presented in Figure 3, for example, is for a rapidly burning fire based on measurements made during a residential fire test. It shows how temperature varied with time as measured by a thermocouple inside the fire room. The jagged line shows the actual temperature measured during the fire and the straight lines show the approximation used for simulating the fire.

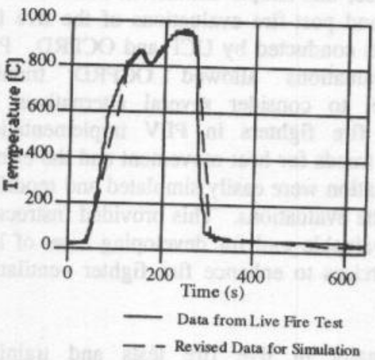

FIGURE 3 Sample Temperature versus Time Trace for Simulation [5]

Since heated air expands and flows out of a burning structure, the volumetric flow rate of the air (Q_{heat}) can be approximated by

$$Q_{heat} = \frac{(m_2 - m_1)_{air}}{(t_2 - t_1)\rho_{air}} \qquad (2)$$

where t_2-t_1 is the time interval for a given temperature change (T_2-T_1) and ρ is the average density of the air. To simulate an actual fire and ventilation process, the water injection rates are simply scaled by

$$Q_{model,heat} = \frac{V_{model}}{V_{real}} Q_{heat} \quad (3a)$$

and

$$Q_{model,fan} = \frac{V_{model}}{V_{real}} Q_{fan} \quad (3b)$$

where Q_{model} is the water injection rate into the model and V_{model} / V_{real} is the model to real volume structure ratio.

In practice, this simple simulation has been used for pre and post-fire evaluations of the live fire PPV tests conducted by UCF and OCFRD. Pre-fire evaluations allowed OCFRD training personnel to consider several alternatives for training fire fighters in PPV implementation. General trends for heat movement and the effects of ventilation were easily simulated and modified during the evaluations. This provided instructors with a valuable tool for developing a set of live fire exercises to enhance fire fighter ventilation training.

Occasionally in live fire tests and training, unexpected events occur. Data analysis and post fire simulation of live fire tests can supply a useful reconstruction of events and environment changes that may illustrate the cause of these unexpected occurrences. Post fire simulations also highlight the merits or the harm of certain fire fighting tactics. In particular, simulation can show fire fighters the benefits of PPV when it is properly applied and the potential problems of improper implementation.

RESULTS AND SUMMARY

Nine structural research and training fires were ignited and extinguished in four donated residences in the Orlando area. Each fire was simulated with the underwater scale model method described.

1. Based on actual live fire tests, PPV has been shown to be an effective fire attack tool that can significantly reduce temperatures, lower levels of toxic combustion products and greatly enhance visibility. Training is required to properly implement PPV and simulation can support a training program.

2. Underwater, scale model physical simulations add to the learning and training process by accurately simulating heat spread and ventilation. Table I shows a representative comparison of live fire events to those simulated with underwater models. As shown, live fire behavior is accurately represented in real time by using the simulation technique described in this paper. Hence, a large data base of PPV experiences can be gained through simulation with an expected high level of confidence.

TABLE I Comparison of Real Fire and Simulation

Scheduled Event	Real time (min:s)	Simulation time (min:s)
Start of Fire	0:0	0:0
TC in hall responds	0:30	0:22 - 0:40
TC1 in BDRM #1 responds	0:50	0:50 - 1:00
TC2 in BDRM #1 responds	1:25	1:15 - 1:25
Fire room window breaks	1:42	1:42
TC in BDRM #3 responds	1:50	1:50 - 2:00
PPV fan ON	2:12	2:12
Fire Out	4:30	4:30

3. Results from the scale model simulations can be used to develop and test future computer simulation packages. A simple PC-Based computer package is currently under development which incorporates the simple momentum and buoyancy driven flow behavior indicative of the scale model simulations.

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ACKNOWLEDGMENTS

This work has been supported, in part, by the UCF Institute for Simulation and Training (IST) and the Orange County Fire Rescue Division (OCFRD). The authors wish to thank the OCFRD fire fighters and UCF student researchers for their support and interest.