#3905

INFORMATION-BASED SMOKE CONTROL SYSTEMS

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ABSTRACT

Until recently fire management and smoke control systems (FM&SCS) provided only the minimum functionality necessary for life safety in buildings. Because of this it was difficult to understand what happened in a building during fire conditions. For example, during a real alarm, users needed to know if the automatic control system performed the necessary functions. Since the FM&SCS did not provide feedback, it was difficult for system operators to understand what happened in a building during fire conditions. The resultant trend was to simplify the automatic smoke control sequences ("keep-it-simple" concept) so that feedback wasn't a necessary function.

In parallel, the research and experimental testing of smoke movement in buildings continued and it was found that smoke containment is a dynamic process and building conditions vary during fire situations. Research was also conducted on the use of elevators, not only for firefighting, but also for evacuation of the handicapped and elderly. At the same time, rapid development of microelectronic technology took place to provide cost-effective solutions.

Today, with the emergence of new sensor technology and with the opportunities of distributed processing, a systems approach to fire and smoke control may provide the tools to resolve problems with existing systems. HVAC control systems designed to work effectively with FM&SCS can now provide a cost-effective and highly reliable total system approach to life safety.

INTRODUCTION

The evolution of smoke control in high-rise buildings has been slow in the years since its introduction in 1970 (GSA 1970). Progress was made in two major areas: design of systems for smoke containment and the control necessary to operate the systems.

A great deal of research, analysis, and experimentation took place to establish the methodology for smoke evacuation using smoke shafts with natural and forced convection (Tamura and Shaw 1978), smoke containment by pressurization of egress stairwells (Tamura and Manly 1985; Shaw and Tamura 1976), determining the proper location of pressurization fans, analyzing the leakage through wall openings (Tamura and Shaw 1976), providing evacuation with and without elevators (Klote and Tamura 1986, 1987; Tamura and Klote 1987), handling the special requirements of handicapped and aged people (Klote and Tamura 1986; Tamura and Klote 1987), and determining the leakage through dampers (McCabe 1984). Experiments have been conducted in actual buildings and in fire towers to determine the basic design methodology. In the early 1980s, greater focus was given to total system approach as well as to fan systems with pressure feedback (Shavit 1983) to give better stairwell and shaft pressurization.

Similarly, there was a gradual evolution in smoke control systems. Until recently, the control systems operated on a very simple principle: detection, annunciation, and pressurization. Upon detection of smoke (regardless of the source), the system initiated the pressurization process. However, since no feedback was provided to verify the system's performance, the pressure in stairwells was allowed to go out of control and the system did not perform according to design criteria. Since FM&SCS solutions were not provided, the industry uses mechanical means to alleviate some of the problems. Oversized fans and barometric pressure dampers were installed at the top of the shaft to maintain a given pressure level. However, these dampers could not compensate for seasonal variation and/or wind speed and direction. There also was no way to verify whether these dampers were operative or not. Similarly, pressure change due to window breakage was not compensated for since there was no feedback regarding shaft pressurization.

Smoke detectors used on FM&SCS were binary-type sensors. When the smoke level reached an obscuration of 4%, an alarm was initiated. The actual location of the alarm was known by zone only, and the specific location of the fire was not known. Additionally, there is no intermediate information to indicate the rate of change of smoke level. Clearly, the evolution of smoke control systems from on/off control, hard-wired systems to distributed processing, information-based systems is a vital step forward.

FEEDBACK INFORMATION AND CONTROL

The simple conventional HVAC control loop has few basic elements: controller, actuator, process to be controlled, and sensor to measure the output and provide

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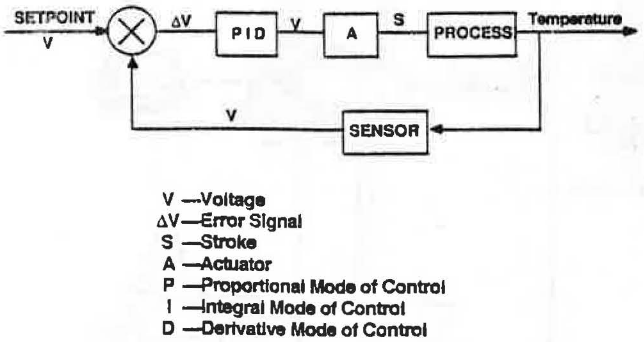

Figure 1 Feedback control loop

feedback from the process and to the controller (Figure 1). The controller compares the sensor value to a given setpoint. The difference is the error signal that is used to compute controller output based on the selected mode of control (proportional, integral, or derivative). The controller output operates an actuator that, in turn, changes the process output.

Conventional fire management and smoke control systems have sensors, actuators, and a process to be controlled. Fire sensors (smoke detectors) provide a command to a controller to turn fans on and off and to open and close dampers to contain the smoke. Once this action is initiated, in many systems there is no sensor to provide feedback to verify whether the desired pressure is maintained. There is no information indicating how well the smoke is contained or whether there is a failure in the smoke control process.

Fire monitoring and smoke control systems were initially designed with sensors sensitive to a given obscuration (smoke) level. Systems did not provide any intermediate information in a fire situation or during normal building operation. Life safety systems are not exercised most of the time. Smoke detectors are supposed to be on at all times, but there is no feedback on whether the detector is operative or not. Communication lines are monitored for open and short conditions. There is no information on whether the smoke dampers will work and/or close in case of a fire.

The industry experienced problems in the past in maintaining the proper pressure in stairwells when pressurization fans were turned on. The problem was over- or under-pressure based on the season of the year as well as occupant movement. To alleviate this type of problem, a barometric damper was installed at the top of the stairwell to regulate pressure. The damper was set for one pressure level. There was no way to compensate for the setting due to outdoor conditions or changing internal conditions. It was found (Klote and Tamura 1986) that it is desirable to maintain a high and a low pressure in vestibules near elevators and it cannot be done by a single setting. Additionally, it was not known whether the smoke dampers were operative or not since most of the time the pressurization fans were off.

There was a trend in the early 1980s to keep fire management and smoke control simple. It was justified as long as these systems could not provide needed information. However, since then, analysis, experiments, and tests have provided a better understanding of smoke movement in buildings. At the same time, system integration, HVAC, and fire management and smoke control were evolving (NFPA 1988). Control system architecture improved and reliability increased. It was established that:

—It is important to have better feedback and verification during normal operation so that all components of the fire monitoring and control systems are operative.

—Feedback is important to verify system operation and performance during a fire situation.

SYSTEMS REQUIREMENTS

In the process of designing systems for fire management and smoke control in buildings, four areas need to be discussed in greater detail.

Elevators

In the past, elevators were dedicated to firefighting. Recently, analytical and experimental studies (Tamura and Shaw 1976; Tamura and Klote 1987; Klote and Tamura 1987) recommended that elevators also be used for evacuation of handicapped people and other occupants.

It is mandatory to keep the elevator shafts free of smoke; therefore, the shafts are pressurized. Vestibules near the elevators should also be pressurized with respect to occupied areas. Elevator movement in the shaft and the opening and closing of elevator and vestibule doors create a dynamic situation. The pressurization system has to respond to this change and increase, decrease, or hold the air supply to maintain the desired pressure. Additionally, different situations exist in summer and winter and the system has to respond to these varying conditions. This information is important during the firefighting process, since it helps the fire marshal to identify where the containment process holds and where it fails and the rate of change when deviations take place.

Fan System and Air Distribution

The most common air-handling system for comfort is the variable-air-volume (VAV) system. The air-handling unit has to respond quickly in case of a fire. The floor(s) that have the source of the fire have to be isolated, and floors above and below have to be pressurized to contain the smoke. The VAV fan has to change from the present mode to maximum air supply in a short time. At the same time the smoke dampers are activated, the VAV boxes have to be set in the fully open position in the zone above and below. Pneumatically controlled boxes have a relay in the actuator branch line to provide maximum pressure. Electronic VAV boxes have to be fully opened and the actuation speed should be short (approximately 1 minute), otherwise it is difficult to contain the smoke.

The VAV air-handling system and electronic VAV box have the necessary feedback to verify system performance. The fan system airflow control provides airflow information. Similarly, the electronic VAV controller provides the same information. These systems are in operation day in and day out, and the system gives feedback in case of malfunction.

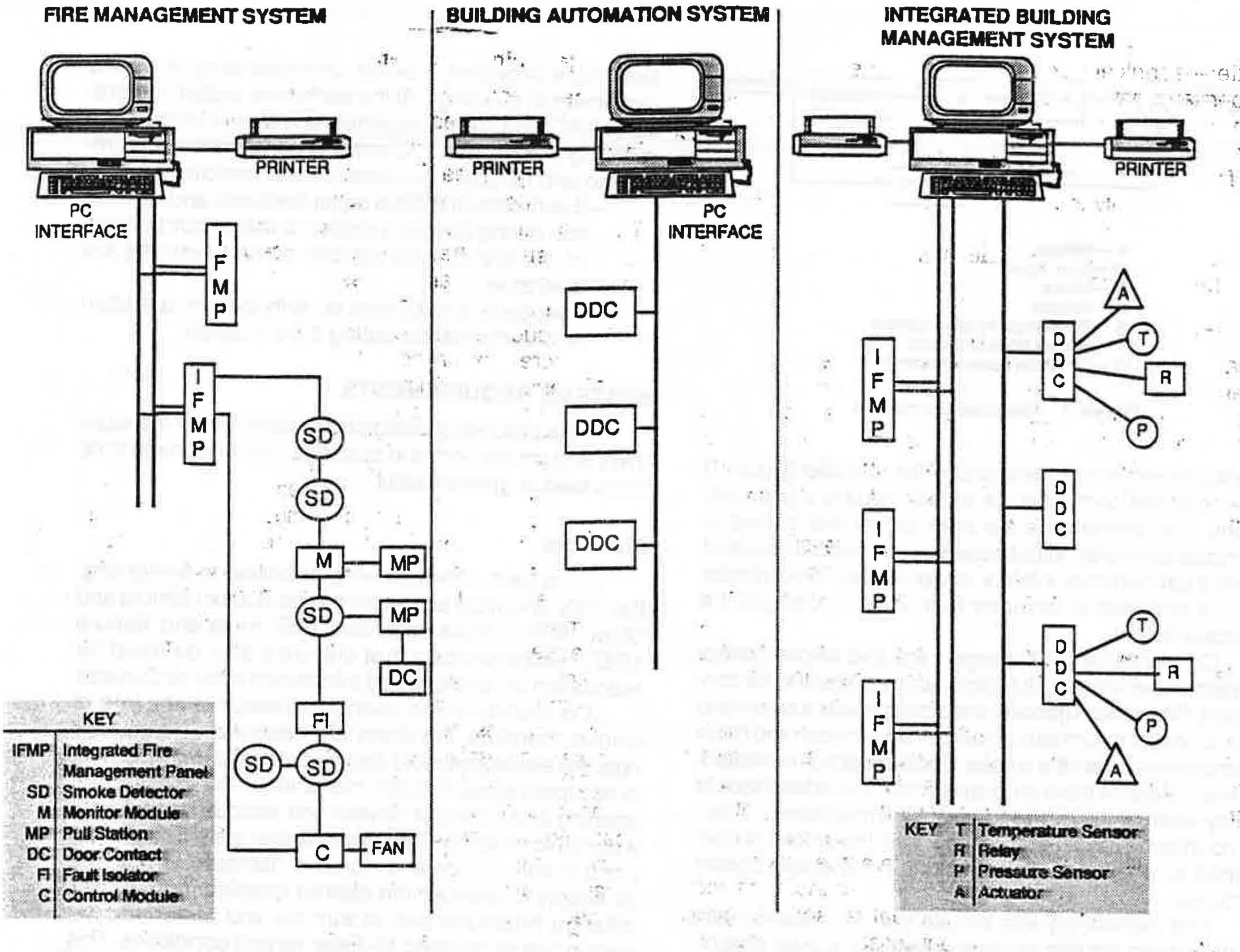

Figure 2 *System architecture*

Pressurization Fan System

Pressurization fans for shafts and stairwells should be part of the variable-air-volume system (Shavit 1983). Airflow through the height of the shaft is supplied through ducts (Erdelyi 1975). The air supply at each level is controlled by measuring the pressure difference between the shaft and the surrounding environment. In the case of an elevator shaft, the shaft and the vestibule have to pressurize. Local control is done by a feedback control loop to maintain the desired pressure level.

Compartmentation

There are buildings in which people cannot move or evacuate as normal people do, e.g., in hospitals, homes for the aged, and low-cost high-rise buildings for the elderly. In these cases, it is necessary not only to contain smoke propagation by vertical pressurization but also to create safe compartments within the floor. In such cases, it is necessary to measure not only the level of smoke but also whether the pressure level is maintained. This information is essentially so the fire marshal can set priorities and determine whether to fight the fire or evacuate.

RECENT DEVELOPMENTS IN FIRE MANAGEMENT AND SMOKE CONTROL SYSTEMS

A considerable amount of energy was invested in understanding smoke movement in buildings. Many theoretical studies and experiments were conducted to verify that design concepts and guidelines provided the necessary functionality. Fire management and control system technology did not change very much until recently. Microelectronic technology has finally caught up with the industry and presently many activities have taken place.

Figure 2 illustrates the traditional system architecture for fire management and smoke control. There are four basic elements in the system: sensoring, an intelligent fire management panel (IFMP), central processors and an operator interface station, and integration with the HVAC system.

Sensoring

In the past, designers debated the role and preferability of the various types of sensors (ionization, photoelectric, etc.). Also, there was an argument as to what was better—sprinklers or smoke control systems. Now we understand that each of these has its application and functionality and, at times, it is necessary to use multiple sensor technologies to accomplish the necessary protection of life and property.

Until recently, the three space input devices in FM&SC systems were:

smoke detectors (ionization or photoelectric),
heat sensors, and
pull stations.

The sensing technology of smoke sensors has not changed much in the past few years. However, the information provided by these sensors to the fire management panel changed drastically. In the past, a zone had a twisted pair wire loop and many smoke detectors were connected to this loop. An alarm at a given location was identified by the zone (many thousands of square feet in area) and maybe included multiple floors.

The change to date is in two major areas:

—addressing of individual sensors, and
—time-dependent information regarding smoke build-up.

These two changes are very important, since they provide the geographical location of the sensor and can help to dispatch a firefighter to the specific area without searching for the location. The time-dependent information on the increase in the level of obscuration in the area provides the rate of smoke generation. This information can be used for a pre-alert level in which a person can be dispatched for verification. The information also can be used to determine whether a sensor drifts and different sensitivity levels should be assigned. Additionally, there is basic information to determine whether an individual sensor is in good operating condition. With present sensors, performance is determined only when there is a fire or when smoke is introduced to the area. This may happen once a year or maybe never. The new sensor is monitored every few seconds and a "health check" is done every scan cycle.

A heat sensor traditionally is associated with water sprinklers. The water sprinkler is heat sensitive and activated only when the temperature in the space is above a given level, say, 135°F. However, this sensing element is an on/off device and does not provide any intermediate information. Assume that a fire has started on the 5th floor and smoke is detected on the 31st floor. With the supplemental information of heat (temperature) sensors, it is possible to determine whether the 31st floor or the 5th floor is the fire floor. Without this information, firefighters may go to the wrong floor. Therefore, analog-type heat (temperature) detectors with communication to FM&SCS provides an important improvement.

A pull station in the past had the same status as a zone smoke detector. The indication was an alarm in the zone. With the new systems, the pull station has an address and the actual location is known. It may happen that a person sees smoke and panics, runs down a few flights of stairs and remembers that he or she did not use a pull station to notify the operator. The information on the location of the pull station and analog information from the smoke and heat detectors helps to dispatch people to the proper place and get a better understanding of evolving conditions while fighting the fire.

Intelligent Fire Management Panel (IFMP)

The introduction of microprocessors in building control systems occurred in 1975. Since then the explosion of microelectronic technology has put microprocessors in almost every device. The control industry has capitalized on this technology and introduced distributed processing. The distribution of processing power brought intelligence to subsystems that in the past used only hardware technology. A local processor provides the following functionality:

—reduces system complexity
—increases functionality
—reduces product cost
—increases reliability
—simplifies system configuration
—provides on-site reconfiguration.

A microprocessor-based system provides the opportunity to do all the control logic and sequencing in software. What in the recent past required many electronic boards—and many panels—can now be done with software. The dramatic reduction in memory cost makes the systems very cost effective. The number of components decreased by an order of magnitude that makes the systems much more reliable, and panel size decreased by more than 60%. Electrically erasable programmable memory makes the system nonvolatile (memory is not lost in case of power failure). Most components are made from CMOS technology, which requires low power; hence, it reduces the size of the power supply and the backup batteries or provides a longer time of operation during a power failure. All these factors reduce product cost dramatically and increase functionality, at times at no added cost.

On-site programmability provides much higher system availability (combination of mean time between failure and mean time to repair). The EPROM (erasable programmable memory) in the past—and recently in some systems—hindered the repair process since it had to be shipped hundreds of miles away at times and the process of change and rewrite took days. Now all additions and modifications can be done on-site with the properly trained and authorized personnel.

Functionality increased and systems are much more flexible. Systems offer features such as "alarm verification." In case of alarm, the panel resets the zone to verify whether the alarm reappears. If it does, it is a true alarm; if not, it was a false alarm. With analog sensors, multiple alarm levels can be set. Alarms can be handled differently as a function of the sensor location (cafeteria, office, laboratory). At times, different levels of the alarm can be set for day and nighttime operation.

Control Processors and Operator Interface

The explosion in personal computer (PC) technology in the last few years has had an impact on the availability of sophisticated hardware and software. Many companies offer compatible PCs. Many third parties offer a variety of interface boards for communication, graphics, and peripheral interface. Color graphic monitors became an industry standard and software packages are available for database management and graphics generation. All these

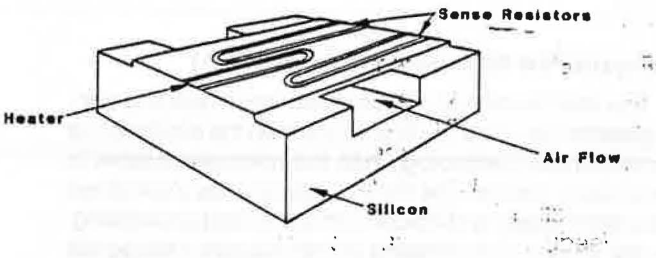

Figure 3 *Conceptual view of microbridge sensor*

developments helped dramatically in reducing the time needed to develop the necessary operator interface function for fire management and smoke control systems. Graphics showing floor layout, building elevation, and smoke intensity and movement help greatly during the firefighting process. The opportunities are there; their exploitation depends solely on the life-system designer.

The reliability of a PC is high. Some PCs are UL-approved as devices for life-safety systems, which provides the opportunity to integrate the HVAC and fire function in the same PC (Figure 2).

Integration with HVAC Control System

With the power presently available in personal computers and with distributed processing architecture, it is much easier to integrate a fire management system with an HVAC control system. During a fire, smoke dampers and the HVAC equipment perform smoke containment. The HVAC control system is continuously in operation and the building operator is continuously updated on the wellness of the system. The fan system starts and stops daily and the dampers open and close daily. The electronic VAV box controller continuously measures airflow to the space and so do the supply and return fan systems.

In the present mode of operation, the smoke damper is activated only during a fire. There is no feedback as to whether it works. McCabe (1984) identifies the opportunities for multifunction dampers. It is worthwhile to use a damper on a daily basis, say, for the first-level flow balancing for floors and zones. Thus, the damper will be in continuous operation. It will provide better flow distribution as well as act as a smoke damper during a fire and, through airflow measurement, the operator will get the necessary feedback.

The reliability of HVAC control has increased and direct digital control (DDC) is being applied throughout the industry. Therefore, a lot of the functions presently done by home-run wiring from the fire panel to override HVAC control can be done by the HVAC control itself. This reduces the cost of installation considerably (Figure 2).

An HVAC control system also can provide the necessary feedback to determine if the pressurization level is achieved. It can control airflow to achieve the proper level of pressure in the dynamic conditions that exist during a fire. Additionally, space temperature sensors can be used as thermal sensors complementing the smoke detectors.

Very often it is said that pressure sensors are costly and those that are not costly drift and require periodic calibration. The explosion in microelectronic technology has had a great impact on the development of micro-

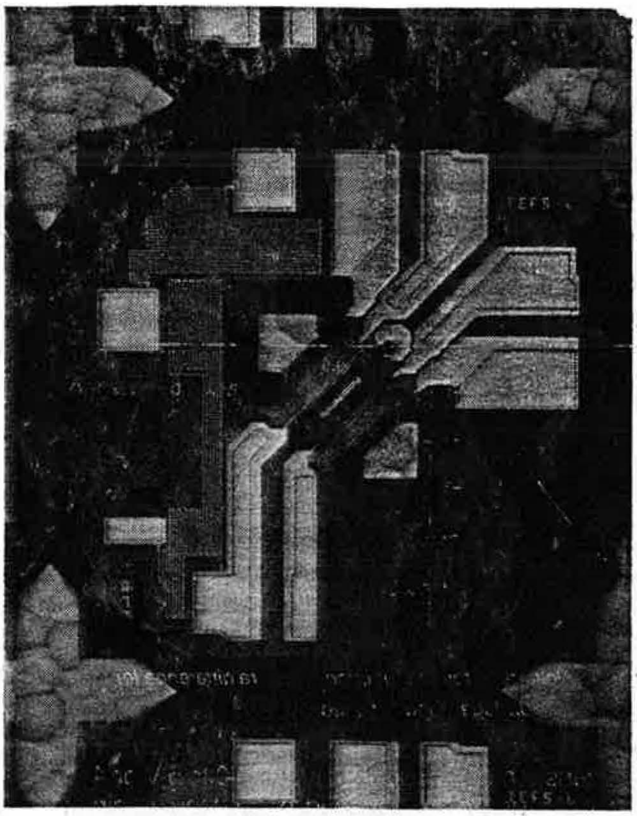

Figure 4

electronic-based sensors. These sensors are emerging in all areas applicable to building control: temperature, humidity, pressure, vibration, acoustics, and velocity. Of particular interest is the velocity sensor.

Pressure Sensor

Shavit (1983) identified three types of pressure sensors that can be used for monitoring and getting feedback on whether a system operates properly: pneumatic-differential pressure and velocity sensors, electromechanical transducers, and piezoelectric transducers. The evolution in microelectronic sensors has recently provided a new sensor to measure pressure difference and identify the area of higher pressure. The sensor is based on microstructure on a silicon-based microelectronic device.

The microbridge velocity sensor works similar to the hot-wire anemometer (Figure 3). The device contains three microstructure beams over a channel. The middle beam is heated. As the airflow passes over and under the beams, the air is heated. This results in a change of resistance of the downstream beam (Figure 4). Thus the change in resistance is proportional to the velocity and it identifies airflow direction. The sensor is integrated with an assembly and 1/4-in tube. The sensor is placed on the wall separating the zone of a desired high and low pressure.

The 1/4-in tube connects the two chambers. As the pressure on one side increases, air flows through the tube and is detected by the sensor. The velocity is proportional to the pressure difference. Figure 5 shows the sensor calibration curve.

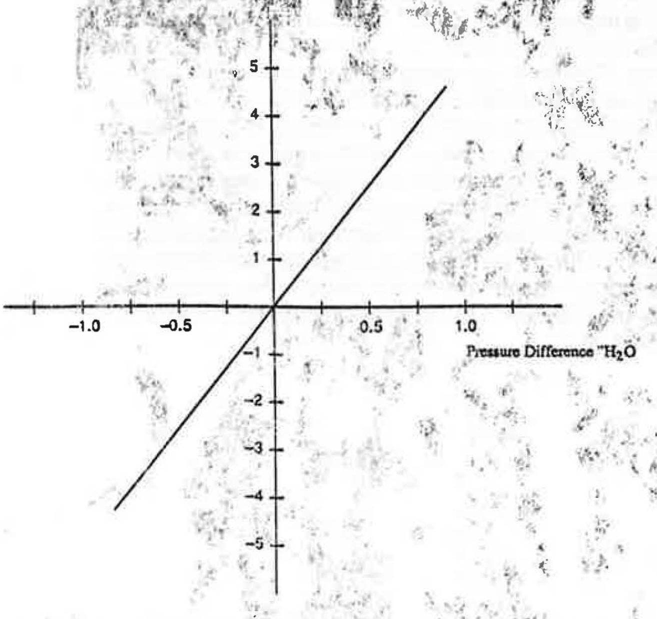

Figure 5 *Voltage output as function pressure difference for the microbridge velocity sensor*

The sensor has a standard output of 0 to 5 V or 4 to 20 MA such that it can be interfaced to any standard direct digital control panel. The resolution and accuracy are very good for measuring pressure differences in the range of 0 to 1.0 in H2O. Microelectronic implementation makes it an accurate, reliable, and cost-effective sensor.

SUMMARY

The recent evolution in the research of smoke immigration in buildings and the technology of fire management and smoke control systems opens the door for another step change in system approach to life safety in buildings. The opportunities are:

1. Provide an information-based system so that the operator and the fire marshal will be able to act intelligently during a fire situation.
2. Provide a distinction between an alarm based on smoke migration and one based on the source of the fire.
3. Provide identification of the actual geographical location of the point of alarm.
4. Provide dynamic response to changing conditions during the pressurization and evacuation process.
5. Provide pressure level feedback during the pressurization process.
6. Provide continuous feedback on the status of the various devices that are part of the fire control systems during normal operation.
7. Minimize (eliminate) false alarms.
8. Provide a system with higher reliability.
9. Provide a cost-effective integrated control system.

There was a trend in the early 1980s to keep fire management and smoke control simple. It was justified as long as these systems could not provide needed information. However, since then, analysis, experiments, and tests have provided a better understanding of smoke movement in buildings. At the same time, system integration, HVAC, and fire management and smoke control were evolving (NFPA 1988). Control system architecture improved and reliability increased. It was established that:

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DISCUSSION

M.E. Dillon, Robert M. Young & Associates, Pasadena, CA: Should not caution be used in instrumenting a building in order to avoid "information overload"? After all, a fire emergency is not a time for scientific data gathering. Is there not a very practical limit to the amount of useful information a person can digest and act upon under stress?

G. Shavit: The limited information available in systems of the recent past caused the problems the industry faced. For example, the fire marshal from Austin, Texas, mentioned that in 1987 he had 770 alarms in Austin and only 10 of them were true alarms. Additionally, the system technology has changed considerably and the processors have more power and greater speed to process the information. Last but not least, the emerging and future systems do not send all the information all over the place. The distributed processing technology allows the processing of information locally and reporting by exception, i.e., only what is required to be sent.

Dillon: How can the omnipresent hysteresis in any control sequence be overcome? By the time the damper has begun to stroke, the cause has changed and conditions have varied again. It takes far less than 20 seconds to open and close doors.

Shavit: The process of evacuation is not limited to one-person leaving the floor; hence, door opening and closing by one person evacuating is the exception. Additionally, now we see flooding of the market with effective microcontrollers of small cost. A single controller can have one pressure input and one actuator output. The controller function is only to control the amount of airflow as a function of pressure difference. A high gain amplifier with a pneumatic actuator can provide a response in a few seconds less than five. A high-speed electric actuator can be as cost-effective. The sensor technology that was introduced in this paper is such that it responds to pressure changes in a few milliseconds. The technology is here and we need to make use of it.

Dillon: How do you "fire harden" such a system, that is, protect *all* portions—wiring, power, and components—from the effects of fire, water, and smoke throughout the whole of the building?

Shavit: The function of smoke control in buildings is to minimize the smoke migration in buildings. Once fire and water overcome the area in question, then none of the control systems are operative. Therefore, the design is such that smoke and fire dampers stay shut under all conditions. Additionally, if there is a breakdown locally on a given floor, the information-based fire and smoke control system can adjust and move the protective boundaries on one or two floors above and below the area of concern. The technology of today can support "fire-hardened" systems. Also, installation of the wiring and controller in the proper places will help to prolong their operation. The purpose of smoke control is to contain the smoke for the longest time possible. The systems are intended to be operative in an environment that is consumed by fire.