FIRE PROTECTION & SMOKE CONTROL

#6109

SMOKE CONTROL in BUILDINGS...

THREAT or PROMISE?

The objectives of a smoke control system are to limit the spread of smoke throughout the building so that occupants can reach safety before a fire is extinguished or to permit them to remain safely in the building until the fire is put out if they cannot completely evacuate the building. Means of achieving the objectives are discussed, viewing the smoke control system as a subsystem of the life safety and property protection systems. This paper was presented at a Symposium on Control of Smoke and Fire at ASHRAE's 1975 Annual Meeting in Boston.

WILLIAM A. WEBB

BEFORE a smoke control system, a fire safety system, or the building itself can be designed, the goals or objectives for the systems must be established. While this may appear to be quite obvious, it is often overlooked in fire safety system design.

For any building, it is recognized that sufficient safety must be provided in the building design to permit occupants to reach a place of safety from a fire within a reasonable length of time. A secondary objective, which is often overlooked in building design is to provide fire department access to the fire to effect extinguishment.

Designers are charged with providing personnel safety and setting certain minimum goals in this regard. Fire safety systems will be dictated by the building design. For example, if complete evacuation can be achieved in a reasonable time, fire safety and smoke control systems can be rather simple to achieve personnel safety. There will also be property protection goals imposed by the client which may set a higher level of safety for the occupants even though they are able to evacuate the building.

Where evacuation in a reasonable length of time cannot be accomplished, occupants must be able to reach an area of safety within the building. They must be able to stay there for the duration of the fire. Under these circumstances, a higher level of fire safety and smoke control will be needed. The General Services Administration has established 6½ minutes as the upper limit of evacuation time for downward travel. Other jurisdictions have established the need for smoke control on the basis of fire department access from the exterior using fire department aerial ladder equipment. We can conclude therefore, that the objectives of smoke and fire control systems, are to limit smoke and fire spread until occupants can reach a place of safety and until the fire department can gain access to the fire to extinguish it.

SMOKE CONTROL MEASURES

Generally, an effective, low-cost, reliable means of achieving smoke control is through use of complete automatic sprinkler protection. The fire is kept small, or at least manageable, by automatic sprinklers, thereby limiting the smoke generated.

Recent changes in the National Fire Protection Association's Standard for the Installation of Automatic Sprinklers, NFPA No. 13, have permitted reductions in sprinkler system costs

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through combined sprinkler and standpipe risers, reduced piping sizes for hydraulically designed systems, and extended area coverage for individual sprinkler heads.

The trend in high-rise fire safety is toward complete automatic sprinkler protection. The tallest building in the world, The Sears Tower in Chicago, is fully sprinklered. Water Tower Place, a 70-story megastructure under construction, also in Chicago, will be protected by sprinklers, even though it is a reinforced concrete building. The General Services Administration has recently issued a directive requiring GSA buildings over 5 stories in height or buildings having open plan office space greater than 1,000 sq. ft. in area, to be fully sprinklered.

While the trend in new building design may be toward automatic sprinkler protection, it will be quite some time before all new buildings are planned to be sprinklered, if this is ever achieved. Consequently, we must consider other means of achieving smoke control in buildings. Methods often used are discussed below.

BUILDING PRESSURIZATION

The pressurized building method of controlling smoke on high-rise buildings has been described in an article of the same name by G. T. Tamura and J. H. McGuire published as technical paper no. 394 of the National Research Council of Canada. Simply described, the method consists of exhausting the fire floor while pressurizing surrounding floors. Often this is accomplished by operating automatic dampers in the building ventilation system. Return dampers on the fire floor remain open and all other return dampers in the system close. Supply dampers to the fire floor will close and all other supply dampers will remain open. Under this system, some auxiliary means may be needed to keep egress routes free of smoke. Tamura and McGuire suggest an air injection rate of 300 cfm for each typical stair door into the stair shaft.

Instead of using the return as an exhaust, the fire floor could be directly vented through automatic dampers, or a smoke shaft could be utilized. Of the three alternatives, direct venting is considered to be the most reliable. While this system would appear to be effective, it has not been tested under real fire conditions. It is a sophisticated system requiring reliance on a great deal of hardware. It offers the advantage of utilizing the building HVAC system which tends to reduce costs. It also, to a certain extent, becomes a self-supervising system.

NATURAL VENTING

Natural venting to control smoke movement in buildings via vertical shafts, is described in paper no. 510 of the same name by G. T. Tamura and A. G. Wilson of the National Research Council of Canada (ASHRAE Transactions, Volume 76, Part 2, 1970). Simply described, the method utilizes smoke shafts to exhaust smoke from a building. Elevator and stairwell shafts are vented to the outside at the top or bottom. Top venting increases the number of stories from which air flows into the shaft and decreases the number of stories into which air flows from the shaft. Bottom venting has the opposite effect. This method does present a satisfactory arrangement under cold weather conditions. During summer, a reversal of the normal stack effect could occur and permit smoke to exhaust through the bottom vented shaft. If this were the stairwell, occupants would be exposed to smoke as they moved down through the stairway and as they were trying to discharge from the stairwell. Another problem can occur in the pressure difference at the bottom of bottom-vented shafts during winter conditions. The force in a tall building could be excessive for the stairwell door at the base of the shaft.

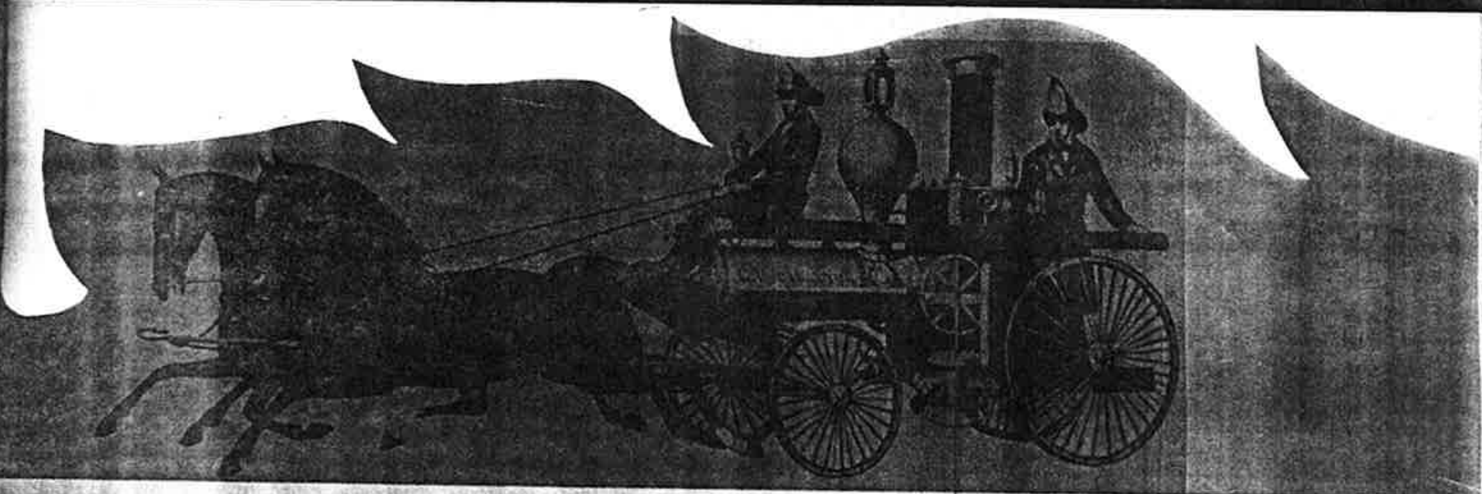
Another means of natural venting which has proved to be effective, is to provide a smoke vestibule at each stair with direct access to the outside. The most reliable means to achieve the ventilation is to have an open air balcony. Where weather conditions prohibit such an arrangement, automatically operated dampers on the exterior wall can be utilized.

STAIR PRESSURIZATION

The method of smoke control which has received the most attention and which has been subject to most testing is stairway pressurization. While this method appears to provide a simple and effective means of maintaining egress paths free of smoke, there is controversy on specific arrangements. The controversy is centered around the location for injection of air into the stair shaft, that is:

- Top pressurization;
- Bottom pressurization;
- Pressurization of the stair shaft with a pressurized vestibule;
- Pressurization of multiple levels.

A top pressurization stairwell system is described in a report by Francis C. W. Fung entitled, "Evaluation of a Pressurized Stairwell Smoke Control System for a 12-Story Apartment Building." Air is injected in the shaft at the top with additional allowances added for each door opening into the stair: 100 cfm for each door having a perimeter of not more than 20 ft. that is equipped with a tight fitting weather stripping or 200 cfm for every other door having a perimeter of not more than 20 ft. into the stair shaft. Each stair shaft has a vent at street level opening either directly outside or into a vestibule or corridor that has a similar opening to the outside having an opening of not less than .5 sq ft for every door that opens into the stair shaft other than doors at the street level, but in no case less than



20 sq ft.

The system was evaluated through smoke movement tests utilizing sulphur hexaflouride (SF-6) trace gas. Further evaluations were performed utilizing computer simulation techniques.

While the tests and computer simulation demonstrated that the stairwell would remain free of smoke, the high noise level of the large, high velocity pressurization unit required to achieve pressurization could be objectionable. It was also determined that the force to open stairwell doors under stairway pressurization could be excessive, and a design specification would be required to limit the maximum force needed to open the pressurized stairwell doors.

Bottom ventilation of stairs was advocated in a report of fire tests, analyses, and evaluation of stair pressurization and exhaust in high rise office buildings prepared by the Polytechnic Institute of Brooklyn's Center for Urban Environmental Studies. The report concluded that the direction of air flow in the stairs should be upward at all levels. This will prevent any initial smoke and gases which may have entered the stair from traveling downward. The roof terminus for the exhausted smoke and gases is also considered to be preferable to the street (lobby) level (with downward flow) where fire fighters will be entering and occupants leaving. It was learned that with more than 3 doors open into the stair shaft, the stair pressurization was defeated. In addition, the same problems with the force to open the door as encountered with top pressurization can occur with bottom pressurization.

Bottom pressurization with the vestibule pressurized were reported in an article entitled "Fire Spread and Smoke Control of High Rise Fires" by Zinn, Bankston, Cassanova, Powell, and Koplon in the February 1974 issue of *Fire Technology*. The article reports on fire tests conducted at the Henry Grady Hotel in Atlanta. The report concluded that stairwell pressurization at a maximum of .15 in. of water column combined with vestibule pressurization prevented smoke movement from the fire area to the stairwell with the stairwell doors closed. In addition, the open door flow rate used by stairwell and vestibule supply fans prevented the movement of smoke into the stairwell when the vestibule and stairwell doors were held open to the fire area for several minutes. No more than three doors were opened into the stairwell at a time. The effectiveness of the system is in doubt if additional doors were open.

The report also stated that stairwell door measurements show that the pressure losses are large when a single fan pressurizes a vertical shaft in a multi-story building. **"Such an arrangement requires unacceptably high pressures near the supply fan in order to maintain necessary minimum pressures at the opposite end of the shaft. The use of several smaller fans is a possible alternative to the single fan approach. A multifan system will require the determination of the number, size, and location of fans for optimum pressurization conditions. The multifan scheme would also probably reduce the shaft region affected by large pressure tops to open doors."**

EFFECT OF DESIGN

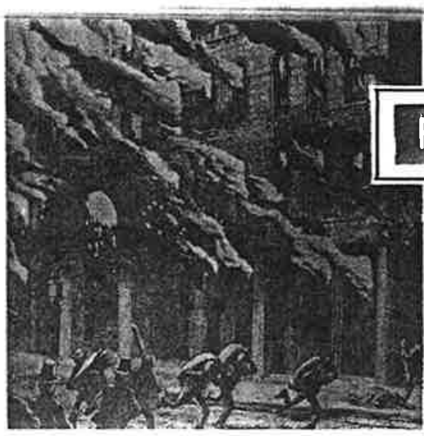
While by now it should be clear that there is no single answer to smoke control in buildings, we can conclude that certain types of buildings need our best efforts at a smoke control system and are more amenable to one arrangement than another. Office buildings should be provided with a means of smoke control. They are characterized by a high population, with large open areas and significant combustible loading. They will also usually have a central ventilating system so building pressurization will often be an economical arrangement for achieving smoke control. For residential buildings, the need for smoke control is less than for office buildings. They are characterized by relatively small compartments and generally have no central HVAC system. Smoke control could perhaps be achieved by other means such as detecting a fire early by the use of smoke detectors in the living spaces and confining the fire to the area of origin by construction and apartment door closers. Natural venting or stair pressurization would be used to maintain the vertical shafts clear of smoke if this were deemed necessary.

Low-rise shopping plazas would generally rely on automatic sprinkler protection and gravity venting for smoke control. The sprinklers would usually be required for property protection in any case. High rise shopping plazas would utilize automatic sprinklers and one of the other means of smoke control.

Atrium-type buildings should have automatic sprinkler protection and could utilize a natural venting technique. High-rise atrium-type hotels could utilize the building pressurization technique. During a fire in a room, the atrium space would serve as a supply with the rooms being exhausted with their supply stopped.

CONCLUSIONS

It can be concluded that further test work under actual fire conditions is needed to clearly establish the efficacy of most of the smoke control systems proposed. Automatic sprinkler protection does appear to afford an effective smoke control means for most commercial and residential high rise buildings. Directly vented stairs or floors also provide effective means of maintaining egress routes free of smoke. □□



FIRE PROTECTION & SMOKE CONTROL

DETECTORS: First Line of Defense

Every year destructive fires take a huge toll in lives, injuries and property losses here in America: 12,000 deaths, more than 300,000 serious burn injuries, and property loss exceeding $3 billion. Obviously, fire is a great problem. But we can do something about it.

H. LEIN

COMMON sense suggests that the sooner the proper authorities can be alerted to the presence of fire, the better the chances are that real and tangible losses, both in lives and dollars, can be considerably reduced. Fire officials are unanimous in their appeal for a system of fire detection that will give an alarm in the earliest stages of combustion. Many times there are only a few minutes between the beginning of combustion and the development of a truly destructive fire. Given these few minutes of grace, occupants may be safely moved to an area of refuge, portable equipment may be used to extinguish or control the fire, sometimes before firemen arrive.

This process of being alerted to a fire involves the human response factor with assistance from a wide variety of automatic fire detecting devices. The most common ones are activated by heat, smoke or flame.

THE FOUR STAGES OF FIRE

Fire is a chemical combustion process created by the combination of fuel, oxygen and heat. Fire development relative to detection may be considered to progress through four distinct stages:

- **Incipient stage.** No visible smoke, flame or significant heat is developed. However, a condition exists which generates a significant amount of combustion particles. These particles, created by chemical decomposition, have weight and mass but are too small to be visible to the human eye. They behave according to gas laws and quickly rise. This stage usually develops over an extended period . . . minutes, hours, sometimes even days.
- **Smoldering stage.** As the fire condition develops, the quantity of combustion particles increases to the point where their collective mass becomes visible. This we refer to as "smoke." There is still no flame or significant heat.
- **Flame stage.** As the fire condition develops further, the point of ignition occurs. Infrared energy is now given off by the flames. The level of visible smoke usually decreases and more heat is developed.
- **Heat stage.** At this point large amounts of heat, flame, smoke and toxic gases are produced. The transition from third to fourth stage is rapid, usually seconds.

DETECTION EQUIPMENT

There are many types of fire detectors, suitable for various situations, and particularly useful at various stages of a fire. Most manufacturers and distributors offer several or all of the commonly used types, and will engineer a "mixture" of equipment into a coordinated system to best meet the particular set of performance parameters under consideration.

THERMAL DETECTORS

- **Fixed temperature detectors** detect the heat of a fire (fourth stage). They are based on a bimetallic element, made of two metals which have different coefficients of expansion. When heated, the element will bend to close a circuit, initiating the alarm. Or a thermal detector may use a fusible, spring-loaded element which melts at a certain temperature, releasing the arm to close the circuit.

This is a simple device, inexpensive, and requiring a very low voltage draw to keep the normally open contacts supervised through an end-of-line resistor. The simplest form, mechanically, is set to go off at a given temperature.

- **Rate compensation thermal detectors** work by the expansion characteristics of the contact arm within a hollow shell. When heated, the shell expands and stretches, compressing interior struts. At the same time, the bimetallic element tends to hold the struts open. On a rapid heat rise the shell stretches faster than the element can compensate, thereby closing the contact. As this detector responds to a differential, it will trigger an alarm on detecting rapid heat rise from any temperature, and so it tends to operate faster.
- **Rate-of-rise thermal detectors** use an enclosed vented hemispherical chamber containing air at atmospheric pressure, with a small pressure-sensitive diaphragm at top. At normal rise in temperature the excess pressure is vented, but rapid heat rise will deflect the diaphragm faster than the small vents can operate, triggering an alarm. This unit responds quickly to a fast heat rise, perhaps 15 to 20 degrees per minute.

Thermal detectors are reliable for what they do. However, they can only detect the heat of a fire, which usually will not build up to significant levels until the fourth stage. Many fires start slowly, with little heat generated at the beginning, and will be well under way by the time a thermal detector comes into operation. Where the building is fully sprinklered, a thermal device may operate in time — most sprinklers are, in fact, set off by their own built-in thermal detectors. But thermal detectors are not designed to provide the invaluable lead time needed to get the jump on a fire.

Flame Detection

- A **Flame** fire detector senses light from flames. Sometimes it works at the ultraviolet, but more often at the infrared end of the visible spectrum. To avoid false alarms from ambient light sources, it is set to detect the typical flicker of a flame, perhaps at 5 to 30

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cps. Or, there may be a few-second delay before alarm to eliminate false alarms from transient flickering light sources, such as flashlights, headlights, shimmering water, etc.

Smoke Detection

Photoelectric detectors are designed to detect smoke — the second phase of the fire.

• **The beam type photoelectric detector** works on the obscuration principle. A long beam is directed at a photocell. Rising smoke tends to obscure the beam, decreasing light transmission and sounding an alarm. This method is an inexpensive way to cover large spaces, such as a warehouse (at knee level, the same system can be used to detect intruders). It is, however, sensitive to voltage variations, dirt on light or lens, and also to flying insects or spiders which sometimes accumulate, seeking the light or a warm berth in cold weather.

• **"Tyndall effect" photoelectric detectors** use a beam of light in a chamber, with a photocell normally in darkness. Should visible smoke particles enter the chamber, they scatter the light and reflect it onto the cell, causing a change in electric conductivity which results in an alarm.

Photoelectric detectors are line powered and usually include lamp supervision circuitry and annunciation in case of lamp failure. An incandescent light source may be used, or a high-intensity strobe lamp which generates a stronger reflection, so that fewer or smaller smoke particles will actuate the photocell.

Some specialized applications of photoelectric detectors use a fixed piping system and an electric driven air pump which continuously draws air samples through the piping system to a detector cabinet containing a photoelectric analysing chamber. Through the operation of a mechanical valving arrangement, each air sample is sequentially analyzed for smoke content.

Combustion Detectors

• **The ionization detector** senses the invisible products of combustion which are suspended in air. It consists of a chamber with positive and negative plates and a minute amount of radioactive material which ionizes the air within the chamber. The potential between the two plates causes the ions to move across the chamber, setting up a small but measurable current. When aerosols from incipient fires enter the chamber, they cling to masses of moving ions, slowing them and increasing the voltage necessary for them to make contact. This imbalance, amplified by electric circuitry, triggers an alarm.

• **The single-chamber ionization detector** is most economical. The chamber is open to atmosphere; current flow between two poles is measured, and combustion aerosols increase required voltage, closing the contact and sending an alarm through the relay.

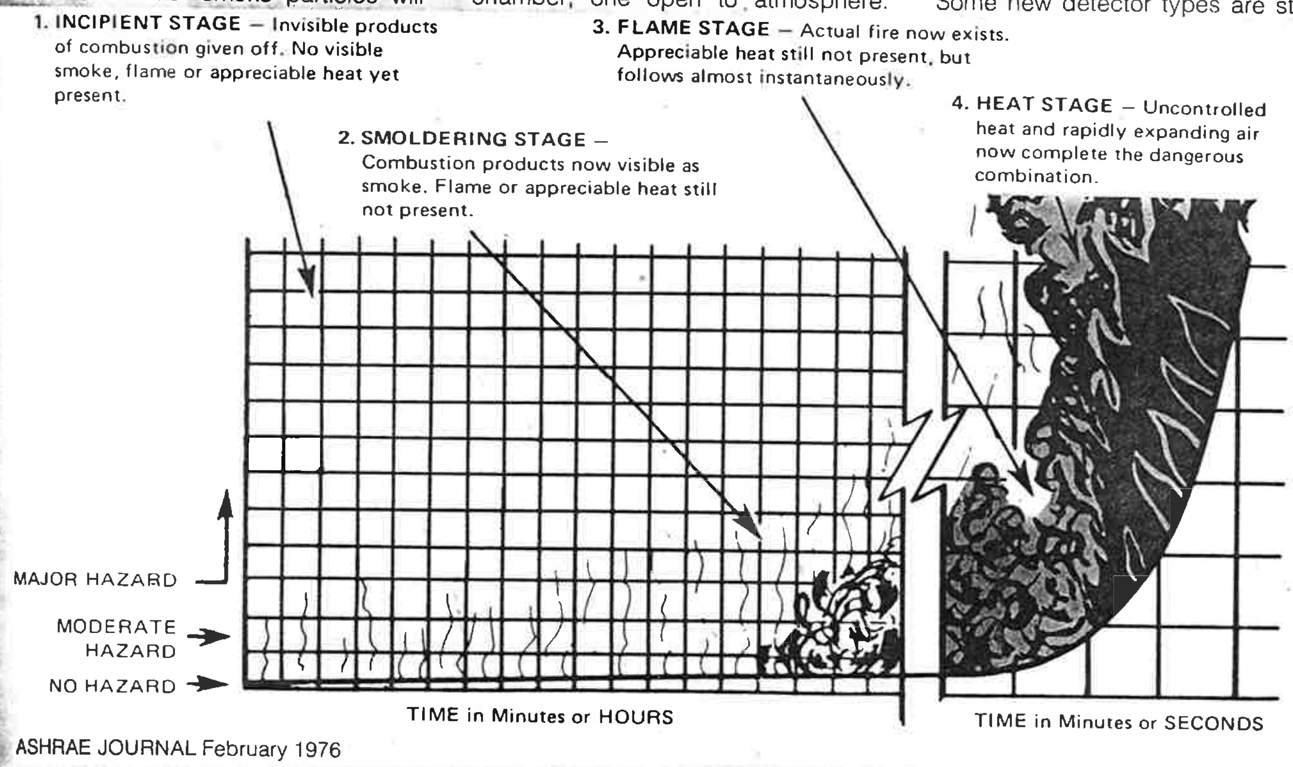
• **The dual-chamber ionization detector** has two identical sources of radiation, one in an essentially sealed chamber, one open to atmosphere. The inner ionization chamber monitors ambient conditions and compensates for the effect on the ionization rate of barometric pressure, temperature and relative humidity. This construction therefore accepts a much wider range of pressure, temperature and humidity without giving false alarms.

• **The low-voltage ionization detector** is relatively new. While the conventional type needs 220 v, a low-voltage detector needs only 24 v. Theoretically, an installation would cost less, because low-energy non-armored cable is cheaper and easier to install, with essentially no danger of short-circuit or shock. Most large cities, however, require armored conduit for low-voltage detectors, so cost savings may be less than expected. Nevertheless, most systems specified today are low-voltage, as the low-profile detector heads are less obtrusive, while equally sensitive and reliable.

Ionization detectors sense fire at the earliest practical detection stage. They are the best method for detecting slow, incipient fires in commercial occupancies: A cigarette in a wastepaper basket, for example, which might be in a pre-smoldering condition for 30 minutes or more. A further advantage: The ionization detector operates in the failsafe mode. In case of doubt, for example, if excess dust should enter, the device will give the alarm. They also tend to receive more maintenance than less sensitive detectors to avoid excessive unwarranted alarms.

Other New Detectors

Some new detector types are still ex-



perimental or under development. The *Wilson cloud chamber detection device* so far requires elaborate "plumbing" and hardware, and is overly sensitive. While a number of pilot installations have been made, this device is not generally accepted as a standard piece of fire detection hardware.

A sophisticated *laser beam detector,* measuring differences in index of refraction of combustion gases vs. air, can detect heat and smoke simultaneously, but promises to be expensive. The *Taguchi gas sensor,* operating from gases driven off by fires, might be low-cost but is not fully tested long-term, and has the problem of responding to gases with no connection to combustion.

With the four basic detector types, we have the tools to do an excellent job on most applications. Each general type has a specific part to play in the total detection picture.

SYSTEM DESIGN

Since a fire resistant structure can be expected to withstand the ravages of fire for a longer period of time than a structure constructed of combustible materials, it follows that early warning is of greater importance in the latter structure. Unless forces are brought to bear on the fire, the building will be quickly engulfed, making the task of the fire fighters most difficult, if not impossible. This point should be kept in mind by the system designer, and consideration given to covering combustible buildings with a heavier concentration of detectors than would normally be used. This, coupled with a tie-in to the local fire department or central station, will go a long way in minimizing building damage.

To determine the number of detectors required for a given area, consideration must be given to a number of factors. In general, the more detectors installed, the greater the protection provided. If the number of detectors in a given area were doubled, the distance and the time combustion products would have to travel from the furthest point in the room to a detector would be proportionately reduced.

The area coverage of an ionization type detector, for example, depends upon total area, building construction, area contents, air movement, value of building and contents, ceiling obstructions, cost of equipment downtime due to fire.

There is a temptation to try to protect many thousands of square feet of building space by placing smoke detectors in the air handling system. Since the products of combustion become diluted by air in their travel toward the detectors in the air handling system, it follows that in order to detect smoke with the detectors located in the vicinity of the fan, a very heavy smoke concentration must exist in the occupied area of the building. The air duct detector is designed to detect heavy volumes of smoke in the ventilating system, and to shut down the fans to prevent recirculation of smoke throughout the building. This being the case, it cannot be used as an early warning device to protect the various occupied areas of the building.

There are four basic reasons which prevent smoke detectors located in the ventilating system from being used as a complete fire detection system:

1) When the public utility power fails, the air handling system is out of service. With no forced air movement in the duct there would not be an operable fire detection system.

2) The installation of one or two air duct detectors cannot be expected to do the work of 10 to 20 ceiling mounted detectors in the occupied spaces. An air duct detector located in the return air of a fan whose capacity is 1200 to 2000 cfm would be monitoring an area of 1,000 sq ft to as much as 200,000 sq ft. Obviously, under these conditions early warning cannot be expected.

3) Air handling systems may be programmed to shut down during certain periods of the day, typically at night when the building is virtually unoccupied. When the fans are off the air duct detectors would be inoperative.

4) If the filters in the air handling system become clogged through the accumulation of dust and dirt, air volume may be reduced causing a reduction in the operating effectiveness of the smoke detection system.

In many ventilating systems, the return air is directed into a return air plenum on each floor of the building, before entering the return air shafts. These plenums are usually located in the concealed space above the ceiling. Since these are concealed air handling spaces through which fire can be rapidly propagated, it is recommended that detectors at approximately 500 sq ft spacing be used in such areas.

MAINTENANCE

Every fire protection system needs periodic maintenance! It cannot be overemphasized that any fire protection system must be installed, regularly inspected, and periodically tested by a knowledgeable, responsible person. Without periodic inspection and testing of each and every component, no system can be considered reliable!

It is often recommended that this work be done on a contract basis by an organization whose specialty is installing and servicing the type of equipment selected. It is, however, possible for user personnel to become relatively expert at routine inspection procedures. They should begin, of course, by attending a service school, such as the classes offered by many manufacturers of fire detection systems.

The proper functioning of the system should be checked at regular intervals. This can be done by applying heat to a thermal detector or introducing smoke directly into a smoke or ionization detector. A spot check of one or two detectors each month can be made part of a regular fire prevention inspection. Different detectors should be actuated each time, so that in the course of a year all components of the system will have been tested.

Every six months, each detector head screen in the system should be inspected for dust accumulation and cleaned if necessary. (This recommendation is average. In a very dusty location, such as a textile mill, much more frequent cleaning may be necessary.) Then a detector should be activated and control unit indications checked; supervisory circuits are checked via the "reset" switch.

On a yearly basis, each detector on the circuit should be checked for operation and sensitivity; alarm relay contacts should be checked for proper operation.

CONCLUSION

No longer is it necessary to record the loss of 12,000 Americans yearly and serious burn injuries exceeding 300,000. No longer must we sustain property losses in excess of $3 billion. Technological advances, growing awareness on the part of regulating authorities, and the increasingly complex specifications of building owners have resulted in the development of highly sophisticated fire protection signaling systems. These systems, by providing an essential safeguarding function for both occupants and owners, are vital to the safety and efficient operation of any building. □□