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by

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PREVENTION DE LA PROPAGATION DES INCENDIES DANS LES INSTALLATIONS DE VENTILATION

SOMMAIRE

L'évolution des méthodes de construction, l'utilisation de nouveaux matériaux et l'érection de plus en plus fréquente d'édifices-tours, renforcent la nécessité de la prévention des incendies. L'examen critique du rôle fondamental des cloisons ignifuges comme barrières contre la propagation de feu, souligne l'importance des nombreuses trouées pratiquées dans ces cloisons pour y faire passer les conduits et y installer des bouches et des grilles, et la nécessité de parer au danger qu'elles présentent. L'emploi de volets pare-feu tels que décrits par la norme 90A du NFPA est habituellement exigée, mais il reste fort à faire pour mettre au point des critères améliorés, de meilleures méthodes d'essai et une plus grande variété de dispositifs adéquats. Pour mieux comprendre les problèmes relatifs aux incendies, il est nécessaire de bien faire la différence entre la protection contre le feu et celle contre la fumée. Cette dernière constitue un danger grandissant dans les édifices-tours. Les études du déplacement de l'air dans les bâtiments, qui traitent également de l'effet de tirage, permettent de mieux comprendre les divers aspects du déplacement de la fumée et de mettre en oeuvre des moyens de lutte efficaces.

Fire Protection in Air System Installations

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FIRE protection is probably the most hotly debated aspect of air system installations today. This is rather surprising, in some ways, since the principles have not changed rapidly but have developed slowly over many years. Despite the rather obvious potential involvement of air systems in building fire situations, designers have been slow to recognize the full import of fire safety in their work and to seek active participation in the development of necessary codes and specifications.

The activity and publicity associated with the present revision of the National Fire Protection Association's Standard 90A for the *Installation of Air Conditioning and Ventilating Systems* have served to promote a further awareness of its implications.

The standard, for many years, has been widely accepted and referenced by regulatory authorities. It has often been honored more in the breach than in the observance. The chairman of the NFPA 90A Committee referred to it recently as "the most widely referenced and least read such standard."[1] Increasing attention to enforcement in the face of changing conditions and problems may well be another reason for the increasing concern of the air system designer.

Changes in Buildings

Changes in the nature of buildings and their uses raise some obvious questions about fire safety. There has been a marked increase in the number and size of the unbroken floor areas demanded for mercantile and manufacturing enterprises, and for offices and schools. This has been greatly promoted by modern lighting and air conditioning, which have eliminated dependence on windows and enhanced the value of interior spaces.

New architectural features combined with mezzanines and escalators introduced into large interior spaces are leading to a loss of the horizontal separations normally provided by floors to limit fires to one story. Materials are being introduced, with increasing rapidity, for use in new and unusual applications. When combustible, these materials not only add to the fuel load but also contribute unusual products of combustion and amounts of smoke. In addition, the replacement of certain noncombustible parts with combustible ones can introduce new and quite critical features into the safety of a building under fire conditions in ways not always apparent.

Fire Safety in High Buildings

The most dramatic change, however, as far as air systems and fire are concerned, is the rapid growth of high rise building construction. The implications of building height for fire safety in general were discussed at a recent symposium.[2] Rapid evacuation of the population of a tall building, on the sounding of an alarm, cannot be achieved in a few minutes. Times of 20 or 30 min may be required for evacuation in the case of very tall buildings. Clearly, the safety of the occupants must be assured within the building over a substantial period of time following the outbreak of a fire. They must be provided with areas of refuge and with escape routes that will remain smoke-free and will not be cut off by fire. Thus, the need exists to provide more positive control of fire and smoke in the face of certain additional difficulties inherent in the high rise building.

Also, emphasis should be placed on the fact that firemen may be greatly limited in their attack on a high rise building fire. It is thus highly desirable, if not essential, that the inherent characteristics of the building be sufficient to prevent the spread of fire from one floor to the one above. Without this assurance, there is a high probability that every floor above the original fire will ultimately become involved, with great risk of trapping occupants of upper floors and endangering buildings and persons in the vicinity.

No building is free from the threat of fire. Eliminating all possibility of ignition or all combustible materials is not practical. Regulations intended to do away with the more hazardous combinations of ignition and fuel are often difficult to enforce. Something more is required, and the next and most important thing to consider is the introduction of means to prevent, or at least to delay, the spread of a fire once it has started.

Fire Separations

The spread of a fire between buildings can be prevented by suitable spatial separations. When buildings are too close together for effective spatial separation, or when one building contains occu-

[1]Superscript numerals indicate references at end of article.

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pancies that are to be completely separated, a barrier in the form of a construction separation (known as a firewall) can be used. Further division of a building within an occupancy into a number of compartments can be accomplished by the use of additional fire resistant constructions.

The use of fire separations, as the various forms of construction separations are commonly designated, is a most effective way of controlling the spread and ultimate size of a fire. Thus, these separations reduce the hazard to occupants, to the building and its contents, and to the public. Fire separations may be specified by insurance agencies as a condition of underwriting fire risk. They are extensively called for in building codes and are one of the principal means by which fire safety is regulated. Fire separations may also be selected by the designer who, in the interest of his client, wishes to insure a degree of control over fire hazard beyond the minimum required by regulations.

Fire Endurance of Separations

The fire endurance, or fire resistance, of an element of construction is its ability to remain in place and continue to perform all required functions during the course of a fire. Columns and beams must continue to carry the loads imposed on them. Walls and floors must remain in place and retain their integrity as barriers against the spread of fire. Fire endurance is measured in terms of hours-to-failure under the standard fire test exposure. The degree of fire endurance required is based on the fire load provided by the occupancy in the space involved, on the premise that the construction should withstand a complete burnout of its contents.

Firewalls, being primary barriers, are required to have a fire endurance of 4 hr or more. Other wall constructions used as fire separations may have a fire endurance varying from ¾ to 2 hr or more, as required. Walls that must have a fire endurance of 2 hr or more are called "fire partitions" in NFPA Standard 90A. Floor-ceiling assemblies are normally required to have a fire endurance of 1 or 2 hr, depending on occupancy, type of construction, and building height. Two hr is commonly required in codes for office buildings of unlimited height and area. Fire endurance requirements vary even among model building codes and among municipal bylaws.

The foregoing review of fire separations in the control of building fire hazards serves as a basis for identifying clearly one of the two main concerns over air systems in fire situations. The openings required to accommodate ducts, registers, and grilles of air systems generally constitute a weakness or breach in any walls, floors, and ceilings required to act as fire separations. All such points of weakness must be adequately protected, or compensated for, in some suitable way to preserve the fire endurance of the separations.

Fire Dampers Important

The form of "closure" envisaged where ducts pass through fire separations is the fire damper, equipped with a fusible link that allows it to close on any undue rise in temperature. This damper is the focal point of much current debate on fire protection. Two papers presented at the ASHRAE Symposium at Lake Placid last June attempt to clarify the situation,[3,4] and NFPA Standard 90A is about as clear and as specific on the subject of when and where fire dampers are required as is possible to be at the present time.

There are several underlying causes for dissatisfaction with the present position on fire dampers. On one hand, there is great difficulty in establishing adequate performance criteria for them. It follows, almost as a direct consequence of this, that the test methods, standards, and range and quality of devices offered as closures are inadequate. Codes inevitably reflect these deficiencies in test methods and standards.

The mechanical engineer, on the other hand, is understandably quite disturbed at regulations that force him to add large numbers of fire dampers to the air system he has designed. These devices are at best a complication to him in the design, construction, and normal operation of the air system; and it is not always evident to him that they will perform as intended in the event of fire.

These difficulties are unlikely to be resolved soon. The need for adequate fire separations is increasing, as indicated by the earlier discussion of high rise buildings and the importance of insuring that fire will not spread progressively upward. It is now becoming evident, however, that the fire damper should not be considered in isolation but must be assessed in relation to the response of the whole building to the fire situation and to the total hazard involved.

As an example, the flow of hot gases through a duct and damper arrangement, which is one way fire will spread, may often be determined by the air pressures, which determine the magnitude and direction of flow. Clearly, these relate to the building and its air system. It is almost self-evident that such things should be well known and taken into account in determining the need for fire dampers and establishing performance criteria for them.

Smoke: A Separate Problem

This line of thought leads directly to questions of smoke and the recognition of the hazards it poses. Consideration of smoke has been avoided deliberately in the discussion of fire dampers to emphasize that the spread of fire is one problem and the spread of smoke another. Thinking on these two problems has tended to be very confused; and it has taken experiences with fires in high rise buildings to demonstrate, often quite dramatically, just how distinct and different they are. The extreme example is the loss of life from smoke 22 stories above the fire.

Fire separations and fire dampers relate primarily to the prevention of fire spread, while smoke separations and smoke dampers relate to smoke spread. A fusible link will respond to a rise in temperature, which is an indication of fire, but a smoke detector must be used if it is important to sense smoke. A fire separation with proper fire dampers may also serve as a smoke separation, but doors and dampers in a fire separation will always suffer severe temperature distortion under actual fire conditions and will not be smoke-tight.

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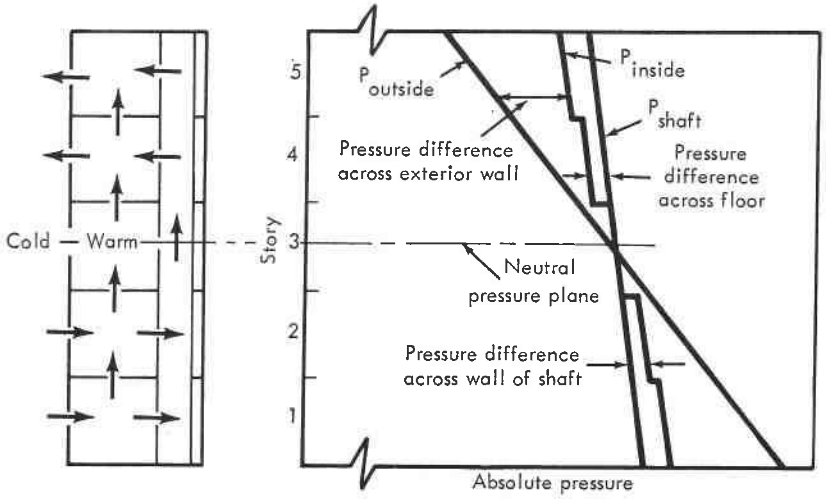

1 STACK EFFECT FOR IDEALIZED BUILDING shows absolute pressures inside and outside. Pressure differences between building, shaft, and outside are illustrated by differences between appropriate curves.

Causes of Smoke Spread

The role of the air system operating with recirculation in distributing smoke throughout a building is readily and widely appreciated and needs no elaboration. Less widely appreciated is the fact that smoke can spread rapidly throughout a building because of other forces, even when the air system is operating. The causes of these effects are of some importance in determining what can be done to control and clear smoke by judicious operation of an air system. Although they have been reviewed recently,[2] some of the major points bear repetition.

The most common smoke condition is likely to be that experienced at some distance from the fire, involving smoke that has been diluted and cooled but still capable of interfering with visibility and producing toxic and irritating effects. The movement of such smoke will follow the pattern of air movement in a building and can be inferred from knowledge of air flow. Air movement results from pressure differences produced by wind effects, the operation of air systems, and buoyancy or stack effect.

Wind and Stack Effects

Wind effect is highly variable with time. The effects of air systems are related directly to operational patterns. Stack effects, which result from differences in density of the air, are produced mainly in proportion to indoor-outdoor temperature differences. Stack effects are therefore relatively substantial under winter conditions when temperature differences are greatest, and may be relatively small, or even negative, under summer conditions. Stack effects will vary in response to daily temperature variations, and may be negative during the day and positive at night. Thus, they may be positive for six to nine months of the year.

The basic nature of stack effect is evident in Fig. 1, which shows absolute pressures inside and outside a building. Pressure differences between the building, the shaft, and the outside are shown by differences between appropriate curves. The curve of outside pressure changes more sharply with height than the others because the colder air outside is more dense. The case for a five story building having a uniform and symmetrical disposition of openings is illustrated. The neutral zone, at which pressure differences are zero, is at mid-height for both building and shaft.

The magnitudes of wind and stack effects can be seen in Table 1 (reproduced from Reference 2). A building 400 ft high with outdoor conditions of −10 F and indoor conditions of 70 F can have a theoretical stack draft of 1 in. WG. For symmetrical conditions with the neutral zone at mid-height, the pressure inward across walls at ground level and outward at upper levels could be as much as ½ in. WG.

Characteristics of Stack Effect

Several important characteristics of stack effect in buildings can now be identified in relation to the effect on smoke movement:

1) Smoke from a fire on any one story will travel upward (when stack effect is positive, as shown) from one floor to the next, in series, through openings in the floor.

2) The floor above the fire floor could be rendered untenable very quickly because of smoke. As shown by McGuire,[5] however, the effects of serial dilution with flow upward from floor to floor are such that some considerable time will elapse before upper floors some distance above the fire floor will become untenable.

3) Smoke can also travel upward from any room below the neutral zone to any room above via shafts.

4) In the case of high rise buildings, rapid transmission of smoke can occur through shafts.

5) Venting a shaft to the outside by an opening at its top will raise its neutral zone. Fewer floors will receive smoke from the shaft, and more will deliver smoke to it.

6) With appropriate top venting, a shaft can generally be prevented from delivering smoke to upper floors, but in the process it becomes smoke-logged.

7) With appropriate bottom venting, a shaft can generally be prevented from becoming a means of delivering smoke to upper floors since smoke will not enter the shaft. It will remain smoke-free.

8) When stack effect becomes negative, as in the summer, the flow directions will be reversed from those in 6 and 7 above. Outside air will enter through top venting, and inside air will leave through bottom venting.

9) Stair shafts and elevator shafts that are to remain smoke-free for use as escape routes must not be top vented under conditions of positive stack effect since this promotes smoke-logging.

The matters just discussed are amenable to calculation, provided that leakage characteristics of various parts of the building are known. Tamura and Wilson have been making measurements on tall buildings and have examined a hypothetical building case by calculation.[6,7,8] Barrett and Locklin have used a computer to analyze a projected building.[9]

The analysis of buildings with shafts does not appear to be too difficult, provided the appropriate leakage characteristics are known. It may be possible to treat air systems similarly for the case when all fans are shut down. Air systems can be regarded as shafts having openings at each story and restrictions to flow between stories corresponding to duct friction.

Until such time as considerably more information on the characteristics of buildings and their systems can be developed, the guidance to designers that is implicit in NFPA Standard 90A (on fire and smoke), including amendments currently proposed, can be regarded as the best available. There does not appear to be any conflict with what has been said here and elsewhere about stack effect.

The general rule must be to arrange to shut down air systems as soon as warning of a fire is received. The possibilities for operating special equipment in an emergency, or of continuing the normal system in operation or changing its operating pattern to suit the emergency, must always be examined carefully in the light of the specific case involved. One obvious use of emergency equipment is the pressurization of stair shafts and elevator shafts to keep them smoke-free. An uninterrupted power supply must be guaranteed. While preliminary study indicates that the fan capacity for a stair shaft with all doors closed may not be unreasonably high, the situation with doors open at several floors at one time could be quite impossible.

Suggestions have been made that the air system exhaust from a smoke-logged area should be continued as long as possible. This can only be considered seriously if all smoke-laden air can be rejected. It must be determined that the rate of air withdrawal in relation to the leakage characteristics of the enclosure of the space involved will create a significant and useful pressure difference. Finally, it must be possible to detect the time at which dangerously hot gases are about to be drawn into

ABLE 1 — COMPARISON OF PRESSURES from wind and stack effect is shown.

Wind pressures (stagnation values)			Chimney pressures (effective height, 100 ft)		
Velocity, mph	Pressures in. WG	Pressures lb/sq ft	Temperature difference, F	Pressures in. WG	Pressures lb/sq ft
5	0.012	0.062	20	0.055	0.296
10	0.048	0.250	40	0.115	0.598
15	0.104	0.541	60	0.179	0.931
20	0.193	1.000	80	0.250	1.300
25	0.301	1.560	100	0.326	1.700

the exhaust system and to shut it down to avoid forced spread of fire via the duct system.

Summary and Conclusion

There is greater need than ever for measures to prevent or restrict the spread of fire and smoke throughout buildings. The use of fire separations is still the principal means available by which fire spread can be controlled. Penetrations of fire separations must be protected.

There is no substitute alternative to the use of fire dampers as the means of protecting openings in fire separations through which ducts, registers, and grilles penetrate. Substantial improvement in the understanding of fire spread through openings in fire separations, including interaction with the total building situation, is needed. With better understanding, better performance criteria can be written, and improved test methods and standards should follow.

Spread of smoke, which should always be considered as a potential problem quite apart from fire spread, is becoming a greater threat as buildings increase in height. Smoke can spread rapidly through vertical shafts to become a threat to occupants before they can escape from a building. The time required for escape is increased, and refuge and escape routes must be kept safe and smoke-free for much longer periods. The air system can spread smoke rapidly, and normally should be shut down in the event of fire. Special operating modes, other than shutdown, may be devised in particular situations; but they must always be studied carefully, taking into account the possibility of limited effectiveness and excessive system complication. Stack effect in buildings, along with wind effects, can produce other effects that will often override the air system, and these can be a major factor in smoke spread. Stack effect should be well understood and taken into account in devising any measures to control smoke.

Finally, it is difficult to avoid the conclusion that hazards from fire and smoke are the business of the air systems designer. They call for studies for which his special capabilities are required. Whether he likes it or not, they call for functional capabilities of his systems, and he should be prepared to contribute to the better understanding and further development that are now greatly needed. ⌿

References

1) Brown, M. M., *Problems in Applying NFPA Standard 90A*, ASHRAE Journal, Vol. 10, No. 8, August 1968, pp. 50-52.

2) Hutcheon, N. B., and Shorter, G. W., *Smoke Problems in High-Rise Buildings*, ASHRAE Journal, Vol. 10, No. 9, September 1968, pp. 57-61.

3) Zimmer, B. A., *Protection of Duct Openings in Fire Resistive Construction*, ASHRAE Journal, Vol. 10, No. 9, September 1968, pp. 51-53.

4) Ollinger, J. C., *Protection of Duct Penetration in a Fire Resistive Ceiling*, ASHRAE Journal, Vol. 10, No. 9, September 1968, pp. 53-57.

5) McGuire, J. H., *Smoke Movement in Buildings*, Fire Technology, Vol. 3, No. 3, August 1967, pp. 163-167.

6) Tamura, G. T., and Wilson, A. G., *Pressure Differences for a Nine-Storey Building as a Result of Chimney Effect and Ventilation System Operation*, ASHRAE Transactions, Vol. 72, Part I, 1966, pp. 180-189.

7) Tamura, G. T., and Wilson, A. G., *Building Pressures Caused by Chimney Action and Mechanical Ventilation*, ASHRAE Transactions, Vol. 73, Part II, 1967, pp. 2.1-2.9.

8) Tamura, G. T., and Wilson, G. T., *Pressure Differences Caused by Chimney Effect in Three High Buildings*, ASHRAE Transactions, Vol. 73, Part II, 1967, pp. 1.1-1.10.

9) Barrett, R. E., and Locklin, D. W., *Computer Analysis of Stack Effect in High-Rise Buildings*, paper presented at ASHRAE annual meeting, Lake Placid, N.Y., June 24-26, 1968.