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Please note

During the lifetime of any building in Canada it is probable that one or more "unwanted" fires will occur. "Fire Loss in Canada, 1959," the report of the Dominion Fire Commissioner, states that for the period 1950-1959 the average number of reported fires per year was 73,000, with over 95 per cent of them occurring in buildings. The size of fires can vary from extremely small ones, a cigarette scorching a hole in a rug, to those causing complete destruction of both building and contents. It is important to keep constantly in mind that almost all fires, if allowed to spread unchecked, can result not only in financial loss but give rise also to bodily injury and in some cases to death itself.

An indication of the financial loss to the country from fire is the average annual property loss, which is in excess of $100,000,000. This figure does not represent the complete financial loss from fire, as in many instances wage earners become unemployed, production of goods is halted, business is interrupted and institutional facilities are depleted.

It is apparent that one of the present-day fire problems in Canada is the large-loss fire involving only one or two buildings, as compared to the era ending about the turn of the century when many buildings in a city could be involved in a single fire. In 1959 over 40 per cent of the total fire loss was accounted for by large-loss fires, each causing damage of $50,000 or more, even though less than half of 1 per cent of the total number of fires was involved. This, of course, is explained by the fact that the majority of these large-loss fires occurred in manufacturing, mercantile properties and institutional buildings.

Statistics are available only for those injuries leading to death. There is an annual loss of 540 lives, with approximately 75 per cent occurring in private dwellings and apartments. Canada has been fortunate over the last several years in that no single building fire bas claimed a large number of lives. The development of more stringent fire prevention and building regulations for larger buildings has undoubtedly done much to reduce the hazard of large life loss; but there should be no complacency regarding those features that affect life safety. Given the right set of circumstances disasters could still occur. Efforts should be made not only to minimize further the likelihood of a large life loss, but also to reduce present losses, particularly those in residential occupancies.

The main purpose of this Digest is to discuss principles and features of effective fire protection. In designing a building these features should be fully considered at the earliest possible stage, for it is quite likely that much more effective protection can be provided at little if any extra cost. Although fire, and in particular fire in buildings, is an extremely complex subject, the designer can, with some knowledge of the basic principles involved, give rational consideration to the fire protection features of buildings.

Combustion

Combustion is a chemical reaction involving, mainly, oxidation, which, produces heat as it proceeds. Such a chemical reaction can proceed rapidly only if the molecules of the fuel are intimately mixed with the molecules of oxygen with which they must combine. This condition is achieved most readily with gaseous fuels. Liquid fuels must first be vaporized before the, necessary mixing with oxygen can take place, and the heavier of these may require the application of considerable heat. Solid fuels must always be heated to convert them to gaseous form for proper mixing with oxygen.

Once a fuel is available in a gaseous state it will diffuse in air and form a flammable mixture when the proportions of gas and air fall within certain limits. These are called the "flammability or explosive limits" and give the range of concentrations of fuel in air within which ignition can occur. Ignition will take place if the mixture is raised to a temperature at which self-ignition can take place, or more commonly, if an external high temperature ignition source is present. Such an external source may be extremely small, provided its temperature is sufficiently high, as in the case of electrical and other kinds of sparks, tiny flames and glowing objects such as embers and lighted cigarettes.

When solids are present in a finely divided state, as in grain, coal, wood and certain metal dusts suspended in air, they can be almost as easily ignited as gaseous mixtures, within appropriate concentration limits. A solid material heated to ignition point in a stream of hot gases will reach that point more rapidly, other things being equal, if it has a high specific surface - a large surface area in relation to its volume.

The process of internal generation of heat leading to what is commonly known as spontaneous ignition is an interesting phenomenon often given as the cause of mysterious building fires. It occurs less frequently than is generally supposed, since unusual conditions must exist. A material must be present that oxidizes at a significant rate at ordinary temperatures. Most commonly this will be provided by a few special oils of the type used in paint or that occur naturally in certain plant materials. The drying oils in paints are selected for their ability to oxidize in this way and thus promote drying of the paint films. As normally used they present little hazard, but when dispersed in a bundle of waste paint rags so as to provide a large surface area for oxidation with a minimum of opportunity to cool, the oxidation rate increases as the temperature rises. When conditions permit, the temperature may eventually reach the self-ignition point and a fire result.

Still another form of spontaneous heating can occur when a material such as wood fibreboard is stored in large quantities. There is a critical size of pile, depending on the temperature of the board at the time, above which the boards will gradually self-heat. This can raise the temperature of the material to its ignition temperature. A similar process can take place in stored agricultural products. In these cases self-heating may be initiated by the action of bacteria and may then proceed through an oxidation induced by the higher temperatures until self-ignition and fire occur.

It has been suggested that combustible material may be classified as tinder, kindling, and bulk fuel. Tinder can be ignited by a match and continue to burn of its own accord; common examples are paper, cardboard, and volatile combustible liquids. Kindling is any material that will ignite and burn if associated with sufficient tinder, although a match will not produce a continuing fire in it; plywood materials qualify as kindling. Bulk fuel is difficult to ignite and usually requires a supporting fire to keep it burning; heavier construction timbers and baled or compressed combustible goods such as textiles and papers fall into this class. Any timber having a thickness greater than ½ inch can be classified as bulk fuel. It is obvious from this that fire will develop much more rapidly in a furniture factory than in a warehouse containing only structural timbers.

Oxygen is an essential ingredient in the chemical reaction of burning, so that the development of a fire is limited by the oxygen supply. Where it is restricted, as in the extreme case of fire in a tightly sealed room, the oxygen in a room of average size is sufficient only for combustion of a small quantity of fuel, say 5 or 10 pounds; the heat produced will probably be insufficient to cause any damage to the structure that will permit more air to enter and the fire will die out from lack of oxygen. A building is seldom tightly sealed in practice, however, and if there are openings at two levels, natural convection, aided perhaps by wind, will ensure the escape of the products of combustion at the higher opening and a continuing supply of oxygen through the lower one. This permits a build-up of temperature until a balance is reached between heat produced and heat transmitted. The fire will then continue at this level until the fuel is exhausted.

In practice, heat may cause damage to a structure in such a way as to improve the air supply before equilibrium has been reached. Windows often crack first. After this, the temperature may rise rapidly until the stage at which surfaces receive sufficient heat by radiation to "flash over."

It may be seen that combustion can be described as the distillation of gases from combustible materials, the mixing of these gases with oxygen in the air, then the further heating of the mixture, usually only locally, until it ignites spontaneously or more commonly is ignited by flame or adjacent hot material. The chemical reaction which follows produces various results: heat is generated that can sustain and expand the fire; the combining gases produce other gases, mainly carbon dioxide and steam, although there may be more toxic ones, depending upon the substance being burnt. Combustion may not always be complete and carbon may be freed, producing smoke, which is the visible portion of the gases of combustion and will vary in quantity with the nature of the material. The rate at which the fire develops will depend upon the relative rates at which heat is liberated and dissipated, i.e. upon what can be termed the heat balance.

Development of Fire

For fire to spread in a building, heat must pass from one part to another in order to distil and ignite the combustible gases. This can be accomplished in several ways. It can be conducted along or through materials of high conductivity such as metals, which are not of themselves readily combustible, in this way passing through an incombustible partition until the temperature of combustible material on the far side is raised to the point of ignition. Convection currents can quickly spread hot gases throughout a whole building and may also carry combustible gases distilled out of the material adjacent to the fire but not burnt because of lack of oxygen. On reaching a new supply of oxygen these gases may then burst into flames. Radiant heat can cause the fire to jump wide gaps if the heat rays fall upon suitable tinder such as curtains in a window across the street, and flames can spread over the surface of combustible material and carry fire along corridors and into other rooms. Finally, there is the explosive propulsion of fire-brands or other burning material that can enable fire to jump incombustible gaps.

Fire and the Design of Buildings

In general, a designer is not concerned with the ignition phase of a fire, except in the case of special hazard areas. In all areas where flammable vapours are normally present, explosion-proof electrical equipment must be installed and facilities provided for the removal of these vapours. As so many ignition sources exist in most buildings, such as the carelessly disposed-of glowing cigarette butt over which he bas little if any control, a designer should assume that a fire can occur almost anywhere and design accordingly. His main responsibility is, therefore, to design so as to limit the spread of fire in order to minimize life hazard and property damage.

The rate at which fires develop is extremely variable, depending on ventilation, amount and distribution of combustible contents, and the type of lining materials. At present there is very little quantitative information available on the behaviour of fire once "flaming combustion" has commenced. Several research organizations in various countries are attempting to study this problem using models, but these investigations will extend over several years. From a study of fires in the past, however, it is possible to make some comments of a general nature on their development. There are three recognizable stages. There is a period when the temperature rises rapidly as the fire spreads; this development is limited by the warming up of the fuel surfaces and the penetration of oxygen into the fuel. There is a period when the temperature rises more slowly; it is generally referred to as the "fully developed fire," which is in turn limited by the access of air through openings in the perimeter walls of the building. Finally, there is the decay period when the temperature is falling; during this time the volatile fractions of the fuels are exhausted.

The rapidity of the development of fire in the first period affects the hazard to human life, damage to contents and the size of the problem facing the fire department. One factor that affects this speed is the type of interior linings installed. More flammable linings, other conditions being equal, will allow a fire to develop more rapidly than less flammable linings. The designer should, therefore, keep their use to a minimum so as to give as much time as possible for occupants to escape and for fire fighting.

The period of the fully developed fire, and to a lesser extent the decay period, largely determine the extent of the damage to a building structure. It is during this time also that the building presents the greatest exposure hazard to adjacent buildings. One of the major factors, in addition to ventilation, that affects the duration of this period is the amount and distribution of combustible material per square foot of floor area. The greater the calorific content of the materials in the building, the greater is the potential severity of the fire.

The final stage in the reaction is extinction. Flaming ceases when flammable vapours are no longer produced at a sufficient rate to form a flammable mixture with air. Extinction may be due to depletion of either fuel or oxygen. Carbon dioxide fire extinguishers work on the principle of blanketing the fire by cutting off the oxygen and so extinguishing it. Water does this too, but it cools the burning material as well, thus giving a negative heat balance and causing the fire to die down.

Conclusion

In summary, the combustibility, flammability and fire endurance of building materials are all factors to be considered in designing buildings. But although over-all combustibility is of importance, it is the flammability of lining materials that is critical. It influences the speed with which a fire develops; a corridor lined with highly flammable materials can even be rendered useless as an avenue of escape. Several tests are available for classifying materials as to their flammability; the flame spread test, which enjoys the widest acceptance on the North American continent, is ASTM Standard E84 - Surface Burning Characteristics of Building Materials.

Compartmentation is another most important consideration from the standpoint of limiting the spread of a fire; and the fire resistance of the enclosing elements will determine its effectiveness, whether it is the separation of occupied areas, either vertical or horizontal, or the enclosure of stairways.

In order to assess the performance of walls, columns, floors and other building members under fire exposure conditions, standard fire resistance tests intended to simulate the development of a fire have been developed over the years. To pass the test, the component must prevent the passage of fire; it must not collapse nor develop fissures, nor may it conduct sufficient heat to develop temperatures on the unexposed side that would endanger combustibles stored there. On this continent the most widely used tests are the ASTM standards:

E119-Fire Tests of Building Constructions and Materials
E152-Fire Tests of Door Assemblies
E163-Fire Tests of Window Assemblies.

In each of these tests there is a rapid initial rise in temperature (the temperature in the test furnaces reaches 1000°F in 5 minutes), after which it continues at a decreasing rate. The duration of the test fire has been related to the "fire load" (weight of combustibles per sq ft of floor area i.e. 1-hour endurance corresponds to a fire load of 10 lb/sq ft of combustible material having a calorific value of 8000 Btu/lb. Temperature measurements obtained during the St. Lawrence Burns operation provided further verification that the time-temperature relationship used at present in the standard fire endurance tests is a reasonable approximation of conditions that can obtain during a fire.

Although the designer can reduce the possibility of fire in a building, he cannot prevent one from starting. He can, however, ensure through proper design that the fire loss will be kept to a minimum. A knowledge of the basic principles involved is essential if the building is to be designed not only to resist the action of fire but also to provide safety for its occupants and contents.