Basic principles of smoke management for atriums
Lougheed, G. D.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20327478
Construction Technology Update, 2000-12-01

NRC · CNRC

Construction Technology Update No. 47

Basic Principles of Smoke Management for Atriums

by G.D. Lougheed

Fires in atrium buildings can pose a serious threat to occupants as a result of smoke migration. This Update, intended for building designers and property managers, outlines the basic principles of smoke management in atriums that must be understood in order to enhance occupant safety.

Atriums have become popular elements in commercial, office and residential buildings because they can provide attractive, environmentally controlled, naturally lit spaces. Such spaces, however, present a challenge for fire protection engineers because their height (typically greater than 20 m) decreases the effectiveness of automatic sprinkler systems and because they lack the floor-to-floor separations that can limit the likelihood of fire and smoke spreading from the floor of fire origin to other areas of the building. Evacuation routes in atriums are of greatest concern because they become vulnerable to spreading smoke unless smoke management measures are used.

Smoke Hazards

Most fire-related deaths are attributable to smoke inhalation rather than burns. In the context of fire-safety engineering, smoke is defined as the combination of airborne solids, liquid particulates and gases produced when a material burns plus the air that becomes entrained (incorporated into the mix).[1] Hazards from smoke in buildings include:

- **Toxic gases**. Carbon monoxide is the most common of these. Narcotic gases (which can render a person unconscious) such as hydrogen cyanide and irritants such as acidic halides and acrolein may also be produced, depending on the combustible materials present.
- **Reduced oxygen levels**. This can result in suffocation.
- **High temperatures**. Extreme heat is potentially hazardous to people immersed in the smoke or exposed to its radiation.
- **Reduced visibility**. This can hinder both evacuation and rescue efforts.

The reduction in visibility is a major hazard in atrium fires that needs to be considered in any smoke management design, especially as it affects occupants who are not located in the immediate fire area. If they have to evacuate through the smoke, the occupants may become disoriented. In general, if there is enough visibility through the smoke for people to see the emergency exits, toxic products are unlikely to prevent them from escaping. To achieve sufficient visibility, building occupants should be physically separated from the smoke or the smoke concentration should be limited.

A wide range of acceptable levels of visibility has been suggested in the fire protection literature.[2] For occupants familiar with a building and able to evacuate quickly, being able to see a distance of 3-5 m may be sufficient. For those less familiar with the building, a distance of up to 25 m has been recommended. The latter criterion was used in the tenability requirements for escape routes in high-rise buildings first introduced in the 1970 edition of the National Building Code

construction

Published by

Institute for Research in Construction IRC

of Canada.[3] Internationally, a distance of 10 m is widely accepted and used.[4]

The effects of other smoke hazards (toxic gases, high temperatures and reduced oxygen levels) can be serious for occupants who are close to the fire when it starts or who become immersed in the smoke flow. Extensive discussion of the effects of exposure to smoke, including toxic gases, and of the tenability limits used to estimate the probability of incapacitation or death, can be found in the literature.[5]

Objectives of a Smoke Management System

Where smoke from a fire in an atrium, or in a room adjacent to the atrium, has the potential to spread to other occupied parts of the building, there is a threat to the safe evacuation of occupants. This threat is the primary consideration in the design of smoke management systems. It can usually be addressed by limiting the production of smoke and its migration, thus maintaining a tenable environment in the egress routes (corridors or stairs).

Smoke management systems can also be designed to assist emergency response personnel in conducting search-and-rescue operations, and in locating and controlling the fire. Generally, measures to protect egress routes make it easier for firefighters to enter the building, and can reduce property damage. Such measures can aid in post-fire smoke removal as well.

General Approaches to Smoke Management

Various engineering approaches, used singly or in combination, can reduce the production of smoke or modify its movement, hence mitigating its effects on occupants. These approaches include installing automatic sprinklers and limiting the use of combustible construction materials and furnishings.[1,6]

Automatic sprinkler systems are most effective in controlling fires in spaces with a relatively low ceiling height, such as those found in the areas adjacent to the atrium. For fires on the floor of the atrium, the situation is quite different. The smoke in the fire plume (see Figure 1) cools substantially as it rises to the ceiling, and in the case of high atriums (more than 20 m in height), the sprinklers will not be activated until the fire has become large. This means that substantial smoke spread can occur, both within the atrium and in the communicating spaces,[2] before the sprinklers are activated.

Currently, there is very limited information on the size of sprinklered fires in atriums. As a result, a variety of approaches are used to design adequate smoke management systems for sprinklered buildings.[1,6] However, there is no consensus as to which is the best approach.

In addition to sprinklers, “active” approaches (requiring a manual or automatic response) to smoke management include venting smoke from the atrium either through openings in the ceiling or by means of mechanical exhaust systems (fans) to limit its accumulation and reduce its spread to other (connected) areas of the building. Venting systems can be activated manually or automatically in response to heat or smoke detectors.

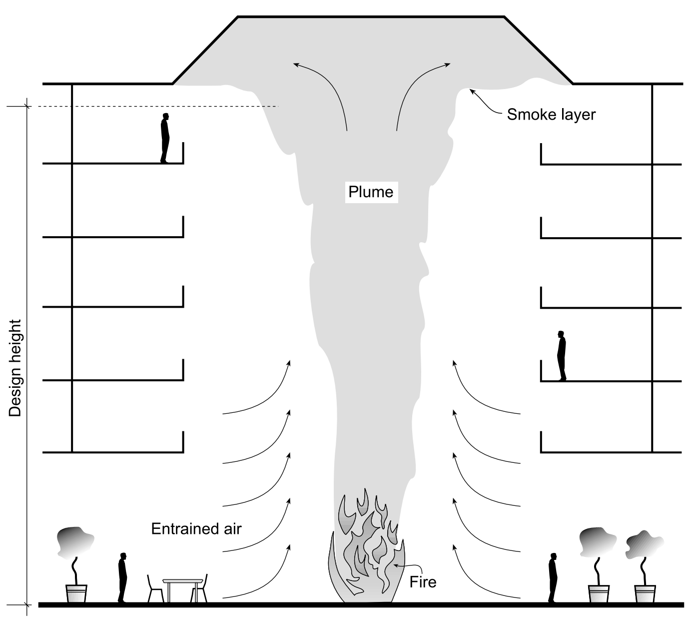

Figure 1. Smoke plume and smoke layer in an atrium fire[1]

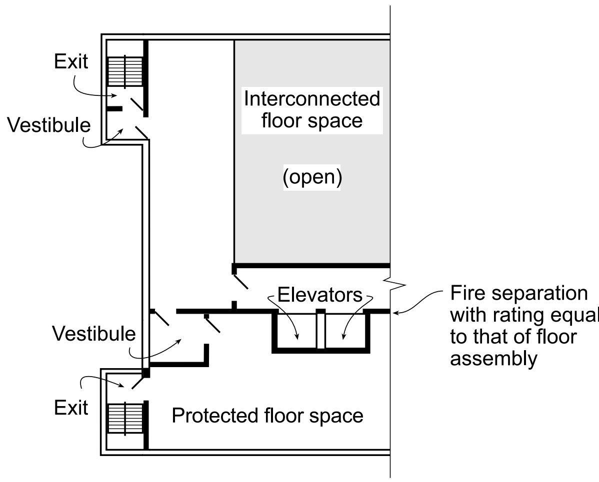

Figure 2. Vestibules and protected floor spaces

There are also "passive," or built-in, approaches to smoke management based on limiting smoke movement; for example, evacuation routes can be separated from the atrium by using barriers to fire or smoke, thus reducing the threat to occupants.

National Building Code of Canada Requirements

The National Building Code of Canada 1995 (NBC) addresses the hazards from smoke in atriums with requirements for interconnected floor space[3] (Articles 3.2.8.3. to 3.2.8.9.).[3,7] These fire-safety requirements can be summarized as follows:[4]

1. **Construction requirements**. The building shall be of noncombustible construction. (Heavy timber construction is permitted if Subsection 3.2.2. permits the building to be of combustible construction.)
2. **Sprinklers (fire suppression)**. The building shall be sprinklered throughout.
3. **Vestibules**. These are required at each level for exits opening directly into an interconnected floor space. If an elevator hoistway opens into the interconnected floor space and into storeys above it, vestibules are required to protect either the elevator door openings in the interconnected floor space or the elevator door openings in the storeys above the interconnected floor space (see Figure 2).
4. **Protected floor space**. A protected floor space can be used to accommodate peak traffic during evacuation. It shall be designed so that an exit can be reached without entering the interconnected floor space and shall be separated from the interconnected floor space by a vestibule (see Figure 2).

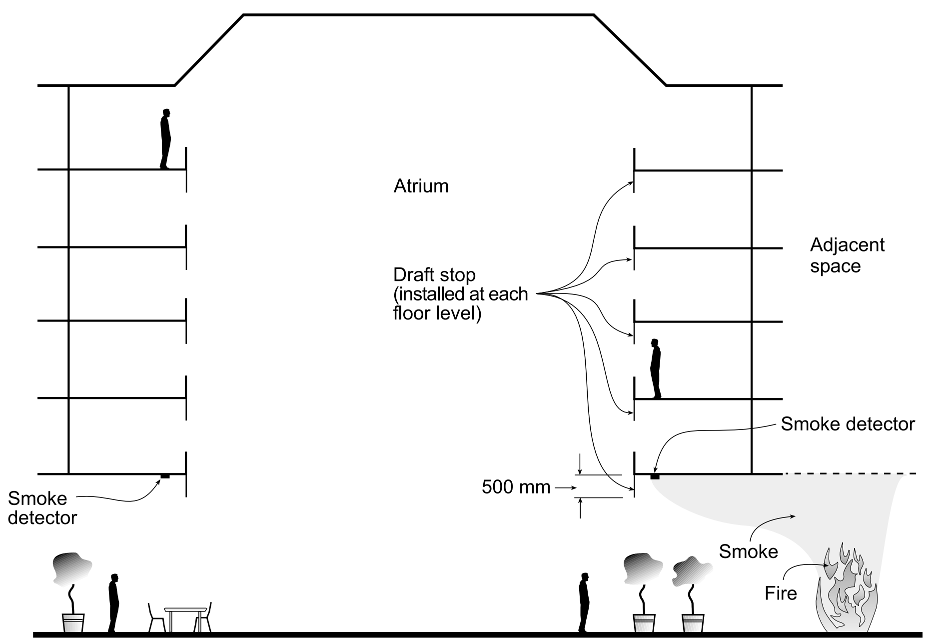

Figure 3. Atrium space with draft stops

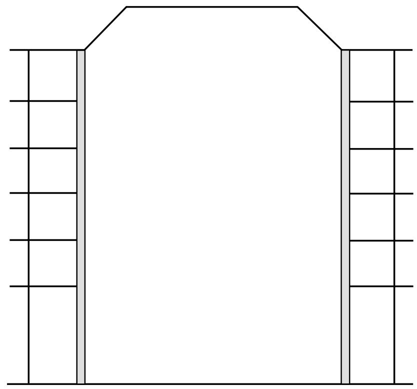

Figure 4. "Sterile tube" atrium

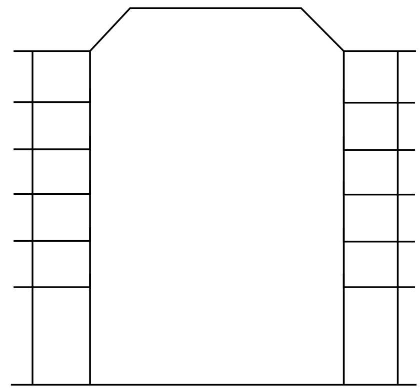

Figure 5. Atrium with glazed walls

5. **Draft stops**. These shall be installed at each floor level, immediately adjacent to and surrounding the opening to provide a smoke reservoir at the ceiling so that the smoke can be detected. Draft stops must be at least 500 mm deep, measured from the ceiling level to the bottom of the stop (see Figure 3, p. 3).
6. **Mechanical exhaust system**. This type of system shall be provided to remove smoke from the interconnected floor space at a rate of four air changes per hour. Its purpose is to aid firefighters in removing smoke, and it is designed to be actuated manually by the responding fire department.
7. **Combustible content limit**. The interconnected floor space shall be designed so that the combustible contents, excluding interior finishes, in those parts of a floor area in which the ceiling is more than 8 m above the floor, are limited to not more than 16 g of combustible material (e.g., furnishings and items related to the occupancy) for each cubic metre of the interconnected floor space. This requirement is also referenced in the National Fire Code of Canada (NFC), Sentence 2.3.1.4.(1).[8]

These smoke management requirements provide building designers with the basic approach for meeting one of the objectives of the NBC, which is to protect human life. Such approaches are based primarily on reducing smoke production by requiring the installation of automatic sprinkler systems (to control the fire) and the use of noncombustible materials, such as metal, brick, stone and gypsum board, for major building elements, interior finishes and furnishings. The NFC limits the quantity of combustible content related to the specific occupancy. In addition, exits must be protected by providing them with vestibules.

Evolution of Atriums and Related Smoke Management Issues

When atriums had no real function other than as circulation space (see Figure 4), the main approach to fire protection design was to ensure that the atrium boundaries — wall assemblies or glass — were fire resistant. This approach was frequently used when the atrium was basically a covered space linking separate buildings — a "sterile tube."[9]

Since experience with atrium fires, particularly in fully sprinklered buildings, has shown that the impact on life safety as a result of flame spread is small compared to that from the accumulation and spread of smoke to other areas, there is less need to use fire-resistant materials to separate the atrium from the adjacent spaces in a fully enclosed atrium.[10,11] Glazed non-fire-resistant assemblies (see Figure 5) can provide adequate protection against smoke spread as long as the glass remains intact.

Today, both sterile tube and fully enclosed (with glazing) atriums are considered too restrictive from both design and use perspectives. In more recent designs,

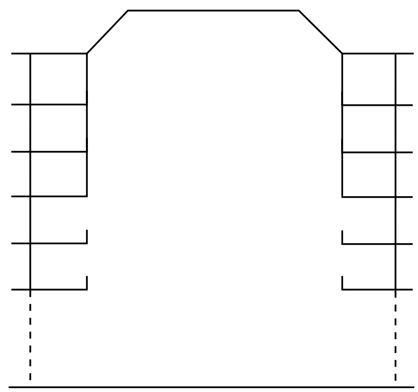

Figure 6. Partially open atrium

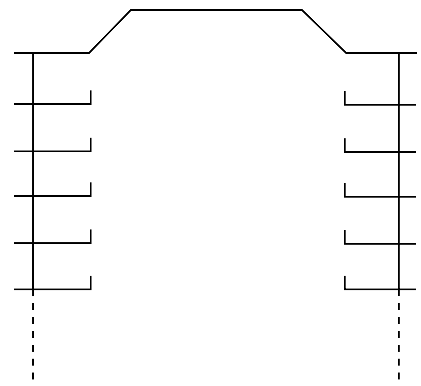

Figure 7. Fully open atrium

the adjacent spaces are often partially or fully open to the atrium (see Figures 6 and 7) so as to maximize the use of the space. This evolution in the design and use of atrium spaces presents two major concerns:

1. The greater the interconnection between the atrium space and the adjacent spaces, the greater the possibility of smoke from a fire on the atrium floor, or from a room adjacent to the atrium, spreading through the atrium to other parts of the building. The complexity of the smoke management system design is directly related to the degree of interconnection of the spaces.
2. Any change in or intensification of use almost certainly means a change in the type and quantity of combustible materials (the fuel load), which in turn affects the size of the fire and the (related) rate of smoke build-up, and hence the demands placed on the smoke management system.

Use of Engineered Design Approaches

While the NBC provides prescriptive requirements for the design and construction of atriums, there are some circumstances that require a performance-based approach to determine whether a particular use and design will meet the intent of the code. Such circumstances include the following:

- When a new use for an existing atrium is contemplated
- When it is difficult to meet the requirements for protected floor spaces
- When a new atrium is designed for a use that is not covered by the NBC
- When the atrium design features a high degree of connectivity between the atrium(s) and the adjacent spaces.

Engineered approaches to the design of smoke management systems, as found in design guides such as NFPA 92B (published by the National Fire Protection Association), provide performance-based tools in the form of empirically based equations and numerical models. The basics of this type of approach are outlined in Construction Technology Update No. 48.

References

1. NFPA 92B, Guide for smoke management systems in malls, atria, and large areas. National Fire Protection Association, Quincy, MA, 2000.
2. Tamura, G.T. Smoke movement and control in high-rise buildings. National Fire Protection Association, Quincy, MA, 1994.
3. National Building Code of Canada. Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, 1970 and 1995.
4. Morgan, H.P., Ghosh, B.K., Garrad, G., Pamlitschka, R., De Smedt, J.-C. and Schoonbaert, L.R. Design methodologies for smoke and heat exhaust ventilation. BRE 368, Construction Research Communication Ltd, London, UK, 1999.

5. Purser, D. Toxicity assessment of combustion products. The SFPE handbook of fire protection engineering, National Fire Protection Association, Quincy, MA, 1995.
6. Klote, J.H. and Milke, J.A. Design of smoke management systems. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1992.
7. User's guide — NBC 1995, fire protection, occupant safety and accessibility (Part 3). Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, 1997.
8. National Fire Code of Canada. Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, 1995.
9. Saxon, R. Atrium buildings: development and design. The Architectural Press, London, UK, 1983.
10. Sharry, J.A. An atrium fire. Fire Journal, Volume 67, 1973, pp. 39-41.
11. Lathrop, J.K. Atrium fire proves difficult to ventilate. Fire Journal, Volume 73, 1979, pp. 30-31.

Footnotes

1. Although the figures show a raised roof system, this is not a requirement of the National Building Code of Canada 1995.
2. "Communicating spaces" refers to those spaces in a building with an open pathway to the atrium such that smoke movement between the spaces and the atrium is unimpeded. This includes spaces that open directly into the atrium as well as those that connect through passageways.
3. An "interconnected floor space" (as defined by the NBC, Article 1.1.3.2.) refers to superimposed floor areas or parts of floor areas in which floor assemblies that are required to be fire separations are penetrated by openings that are not provided with closures.
4. The requirements provided in this Update are limited to those included in the NBC. The specific requirements of locally applicable building and fire codes must be met for all buildings.

Dr. G.D. Lougheed *is a senior research officer in the Fire Risk Management Program of the National Research Council's Institute for Research in Construction.*

December 2000
ISSN 1206-1220

"Construction Technology Updates" is a series of technical articles containing practical information distilled from recent construction research.

For more information, contact Institute for Research in Construction, National Research Council of Canada, Ottawa K1A 0R6
Telephone: (613) 993-2607; Facsimile: (613) 952-7673; Internet: http://irc.nrc-cnrc.gc.ca

Canada