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Smoke Management : Atriums and Plugholes

By G.D. Lougheed and G.V. Hadjisophocleous

Atriums have become popular in commercial, office and residential buildings, providing high marketing value with their environmentally controlled, naturally lit spaces. Such spaces, however, present a challenge for fire protection engineers.

The protection of building occupants from smoke in the event of a fire is one of the primary objectives in the design of any fire protection system. Achieving this objective is difficult when dealing with very large spaces, such as an atrium or an indoor sports arena, where a large number of occupants may be present and the compartment geometries may be complex. By interconnecting a number of floor spaces, an atrium violates the concept of floor-to-floor compartmentation, which is intended to limit the spread of fire and smoke from the floor of fire origin to other stories. A fire on the floor of an atrium or in any space open to it can cause smoke to fill the atrium and connected floor spaces. Elevators, open stairs and egress routes that are within the atrium space can also become smoke-laden.

Because of these difficulties, building codes place restrictions on the use of atrium spaces. Some of the code requirements commonly applied to buildings with atriums include:

- the installation of automatic sprinklers throughout the building,
- limits on combustible materials on the floor of an atrium,
- the installation of mechanical exhaust systems for use by firefighters to vent smoke,

- the provision of smoke management systems to maintain tenable conditions in egress routes.

The use of smoke management systems to maintain tenable conditions in egress routes located in an atrium has become common in recent years. One approach is to use a mechanical exhaust system to maintain the smoke layer above the highest egress route (Figure 1). Design information for these systems is available in engineering guidelines [1,2].

There are a number of situations that may impact the effectiveness of a mechanical exhaust system used for atrium smoke management. One concern, raised by many designers and researchers, is the possibility of fresh air being pulled into the exhaust inlet for systems in which the "headroom" for accumulation of smoke above the highest egress route is minimal. This "plugholing" of the exhaust inlet by the fresh air can decrease the efficiency of the smoke exhaust system and can result in a deeper layer of smoke, to which occupants may be exposed (Figure 2).

In a recently completed research project sponsored by ASHRAE, NRC used full-scale physical model studies combined with CFD modelling to investigate this issue [3-5]. The results demonstrated that a design approach similar to one used in the United Kingdom to prevent plugholing in gravity venting systems could be applied to an atrium mechanical smoke exhaust system. A design approach was developed and has been approved by the NFPA Smoke Management Committee for inclusion in the next edition of NFPA 92B.

To minimize plugholing, multiple inlets should be used for the mechanical smoke exhaust system. Also, the maximum mass (volumetric) flow rate through each exhaust inlet must be limited depending on the depth of the smoke layer below the exhaust inlet. Using mass flow rate, the design criterion is given by:

$$m_{max} = C\beta d^{5/2}\left(\frac{T_s - T_o}{T_s}\right)^{1/2}\left(\frac{T_o}{T_s}\right)^{1/2}$$

where

m_{max}	=	maximum mass rate of exhaust without plugholing, kg/s;
T_s	=	absolute temperature of the smoke layer, K;
T_o	=	absolute ambient temperature, K;
d	=	depth of the smoke layer below the exhaust inlet, m;
β	=	exhaust location factor (dimensionless);
C	=	3.13 (constant).

Based on limited information, suggested values for β are 2.0 for a ceiling exhaust inlet located near a wall, 2.0 for a wall exhaust inlet located near the ceiling, and 2.8 for a ceiling exhaust inlet far from any walls.

In addition to limiting the maximum flow rate through each exhaust inlet, the designer should ensure that there is a minimum separation between inlets to minimize interaction of the smoke flows near the inlets. Design criteria for spacing the exhaust inlets will be provided in the next edition of NFPA 92B.

The plugholing of fresh air into an atrium smoke exhaust system has the potential to expose occupants to smoke during evacuation. Appropriate selection of the number of exhaust inlets can minimize the effects of plugholing and improve the efficiency of the exhaust system. Such considerations are particularly important in retrofits or other applications in which the headroom above the highest evacuation route in the atrium is minimal.

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3. Lougheed, G.D. and Hadjisophocleous, G.V., Investigation of Atrium Smoke Exhaust Effectiveness, ASHRAE Transactions, Vol. 103, 1997, pp 1-15.
4. Hadjisophocleous, G.V., Lougheed, G.D. and Cao, S., Numerical Study of the Effectiveness of Atrium Smoke Exhaust Systems, ASHRAE Transactions, Volume 105, 1999, pp. 699-715.
5. Lougheed, G.D, Hadjisophocleous, G.V., McCartney, C. and Taber, B.C., Large-Scale Physical Model Studies for an Atrium Smoke Exhaust System, ASHRAE Transactions, Volume 105, 1999, pp. 676-698.

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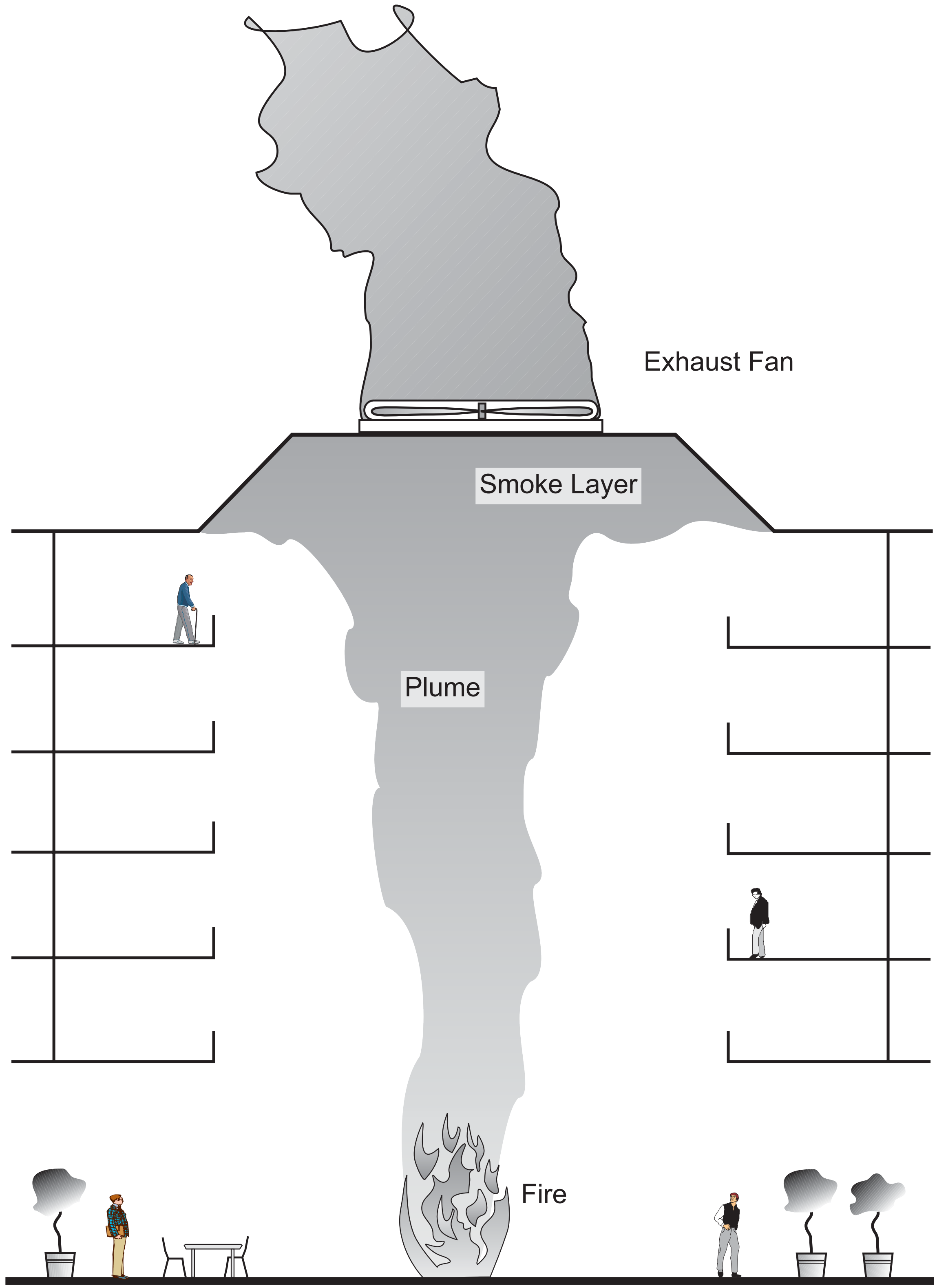

Figure 1. Smoke exhaust to maintain smoke layer above evacuation routes.

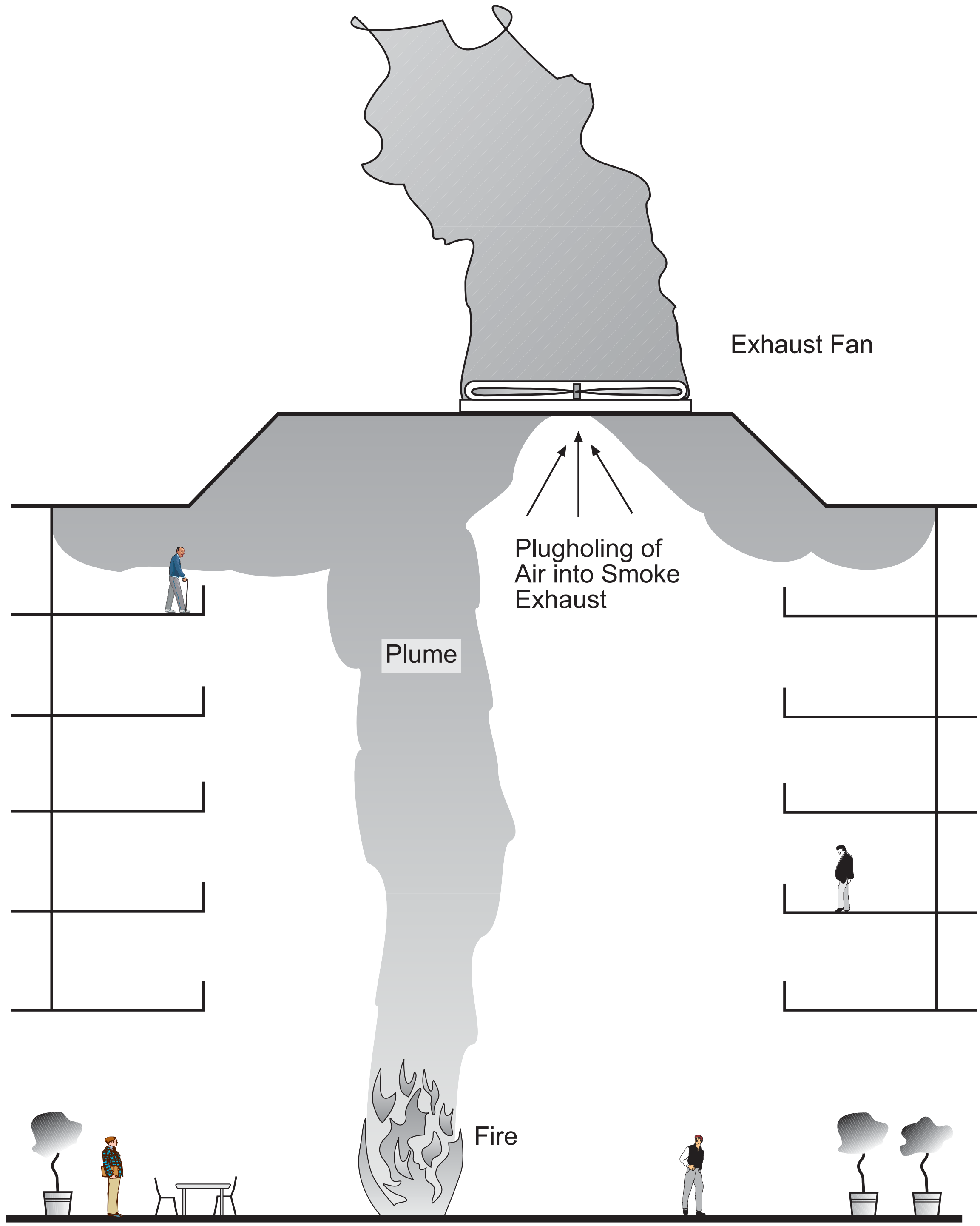

Figure 2. Pulling fresh air into the smoke exhaust resulting in plugholing.