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909.7

Airflow design method.

When approved by the fire code official, smoke migration through openings fixed in a permanently open position, which are located between smoke-control zones by the use of the airflow method, shall be permitted. The design airflow shall be in accordance with this section. Airflow shall be directed to limit smoke migration from the fire zone. The geometry of openings shall be considered to prevent flow reversal from turbulent effects.

♦This method is only allowed when approved by the building official. As the title states, this method utilizes airflow to avoid the migration of smoke across smoke barriers. This has been referred to as opposed airflow.

Specifically, this method is suited for the protection of smoke migration through doors and related openings fixed in a permanently open position. This method consists of providing a particular velocity of air based upon the temperature of the smoke and the height of the opening. The temperature of the smoke will depend on the design fire that is established for the particular building. The higher the temperature of the smoke and the larger the opening, the higher the velocity necessary to maintain the smoke from migrating into the smoke zone. It should be noted that the airflow method seldom works for large openings, since the velocity to oppose the smoke becomes too high. This method tends to work better for smaller openings, such as pass-through windows.

Equation 9-2 provides the method to calculate the necessary velocity.

909.7.1 Velocity. The minimum average velocity through a fixed opening shall not be less than:

$v = 217.2 [h(T_f - T_o)/(T_f + 460)]^{1/2}$ (Equation 9-2)

For SI: $v = 119.9 [h(T_f - T_o)/T_f]^{1/2}$

where:

h = Height of opening, feet (m).

T_f = Temperature of smoke, °F (K).

T_o = Temperature of ambient air, °F (K).

v = Air velocity, feet per minute (m/minute).

♦This section provides the formula for the minimum average velocity through a fixed opening. The minimum velocity is based

on the velocity needed to prevent the smoke from migrating into the smoke zone.

Consideration needs to be given to the eventual exhaust of the air introduced for this approach. See the commentary to Section 909.7 for further discussion.

909.7.2 Prohibited conditions. This method shall not be employed where either the quantity of air or the velocity of the airflow will adversely affect other portions of the smoke control system, unduly intensify the fire, disrupt plume dynamics or interfere with exiting. In no case shall airflow toward the fire exceed 200 feet per minute (1.02 m/s). Where the formula in Section 909.7.1 requires airflows to exceed this limit, the airflow method shall not

be used.

♦The airflow method has a limitation on maximum velocity. This limitation is based upon the fact that air may distort the flame and cause additional entrainment and turbulence; therefore, having a high velocity of air entering the zone of fire origin has the potential of increasing the amount of smoke produced.

The velocity may also interact with other portions of the smoke control design. For instance, the pressure differences in other areas of the building may be altered, which may exceed the limitations of

Sections 909.6.1 and 909.6.2. This section requires that when a velocity of over 200 feet per minute (1.02 m/sec) is calculated, the airflow method is not allowed.

The solution may result in requiring a barrier such as a wall or door.

If the airflow design method is chosen to protect areas communicating with an atrium, the air added to the smoke layer needs to be accounted for in the exhaust rate.

909.8 Exhaust method. When approved by the fire code official, mechanical smoke control for large enclosed volumes, such as in atriums or malls, shall be permitted to utilize the exhaust method. Smoke control systems using the exhaust method shall be designed in accordance with NFPA 92B.

♦This method is only allowed when approved by the building official. The primary application of the exhaust method is in large spaces, such as atriums and malls and is the most

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widely used method in the IBC. The strategy of this method is to keep the smoke layer at a certain level within the space. This is primarily accomplished through exhausting smoke. The amount of exhaust depends upon the design fire [see Figure 909.8(1)]. Essentially, fires produce different amounts and properties of smoke based on the material being burned, size of the fire and the placement of the fire; therefore, NFPA 92B is referenced for the design of such systems. NFPA 92B presents several ways to address the control of smoke, which includes the use of the following tools:

• Scale Modeling (Small scale testing)—Utilizes the concept of scaling to allow small scale tests to be conducted to understand the smoke movement within a space.

• Benefits—More realistic understanding of smoke movement in spaces with unusual configurations or projections than algebraic calculations.

• Disadvantages—Expensive and the application of results is limited to the uniqueness of the space being analyzed.

• Algebraic (Calculations—similar to 2003 IBC)—Empirically derived (based upon testing) modeling in its simplest form.

• Benefits—Simple, cost-effective analysis.

• Disadvantages—Limited applicability due to the range of values they were derived from, only appropriate with certain types of design fires, typically over conservative outputs that increase equipment needs, equipment costs and can impact aesthetics

and architectural design.

• Computer Modeling [Computational fluid dynamics (CFD) or zone models]—Combination of theory and empirical values to determine the smoke movement and fire induced conditions within a space and effectiveness of the smoke control system.

• Benefits—More realistic understanding of smoke movement in spaces with unusual configurations or projections and less expensive than scale modeling. Helps significantly in designing smoke control systems tailored to spaces and achieving cost-effective designs, and can help limit the impact to architectural design.

• Disadvantages—Computing time and cost can be longer than algebraic calculations but benefits typically

outweigh this disadvantage.

Early planning is important and can limit these adverse impacts.

In terms of computer modeling, as noted, there are essentially two methods that include zone models and CFD models. Zone models are based upon the unifying assumption that in any room or space where the effects of the fire are present there are distinct layers (hot upper layer, cool lower layer). In real life such distinct layers do not exist. Some examples of zone models used in such applications include Consolidated Model of Fire Growth And Smoke Transport (C-FAST) and Available Safe Egress Time (ASET).

See Section 3-7 of the SFPE Handbook of Fire Protection Engineering for further information. CFD

models take this much further and actually divide the space into thousands or millions of interconnected "cells" or "fields." The model then evaluates the fire dynamics and heat and mass in each individual cell and how it interacts with those adjacent to it. The use of such models becomes more accurate with more numerous and smaller cells but the computing power and expertise required is much higher than for zone models. As noted the use of either types of models can be advantageous but such use must be

undertaken by someone qualified. Proper review and verification of the input and output is critical. The most popular model in the area of CFD with regard to fire is the Fire Dynamics Simulator (FDS) developed by NIST. Other models such as Fluent are sometimes used (Fluent Inc.).

Depending upon the space being evaluated some design strategies may provide a better approach than others. Past editions of the IBC smoke control provisions for the exhaust method mandated the use of the algebraic methods
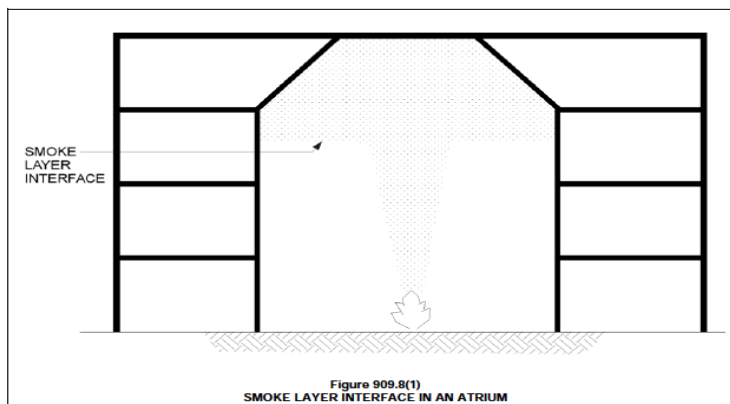
Figure 909.8(1)
SMOKE LAYER INTERFACE IN AN ATRIUM

with a steady fire. This of course also mandated a mechanical system be used whereas NFPA 92B allows an overall review of smoke layer movement and whether the design goals, which in this case are mandated by the code, can be met. Therefore, if it can be shown that the smoke layer interface can be held at the 6 feet (1829 mm) as mandated in Section 909.8.1 for the design operation time required by Section 909.4.6 without mechanical ventilation then the space would comply with Section 909. NFPA 92B presents several design approaches. This allows more flexibility in design than that found in previous editions of the IBC.

NFPA 92B as a standard does not set the minimum smoke layer interface height or duration for

system operation. Such criteria is found within Sections 909.8.1 and 909.4.6, respectively. See the commentary for those sections.

If the algebraic approach is used, consideration of three types of fire plumes may be required to determine which one is the most demanding in terms of smoke removal needs based upon the space being assessed. They include: Axisymmetric plumes— Smoke rises unimpeded by walls, balconies or similar projections [see Figure 909.8(2)].

Balcony spill plumes— Smoke flows under and around edges of a horizontal projection [see Figure 909.8(3)].

Window plumes—Smoke flows through an opening into a large-volume space [see Figure 909.8(4)].

It should be noted that prior to the reference to NFPA 92B in the code, the balcony spill and window plume calculations had been eliminated from the smoke control requirements of the code due to concerns with the applicability of those calculations. The major difference is that NFPA 92B does not mandate the use of such equations as did previous editions of the IBC. The use of such equations will depend upon the design fires agreed upon for the particular design and whether an algebraic approach is chosen. These equations are used to determine a mass flow rate of smoke to ultimately determine the required exhaust volume for that space. If the potential for a balcony or window spill plumes are known to exist within the space, then appropriate measures need to be

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taken to address these, as they typically result in more onerous exhaust and supply requirements. Part of the reason for the initial deletion of these equations was the fact that such scenarios are not as likely or their impact is significantly reduced in sprinklered buildings.

There is also some concern with the applicability of the balcony spill plume equation in a variety of applications. These potential fire scenarios and resulting plumes may further the need to undertake a CFD analysis to address such hazards more appropriately and effectively.

Another key aspect that NFPA 92B included within the algebraic methods is equations to determine that a minimum number

Figure 909.8(2)
AXISYMMETRICAL PLUME

Figure 909.8(3)
BALCONY SPILL PLUME
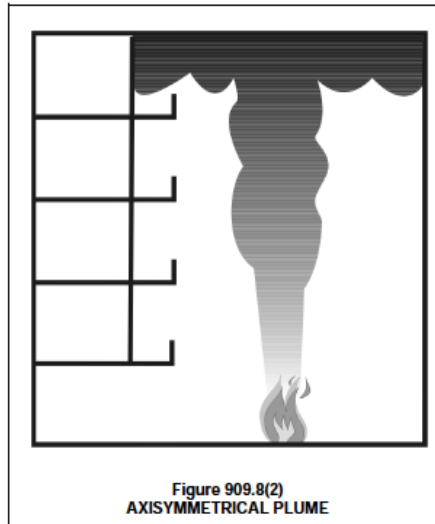
of exhaust inlets are available to prevent plugholing. Plugholing occurs when air from below the smoke layer is pulled through the smoke layer into the smoke exhaust inlets. As such, if plugholing occurs, some of the fan capacity is used to exhaust air rather than smoke and thus can affect the ability to maintain the smoke layer at or above the design height. Scale modeling and computer fire modeling would

demonstrate these potential problems during the testing and analysis, respectively [see Figure 909.8(5)].

It should be noted that this section specifically references NFPA 92B for the design of smoke control using the exhaust method. Therefore the requirements in NFPA 92B related to testing, documentation and maintenance would not be applicable though they may be a good resource.

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Figure 909.8(4)
WINDOW PLUME
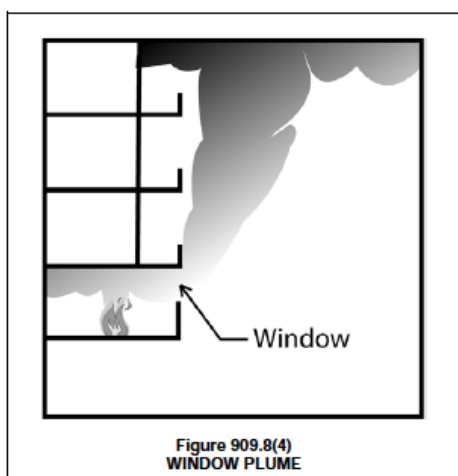
Equipment and controls would be part of the design; therefore, related provisions of NFPA 92B would apply. Generally the IBC addresses equipment and controls in a similar fashion.

909.8.1 Smoke layer. The height of the lowest horizontal surface of the smoke layer interface shall be maintained at least 6 feet (1829 mm) above any walking surface that forms a portion of a required egress system within the smoke zone.

♦The design criteria to be used when applying NFPA 92B is to maintain the smoke layer interface at least 6 feet (1829 mm) above any walking surface that is considered part of the required egress within the particular smoke zone, such as an atrium, for 20 minutes or 1.5 times the calculated egress time (see Section 909.4.6). Chapter 10 considers the majority of occupiable space as part of the means of egress system.

Also keep in mind that the criteria of 6 feet (1829 mm) does not apply just to the main floor surface of the mall or atrium but to any level where occupants may be exposed (for example, balconies) see Figure 909.8.1(1).

The code uses the terminology "lowest horizontal surface of the accumulating smoke layer interface."

NFPA 92B has several definitions related to smoke layer, which include the following:

Smoke layer. The accumulated thickness of smoke below a physical of
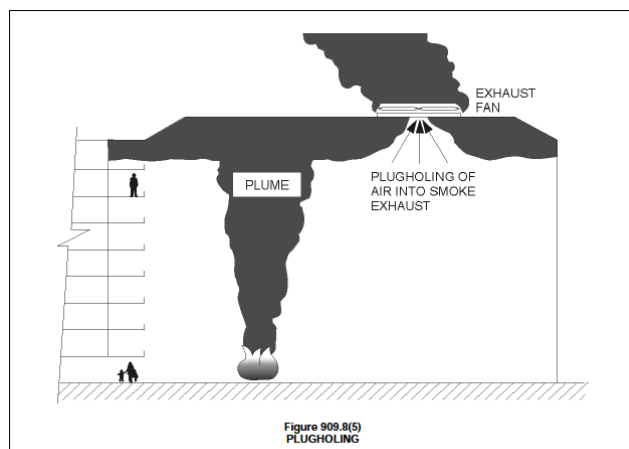
Figure 909.8(5)
PLUGHOLING

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thermal barrier.

Smoke layer interface. The theoretical boundary between a smoke layer and the smoke-free air.

(Note: This boundary is at the beginning of the transition zone.)

First indication of smoke. The boundary between the transition zone and the smoke-free air.

Transition zone. The layer between the smoke layer interface and the first indication of smoke in which the smoke layer temperature decreases to ambient.

The transition zone may be several feet thick (large open space) or may barely exist (small area with intense fire) [see also Figure 909.8.1(2)].

NFPA 92B provides algebraic equations to determine first indication

of smoke but is limited to very specific conditions such as a uniform cross section, specific aspect ratios, steady or unsteady fires and no smoke exhaust operating. When using algebraic equations for smoke layer interface looking at different types of plumes the smoke layer interface terminology is used and the user enters

Figure 909.8.1(2)
SMOKE LAYER INTERFACE

Figure 909.8.1(1)
EXAMPLE OF CRITICAL LEVEL OF SMOKE
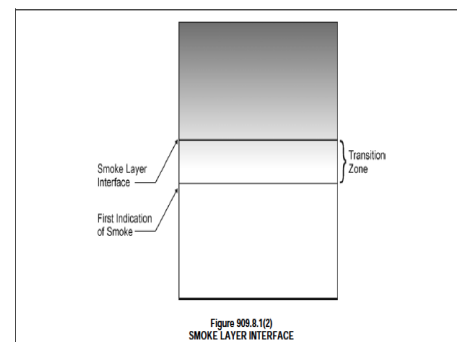
the desired smoke layer interface height. Zone models use simplifying assumptions so the layers are distinct from one another. In contrast, when CFD or scale modeling is used, the data must be analyzed to verify that the smoke layer interface is located at or above the 6 feet (1829 mm) during the event. This is not a simple analysis as CFD and scale modeling provide more detail on actual smoke behavior; therefore, the location of
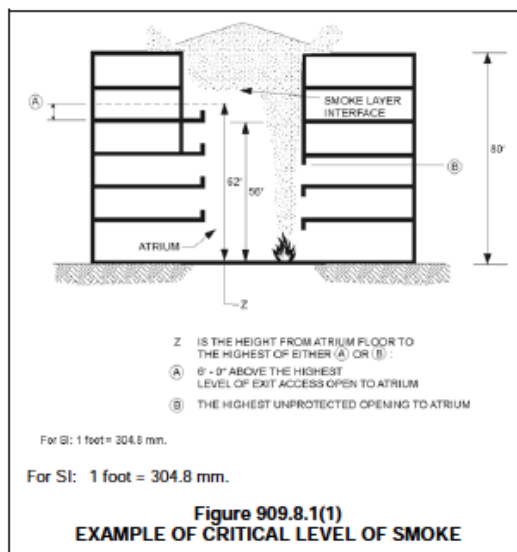
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the smoke layer interface may not be initially clear without some level of analysis. Again it depends on the depth of the transition layer. This may require reviewing tenability within the transition zone. Tenability limits need to be agreed upon by the stakeholders involved. Using CFD or scale modeling would likely need to occur through the alternative methods and materials section (Section 104.9) due to the need to review tenability limits. It should be noted that NFPA 92B Annex A suggests that there are methods to determine where the smoke layer interface and first indication of smoke are located when undertaking CFD and scale modeling using a limited number of point measurements.

Also, Section 909.8.1 specifies a minimum distance for the smoke layer interface from any walking surface whereas Section 4.5.3 of NFPA 92B has provisions that simply allows the analysis to demonstrate tenability regardless of where the layer height is located above the floor. Defining tenability can be more difficult as there is not a standard definition as to what is considered tenable. Any design using that approach would need to be addressed through Section 104.9.

Note that the response time of the system components (detection, activation, ramp up time, shutting down HVAC, opening/closing doors and dampers, etc.) needs to be accounted for when analyzing the location of the smoke layer interface in relation to the duration of operations stated in Section 909.4.6 (see commentary, Section 909.17).

Next Month:

909.9 Design fire. (page 419)

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