

SMOKE AND HEAT EXHAUST VENTILATION SYSTEMS IN ATRIUM BUILDINGS

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Abstract: Almost people hurt or die because of heavy smoke when the building fires. This is the reason that the current codes in many countries require that the smoke layer in an atrium be maintained above the highest means of egress in the space. The smoke exhaust capacity needed to maintain the smoke layer above the highest level of the means of egress can be substantial if that level is near the top of a tall atrium. In spite of this, there are a number of situations that may affect the effectiveness of a mechanical exhaust system used for atrium smoke management and make this problem to become a real puzzle.

Keywords: smoke and heat exhaust ventilation system, smoke management, clear layer height, plugholing, ceiling jet.

1. INTRODUCTION

Atria have become popular in commercial, office and residential buildings because they provide attractive, environmentally controlled and naturally lit spaces. Such spaces, however, present challenge for fire-protection engineers because of their height and the lack of floor-to-floor compartmentalization that, in other buildings, limits the likelihood of fire and smoke spreading from the floor of fire origin to the areas of building. Evacuation routes in atria are of concern because they become vulnerable to spreading smoke unless smoke management measures are used.

Design objectives. Some form of smoke control (known as smoke management in the USA) is often required in atrium buildings primarily for life safety purposes. The design objectives for smoke control systems in atrium buildings are:

- a) Maintain a tenable environment in the means of egress in the atrium during the time required for evacuation.
- b) Confine the smoke in the atrium to a limited region in the space.
- c) Limit the migration of smoke into adjacent spaces from the atrium.
- d) Provide conditions in the atrium that will assist emergency response personnel in conducting search-and-rescue operations and locating and controlling the fire.
- e) Contribute to the overall protection of life and reduction in property loss.

A design may be to achieve either one, or a combination of, these objectives. Also we meet a number of “hazard parameters” in which the design objectives can be evaluated in measurable terms, such as:

- Smoke layer depth
- Visibility through the smoke layer
- Carbon monoxide concentration

An acceptable smoke control system is one which maintains the hazard parameter(s) of concern to within acceptable levels.

2. SMOKE CONTROL STRATEGIES

There are a number of different smoke control strategies available for atrium buildings such as:

- Smoke filling

This approach can be applied to atria which have large volumes, such that smoke ventilation may not be necessary. This strategy becomes viable when smoke can be contained in a roof void for the duration of the required safe egress time for the occupants of the building. In this case, the height of the smoke layer may not reach an unacceptable value before the fire consumes the available fuel. This approach assumes that the fire grows at a predictable rate. This strategy should only be used if the smoke control designer can demonstrate by calculation that smoke ventilation is not necessary.

- Smoke clearance

This approach provides sufficient ventilation to remove smoke from the atrium after the fire has been suppressed.

- Smoke and heat exhaust ventilation from the atrium

This uses the buoyancy of the smoky gases from the fire to form a layer above the occupants of the building, providing a safe means of escape. This form of smoke control provides the main focus for this work and is described in detail in the following section.

- Temperature control ventilation from the atrium

This strategy is used when the height of the smoke layer above the floor is not a critical design parameter. In this case, smoke exhaust can be used to achieve a maximum value of the temperature of the layer of smoky gases. This approach allows the use of materials which would otherwise be damaged by hot gases (e.g. atrium façade materials which are not fire-resisting).

- Smoke and heat exhaust from each storey separately

In some cases it may be impractical to provide smoke exhaust ventilation from the atrium space if the height of rise of the smoke layer from the floor is too large. It may be beneficial to prevent smoke from entering the atrium altogether (particularly for fully open atria). This can be achieved by the use of strategically placed smoke curtains around the atrium space at each storey, and providing smoke exhaust ventilation from each storey separately.

- Atrium depressurization

Where the boundary between the atrium space and the adjacent areas is linked by small openings (e.g. doors gaps, leaky façade), it is possible to prevent smoke from traveling through these openings by reducing the pressure of the gases in the smoke layer. This approach is known as depressurization. The purpose of this technique is to prevent smoke from traveling into the adjacent spaces and does not provide protection to the atrium space. This technique is similar to that employed for natural environmental ventilation in atrium buildings.

- Combination of above strategies (hybrid smoke control)

Various combinations of the above strategies can also be applied, such as atrium depressurization with smoke and heat exhaust ventilation.

3. SMOKE AND HEAT EXHAUST VENTILATION SYSTEMS (SHEVS)

The primary focus of this work concerns Smoke and Heat Exhaust Ventilation Systems (SHEVS) for atrium buildings. This approach provides smoke and heat exhaust from the upper regions of a building to create a clear layer beneath a buoyant stratified smoke layer, thus providing conditions for safe means of escape. For this approach to be effective, it is necessary for the temperature of the gas layer to be high enough to remain buoyant when at the design height. SHEVS may be naturally driven (due to buoyancy of the gases produced from the fire) or mechanically driven (mechanical exhaust fans).

Figure 1 shows the general principle of smoke and heat exhaust ventilation. When designing a SHEVS, an appropriate fire must be specified for the building and its contents. In general, it is necessary to ensure that the size of the fire does not become too large so that the SHEVS does not perform effectively. Therefore, as part of the design strategy, it is often necessary to include the use of sprinklers to control the size of the fire. Smoke from a fire will rise as a plume which will subsequently entrain air. This entrainment will significantly increase the volume of smoky gases produced. The hot gases rise and form a buoyant layer within the enclosure. Smoke and heat will exhaust from the ventilators in the roof of the enclosure either by natural or mechanical means. The hot gas layer will deepen until equilibrium is reached between the quantity of gases being ventilated and the quantity of gases entering the layer. For the smoke ventilation to be effective, it is necessary to provide an adequate amount of inlet air to replace the hot gases being removed.

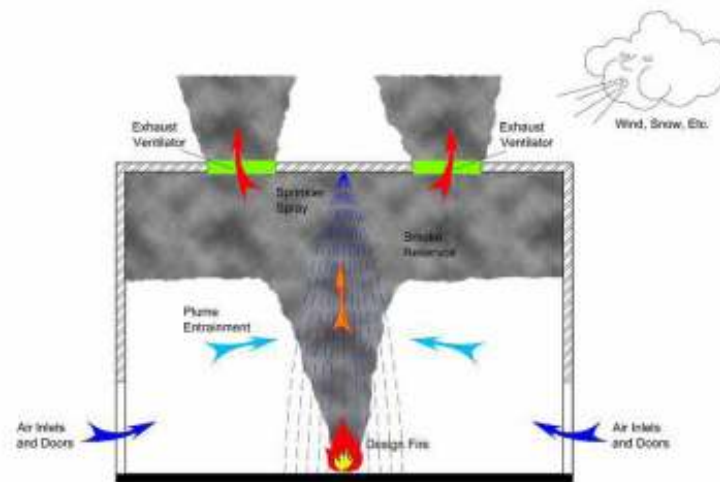


Fig. 1: Principle of a SHEVS

The performance of SHEVS can depend on various factors such as:

- Temperature of the smoke layer
- Aerodynamic free area of natural ventilators/volume of smoke exhausted by mechanical fans
- Wind effects
- Geometry, size and location of inlet air openings
- Geometry, size and location of the smoke reservoir

SHEVS provides the safe use of escape routes which are in the same space as the fire. The amount of smoke exhaust must be calculated to ensure that the smoke layer is at a safe height above the occupants using these escape routes. In addition to providing conditions for safe means for escape, SHEVS also provide improved conditions for effective fire-fighting operations, which in turn can provide improved.

2.1. CLEAR LAYER HEIGHT

When considering life safety, a critical design parameter of SHEVS is the clear layer height. The clear layer height is the height between the level of the fire and the base of the buoyant smoke layer in the atrium. The design clear layer height will usually provide a layer with a safe height above the highest egress route. Figure 2 shows a schematic drawing of a design clear layer height for a multi-storey atrium. This clear layer height will provide a tenable environment for safe egress for the duration of the fire (provided the design fire is not exceeded).

Some national standards provide factors which must be taken into consideration (depending on the design objectives) when identifying a design clear layer height, such as:

- Location of means of egress within the open space
- Separation of adjacent spaces from the open space
- Environmental and geometric factors

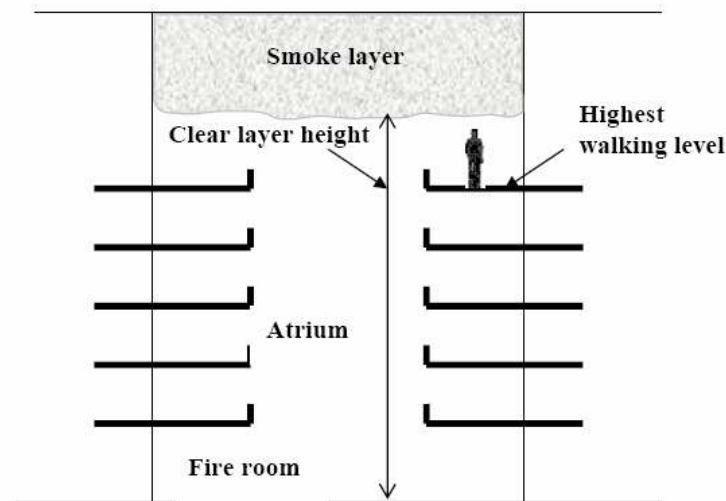


Fig. 2: Clear layer height above highest walking level

To sum up, guidance on the recommended clear layer height for SHEVS varies worldwide.

NFPA 101 states that "a clear layer height of 1.85 m must be achieved above the highest floor level of exit access open to the atrium for a period of 1.5 times the calculated egress time, or 20 minutes, whichever is the greater". Current guidance in the UK recommends a minimum clear height depending on the type of building (see Table).

Recommended clear layer heights in the UK. Table 1

Type of building	Minimum clear height (m)
Public buildings (e.g. covered shopping malls)	3.0
Non public buildings (e.g. offices, apartments)	2.5

Where the predicted smoke layer temperature is less than 50°C above ambient temperature, the minimum clear heights shown in Table should be increased by 0.5 m, as the smoke layer interface may not be well defined. The current guidance within New Zealand recommends a clear layer height of at least 2.0 m above the highest intermediate floor open to an atrium space.

2.2. ATRIUM SMOKE EXHAUST EFFECTIVENESS

There are a number of situations that may affect 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:

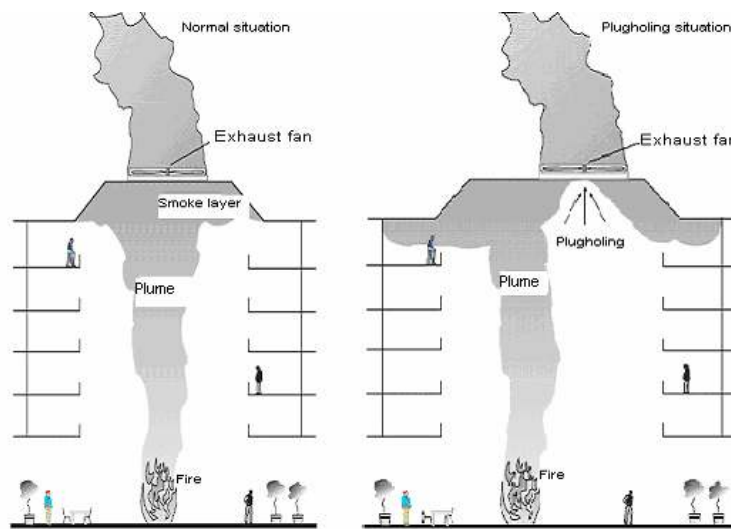


Figure 2: Plugholing of atrium smoke exhaust

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. 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. 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. In addition to the plugholing phenomena, the ceiling jet produced when the smoke plume hits the ceiling can also impact the effectiveness of a mechanical smoke venting system. NFPA 92B (2000) recommends that the smoke layer depth below the ceiling must be deep enough to accommodate the ceiling jet. To achieve this, it is recommended that the smoke exhaust systems be designed assuming a minimum smoke layer depth of 10 to 20% of the floor-to-ceiling height.

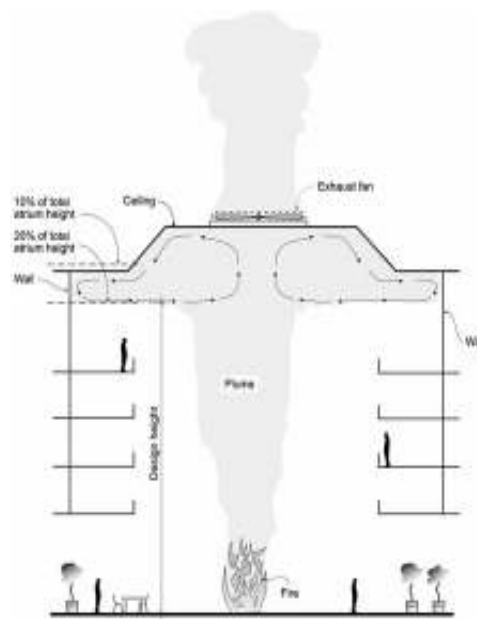


Fig. 3: Ceiling jet of atrium smoke exhaust

3. CONCLUSIONS

For atria smoke management designs in which the smoke layer depth below the ceiling is limited, the impact of plugholing and the ceiling jet must be considered to ensure building occupants will not be exposed to smoke. In addition, algebraic equations are available in NFPA 92B for assessing the conditions in the smoke layer (temperature, smoke optical density and toxic specie concentrations). For high atria in which a large exhaust capacity is required, the smoke and toxic concentrations can be comparable to or lower than the limits typically used for hazard assessments.

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