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# ANALYSIS OF SMOKE MOVEMENT IN A BUILDING VIA ELEVATOR SHAFTS

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# EXECUTIVE SUMMARY

Several code change proposals, which address the reduction of smoke migration throughout buildings, have been submitted to the International Building Code (IBC). These proposed changes will be discussed in Birmingham during the April 2000 International Code Council (ICC) Code Hearings.

Of specific interest are Code Proposals FS13-00, FS17-00 and FS18-00. These proposals address the movement of smoke throughout a building via the elevator shafts or hoistways. This report provides a technical rationale that supports the adoption of these proposed changes.

Smoke movement throughout a building is an important life safety issue in the event of a fire. In the U.S., most fire victims are remote from the fire and thus are killed due to the toxic effects of smoke. The subject of smoke movement throughout a building has been studied; however, the IBC 2000 does not adequately address the migration of smoke throughout the entire building.

One important area that contributes to the movement of smoke is in the elevator shafts. Due to smoke entering and exiting the shafts, and combined with "stack effect," smoke can migrate to the upper floors of a building very rapidly.

The analysis described in this report models smoke movement throughout a building with elevator doors with normal leakage areas and with reduced leakage areas (per the above code proposals).

The results of the model simulations show that the leakage area of the elevator doors is the primary factor in allowing smoke to migrate to upper floors in a building. If the leakage area of the elevator doors is controlled to the reduced levels, then a three-fold increase in visibility can be attained on the upper floors of a typical multistory building. This increase in visibility occurred in all of the simulations (sprinklered as well as unsprinklered).

This three-fold increase in visibility can provide a significant measure of increased life safety to the occupants of the building in the event of a fire, especially to those on the upper floors remote from the fire.

# ANALYSIS OF SMOKE MOVEMENT IN A BUILDING VIA ELEVATOR SHAFTS

## 1.0 INTRODUCTION

Several code change proposals, which address the reduction of smoke migration throughout buildings, have been submitted to the International Building Code (IBC). These proposed changes will be discussed in Birmingham, AL during the April 2000 International Code Council (ICC) Code Hearings.

Of specific interest are Code proposals FS13-00, FS17-00 and FS18-00. These proposals address the movement of smoke throughout a building via the elevator shafts or hoistways. This report provides a technical rationale that supports the adoption of these proposed changes.

## 2.0 BACKGROUND

It is a documented fact that smoke kills approximately 75 percent of the fire victims in the United States. These fire deaths occur in areas remote from the room of fire origin and are due to the toxic effects of the smoke as it migrates throughout a building [1].

Smoke movement throughout a building is, therefore, an important issue with respect to the life safety of people who are in a building when a fire occurs. It also greatly impacts the firefighting efforts both in search and rescue as well as the attack on the fire.

The subject of smoke movement has been studied, and some regulations aimed at limiting smoke movement within a building have been promulgated [2,3]. These regulations have typically focused on limiting smoke movement in areas of egress, both vertically (i.e., stairs) or horizontally (i.e., corridors).

While this approach mitigates some of the smoke movement problems in certain areas of a building, it does not resolve the overall issue of smoke migration throughout a building. This remains an important issue especially for the life safety of people who either cannot or do not immediately evacuate a building. To resolve this problem, an integrated, whole building approach to smoke management must be developed. This will involve the use of both active as well as passive smoke management systems in the design of buildings.

Over the last few years, an increased reliance on the efficacy of sprinkler systems has resulted in significant tradeoffs being allowed when sprinklers are present. With respect to smoke movement, one of the primary arguments in support of these tradeoffs has been that sprinklers will prevent significant quantities of smoke from being generated. This assumes that the sprinkler system will perform in a manner such that the fire is essentially extinguished at a very early stage in its growth history. While this assumption may be appropriate for many fires, it is not appropriate for all fires [4]. In fact, in the light of recent sprinkler head recalls and concerns over the reliability of these systems, it is readily apparent that a more balanced approach must be taken with respect to the overall fire protection in buildings [5]. Since sprinklers are designed to contain fires and prevent flashover and may not immediately extinguish a fire, then the issue of smoke migration throughout a building becomes very important. It is known that large quantities of smoke can be generated by an uncontrolled fire, but it has also been demonstrated that large quantities of smoke can be generated by a controlled fire [6]. In the interest of safety, a single mode failure should not expose building occupants to a significant fire and smoke threat.

While currently mandated smoke management systems may address several areas within a building; one of the greatest potential areas for smoke migration is not adequately addressed. Elevator hoistway shafts provide excellent paths for smoke movement throughout a building. These areas, in conjunction with the "stack effect," can act as chimneys and thus move smoke to all areas of a building.

In the IBC, if sprinkler systems are installed in a building in accordance with the appropriate section of the Code, then smoke movement via elevator hoistways is virtually ignored. The movement of smoke into and out of elevator hoistways is controlled by many factors, but the most significant is the "leakage" that occurs due to gaps around the elevator doors and the supporting construction. It has been postulated that if the leakage into and out of the hoistways is reduced and controlled, then significant reductions in smoke movement throughout the building can be attained. The analysis provided herein addresses the vertical movement of smoke via elevator hoistways that have normal and reduced leakage rates.

## 3.0 ANALYSIS

In order to investigate smoke movement through a building with normal and reduced leakage areas around elevator shafts, a typical building was developed. Smoke movement modeling was then performed using CONTAM96 [7].

### 3.1 Model Information

CONTAM96 [7] is a mathematical network model used to analyze the spread of contamination throughout a building. This contamination spread is based on the model's ability to predict air flows and pressure differences through the spaces in a building. A building is viewed as a number of spaces, with relationships to other spaces characterized as flow paths between the spaces. The model averages the conditions within a specific space, yielding uniform conditions through the entire space.

To calculate the desired airflows and pressure differences, CONTAM96 requires three types of inputs. The first is the volume of the various spaces (called zones within the model), and this is used to determine contamination concentrations. The second input is the leakage areas between the zones of the model. These leakage areas determine the air flows and pressure differences that the model will predict. The leakage areas can range from large openings such as open doors and open areas, to very small ones such as cracks and penetrations in walls. The third input is the operation of any building HVAC systems. If present and operating, these will affect the airflow and pressurization in the building.

## 3.2 Building Details

A 10-story building was used in this analysis. The floor plan of the building was 120 ft x 240 ft, with a floor to floor height of 12 ft. The floor plan at each level contained three sets of stairs and two double elevator shafts. At floors 2 through 10, a lobby area was included around the elevator shafts. Beyond these spaces, the rest of the floor plan remained open.

Four 8 ft x 8 ft elevators were provided. These were located in two elevator shafts, each 128 $ft^2$, in plan, in what could be considered a typical "central core" arrangement. In floors 2 through 10, a lobby (1,120 $ft^2$, in plan) was placed around the central core. The stair shafts (each 180 $ft^2$, in plan) were located throughout the building footprint.

## 3.3 Temperature Details

Temperatures of 0°F and 70°F were used for ambient outdoor and building temperatures, respectively. On the fire floor (1st floor), the temperature of the room of fire origin was varied depending on whether the fire was sprinklered controlled or not. For sprinkler controlled fires, a temperature of 122°F was selected while in uncontrolled fires a temperature of 1472°F was selected.

CONTAM96 models the impact of temperature differences between building compartments on the flow between those compartments. However, zone temperatures are specified rather than being dynamically determined.

## 3.4 Building Leakage Paths

Building leakage was addressed for the following leakage paths:

- Exterior walls,
- Floors,
- Elevator shaft walls,
- Stair shaft walls,
- Elevator shaft vents in accordance with IBC,

- Window opening on the fire floor, and
- Door opening from the lobby to the rest of the floor.

Table 1 provides a summary of all of the leakage paths that were used in the model and their respective leakage values. These leakage characteristics are intended to represent average building conditions and are based on literature information [8].

Table 1. Summary of Building Leakage Values

| Leakage Name | Leakage Path | Leakage Area |
|---|---|---|
| Building Envelope | Exterior Building walls to the outside | $0.42 \times 10^{-3}$ ft$^2$/ft$^2$ |
| Floors | Interior building floors between levels | $0.17 \times 10^{-3}$ ft$^2$/ft$^2$ |
| Tight Elevator Door per FS 13-00 | 3 cfm/ft$^2$ of elevator door area | 0.102 ft$^2$ |
| Leaky Elevator Door | 40.5 cfm/ft$^2$ of elevator door area | 1.375 ft$^2$ |
| Elevator Shaft Walls | Elevator shaft to floor area or lobby. | $0.18 \times 10^{-2}$ ft$^2$/ft$^2$ |
| Stair Shaft Walls | Stair shaft to rest of floor area. | $0.35 \times 10^{-3}$ ft$^2$/ft$^2$ |
| Interior Walls | Lobby to rest of floor area. | $0.11 \times 10^{-2}$ ft$^2$/ft$^2$ |
| Door opening | Lobby to rest of floor area. | 17.5 ft$^2$ |
| Window opening | Broken window on fire floor | 12 ft$^2$ |
| Elevator Vent per IBC w/Sprinklers | None | 0 |
| Elevator Vent per IBC | The larger of 3.5% of shaft area, or 3ft$^2$ per elevator car | 6 ft$^2$ |

Note: Elevator door is 7 ft x 4 ft.

### 3.5 Fire Source

CONTAM96 is an excellent model for tracking contaminant movement within buildings. The fire is considered as a source of contaminant supply, and CONTAM96 applies ideal gas laws to their physical properties. For the scenarios in question, a constant contaminant generation rate of 0.04 kg/s was used. Visibility distances in the fire compartment were also evaluated to assure realistic results.

### 3.6 Criteria

The results of the model report the level of contamination as a concentration. To use this value in a meaningful way, the concentration is calculated to provide a visibility distance using the following equation [9]:

$$V_i = \frac{C_{vk}}{(2.3\, D_m\, M_i)}$$

where $V_i$ = visibility distance in zone I at time x (ft),
$C_{vk}$ = constant of proportionality equals 8 for backlighted exit signs [10],
$D_m$ = mass optical density of smoke (1485 ft$^2$/lb (0.3 m$^2$/g), and

$M_i$ = portion of total mass burned resident in zone I at time x (lb).

This visibility distance is based on the capability of a person to visually see a backlighted exit sign. Generally, the acceptable visibility distance is 30 ft. This value is indicative of a hazardous condition that may impair escape from an area [11]. Thus, in this analysis, a criterion of 30 ft was selected as the acceptance criterion. Visibility distances were determined via the model and compared to this criterion.

### 3.7 Variables

In this analysis, two sets of variables were evaluated:

- A fire in an non-sprinklered condition versus a sprinklered fire that is controlled but not extinguished, and

- Leakage rates for the elevator doors that are defined as
  - Leaky Elevator – 40.5 cfm/ft$^2$ of elevator door area (typical elevator leakage) and
  - Tight Elevator – 3 cfm/ft$^2$ of elevator door area (IBC proposal FS 13-00).

## 4.0 RESULTS

Simulations were run for a 20-minute duration. Tables 2 and 3 provide a summary of the model simulations. In the runs described in Table 2, the elevator hoistways are vented as required by the IBC. In the runs described in Table 3, however, the elevator hoistways are not vented as allowed by the IBC when sprinklers are present.

Table 2. Visibility Distances on the 10$^{th}$ Floor at 20 minutes – Elevator Hoistway Vented per IBC

| Visibility - Top Floor Lobby (ft) | | | |
|---|---|---|---|
| Leaky Elevator Shaft | | Tight Elevator Shaft | |
| Sprinklered | Non-sprinklered | Sprinklered | Non-sprinklered |
| 28 | 19 | 85 | 60 |

Table 3. Visibility Distances on the 10$^{th}$ Floor at 20 minutes – Elevator Hoistway Not Vented per IBC

| Visibility - Top Floor Lobby (ft) | | | |
|---|---|---|---|
| Leaky Elevator Shaft | | Tight Elevator Shaft | |
| Sprinklered | Non-sprinklered | Sprinklered | Non-sprinklered |
| 24 | 15 | 69 | 49 |

Visibility distances within the compartment of fire origin were between 1.8 and 4.5 ft at steady state. The range of distances was due to the dilution caused by the different airflows into the compartment.

The 20-minute duration did not allow for steady state conditions in the upper floors to occur. This means that the concentration of smoke continues to increase and will not attain steady state until after 20 minutes. In order to investigate conditions at steady state, additional simulations were run for a 200-minute duration. The simulations show that at steady state conditions, the visibility distance is approximately 10 ft in all of the scenarios examined.

## 5.0 DISCUSSION

Assume that the building under consideration is sprinklered and meets the current IBC requirements for smoke movement through elevator shafts. If a fire occurs which is immediately controlled but not extinguished, then the model indicates that the visibility distance on the $10^{th}$ floor will be less than 30 ft within 20 minutes. If, however, the elevator shafts were protected as proposed in FS 13-00 (i.e., tight construction), then the visibility distance on the $10^{th}$ floor would be 85 ft. This means that if the elevator shafts were "tighter" with respect to air leakage through the elevator doors, a three-fold increase in visibility distance would be attained.

This three-fold increase in visibility distance would occur even if the elevator shafts were not vented as is allowed by the Code in sprinklered buildings. Also, if the building were not sprinklered, the three-fold increase in visibility distance (15 versus 49 ft) would still occur. Of course, visibility distances in the non-sprinklered cases are significantly less than those attained in the sprinklered cases. It should be noted, however, that in all cases, the "tight" elevator doors always provided a visibility distance greater than 30 ft.

Figures 1 and 2 provide schematics of the air flows and visibility distances for the results in Table 2. As shown, the stack effect and the temperature of the smoke allow the vertical movement of smoke in the elevator shaft. The leakage area of the elevator is the primary controlling factor with respect to the smoke migration into the upper floors. If less smoke can enter or exit the elevator shaft then less smoke will appear in the upper floors.

## 6.0 SUMMARY

The results of the model simulations show that the leakage rate of the elevator doors is the primary factor in allowing smoke to migrate to upper floors in a building. If the leakage rate of the elevator doors is controlled to the “tight” levels, then a three-fold increase in visibility can be attained in a ten-story building. This increase in visibility occurred in all of the simulations.

This three-fold increase in visibility can provide a significant measure of increased life safety to the occupants of the building in the event of a fire, especially to those in the upper floors.

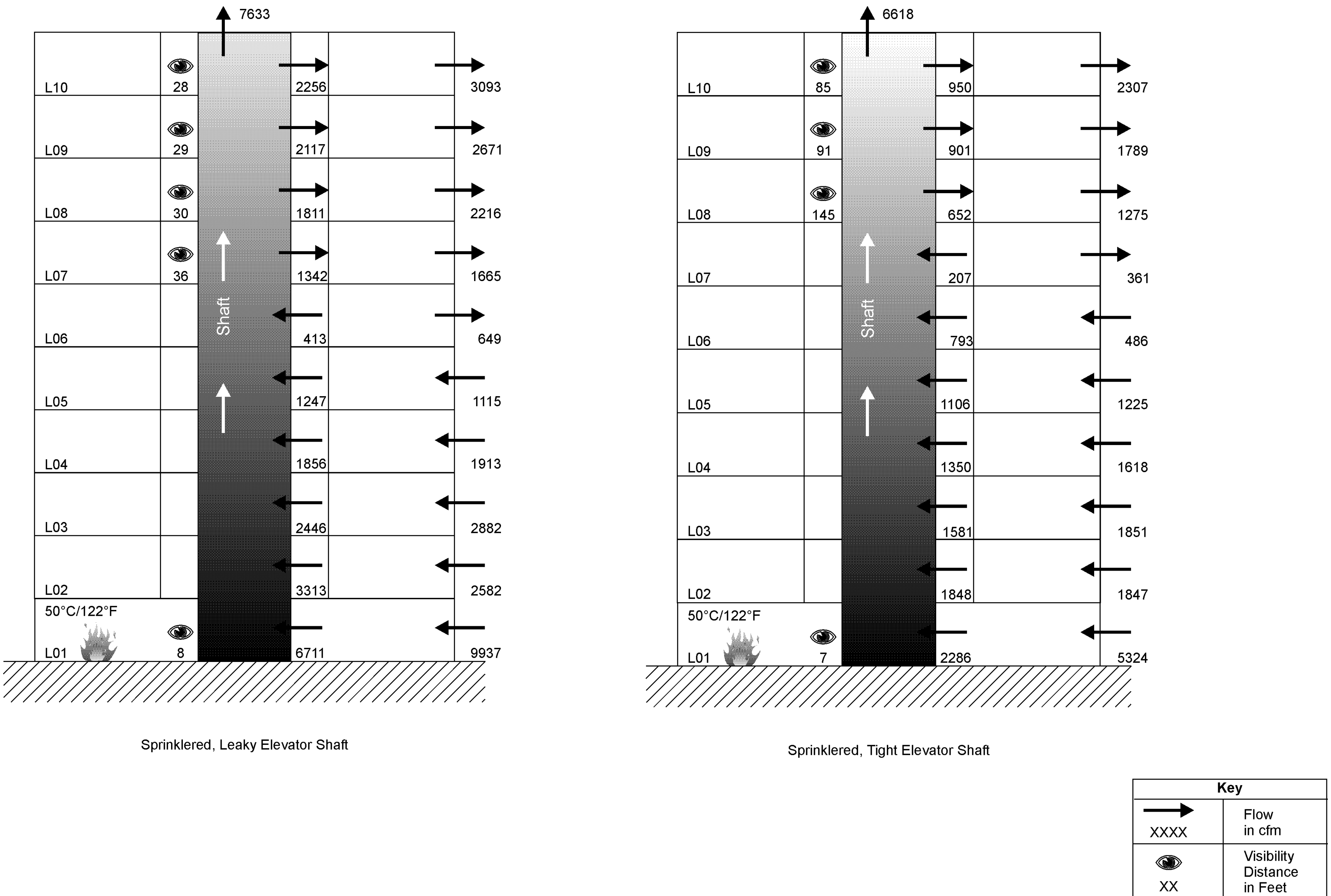


Figure 1. Visibility distances on the 10th Floor at 20 minutes – Elevator Hoistway Vented per IBC (sprinklered)

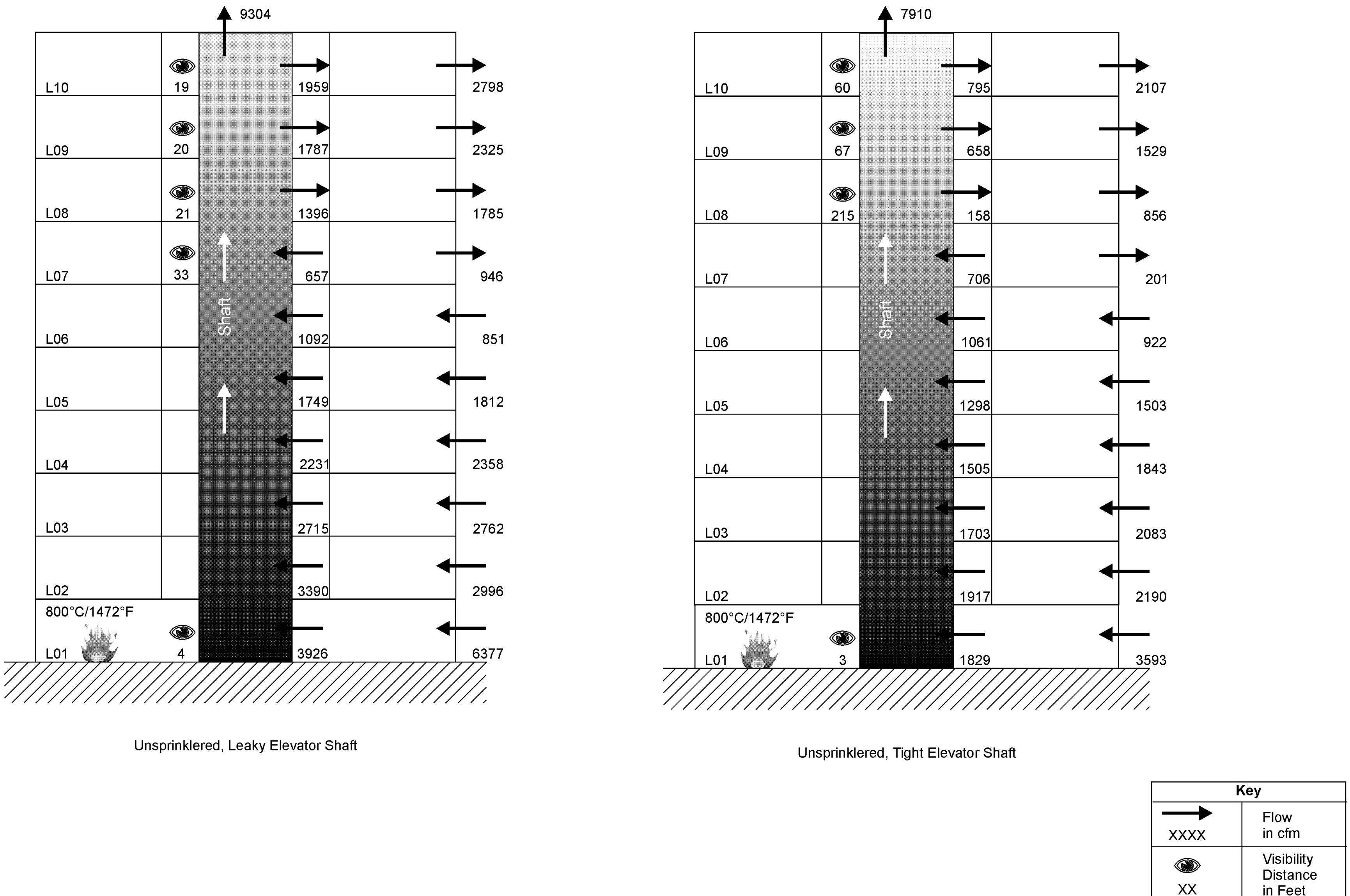


Figure 2. Visibility distances on the 10th Floor at 20 minutes – Elevator Hoistway Vented per IBC (Non-sprinklered)

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