Smoke Control - Elevator Lobbies

An Online Continuing Education Course for Engineers

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Introduction

The issue of smoke migration through elevator lobbies is receiving significant attention in the building code arena. Proposals to modify existing elevator enclosure requirements have been submitted to the International Code Council for possible inclusion in the International Building Code [1]. In addition, modifications to *NFPA 5000®*, *Building Construction and Safety Code* [2], are being considered by the various National Fire Protection Association (NFPA) technical committees responsible for the document.

In some code provisions, elevator lobby protection is being required in buildings that would otherwise have unprotected corridors as a result of complete sprinkler protection. Some proponents of elevator lobby enclosures indicate as much as 80 % of the smoke spread in buildings is through the elevator shafts. Therefore, elevator lobby protection (i.e., enclosures) would ensure that smoke migration through a building is minimal, even if the building is protected throughout by automatic sprinklers.

Additionally, it has been suggested that protected elevator lobbies would provide staging areas for fire department operations, disabled occupants, and possibly building tenants. The potential use of elevators as a component of the emergency egress system is also being discussed. Opponents indicate that the elevator lobby protection provisions are costly and would provide little if any additional safety.

This course presents the results of a literature review conducted to identify existing research related to smoke movement through elevator shafts and protection of these shafts.

The results of the survey are organized into the following categories: smoke movement research, occupant and fire fighter usage, and analysis software. While a significant effort has been expended to discover the major body of work related to elevators and smoke movement, it should not be assumed that every article or research activity related to elevators has been identified. Major work that has not been identified should be brought to the attention of the author.

Smoke Movement Studies

Tests Conducted Without Sprinkler Protection

In the mid-1960's, the spread of smoke, especially in high rise buildings, started receiving considerable attention. The desire to control the spread of smoke from a fire led to research being conducted in the United States, Canada, England, Japan, Australia, France, and West Germany. This research consisted of full-scale tests, field studies, and computer simulations [3].
In addition, some buildings were constructed with various innovative fire protection features as a means to test "smoke control systems."

Some of the earliest studies were conducted in a four story building in Switzerland by Cerberus AG [4]. In these tests, wood and other cellulose-based materials were used for flaming and smoldering tests. One conclusion developed from the tests is the effectiveness of closed doors. The authors' state "closed rooms are protected adequately for a long time from the effects of smoke." In 1968, researchers at the National Research Council in Canada (NRCC) identified some of the major issues associated with smoke and fire in high rise buildings, specifically evacuation, fire fighting, and smoke control [5]. The authors suggest that due to the significant time required to walk up and down stairs in a high rise "it seems unreasonable to continue to forbid the use of elevators during fire emergencies." "Ways must be found so that they can be used safely in the hands of the fire brigade, both for fire fighting and for controlled evacuation."

A paper by M. Galbreath of the National Research Council of Canada also suggests the possibility of using elevators for emergency evacuation [6].

In their book titled Smoke Control in Fire Safety Design [7], Butcher and Parnell cite several examples of "case histories demonstrating rapid vertical smoke movement through buildings". In one example, a fire occurred in an electrical panel located in the second basement of a reinforced concrete airport building. The building was six stories high with two basement levels. Unsealed cable shafts and open stairways allowed the smoke and fire to spread throughout the building resulting in fire damage to approximately 6000 m^2 (64,580 ft^2) and another 30,000 m^2 (322,900 ft^2) damaged by smoke. A second example describes a fire that occurred in a fifty story high rise building in New York City. The fire started in a concealed space on the 32^{nd} floor and spread rapidly due to the presence of plastic materials and the failure of some smoke dampers. The fire resulted in 2 deaths, 30 injuries, and 10 million dollars damage. This fire demonstrated the dangers of transmission of fire from floor to floor, the potential for smoke distribution throughout a building, the failure of elevators, and difficulties in venting fire gases. A third fire in a 21 story high rise, located in Seoul, South Korea, killed 163 people. According to a report by the National Fire Protection Association, the fire and smoke traveled up vertical shafts and ducting igniting items on the upper floors [8]. The fire then burned from the lower three floors and the upper floor towards the middle floors of the building.

Other notable fires in high rise buildings have reportedly demonstrated that elevator shafts and lobbies represent a significant path for smoke travel. A fire in the MGM Grand Hotel in Las Vegas, Nevada killed 85 people with 61 of the fatalities occurring on the 16^{th} through 26^{th} floors [9]. In addition to seismic joints, interior stairways, and building service penetrations, the elevator hoistways provided a major avenue for smoke travel. Open elevator doors on the casino level and the failure of two hoist cables augmented the smoke travel. The air handling system continued to operate during the fire which spread smoke to guest rooms on the upper floors. A fire in the Inn on the Park Hotel in North York, Ontario again demonstrated the potential for smoke to spread through elevator shafts. The doors to two elevator cars were open on the fire floor which allowed smoke to travel from the 6^{th} to the 22^{nd} floor [10]. The service elevator, which served the ground through 62^{nd} floor of the First Interstate Bank Building in Los Angeles, California, served as a major avenue of smoke travel when a fire occurred in that building [11]. Based on smoke detector activation times, it was determined that smoke spread from the fire on the 12^{th} floor to the upper floors in a matter of minutes.

Several factors have been identified as influencing the movement of smoke and hot gases from a fire [12]. Smoke can move as a result of the buoyancy difference between the hot smoke and the ambient air. Smoke also moves due to the expansion of the hot gases. In a building, smoke movement can be influenced by "stack effect", the pressure differential created by the temperature difference between the air inside the building and that outside the building. Wind can significantly influence the movement of smoke in a building. Finally, the mechanical air handling equipment can control where smoke moves in a building. In an effort to develop methodologies for controlling the spread of smoke, researchers have conducted numerous experiments designed to measure the various pressure differences generated by these fire phenomena.

The pressures developed above a fire have been measured by several researchers [13, 14]. The pressure increases with increasing gas temperature and distance above the neutral plane. The neutral plane is a location in an opening above which hot fire gases flow away from the source of the fire and below which cold ambient air flows into the fire area. This flow is caused by a pressure difference across the opening. The height of the neutral plane is the point where the pressure difference is zero. With regard to smoke control, the pressures generated in the immediate vicinity of the fire primarily impact roof venting systems used in single story buildings [15]. A significant quantity of research has been conducted on controlling smoke movement and protecting egress paths in single and multi story shopping malls using roof vents [16-25]. A majority of this research focuses on the vent sizes and numbers of vents required to remove enough smoke to maintain the smoke layer height at an acceptable level. Additional information has been developed regarding the rate of extraction of smoke required when using mechanical ventilation [26].

The concept of using pressurization to control smoke originated in the late 1950's [7]. However, research into the use of pressurization and its impact on smoke flow did not start until the mid to late 1960's. In 1964, the Fire Research Station in England conducted a series of four experiments in a new three story department store to examine the feasibility of using pressurization to control smoke [27]. The experiments used a single fan, with a rated flow of 1.4 m^3/s (3000 ft^3/min), located at the top of the stairs to provide the pressurization. Smoke was generated using a specially designed apparatus capable of producing smoke from the controlled combustion of various cellulosic materials. However, the apparatus did not produce smoke in quantity or temperature typically found in building fires. From the tests, it was concluded that an excess pressure of 12.5 Pa would keep areas sufficiently free of smoke and allow the occasional opening of some doors.

Another series of experiments was conducted by the Fire Research Station at Borehamwood, England using a 4 story test building [28]. The building had a single stair leading to an adjacent room on each floor. Two fans connected to a series of ducts could be used to pressurize the stair. The smoke source was burning wood cribs located in the first floor room adjacent to the stair. Several issues were examined as part of the experimental work. First, the pressure developed at the top of a normal door, 2 m (6.5 ft) above the floor, was measured and found to reach a limiting value of 6 Pa for the experimental conditions. A second part of the study dealt with examining the impact of weather conditions by conducting a series of experiments during the winter months. The maximum pressure differential measured between the fire room and the stair was 12.5 Pa. The third part of the study measured the airflow across the door and the associated pressure differential. It was found that a flow of 0.075 m^3/s (160 ft^3/min) produced a pressure differential of 50 Pa. The fourth part of the study investigated the effectiveness of pressurization to control smoke. Using the wood crib fire source and no pressurization, the stair became completely smoke filled in 11 min, flames penetrated into the stair in 18 min, and the door failed at 25 min. With a pressure difference of 50 Pa, there was no penetration of smoke into the stair.

Nayuki and Kuroda performed tests in a model of a smoke-proof tower in 1970 [29]. The model was 0.3 m (1 ft) by 0.3 m (1 ft) by 1.8 m (5.9 ft) high with a Ni-Chrome wire heater located at the bottom. Air was allowed to enter on one side near the bottom. Measurements of temperature and velocity were taken at the inlet and the outlet at the top. Initial velocities due solely to the starting of the heater were 0.5 to 1.2 m/s (1.6 to 3.9 ft/s). From this work, equations for estimating velocities in the smoke-proof enclosure were developed.

In the summer of 1972, a series of full scale fire tests was conducted in a 22 story office building located in New York City [30]. A large fan, approximately 18.9 m^3/s (40,000 ft^3/min), was placed at the bottom of a stair shaft for pressurization while a smaller fan, approximately 4.7 m^3/s (10,000 ft^3/min), was installed at the top of the shaft to provide smoke exhaust. With all doors closed, a pressure differential of 75 Pa could be obtained at the top of the stairs with a difference of 250 Pa at the bottom of the stair, and a differential of 75 Pa at the bottom would yield a difference of 20 Pa at the top of the stair. A series of four tests were performed using typical office furnishings and other combustible materials distributed in rooms of various sizes to obtain fuel loads of 24.5 to 44 kg/m^2(5 to 9 lbs/ft^2). In one test, the fire source was located on the seventh floor while it was located on the tenth floor for the other three tests. The tests demonstrated the feasibility of stair pressurization to maintain smoke-free stairs in high rise buildings, that as many as three doors could be open and still allow the system to maintain effective pressurization in the stair, and that the test stair provided a “clear and safe passage” for occupants and firefighters even though the corridor and adjacent lobby on the fire floor had heavy smoke levels.

Also in the summer of 1972, tests were conducted in a 14 story hotel in Atlanta, Georgia [31]. Fans were installed at the bottom of each shaft to provide a maximum flow of 10.4 m^3/s (22,000ft^3/min) to the stair shaft and 17.5 m^3/s (37,000 ft^3/min) to the elevator shaft which was common to three elevators. In addition, fans were provided to maintain the approach lobby to the stairwell at either higher or lower pressure than the surrounding areas. With these fans, pressure differences in the stairwell of 200 Pa at the bottom and 25 Pa at the top with all doors closed could be obtained. In the elevator shaft, a pressure difference of 12.5 Pa could be maintained across the closed elevator door at the fifth floor near the fire location when the fan was operating at maximum. Fire tests were performed with the fire located on either the fifth floor or the third floor. Old furniture or wood pallets were used to obtain an approximate fuel load of 19.6 kg/m^2 (4 lb/ft^2). The pressurization system was used to obtain a pressure difference of 37.5 Pa between the stairwell and the fire floor and a pressure difference of 12.5 Pa between the elevator and the fire floor lobby. Based on the study, the authors concluded that pressurization of stairwells and elevator shafts was feasible and effective for limiting smoke migration into these shafts.

As part of an acceptance test by the local jurisdiction, an actual fire test was required in a six story office building in Hamburg, Germany [32, 33]. The smoke control system for the building was designed to provide a pressure difference between stairs and elevator shafts and the associated lobbies of 15 Pa under normal conditions and 50 Pa under emergency conditions. The fire load consisted of 370 kg (810 lb) of wood arranged in two groups of eight cribs with large slabs of expanded polystyrene foam. The fire room was approximately 4 m (13.1 ft) by 15 m 49.2 ft) and located on the second floor. While a comprehensive set of measurements were obtained during the fire test, only one fire test was performed. No information is available concerning the flows in the building during a fire without pressurization.

Air leakage through elevator and stair doors was measured experimentally by Tamura and Shaw [34]. At a pressure difference of 75 Pa, the air leakage through an elevator door was determined to vary approximately linearly with the width of the crack between the door and doorframe. For a crack width of 2.0 mm (0.08 in), the air leak rate … ured at 0.10 m^3/s ($3.5 ft^3/s$).
For a crack width of 7.0 mm … 45 m^3/s ($15.9 ft^3/s$). Typical
crack widths for el… 27 in) compared to stair door
clearances of 2.0 t…

Several studies hav… the National Research
Council in Canada t… levator shafts during a
fire. In one set of tes… and located on the
second floor of the 1… sured in the elevator shaft
at the 3.08 m (10 ft) l… Pa [28]. In another series
of tests with a similar… measured with all
outside wall vents clo… h vents closed, the
pressure immediately … ubsequently gradually
decreased to 6 Pa whe… 12 °F). In the test with
open vents, the pressu… to 7 Pa [35].

Wind can also have an … lobby wall. Tamura
investigated the effects … lity at the NRCC [36].
Using the floor space p… varied from 0.1 Pa to 0.5 Pa
with all vents closed. W… was opened on the windward side of the
building at the 2nd floor … the pressure difference ranged from 1.5 Pa to 9.6 Pa. When the leeward vent was the only one open, the pressure difference was 0.0 Pa to 6.0 Pa; with all vents open, the pressure difference was 0.1 Pa to 1.8 Pa. The values for the leeward vent open only case represent flows in the direction from the elevator shaft into the lobby. All of the other cases produced flows from the elevator lobby into the elevator shaft. Mechanical pressurization of the elevator shaft reduced the possibility of smoke contamination of the elevator shaft and lobbies due to wind action.

The desire to use elevators for evacuation of occupants and transportation of fire fighters has led to research into the impact of operating elevators during fire emergencies. The "piston effect" created as an elevator moves pass a fire floor can have an adverse impact on efforts to control the movement of smoke from the fire floor [37]. A method for analysis of the effect of a single elevator car moving downward in a single or multiple car shaft was developed by Klote [38]. A