1. *Third International Conference on Construction in the 21st Century (CITC-III)*
2. *"Advancing Engineering, Management and Technology"*
3. *15-17, September 2005, Athens*

Analysis of Smoke Control Systems at Airports

Mario Berrios
P.E., M.Sc., Florida International University, Miami, Florida, USA

Juan Zheng
Florida International University, Miami, Florida, USA

Weihua Mao
Florida International University, Miami, Florida, USA

Abstract
Studies show that death by burns has fallen in the USA by 50% and death by smoke only by 15%. In order to save life, smoke control systems are highly recommended in all kind of buildings. Smoke control systems at airports are exceptionally important as thousands of people take flights at airports every day. A brief review of fire/smoke accidents at airports in the past reveals the extreme importance of smoke control systems at airports. Stairwell pressurization, zoned control systems and roof mounted air handling systems are nested with fire sprinklers, speakers, smoke detectors, air conditioning systems and fire alarm systems to help control smoke at airports. Enclosed public areas, ramp level tug drives, concourse /corridors, and automated people mover stations have been identified as having unique design requirements and therefore will have different design and testing criteria established for each. There are also several computer programs in the market to simulate the spread of smoke. It is expected that with these different smoke control systems and techniques, smoke at airports will be greatly minimized and controlled.

Keywords
Smoke Control, Safety, Fire, Airport

1. Introduction

Smoke control systems are highly recommended in all kind of buildings to save life. Smoke obstructs visibility in buildings not allowing people to see the exits in order to escape. Most of the victims in fires are incapacitated by smoke inhalation first. Smoke inhalation is the leading cause of fire deaths, exceeding burn deaths by roughly seven to three as of 1990. Smoke from smoldering fires release invisible lethal chemicals from plastics widely used today in the constructions industry and by interiors designers. Studies show that death by burns has fallen in the USA by 50% and death by smoke only by 15%.

Even if materials are fire rated or fire treated, these products under fire conditions will release the chemicals embedded in them. The contents of buildings are combustible: wood (the use of wood and plastic is very restricted and controlled in the Miami International Airport), furniture, paper, carpeting, wall coverings, etc.. There is a tendency to use synthetic materials for carpeting and interior decorations. Changes in the composition of furnishings, finishes, and other materials in buildings generate smoke more rapidly or produce smoke that is more toxic than was true in past decades, leading more quickly to incapacitation and fatalities if a large fire occurs. Due to the Energy Codes, air tight construction and smoke producing substances expected to be found in a fire would result in an untenable environment full of smoke. The high cost of repairs by owners far surpasses the cost of smoke control systems.

2. Fire/Smoke Accidents at Airports

2.1. Airports

1. Schiphol International Airport in Amsterdam, Netherlands. On April 9, 2001 a fire erupted in the kitchen of the Burger King Restaurant in the passenger terminal due to a French fryer overheated. One person was treated for smoke inhalation. The airport was closed. The explosion sent a burst of flame and smoke through exhaust shaft to the roof. Incoming and outgoing flights were delayed. Passengers were evacuated. Traffic was halted from highways leading to the airport, and all entrances were blocked. There was panic.

2. Heathrow Airport, London. On December 12, 1997 a fire started in a Burger King restaurant in Terminal One. The fire sent smoke billowing from the roof and disrupted hundreds of flights. There were 307 flights cancelled at the airport. The chaos stretched from the runways to the roads (massive jams) serving the airport. Five percent of the terminal was damaged mostly by smoke. The smoke filled the terminal and flames licked through the roof. The fire caused travel misery for thousands.

3. Dusseldorf Airport, Germany. On April 11, 1996 a fire begun (caused by welding) killing 16 people, injuring 60 and producing an economic damage of several hundreds of millions of German Marks. The fire was small at the first floor at the open entrance but the smoke went up thru crevices killing people in the private club of Air France in the 3rd floor far away from the fire. After the fire the airport was completely shut down. The airport had been reaping profits for more than 30 years.

2.2. Airport Hotels

Since some airports have hotels in the center of the terminals, information about hotel fires are given below.

- The MGM Grand Hotel (Las Vegas, Nevada) fire is an example of the smoke problem. This fire killed 85 people and injured 600. The building did not have smoke control, fire sprinklers, stairwells pressurization, elevator shafts pressurization, or smoke detectors in the air handling units of the air conditioning systems.
- Paris Opera hotel. Paris. April 15, 2005. Twenty persons are dead. People jumped from windows or screamed for rescue from flames Friday as a pre-dawn fire roared through a Paris hotel used by City hall to house needy African families, officials said. At least 20 people were killed, half of them children. More than 50 people were injured, with 11 seriously injured. Eight hours after it was extinguished, rescue workers were still pulling bodies from the inside the scorched building. The fire broke at 2 AM. Fire officials said some people jumped out of windows to escape the smoke and flames. Nearly all of the hotel's six floors were blackened inside.

3. Smoke Control Systems

3.1. Stairwell Pressurization

Supply fans are used to inject air into the stairwell from the outside. This will prevent smoke from getting into the stair, which is used by people to escape. Consideration must be given to opening and closing of doors and wind effect (Klote, J.H., 1993). A typical sequence of operation is as follows: Smoke detectors in alarm shall initiate stairwell pressurization. Smoke control sequence for its control zone, and initiate alarm zone notification appliance circuits.

3.2. Zoned Control Systems

In the airport, zone control systems are used in areas of 20,000 sq ft to 40,000 sq ft nested with fire sprinklers, speakers, smoke detectors, air conditioning systems and fire alarm systems. If an area of 20,000 sq ft is in fire, this zone is going in exhaust mode and in all the adjacent areas the air conditioning air handlers are going in to 100 % outside air supply into the building. During this time, only smoke is generated (smoldering fire); at this stage there is not flaming fires. There is a misconception about the smoke control systems are for fire. They are not. By the time flames are produced, the fire sprinklers will put them out. Smoke control systems should be designed for all classes of smoke. Test had been made at the Plaza Hotel in Washington, D.C. for zoned smoke control (Klote, J.H., 1990).

3.3. Roof Mounted Air Handling Systems

Roof mounted air handling systems (AHS) will provide the cooling supply air (SA) necessary to serve the project air conditioning needs. Pressurization supply air, required as part of a smoke control system sequence, is also provided by each air handling system.

Various air handling systems will be strategically placed throughout the terminal and concourses roofs based upon such factors as phasing and available space influencing the quantity.

3.4. Smoke Detectors

The smoke detectors used at the airport are intelligent, addressable connected to Honeywell fire alarm panels which in turn are connected to an operating control room attended 24 hours. The detectors used are photoelectric and beam detectors. In case of fire, the opening of one sprinkler will activate the smoke exhaust fans. In case of smoldering fire, the smoke will activate smoke detectors arranged in a matrix or counting system to turn on the smoke exhaust fans. There are in the market ionization detectors and photoelectric detectors. At the airport only photoelectric detectors are used due to false alarms occasioned by ionization devices. Recently other devices are being developed like addressable analog detection with verification and aspirating detection (e.g. VESDA). Fiber optic smoke sensors have been developed (Whitesel, et al 1994).

4. Typical smoke control calculations

4.1. Volume calculation

Club 10,200 sq ft x 15 ft high = 153,000 cu ft

Adjacent corridors /offices 3,700 sq ft x 15 ft high = 55,500 cu ft

Total = 208,500 cu ft

4.2. Exhaust requirements

9 air changes per hour = (208,500 cu ft x 9): 60 min/hr = 31,275 CFM (cubic feet per minute)

4.3. Supply requirements

6 air changes per hour = (208,500 cu ft x 6): 60 min/hr = 20,850 CFM

4.4. Summary

Exhaust air for Club area provide by SEF-18C = 33,000 CFM

Supply air for Club area provided by full open VAV boxes:
18-15 1470 cfm ; 18-16 640 cfm; 18-17 600 cfm; 18-18 1700 cfm; 18-19 1170 cfm; 18-20 1350 cfm; 18-21 960 cfm; 18-12 1800 cfm; 18-23 1600 cfm; 18-24 2565 cfm;18-25 2065 cfm;18-26 1500 cfm ; 18-27 500 cfm.

Total = 17,920 cfm cooling mode

Total = 20,920 cfm smoke control mode

AHU-18 total during smoke mode = 45,000 cfm supply air

5. Design

Four types of spaces have been identified as having unique design requirements and therefore will have different design and testing criteria established for each. The four types of spaces are as follows.

5.1. Enclosed Public Areas

Enclosed Public Areas are generally categorized as areas with low ceiling heights broken up by multiple partitions. These areas receive cooling supply and return air, smoke control pressurization supply and evacuation exhaust air, Supply air 6 air changes per hour; exhaust 9 air changes per hour. The zone of fire origin has exhaust; the areas around the fire zone of origin have pressurization.

Enclosed Public Areas are separated into smoke zones by the use of physical (wall or partition) barriers. Initiation of smoke control for typical office ZOFO has simultaneous evacuation exhaust and make-up air supply of the ZOFO, with pressurization supply air provided for the smoke zones immediately adjacent (above, below and next-to, as applicable) to the ZOFO. To avoid delivering excessive make-up air to an enclosed smoke zone, the maximum position on the VAV boxes shall be set by the test and balance agency to obtain the required amount of make-up air.

5.2. Ramp level tug drives (1st floor) (Conveyors of baggage)

Ramp level tug drives is generally categorized as areas with low ceiling (structure) heights located under the building footprint on the first level with both sides of the area almost completely open to the aircraft parking apron. These areas generally have poor habitable environments, due to the proximity to the aircraft exhaust and exposure to products of combustion released by the continuous operation of gasoline driven baggage transportation tugs. Outside air ventilation supply for these areas will originate from supply fans located on the roof. These fans and ductwork provide ramp level ventilation supply air and smoke evacuation duty for both the ramp level and upper building level areas by implementing a series of dampers and bypasses at the fan to change air flow direction.

Areas are separated from miscellaneous small offices and mechanical /electrical spaces by fire rated construction but are open to the aircraft parking apron. Initiation of a smoke control for a typical tug drive ZOFO will de-energize the ventilation supply air fan (located in a 4th level mechanical penthouse) serving the ZOFO. Adjacent to the ventilation fan at the 4th level is a system of by-pass ductwork and dampers which allows this same ventilation fan to perform in an exhaust mode.

These dampers shall open/close to the exhaust configuration and the dedicated smoke exhaust fan serving the ZOFO is then re-energized providing smoke exhaust duty for the ZOFO in alarm. All baggage claim carousels assigned to the ZOFO will de-energize simultaneously, closing the fire rated shutter, isolating the baggage claim from the ZOFO. Once smoke control is initiated, annunciation of any one smoke detector in adjoining ZOFO will initiate the same smoke evacuation exhaust sequence for that ZOFO. The make-up air for the evacuation exhaust originates from adjacent ZOFO remaining in ventilation supply and from the opening onto the aircraft parking apron.

5.3. Concourse/corridors (includes baggage claims, Immigration Naturalization Services processing, Ticketing hall and meeters –greeters areas)

Concourse is generally categorized as areas with high (and low) ceilings, extending great distances without any physical dividing barriers. These areas receive cooling supply air and pressurization supply air from multiple air handling systems and also receive evacuation exhaust air from multiple exhaust fans. These types of spaces also include certain concessions spaces.

Smoke zones consist of long, open areas with high and low ceilings. Each smoke zone is divided into sub-areas. Initiation of smoke control for a sub –area will modulate close 100% all return fire /smoke and isolation dampers serving the ZOFO. Designated isolation dampers and VAV boxes used to bring make-up air to enclosed areas within the ZOFO, will modulate to full open. Evacuation exhaust fan serving the ZOFO shall initiate general exhaust fans shall shut down. Make-up air to the ZOFO is provided from pressurization of the immediate adjacent zones.

5.4. Automated people mover stations (Train stations on the roof of the terminal)
APM (Automated People Mover) stations are generally categorized as long, single room areas (5th floor) partitioned in half to separate the domestic from international passengers. These areas receive cooling supply air and pressurization supply air from a single air handling system and also receive evacuation exhaust air from dedicated fans.

Each automated people mover station is separated into two smoke zones (domestic and international sides). Initiation of smoke control for a typical automated people mover ZOFO has evacuation exhaust from the ZOFO and pressurization supply provided to the adjoining zones. Pressurization supply air is not simultaneously introduced into the ZOFO alarm.

6. Computer Modeling

There are several computer programs in the market to simulate the spread of smoke. A simple smoke filling hand calculable formula for single compartment has been developed (Chiang, Chung Kee et al, 2002). From NIST, there are several free programs, but fire protection engineers engaged in a daily basis in applying the programs should be employed to obtain meaningful results. Contrary to popular belief, the smoke does not rise quickly in a plume but tends to move horizontally (migrating) and thus failing the smoke test by the mechanical and fire inspectors. Research has been done on this (Nakamura, H. et al, 1992).

Computer Fluid Dynamics is being used by designers to simulate fires and the production of smoke. In smoke control modeling important items to consider are tenability criteria, design fires, boundaries conditions. Usually the models assume two zone compartments. Elements to consider are transportation time, ceiling jets, complex geometries, compel fuels, vertical vents, fire suppression systems effects. Equations used are the Navier Stokes equations. Stake holder should agree in the tenability criteria; NFPA 130 gives temperatures from 120 F to 140 F. The radiation can be considered from the fire or from the upper layer or from the lower layer. Visibility for the distance to exits must be determined (see Tadahisa Jin, Society of Fire Protection Engineers Handbook, page 2-42). Toxicity, part per million of carbon monoxide, carbon dioxide, etc., must be also considered. Typical fire sizes are; trash can =250 kW; 2 briefcases = 500 kW; a sofa = 1000 kW; a cubicle with a computer = 5,000 kW =5 mega watts.

7. Conclusion

Smoke from fire damages buildings far beyond the area of the origin of the fire. Smoke not only causes damages in property but losses of lives. The past fire/smoke accidents demonstrates the significance of smoke control systems at airports. Stairwell pressurization, zoned control systems, roof mounted air handling systems and smoke detectors are combined with fire sprinklers, speakers, air conditioning systems and fire alarm systems to help control smoke at airports. Enclosed public areas, ramp level tug drives, concourse /corridors, and automated people mover stations have been identified as having unique design requirements and therefore should have different design and testing criteria established for each. There are also several computer programs in the market to simulate the spread of smoke. Therefore, not only should smoke control systems, design elements, but also mathematical analysis and computer technology should be used in the minimization of smoke/fire accidents at airports.

8. References

Arup Corporation. (2000). "Innovative Fire Strategy." *Smoke Control Systems*. Retrieved April 21, 2005 from **http://users.wpi.edu/~bruoff/smoke.htm**

Chian, Chung Kee et al. (2002). "Simplified smoke filling equation for single enclosure." *Process in Safety Science and Technology part B*, v 3, 2002, p 1568.

Klote , John H. (1990). "Plaza Hotel fire experiment." *ASHRAE Journal*, v 32, n 10, Oct, 1990 , p 25-26, 28-29.

Klote, John, H. (1993). "Design of smoke control systems for areas of refuge." *ASHRAE Transactions*, v 99, n pt 2, 1993,p 793-807.

Nakamura, H. et al. (1992). "Research on smoke control in underground structures." *Tunneling and Underground Space Technology*, v 7, n 4, Oct, 1992, p 325-333.

Tadahisa Jin. (2002). "Visibility and Human Behavior in Fire Smoke." *The SFPE Handbook of Fire Protection Engineering*, National Fire Protection Association, Quincy, Massachusetts.

Whitesel, et al. (1994). "Smoke and mirrors: a fiber optic smoke sensor." *Proceedings of SPIE – The International Society for Optical Engineering.*, v 2292,1994, p 123-133.