“We are building to a height to rival the Tower of Babel” - William Le Baron Jenny, Engineer, 1883 (father of the American skyscraper)
HISTORICAL OVERVIEW | SIGNIFICANT FIRES

contemporary north and south america high rise fires:
year of construction to year of fire event

- one new york plaza 1970
- cook county administration building 2003
- parque central 2004
- mgm hotel and casino 1980
- first interstate bank building 1988
- andraus building 1972
- one meridian plaza 1991

1950 2000
THE HIGH-RISE SOLUTION / TOTAL FIRE PROTECTION

Total Fire Protection Concept

Compartmentation
Personal Education

Sprinkler Systems
Alarm

Detection
Operations
NOTABLE FIRES | MGM GRAND (1980)

- 85 deaths
- 700 injuries
CURRENT TRENDS IN HIGH-RISE DESIGN

Mixed use (office, residential, hotel, hospital, school, university, kindergarten, assembly)

Taller, faster construction (modular construction, composite structural elements and passive systems - 60-300 stories)

Composite floor and structural systems (added complexity to achieve engineering requirements)

Elevator evacuation systems (pressurized shafts and/or lobbies)

Code changes favoring passive systems (4 of eight NCST recommendations related to passive)

Natural Ventilation and passive approaches to smoke management
TALL BUILDING FORCES | STACK EFFECT

Normal Stack Effect

Reverse Stack Effect

\[ \Delta p_{so} = K_s \left( \frac{1}{T_o} - \frac{1}{T_s} \right) h \]
TALL BUILDING FORCES | STACK EFFECT IN A 60 STORY BUILDING DURING THE WINTER

“What makes stack effect significant is the sustained—for months over a winter—unidirectional pressure difference. This sustained pressure difference may result in significant moisture accumulation in cavities and energy loss. It can also cause some air barrier materials to detach or peel from their substrate. These materials must be attached mechanically to prevent this type of failure.”

– Rick Quirouette, Air Pressure and the Building Envelope, 11/04
TALL BUILDING FORCES | ELEVATOR PISTON EFFECT

“Operation of elevators by the fire service during a fire can result in smoke being pulled into the elevator shaft by piston effect. It seems a safe recommendation that fire fighters should favor the use of elevators in multiple car shafts over ones in single car shafts.”

– John Klotte, Principles of Smoke Management

Piston effect pressure – single car (0.26 inches H2O)*
Piston effect pressure – two or more cars (0.05 inches H2O)*

* 700 fpm velocity
Pressure difference across elevator lobby of a Toronto hotel due to piston effect.
Buoyancy forces vary depending on ceiling height and room temperature (typically from 0.01 to 0.5 inches H2O)
**TALL BUILDING FORCES | MECHANICALLY INDUCED PRESSURES**

- **HVAC** generally 0.05 to 0.25 inches H2O. Positive pressure at the building envelope can contribute to smoke spread between floors, as can imbalances in the supply and return if the HVAC is not shut down.

- **LIFE SAFETY**- Elevator pressurization can be incredibly problematic due to the sheer quantity of air being introduced into the building. Quantity of air needed to pressurize elevators may be unworkable in some buildings under specific circumstances (i.e. 169,000-270,000 cfm in 30 story building as per Miller and Beasley).

Extra care is needed to seal elevator lobbies when elevator pressurization is provided to prevent failures of passive barriers.
TALL BUILDING FORCES | EXTERNALLY INDUCED PRESSURES

Wind pressure may easily exceed 0.5 inches H2O for wind speeds in excess of 30 mph.

\[ \Delta p_w = \frac{1}{2} (\bar{C}_{w1} - \bar{C}_{w2}) K_w \rho_o U_H^2. \]
TALL BUILDING FORCES | PRESSURE COEFFICIENT DISTRIBUTION
PASSIVE STRATEGIES | FLOOR-TO-FLOOR SEPARATIONS TO MITIGATE BUOYANCY

The perimeter fire containment system should generally satisfy the following criteria:

- **Curtain wall insulation** should be *mechanically attached* to spandrel, as applicable
- **Mullions** need to be *protected* (especially if Aluminum)
- **Safing insulation** compression fit and clipped in (mechanical fasteners) as per tested assembly
- **Non-structural reinforcement** should be provided at safing line as per the tested assembly
- **Use Flexible firestop coating** required to mitigate smoke movement
PASSIVE STRATEGIES | ISSUES WITH FLOOR-TO-FLOOR SEPARATIONS (PENETRATIONS)

From 2012 IBC 713.3.1:
The material used to fill the annular space shall prevent the passage of flame and hot gases sufficient to ignite cotton waste when subjected to ASTM E 119 or UL 263 time-temperature fire conditions under a minimum positive pressure differential of 0.01 inch (2.49 Pa) of water at the location of the penetration for the time period equivalent to the fire-resistance rating of the construction penetrated.

From 2012 IBC 713.3.1.2:
Through penetrations shall be protected by an approved penetration firestop system installed as tested in accordance with ASTM E 814 or UL 1479, with a minimum positive pressure differential of 0.01 inch (2.49 Pa) of water and shall have an F rating of not less than the required fire-resistance rating of the wall penetrated.
PASSIVE STRATEGIES | ELEVATOR LOBBIES TO MITIGATE STACK EFFECT
PASSIVE STRATEGIES | ISSUES WITH PASSIVE SYSTEMS AT ELEVATORS LOBBIES

- When elevators are pressurized in leaky buildings, or buildings with operable windows, pressures across elevator doors may be large magnitude.
- Dynamic pressures resulting from stack effect and/or pressurization systems can overwhelm the door assembly (i.e. blowing out the door).
- Maintenance is sometimes deferred, leading to problems with activation.
- Smoke doors leak, even when installed properly and in accordance with their listing.
- Architects usually don’t like them.
PASSIVE STRATEGIES | SMOKEPROOF ENCLOSURES TO MITIGATE STACK EFFECT
PASSIVE STRATEGIES | ISSUES WITH SMOKEPROOF ENCLOSURES
PASSIVE STRATEGIES | EFFECT OF ACTIVE SYSTEMS ON BUILDING PRESSURES

- Pressures induced by active mechanical systems vary from 0.05 to 0.35 inches H2O.
- Active systems employ dampers, which may be used for both HVAC and smoke control. Such dampers must be dynamically listed due to the pressures that they would be expected to encounter.
# SUMMARY OF FORCES IMPACTING TALL BUILDINGS

<table>
<thead>
<tr>
<th>Driving Force</th>
<th>Location of $\Delta p$</th>
<th>Conditions</th>
<th>$\Delta p$ (in. H2O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack Effect</td>
<td>Shaft to outside</td>
<td>$T_s = 70^\circ F$</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$h=30$</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$h=300$</td>
<td></td>
</tr>
<tr>
<td>Buoyancy</td>
<td>Fire room to adjacent room at ceiling</td>
<td>$h = 10$ feet</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_f = 212$</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_f = 1600$</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>Windward to Leeward</td>
<td>$U_H = 15$ mph</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$U_H = 30$ mph</td>
<td>0.48</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Across smoke control barrier</td>
<td>N/A</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>Elevator Piston</td>
<td>Elevator lobby to building</td>
<td>Single car</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Double car</td>
<td>0.05</td>
</tr>
</tbody>
</table>
SUMMARY OF THINGS TO THINK ABOUT WITH RESPECT TO TOTAL FIRE PROTECTION

- Tall buildings can generate significant pressures that do not exist in other buildings.
- Trends in tall building design are only making air movement and corresponding pressures worse.
- Total fire protection is a balance of passive and active systems – but we have to be aware of the need to not rely solely on one type of system.
- Passive systems increasingly under assault due to pressures, which requires consideration of more robust approaches.
THANK YOU!

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