Fire Safety in Tall Building: Performance-Based Solutions

Chris Jelenewicz, P.E., FSFPE
Tall Buildings 200 Meters or Taller Completed Each Year from 1960 to 2016

Total Number of 200m+ Buildings in Existence in Each Decade from 1920 to 2015

In the 2013 study (which was conducted before the end of the year so as to release the study at year end), CTBUH projected 73 buildings as having been completed in 2013. That number has been revised to 71 this year, based on the following updates:

- The Central Bank of Kuwait was originally listed as having completed in 2013, however, no information since the beginning of 2014 has validated this. The completion date for this building has now been revised to 2015.
- The AirPun Towers (1 and 2) of Guangzhou, China were included in the original 2013 total. Since then it has been determined that the buildings are actually 100 meters high, which removes the buildings from the 200m+ sample.

Added to 2013 Completion List:

- The AEC. Center 02 in Chongqing, China, was completed in 2013 but was not confirmed at the time of the 2013 study. This has now been confirmed, and has thus been added retroactively to the 2013 completions list.

Note:
1. We can predict 2015–2016 building completions with some accuracy due to projects now in advanced construction. A range is given to indicate the challenging factors in predicting building completion dates.
2. Totals after 2001 take into account the destruction of the World Trade Center Towers 1 and 2.
World's ten tallest buildings according to Height to Architectural Top (as of December 2015)
### Building List

<table>
<thead>
<tr>
<th>#</th>
<th>Building Name</th>
<th>City</th>
<th>Height (m)</th>
<th>Height (ft)</th>
<th>Floors</th>
<th>Completed</th>
<th>Material</th>
<th>Use</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Jeddah Tower</td>
<td>Jeddah</td>
<td>1000</td>
<td>3,281</td>
<td>167</td>
<td>2018</td>
<td>concrete</td>
<td>residential / serviced apartments / hotel / office</td>
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<tr>
<td>2</td>
<td>Burj Khalifa</td>
<td>Dubai</td>
<td>828</td>
<td>2,717</td>
<td>163</td>
<td>2010</td>
<td>steel/concrete</td>
<td>office / residential / hotel</td>
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<td>3</td>
<td>Suzhou Zhongnan Center</td>
<td>Suzhou</td>
<td>729</td>
<td>2,392</td>
<td>137</td>
<td>2021</td>
<td>composite</td>
<td>hotel / residential / hotel</td>
</tr>
<tr>
<td>4</td>
<td>Dubai One</td>
<td>Dubai</td>
<td>711</td>
<td>2,333</td>
<td>161</td>
<td>2020</td>
<td>composite</td>
<td>residential</td>
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<tr>
<td>5</td>
<td>KL118 Tower</td>
<td>Kuala Lumpur</td>
<td>644</td>
<td>2,113</td>
<td>118</td>
<td>2019</td>
<td>composite</td>
<td>residential / hotel / office</td>
</tr>
<tr>
<td>6</td>
<td>Signature Tower Jakarta</td>
<td>Jakarta</td>
<td>638</td>
<td>2,093</td>
<td>113</td>
<td>2021</td>
<td>composite</td>
<td>hotel / office</td>
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<td>Wuhan</td>
<td>636</td>
<td>2,087</td>
<td>125</td>
<td>2018</td>
<td>composite</td>
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<td>Shanghai</td>
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<td>Al-Aman World Capital Centre</td>
<td>Colombo</td>
<td>625</td>
<td>2,051</td>
<td>111</td>
<td>2020</td>
<td>composite</td>
<td>hotel / office</td>
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<tr>
<td>10</td>
<td>Rama IX Super Tower</td>
<td>Bangkok</td>
<td>615</td>
<td>2,018</td>
<td>125</td>
<td>2021</td>
<td>composite</td>
<td>serviced apartments / hotel / office / retail</td>
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<td>11</td>
<td>Tradewinds Square Tower A</td>
<td>Kuala Lumpur</td>
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<td>1,995</td>
<td>110</td>
<td>-</td>
<td>office</td>
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<td>Hyderabad</td>
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<td>Makkah Royal Clock Tower</td>
<td>Mecca</td>
<td>601</td>
<td>1,972</td>
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<td>2012</td>
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<td>other / hotel</td>
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<td>Shenzhen</td>
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<td>1,969</td>
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<td>-</td>
<td>composite</td>
<td>hotel / office / retail</td>
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<td>Shenzhen</td>
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<td>1,965</td>
<td>115</td>
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<td>composite</td>
<td>office</td>
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<tr>
<td>16</td>
<td>Goldin Finance 117</td>
<td>Tianjin</td>
<td>596.5</td>
<td>1,957</td>
<td>128</td>
<td>2016</td>
<td>composite</td>
<td>hotel / office</td>
</tr>
<tr>
<td>17</td>
<td>Rose Rock International Finance Center</td>
<td>Tianjin</td>
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<td>1,929</td>
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<td>-</td>
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<td>Shenyang</td>
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<td>1,864</td>
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<td>Lotte World Tower</td>
<td>Seoul</td>
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<tr>
<td>20</td>
<td>Baoneng Binhu Center Tower</td>
<td>Hefei</td>
<td>550</td>
<td>1,804</td>
<td>121</td>
<td>-</td>
<td>composite</td>
<td>office</td>
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<tr>
<td>21</td>
<td>Burj 2020</td>
<td>Dubai</td>
<td>550</td>
<td>1,804</td>
<td>-</td>
<td>-</td>
<td>steel</td>
<td>office</td>
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<tr>
<td>22</td>
<td>One World Trade Center</td>
<td>New York City</td>
<td>541.3</td>
<td>1,776</td>
<td>94</td>
<td>2014</td>
<td>composite</td>
<td>office</td>
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<td>23</td>
<td>Central Park Tower</td>
<td>New York City</td>
<td>541</td>
<td>1,775</td>
<td>95</td>
<td>2019</td>
<td>concrete</td>
<td>residential / hotel / office / retail</td>
</tr>
</tbody>
</table>
Kingdom Tower -- Jeddah
Central Park Tower
Tall Buildings 200 meters or Taller Completed in 2014: by Region
SFPE/ICC Guide

• Partnership SFPE/ICC

• Does Not Define “Tall Building”

• Not a substitute for a Building Code

• Identifies challenges & provides inside on how to address in PBD context
Challenges

- Emergency Egress
- Fire Resistance
- Smoke Control
- Suppression
- Facades
- Construction/Demo
- First Responder Issues
Other Challenges in Guide

- International Practices
- Hazard & Risk Analysis
- Integration of Building Systems
- System Reliability
- Detection & Alarm
- Commissioning
Why PBD?

- Evaluate designs of fire protection measures to achieve stated objectives
- Support alternatives to prescriptive-based code requirements
- Evaluate the building fire safety as a whole
- Prescriptive codes can stifle innovation
Figure 3-13.3. Sequence of occupant response to fire.
Design Fire Scenario Standard (under development)

Couples:

- Scenario
- Design Fire
- Acceptance Criteria
<table>
<thead>
<tr>
<th>Area of Origin</th>
<th>Fires</th>
<th>Civilian Fatalities</th>
<th>Civilian Injuries</th>
<th>Direct Property Damage (in Millions)</th>
<th>Fatalities/ # fires</th>
<th>Injuries/ # fires</th>
<th>Damage/ # fires</th>
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<tr>
<td>Kitchen or cooking area</td>
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<td>0</td>
<td>$6</td>
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<td>$0</td>
<td>0.0</td>
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<tr>
<td>Trash or rubbish chute, area</td>
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<td>Fires</td>
<td>Civilian Fatalities</td>
<td>Civilian Injuries</td>
<td>Direct Property Damage (in Millions)</td>
<td>Proportionality Factor</td>
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<td>143</td>
<td>127</td>
<td>3.85</td>
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</table>
Design Fires
Estimate Fire Growth Rate

- Incident data currently have from NFPA
- Incident data need from NFPA
- Expert judgement from committee

\[ Q = \alpha_1 t^2 \]
\[ Q = \alpha_2 t^2 \]
\[ Q = \alpha_3 t^2 \]
\[ Q = \alpha_4 t^2 \]
\[ Q = \alpha_5 t^2 \]
\[ Q = \alpha_6 t^2 \]
Evacuation Strategy

- Simultaneous
- Phased/Progressive
- Refuge Floors/Areas
- Sky Bridges
- Evacuation Elevators
- Combinations
Based-On

- Egress Goals
- Occupants Characteristics
- Building Characteristics
- Evacuation Scenarios
- Emergency Management Personnel
Simultaneous Evacuation

- Popular After 9/11
- Discharge?
- Stairs Only?
- No preference to those in danger
- High demand on stairs
- Other Emergencies

*Assessment of Total Evacuation Systems for Tall Buildings (NFPA Foundation)*
Phased/Progressive Evacuation

- Local Regulations
- Information Age – Difficult
- Efficient Use of Stairs
- Evacuate Those in Danger First
- Not Good for All Emergencies
Refuge Floors

S: Staircase  Direction of people’s movement
Refuge Floors in Hong Kong

- Refuge Floor 20-25 Floors
- Fire Separations
- 50% of Floor Dedicated to Refuge
The victims lived on the 38th floor, far above the fire. They decided to evacuate with their two dogs, and started down one of the two stairwells.

They made it as far as the 31st floor, where they were overcome by smoke.

The fire was burning in a small apartment on the 20th floor, but had not spread.

Firefighters, coming up the same stairwell the victims were using, entered the fire floor, and opened the stair doors and the apartment door, sending the smoke up as if through a chimney. One of the men and both dogs died, and the other man remains hospitalized.
Protect in Place

- Refuge Areas – Residential
- *Occupant Response During a Residential Highrise Fire, CRC Canada, Guylène Proulx*
Sky Bridge -- Petronas Towers
Evacuation Elevators

- Model Codes Have Provisions
- Access for Disabled
- Protection (Shaft, Machine Room)
- Smoke Control
- Back-up Power
- Communication

*NIST Report -- The Use of Elevators for Evacuation in Fire Emergencies in International Buildings*
• SFPE Guide
• Egress Time Prediction (RSET)
## Evacuation Timeline

**Start time** .......... **End Time**

<table>
<thead>
<tr>
<th>Fire Cues</th>
<th>Cue validation process .......... and continuing process</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Receiving cues</td>
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<tr>
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<tr>
<td>Chapter 1 -- Introduction</td>
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<tr>
<td>Chapter 2 -- Context in design and analysis process</td>
<td></td>
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<tr>
<td>Chapter 3 -- Occupant characteristics</td>
<td></td>
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<tr>
<td>Chapter 4 -- Process of taking protective action in a building fire</td>
<td></td>
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<tr>
<td>Chapter 5 -- Occupant behavioral scenarios</td>
<td></td>
</tr>
<tr>
<td>Chapter 6 -- Managing the movement of building occupants</td>
<td></td>
</tr>
<tr>
<td>Chapter 7 -- Enhancing human response to emergency notification &amp; messaging</td>
<td></td>
</tr>
<tr>
<td>Chapter 8 -- Movement concepts</td>
<td></td>
</tr>
<tr>
<td>Chapter 9 -- Effects of exposure to smoke/toxicity</td>
<td></td>
</tr>
<tr>
<td>Chapter 10 -- Hand calculations and models</td>
<td></td>
</tr>
<tr>
<td>Chapter 11 -- Egress model selection, validation and verification</td>
<td></td>
</tr>
<tr>
<td>Chapter 12 -- Uncertainty effects</td>
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</tr>
</tbody>
</table>
Fire Resistance
• Estimation of fuel loads (FPE)
• Evaluation of structural design fire exposures (FPE)
• Evaluation of thermal response of the structure (FPE)
• Evaluation of fire effects on the structural response (SE)
Fuel Loads

- **NFPA 557**

*Fuel load in a conference room*  *Fuel load in an atrium*
Structural Design Fire Exposures

- **SFPE S.01**
  - *Engineering Standard on Calculating Fire Exposures to Structures (2011)*
- Enclosed vs. Local Exposure

*Fire in a conference room*  
*Fire within an atrium*
Thermal Response

- **SFPE S.02**
Structural Response

ASCE/SEI 7 Appendix E

- Performance-Based Design Procedures for Fire Effects on Structures (2016)

1st time fire considered as an explicit structural load in a U.S. standard
Goals & objectives

- Need to be clear what “smoke control” means in the building
  - Containment, exhaust, maintain tenable environment
- Need to understand building design and environmental conditions
- Need to be clear on what fire(s) are used in the analysis
- Include other events?

Smoke Control
Stack Effect
Piston Effect
Wind Effect
Pressure Zones

Suppression Considerations
Express Risers

High Zone Standpipe Outlets

Low Zone Standpipe Outlets

Express Riser, no outlets allowed if pressure exceeds 350 psi
Facades/Exterior Wall Assemblies

Fig. 86.12  Curtain wall supported on slab edge [9]

Fig. 86.13  Curtain wall hung-off Slab edge [9]
COMPOSITE OR COMPLEX ASSEMBLIES

FLOOR-TO-FLOOR DOUBLE GLAZING

CONCRETE SLAB

MINERAL WOOL
ALUMINUM
STEEL
CANTILEVER ANCHOR BRACKET

CONCRETE SLAB
Tamweel Tower, Dubai, November 2012

- Cigarette discarded onto pile of waste materials left by workers next to building
- 5-1/2 hr. fire duration
- Fire spread to interior residential units
Marina Torch, Dubai, February 21, 2015

- Source of ignition: barbecue grill on 51st floor balcony
- Fire damage extended 28 stories to top of building
- 101 apartments damaged
Dubai January 1, 2016

- Address Hotel
Two Career Fire Fighters Die Following a Seven-Alarm Fire in a High-Rise Building Undergoing Simultaneous Deconstruction and Asbestos Abatement—NIOSH
Construction & Demolition

- Careful Planning/Design
- Water Supply
- Fire Suppression
- Standpipe Systems
- Egress Systems
Where is F/F Intervention?

Figure 3-13.3. Sequence of occupant response to fire.
Fire Responder Issues

Command & Control
Communications
Building Access
Operations
Rooftop Helipads
OSHA Guide

Fire Service Features of Buildings and Fire Protection Systems
Introduction to Fluid Mechanics

Bart Merci

Fluid Properties

In this section, a number of fluid properties are defined. An implicit assumption in the classical fluid mechanics is the ‘continuum hypothesis’, implying that the fluid is continuous, certain time is defined as in Equation 1.1, taking the local limit for a small volume.

In an incompressible flow, the density does not vary. In general, liquids can be considered ‘incompressible’. In gases, the density can vary due to variations in pressure or temperature (see...
New Content

• Human behavior in fire -- egress system design, occupant evacuation scenarios, combustion toxicity, and data for human behavior analysis

• Fire protection systems -- selection of fire safety systems, system activation and controls, and CO2 systems.

• Recent advances in fire resistance design

• New chapters on industrial fire protection, including vapor clouds, effects of thermal radiation on people, BLEVEs, dust explosions and gas and vapor explosions.
SAVE THE DATE

11TH CONFERENCE ON PERFORMANCE-BASED CODES AND FIRE SAFETY DESIGN METHODS

23-25 MAY 2016
HILTON WARSAW HOTEL
WARSAW, POLAND
Annual Meeting
### New Committee Structure

<table>
<thead>
<tr>
<th>Committee on Research, Tools &amp; Methods</th>
<th>Committee on Professional Qualifications</th>
<th>Committee on Continuing Professional Development</th>
<th>Committee on Community Outreach and Advocacy</th>
<th>Committee on Members, Chapters &amp; Interest Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal 1 &amp; 2</td>
<td>Goal 3 &amp; 4</td>
<td>Goal 5</td>
<td>Goal 6</td>
<td>Goal 7</td>
</tr>
</tbody>
</table>
Career Resources

www.SFPE.org
Thanks to Simpson, Gumpertz & Heiger for the use of photos.

Feel free to contact me at chris@sfpe.org