



Title: Fire Protection Strategies for an Energy Efficient High- Rise Building

Authors: Fang Li, Vice President, Rolf Jensen & Associates
James Antell, Senior Vice President, Rolf Jensen & Associates
Martin Reiss, Chief Operating Officer, Rolf Jensen & Associates

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Pearl River Tower, Guangzhou: Fire Protection Strategies for an Energy Efficient High-Rise Building

Fang Li¹, James Antell, AIA, P.E.² and Martin Reiss, P.E., FSFPE³

¹Vice President, China Operations, Rolf Jensen & Associates, Inc. (RJA), Shanghai, China
Tel: +8621 2890 9735, Email: fli@rjagroup.com

²Senior Vice President, International Operations, Rolf Jensen & Associates, Inc. (RJA), Chicago, IL, USA,
Tel: +1 312 879 7200, Email: jantell@rjagroup.com

³Chief Executive Officer, Rolf Jensen & Associates, Inc. (RJA), Boston, MA, USA
Tel: +1 508 620 8900, Email: mreiss@rjagroup.com



fli@rjagroup.com



mreiss@rjagroup.com

Fang Li

Fang Li holds a Bachelor's Degree in Chemical Engineering from Jiao Tong University in Xi'an, China. After graduation, she worked for the Xi'an Fire Prevention Bureau as an engineer before going to the United States in order to continue her education. She graduated from Worcester Polytechnic University (WPI) in Massachusetts with a Master of Science Degree in Fire Protection Engineering. While at WPI, she had an internship with the National Fire Protection Association (NFPA) where she worked on developing data bases for materials safety and engineering calculations for fire hazard impact. Upon graduation from WPI in December 2000, she joined Rolf Jensen & Associates (RJA) Boston office as a fire engineering consultant.

Her work included application of modeling protocols for fire dynamic analysis, smoke control analysis and egress analysis. Ms. Li was relocated to Shanghai in 2003 and promoted to the position of Vice President for China Operations at RJA. During her work at RJA, she has had technical articles published in *International Fire Protection (UK)* and *Fire Science & Technology (China)* as well as being invited to give many presentations of performance-based design in China.

Martin Reiss

Martin (Mickey) Reiss' career spans over 30 years, focusing on fire protection through new technology, codes and standards development and proper installation of fire safety equipment. He presently serves as President and CEO of Rolf Jensen & Associates, a global fire protection consulting engineering firm. Mr. Reiss holds a Bachelor of Science and Master of Science degrees in engineering from the Massachusetts Institute of Technology (MIT).

In addition to his professional responsibility, Mr. Reiss serves on a number of boards and committees. He was appointed to the National Fire Protection Association Board of Directors in 1992 and served as its Chair from 2000 to 2002. Mr. Reiss is a member of NFPA's technical committees. In addition, he is the first foreign member of the China Fire Protection Association. Also, Mr. Reiss is a member of the Board of Directors of the National Institute of Building Sciences and the Board of Governors of the World Organization of Building Officials.

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Tel: +8621 2890 9735, Email: fli@rjagroup.com

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³Chief Executive Officer, Rolf Jensen & Associates, Inc. (RJA), Boston, MA, USA
Tel: +1 508 620 8900, Email: mreiss@rjagroup.com

Abstract

The Pearl River Tower in Guangzhou, China is a mixed-use facility of 310 meters and 71 stories including a 3 story podium with a total of 17,000 sq. m. above grade and 45,000 sq. m. below grade. It is the headquarters of the Guangdong Tobacco Company which occupies 10 floors.

The building features numerous design strategies to reduce energy demand from the local grid, which include vertical axis wind turbine and photovoltaic panel energy generation, double curtain wall and radiant metal ceiling cooling system. The combination of these features is unique in a high rise and required an integrated fire protection strategy.

Several features of this building design that are not fully code compliant include travel distance and both smoke and fire compartment size which occur when the flexibility of large open spaces are desired to meet the design team goals. A performance-based approach using computer based fire models with internationally accepted practices was a key element in providing the solutions using the latest advancements in technology.

Keywords: fire protection, fire safety, high-rise buildings, performance-based, sustainable design

Introduction

The Pearl River Tower in Guangzhou, China is a mixed use facility of 310 meters and 71 stories including a 3 story podium with a total of 17,000 sq.m. above grade and 45,000 sq.m. below grade. It is the headquarters of the Guangdong Tobacco Company which occupies 10 floors. They chose Skidmore, Owens & Merrill (SOM) of Chicago to design an energy efficient building to support their commitment to the environment as well as to have a signature building that would attract high level tenants. Rolf Jensen & Associates (RJA) was chosen by SOM to provide both a fire protection strategy for the unique energy efficient systems and a performance-based approach for the building design issues that are not fully addressed by the China codes. The RJA offices in Chicago and Shanghai collaborated on this project.

The building is categorized by the China High-Rise Code¹ as a Category 1 Multi-Use Building, over 50 m in height with floor areas greater than 1,000 sq.m. According to the National Fire Protection Association (NFPA) *Life Safety Code*² for hazard classification of building areas, the offices, conference rooms, lobbies and restaurant seating areas are considered low hazard occupancies with limited ignition sources. Utility spaces,

kitchens and the parking garage are considered ordinary hazard occupancies with moderate combustibles and the possibility of increased smoke volumes.

Overall Fire Safety Approach

The fire safety approach for the building is to create a functional, efficient and profitable facility while maintaining a level of safety that is equivalent or exceeds the National Standards of the People's Republic of China for life safety, property protection and continuity of use. The overall approach is based on the following:

1. The building will comply with the applicable China codes where feasible. Only when the strict compliance with the codes compromises the functional use of the building or does not provide the proper level of fire safety, other approaches will be used.
2. When code compliance is not followed, fire safety enhancement best practices will be provided similar to those used in other high-rise facilities in China as well as in other countries.
3. The building features numerous design strategies to reduce the energy demand from the local grid, which include vertical axis wind turbines, photovoltaic panels, double curtain wall and

radiant metal ceiling cooling. They will be protected in accordance with applicable codes and standards.

4. The unique curve ceiling design on the typical office floors required an engineering analysis for the proper location of sprinkler heads and smoke detectors.
5. Some building features required variances such as the ground level fire fighting staging area layout and the double curtain wall fire resistance sealing to prevent vertical fire spread.
6. Several other key design features are not compliant with the China codes and will be designed using a performance-based approach. These features are:
 - The building entrance lobby is open to a mezzanine and a small portion of levels 2 through 5. The resulting fire compartment is greater than the allowable 2000 sq.m.
 - The typical office level fire compartment is greater than the allowable 2000 sq.m.

Goals

The overall goals of the fire and life safety design are:

1. Protect the life safety of building visitors, staff and responding fire service personnel
2. Maintain the structural integrity of the facility throughout a fire
3. Protect the building contents and continuity of building operations

Performance Objectives & Criteria

The performance objectives for life safety are intended to establish a design in which the occupants will not be exposed to smoke or heat effects that would cause injury. These objectives are in the form of specific tenability conditions that occupants could be exposed to during a fire. The tenability criteria are evaluated at 2 meters above the floor (at occupant breathing height). The performance criteria are shown in the Table 1 below³:

Tenability Parameter	Performance Criteria
Visibility	10 meters
Radiation	2.5 kW/m ²
Temperature	60°C
Carbon Monoxide	500 ppm

Table 1 – Tenability Performance Criteria

The performance objectives for building contents and continuity of operations are intended to measure the extent of damage that may render a building unusable for a period of time. These criteria are more subjective in nature, but are intended to establish a level of property protection equal or better than the provisions of the Chinese code. The criteria for limiting damage to contents are:

1. Limit fire spread to one fire area. For the entrance lobby, this would be the fire area including the ground level, mezzanine and the portions on other levels enclosed by fire shutters. For the typical office levels, this area would be equal to one fire zone.
2. Maintain tenable conditions, as defined for life safety, during evacuation of the fire area and limit significant smoke spread to one smoke compartment

Sustainable Energy Systems Assessment

One of the key challenges of the project was the fire safety impact of many of the new sustainable energy technologies. As with any new building technology, it was critical to understand what new fire hazards, if any, these new technologies might introduce into the building. This required a hazard assessment of each of the technologies and a report to the local fire service identifying each potential new hazard and how it was mitigated.

Wind Turbine

Vertical axis wind turbines were used that do not need to be pointed into the wind direction and work efficiently at low speeds with frequently changing directions. There are two mechanical levels at floors 24 and 50 with the turbines located within the building footprint. The turbine, generator and bearings are located exterior to the building construction. The DC rectifier interface, ground fault protection and disconnect switch, AC/DC inverter, AC isolation transformer, fused disconnect and 50 Hz interconnect to building system are located within the mechanical rooms.

The fire protection strategy for the exterior components of the wind turbines is by means of fire rated or reinforced construction to separate adjacent fire zones and vulnerable interior spaces. The separation from the floors above and below are by 1 ½ hour fire resistant rated floor slabs while adjacent portions of the floor are separated by reinforced construction shown in Figure 1.

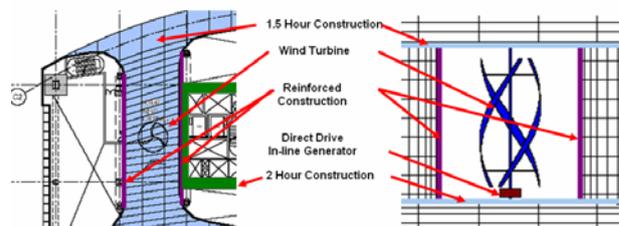


Figure 1 - Wind Turbine Layout and Protection Strategy

The interior components, located in the adjacent mechanical spaces, are protected in accordance with the China high-rise code. In addition to the physical protection using suppression and construction, the wind turbines have multiple means for system shutdown. There is direct access for authorized service personnel provide system status checks.

Photovoltaic Panels

The building uses two types of panels. The first is an industrial-grade solar module that has been certified to IEEE 1262 and IEC 61215 and listed to Underwriters' Labs (UL) 1703 for Class A Rating. The second panel is a frameless, semitransparent solar module certified to IEC 61646 Safety Glass II. In both cases, the use of combustible materials in the panels was minimized. The photovoltaic panels are integrated into the building's curtain wall system. Four sunshades extend the span of each floor. The panels are mounted to the exterior sunshades on the western face. Additional panels are located on the two mechanical levels on the southern face and above the building club level. Figure 2 shows the details.

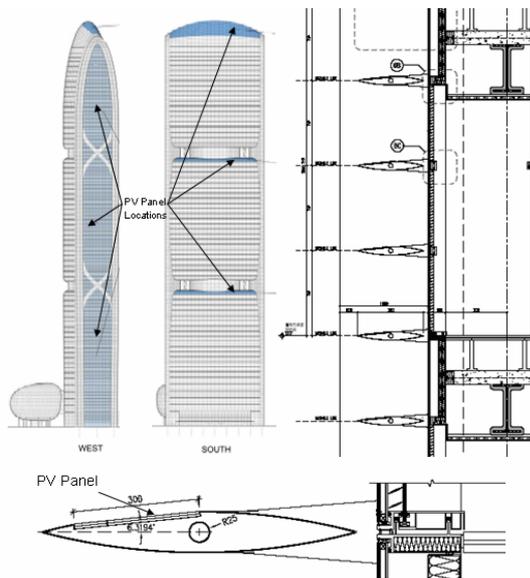


Figure 2 - Photovoltaic Panel Locations and Building Integration

The DC Interface is located within the raised floor concealed space on each floor and consolidates the panel array wiring. The wiring is routed from the DC Interface to the floor electrical closet and through the riser to the mechanical room which contains the system electrical components.

The electrical wiring is installed in accordance with applicable codes and standards. The transformer rooms and typical floor electrical rooms are protected by smoke detectors and carbon dioxide fire extinguishers in accordance with the code.

Double Curtain Wall

The double curtain wall system is designed to reduce the solar heating. The double façade traps the solar energy within the curtain wall cavity and removes the heated air via the ceiling relief duct. The wall design is code compliant.

The building floor slab is required to maintain a 1 ½ hour fire resistance rating. The individual floor systems are separated at each floor to maintain the required fire

resistance. The original double curtain wall design spanned multiple floors without floor to floor separation. The local fire service insisted on separation at each floor and this was incorporated into the fire safety strategy and into the energy saving strategy of the design. Figure 3 below shows a detail of the fire-stopping system integrated into the double curtain wall system.

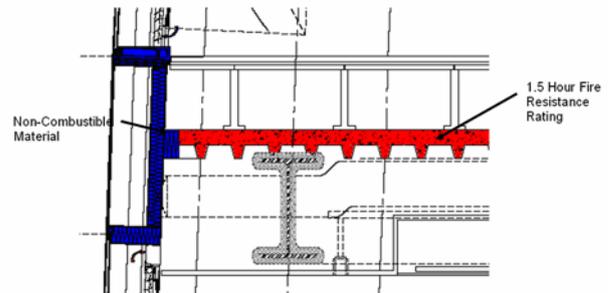


Figure 3 - Typical Fire-resistant Joint System at Double Curtain Wall

The detail fire separation measures are:

1. The gap between the curtain wall and the floor slab is filled with non-combustible materials
2. The windowsill wall is filled with non-combustible materials to a height greater than 0.8m
3. The horizontal spandrel has a depth of approximately 300mm and to prevent vertical fire spread

Performance-Based Design Scope

In order to meet the functional objectives of both the owner and the design team, certain key aspects of the design need a performance-based approach while still meeting the China code level of safety. These design features that will be evaluated are:

1. The design of the entrance lobby includes an increased fire and smoke compartment size, which utilizes a passive smoke control method to collect into the atrium reservoir. The atrium connects the ground floor through level 5 with rated fire shutters on levels 2 through 5. Smoke accumulating in the atrium reservoir can be exhausted by a supplementary mechanical smoke control system.
2. The design of a typical office floor features an open office layout with each floor a separate zone. Each floor is served by a looped exhaust duct capable of providing 60,000 CMH of exhaust.

The analysis for the performance-based approach will include the following in developing the recommended solution:

1. Heat effects and smoke flow from design fires
2. Activation of automatic fire detection systems
3. Activation of automatic fire suppression systems
4. Smoke control and exhaust methods
5. Tenability conditions of egress routes
6. Evacuation time from atrium and office floors
7. Performance and reliability of facility fire safety features

Fire Model

The Fire Dynamics Simulator (FDS version 4/0/7) fire model developed at the US National Institute of Standards & Technology (NIST)⁴ will be used to predict the environment resulting from credible, severe-case design fires. FDS is a computational fluid dynamics model based on the concept of the finite element method. It is the current state-of-the-art in verified fire models. In addition to raw data output, the FDS model has several graphic output formats. Visualization is done through the SmokeView program which was specifically developed for use with FDS.

The fire scenarios are described in the following Table 2:

Scenario	Description
Scenario F-1	Entrance Lobby This scenario is intended to evaluate the impact of a fire on the ground floor in the entrance lobby. The scenario will be used to evaluate the entrance lobby fire compartment which exceeds 2,000 m ² , the smoke compartment which exceeds 500 m ² , and with egress modeling to evaluate the passive smoke control design to maintain tenable conditions during evacuation.
Scenario F-2	Typical Office Floor. This scenario is intended to evaluate the impact of a fire within a typical office floor. The scenario will be used to evaluate the typical office floor fire compartment which exceeds 2,000 m ² , the smoke compartment which exceeds 500 m ² , and with egress modeling to evaluate smoke control system exhaust design and capacity to maintain tenable conditions during evacuation.

Table 2 – Fire Scenarios

Design Fire Scenarios

Entrance Lobby

The design fire for the entrance lobby is on the ground floor and represents a severe-case for a typical circulation space. It is under the higher ceiling level (not under the mezzanine) and thus ceiling sprinklers will have a delayed activation. Figure 4 illustrates the location of the design fire:

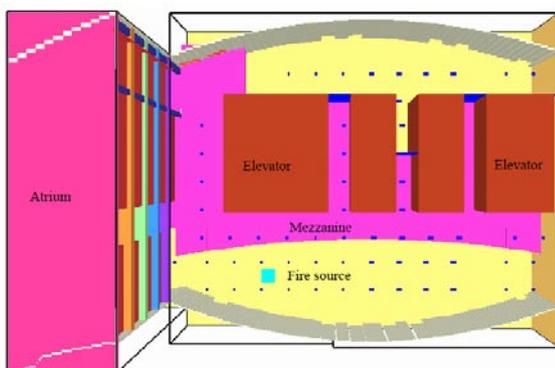


Figure 4 - Entrance Lobby Layout and Fire Location

The anticipated fuel load within the entrance lobby circulation are included a three cushion sofa. Test data indicates that this load will peak at 3000 kW before being controlled by the sprinklers. In order to account for the different number of potential fuel packages, the fire growth was determined to be a t-squared “fast growth” rate for light combustible materials. This is consistent with the values specified in NFPA 92B, Standard for Smoke Management Systems in Malls, Atria and Large Areas⁵.

The sprinkler activation model was DETACT from NIST. It includes the following input parameters:

1. Ceiling Height
2. Distance to Sprinkler from Axis of Fire
3. Initial Room Temperature
4. Sprinkler Activation Temperature
5. Sprinkler RTI

The entrance lobby primarily uses the atrium as a passive smoke reservoir to accumulate smoke and hot gases while occupants on the ground floor and mezzanine evacuate. While not included in the FDS model, a smoke exhaust system is provided at the top of the atrium smoke reservoir to supplement the passive smoke control strategy with an extra level of safety.

Typical Office Floor

The design fire for the typical office floor is located within the office space and represents a severe-case for this occupancy. The office area will be protected by a fast response automatic sprinkler system and it is assumed that it will control the fire. Figure 5 illustrates the location of the design fire:

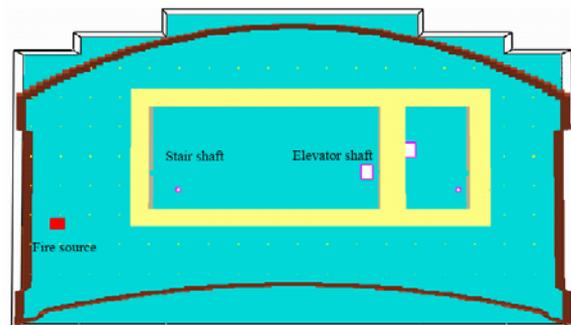


Figure 5 - Typical Office Floor Layout and Fire Location

The anticipated fuel load includes typical office materials of wood, plastic and fabrics. Fire and heat release data is available from NIST. The growth rate was consistent with a number of various materials and was determined to also be a t-squared “fast growth” rate for light combustible materials. In order to provide a conservative fire representation with respect to soot production, which have a direct impact on smoke visibility, the design fire was assumed to be a 50 percent cellulosic (wood, paper) and 50 percent synthetic

(plastics, fabric, polyurethane foams) materials. DETACT⁶ was used for sprinkler activation modeling.

Egress Model

The PathFinder egress model used for analysis is a graphical dynamic evacuation simulation model developed by RJA.

It graphically represents the evacuation process modeled by formulas presented in the Society of Fire Protection Engineers *Fire Protection Engineering Handbook*, Section 3, Chapter 14 (2nd Edition)⁷. PathFinder uses CAD drawings and the occupant loads for the building. The total egress time is the sum of the following times:

1. Detection time
2. Notification time
3. Pre-movement delay time
4. Safety Factor

PathFinder is useful for this type of analysis because of the ability to change parameters and rerun the simulation while exploring various possibilities in terms of travel distance and exits. It allows the user to eliminate egress routes blocked by the fire or the movement of smoke. The occupant loads were determined in accordance with the China codes.

Figure 6 is a still image of the animated graphical output created by the PathFinder model for the ground level. Similar outputs were created for the mezzanine level and the typical office floors. The small black dots represent occupants as they move toward the available exits.

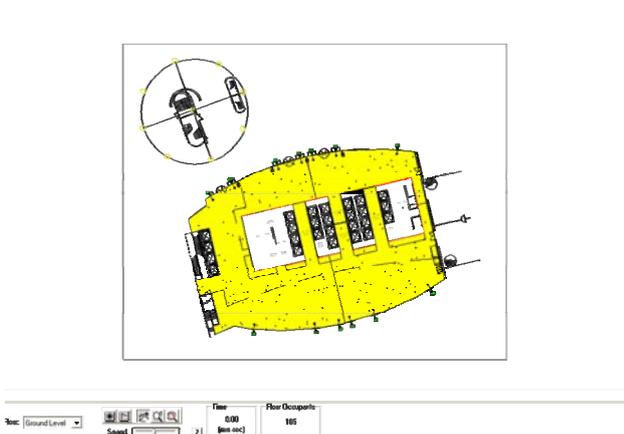


Figure 6 - Ground Level Pathfinder Model Output

Considering the open layout of the entrance lobby and mezzanine, the time for detection, notification and pre-movement are diminished due to the fire development and smoke spread being visible from most spaces. The occupant load factors were based on the NFPA 101 *Life Safety Code* as there are no specific occupancy loads defined in the China high-rise code. The time for occupants to detect the fire and respond would be within 60 seconds after fire ignition. The

pre-movement delay would not exceed 30 seconds. The PathFinder simulation calculated a time of 19 seconds for egress of all occupants on the lobby level. A safety factor of 1.5 is added to the simulation time to provide for a conservative estimate of the variables that are not quantified by the model which include limited mobility occupants, way finding delays and merging flows. The total egress time for this scenario would be:

$$\text{Total Egress Time} = 60 \text{ seconds} + 30 \text{ seconds} + (19 \text{ seconds})1.5 = 119 \text{ seconds}$$

The determination of the safe available time for the entrance lobby would be determined by the FDS results in the design fire scenario. The available time would be based upon the time when hazardous conditions exist at the occupant breathing level (2 meters above the floor) considering the tenability criteria. The result of the FDS model for the entrance lobby design fire is shown in Figure 7 at 180 seconds after ignition. The dark colored contours illustrate the untenable conditions due to low visibility. Untenable radiation exposure, temperatures and carbon monoxide concentrations do not occur 2 meters above floor levels until after all the occupants have exited.

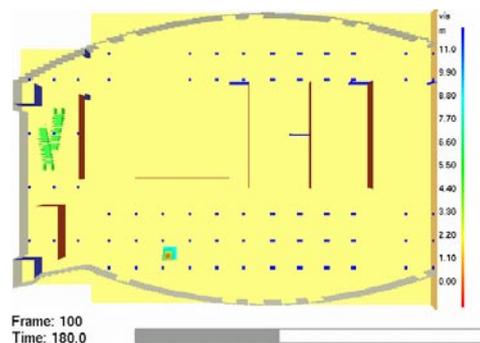


Figure 7 - Ground Level Visibility Results (10 meters of Visibility or Less)

Conclusion

Fire protection strategies for high rise buildings that can meet the goals and objects of the owners, fire officials and design team stakeholders is a challenge that can be met with creative solutions. The addition of unique systems for energy efficiency, provide additional challenges for the design team to integrate into the overall building. The Pearl River Tower is an example of a success in achieving a fire safe building design which incorporates cutting edge green building concepts with well defined fire and life safety strategies.

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- NFPA STANDARD 101, LIFE SAFETY CODE, 2003 Edition. Published by the National Fire Protection Association, USA
- SFPE Fire Protection Engineering, 2nd Edition, Tenability criteria are based on references found in SFPE. Published by the Society of Fire

Protection Engineers, USA and in the current working draft of the National Standard of the Peoples Republic of China for Performance Based Design

FIRE DYNAMICS SIMULATOR (FDS version 4/0/7), is a Computational Fluid Dynamics computer model developed and maintain in the public domain by the United States Government Department of Commerce, National Institute of Standards & Technology, Building and Fire Research Laboratory (NIST). It is available at www.bfrl.nist.gov

NFPA STANDARD 92B, STANDARD FOR SMOKE MANAGEMENT SYSTEMS IN MALLS, ATRIA AND LARGE AREAS, 2003 Edition. Published by the National Fire Protection Association, USA.

DETECT is a Fire Detection Activation Time computer model developed and maintain in the public domain by the United States Government Department of Commerce, National Institute of Standards & Technology, Building and Fire Research Laboratory (NIST). It is available at www.bfrl.nist.gov

SFPE Fire Protection Engineering Handbook, 2nd Edition. Published by the Society of Fire Protection Engineers, USA