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Fire & Life Safety Challenges in Sustainable Tall Building Design

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Abstract

The movement towards sustainable building design can result in unique fire protection challenges and concerns, especially with super tall buildings in relationship to traditional prescriptive code compliance. Different countries haves different code requirements as well as local best practices and may cause conflict with the design features when designing green buildings. These include, but not limited to green roofs, sprinkler water quality and testing, fire department access and areas of refuge with direct or indirect impact by the perspective code compliance. The solutions to these prescriptive code challenges and fire safety concerns can range from simple alternatives to more detailed engineering performance-based design analyses with good solid practice.

Keywords: Fire protection, Fire safety, Life safety, Performance-based design, Code compliance, Tall buildings, Green buildings

1. Introduction

The movement towards sustainable or environmentally friendly building design can result in unique fire protection challenges and concerns, especially with tall buildings in relationship to traditional prescriptive code compliance. The solutions to these prescriptive code challenges and fire safety concerns can range from simple design alternatives to more detailed engineering performance-based design analyses (Hofmeister, 2010).

Fire protection design usually does not have a major direct impact on obtaining green building certification by standard thinking, but considering the current fast pace economic growth within China, the rise in high profile fire incidents could be one of the critical challenges to this continued growth. Calling for close attention by the policy makers to develop a strategic plan and tailor specific measures to mitigate the risk for unique building design features, particularly for super high rise building will be critical. Challenges brought to the construction project team could be significant without close coordination among the entire design team, balancing the various design goals to suit the needs of all stake holders. Aside from general life safety benefits, a good design approach to fire protection solutions could be also beneficial to the building design in achieving the green building certification by developing an alternative or performance based design.

The new Green Building Standards draft issued in China on May, 2012 provides design guidance for super high rise buildings to achieve the green building certification to meet the request for Chinese to integrate into the international Leed process. This focus is on the super tall building based on the large proposed super tall and mega tall buildings in the (pipe line) to be built in China.

Highlighted design features which have connection with fire protection including, but not limited to the following:

1) Energy consumption (water, electricity, heating construction material etc)
2) Transportation access
3) Green ratio
4) Landing usage
5) Building management

The above 5 points contribute to the green building design and could be in conflict or favored points to fire protection design.

Table 1 below, from the Standards, illustrates the items that account for the grading of the green certification.

To expand on the above, detailed indentified issues are as follows:

1.1. Energy consumption (water, electricity, heating, construction material etc)

Water is one of the most valuable resources people rely on every day. A target for the green building is for resource conservation and critical to this is water consumption. Water conservation must be a fire protection design criteria as water is the most reliable and cheapest media for fire suppression. For a super high rise, a building fire defense line with automatic fire suppression system as well as standpipe system is the most efficient means for firefighting.

The new draft standpipe code proposes enhanced stand-

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Table 1. Items for Classification of the Green Super-Tall Buildings (operational/occupied phase)

Classification	General Evaluation Items (a total of 49 items)				Optional Evaluation Items (a total of 17 items)		
Land conservation and environment (a total of 7 items)	Energy Saving and energy usage (a total of 12 items)		Water conservation and usage (a total of 7 items)	Building material saving and usage (a total of 9 items)	In-door environment quality (a total of 7 items)		Operation and management (a total of 7 items)
★	4	5	4	6	4	4	-
★★	5	7	5	7	5	5	7
★★★	6	10	6	8	6	6	12

Table 2. Fire Water Supply System

Name	Number of People	Number of Residents Nearby (10,000 people)	Notes
Factory	100	1.5	
Warehouse and Civil Buildings	Unlimited	Unlimited	Calculation factor for civil buildings should be 20 to 40 m^2/occupant. The occupants should not exceed 250,000

pipe water capacity with increased water tank at the roof top of the building. From the table below, the water supply's serving zone is based on the size and occupancy level. For mega size buildings, such as building over 500 meters, the total number of occupants could be over 25,000 persons, and can bring a debated issue over the water supply design criteria. Table 2 shows the Fire Water Supply System.

The large water consumption required along with the associated increased water tank size located at both the underground space and roof top, highlights the need for smart fire suppression system.

New technologies must be employed to address these issues such as water mist system technology to be used in expanded function space and the intelligent water cannon system used in large high ceiling space for fire suppression. Figure 1 is an image of the water cannon system suited for large open ceiling space. This application, as well as the water mist system could be good alternatives for such spaces which require less water consumption than standard sprinkler systems.

Electricity consumption can be an issue considering elevated building height. Occupant egress could be challenging as the code requires the egress stair enclosure to maintain a 2 hour fire rating and emergency lighting. Below is some detailed analysis discussion for an on-going project RJA is working on for such studies. The goal is to evaluate the worst case egress time for the entire tower and determining the best strategy for using the elevator as assisted egress.

Figure 1. Large Space Intelligent Fire Suppression System.

2. Evacuation Scene 1: The Evacuation Simulation of People Using Stair to Evacuate in the Whole Building

Evacuation scene: In extreme case, occupants in the entire building are informed to evacuate. It's simulated by STEPS.

Number of people: According to personnel density and personnel distribution as required by relevant code, the total number of people is 24963. See Fig. 2.

Safety exit setting: This scene is based on the worst evacuation situation to execute evacuation of the entire building, namely all occupants in the building will be evacuated through the safety exit on the ground floor to the outdoors. Number and width of safety exit meet 100 per/m. See Figs. 3 and 4.

Conclusion: It can be seen from simulation result that under the circumstance this evacuation takes a total evacuation time of 2:27:42 due to more people needing to be evacuated. See Fig. 5.

Simulation pictures:

The above image shows the detailed computer modeling output demonstrating the evacuation time based on va-

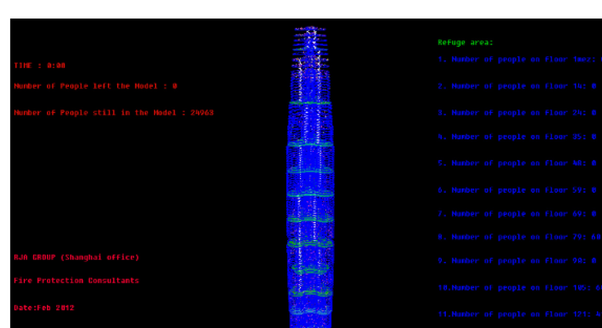

Figure 2. Case studies of people on each floor are uniformly distributed in the model.

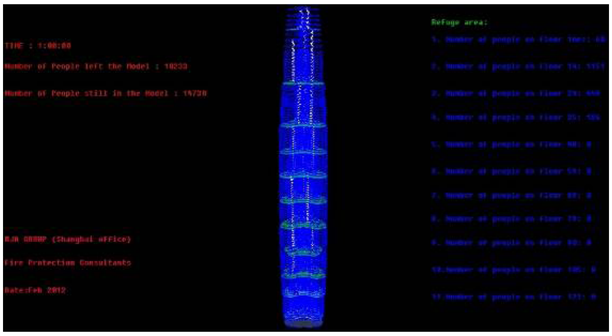

Figure 3. People evacuation continues at 60 mins.

rious criteria and factors. The purpose is to help improve the building design with egress design configuration and using supplemental elevators for egress.

3. Evacuation Scene 2: People on the Top of Building (F123 To F125) Use Stair to Evacuate to the Ground Floor

Evacuation scene: According to the requirements of evacuation alarm linkage, when any floor is on fire, it should inform people on the fire floor, the floor above and the floor below to evacuate together. This evacuation scene considering F124 is on fire, the evacuees on level F123 to F125 will do the evacuation from the building top to the ground floor outdoors. It's simulated by STEPS. See Fig. 6.

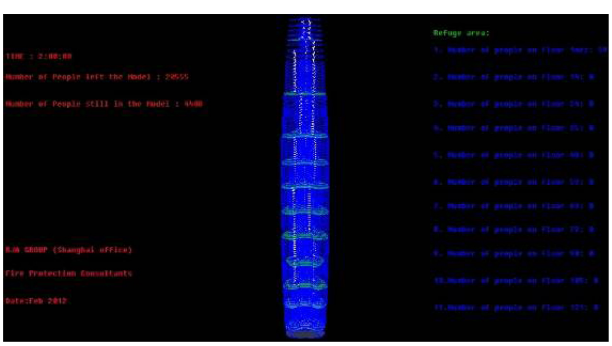

Figure 4. People evacuation continues at 120 mins.

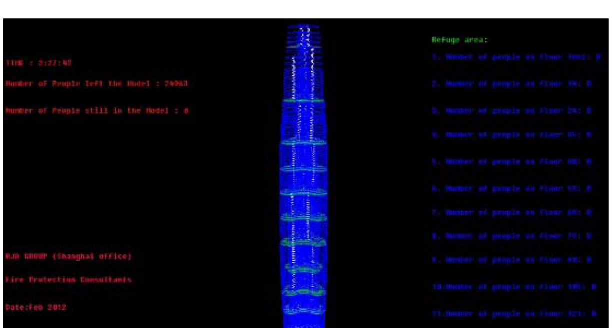

Figure 5. All the people have been evacuated out of the building to the outdoors at 2:27:42 (The evacuation is over).

Number of people: According to personnel density and personnel distribution as required by relevant code, the total number of people is 518.

Safety exit setting: This scene considering F124 is on fire and three floors' people on the top of building are informed to evacuate, the evacuation simulation will be finished when all people evacuate to the outdoor on ground floor. Number and width of safety exit meet 100 per/m.

Conclusion: When people on the top of the tower (F123 to F125), it can be seen from simulation results that the total evacuation time is at 52:40 when all people in these floors have been evacuated to the ground floor, shown in Fig. 7.

Simulation pictures:

4. Evacuation Scene 3: People in Each Section Use Stair to Evacuate to Refuge Area

Evacuation scene: Considering the building contains several refuge floors, base on the code's requirement, people can escape to the AOR floor first and then go on evacuating or awaite rescue. This scene considering the evacuation between two AOR floors that all people in this section will evacuate, namely all people in the same section is informed to evacuate. It's simulated by STEPS.

Number of people: According to personnel density and personnel distribution as required by relevant code, the total number of people is divided into 11 sections as shown in Table 3 below.

Safety exit setting: Number and width of safety exit meet 100 per/m.

Conclusion: The summary results in Table 4 are peo-

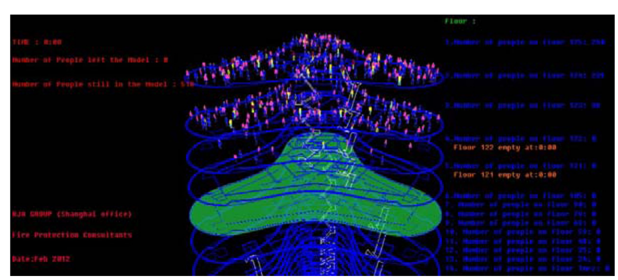

Figure 6. People on F123 to F125 floor are uniformly distributed on the top of model.

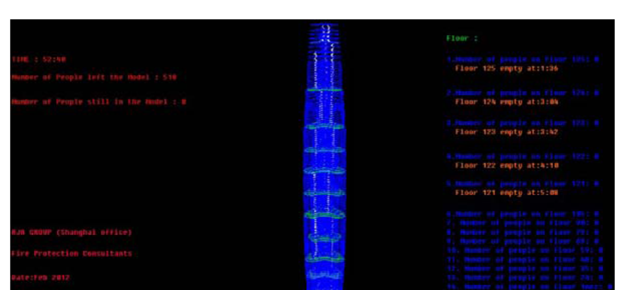

Figure 7. All people evacuate to the ground floor outside.

Table 3. The statistical table of the personnel in each zone

Section	Service area	Number of people	Section	Service area	Number of people
Section 1	F1 MEZ ~ F 13	3462	Section 7	F69 ~ F78	810
Section 2	F14 ~ F23	3367	Section 8	F79 ~ F89	660
Section 3	F24 ~ F34	3328	Section 9	F90 ~ F104	869
Section 4	F35 ~ F47	3624	Section 10	F105 ~ F120	2189
Section 5	F48 ~ F58	3274	Section 11	F121 ~ F125	599
Section 6	F59 ~ F68	2444			

Table 4. The statistical table of the personnel evacuation

Section	Service area	Number of people	Altitude difference	Evacuation time (People in the same zone evacuate to refuge area)
Section 1	F1 mez ~ F 13	3462	54	13:42 / See Figures 8 and 9
Section 2	F14 ~ F23	3367	40.5	12:56
Section 3	F24 ~ F34	3328	45	12:36
Section 4	F35 ~ F47	3624	54	13:24
Section 5	F48 ~ F58	3274	45	13:00 / See Figures 10 and 11
Section 6	F59 ~ F68	2444	41.3	9:34 / See Figures 12 and 13
Section 7	F69 ~ F78	810	37.4	3:50
Section 8	F79 ~ F89	660	40	4:48
Section 9	F90 ~ F1045	869	60	5:34
Section 10	F105 ~ F120	2189	68	9:50
Section 11	F121 ~ F125	599	26	4:48 / See Figures 14 and 15

ple's evacuation in each section to corresponding refuge floor.

Simulation pictures:

Section 1:

Section 5:

Section 6:

Section 11:

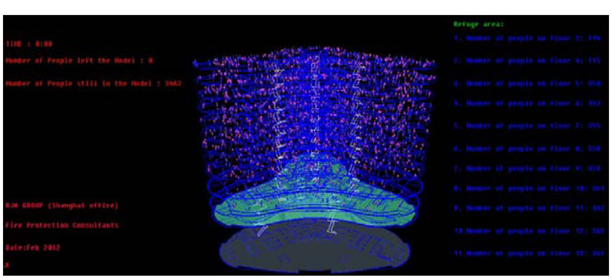

Figure 8. People in Section 1 are uniformly distributed in the model.

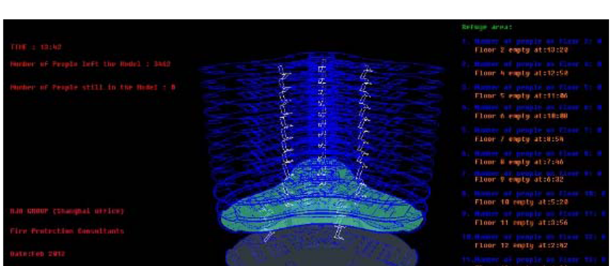

Figure 9. All people in Section 1 have evacuated to refuge floor.

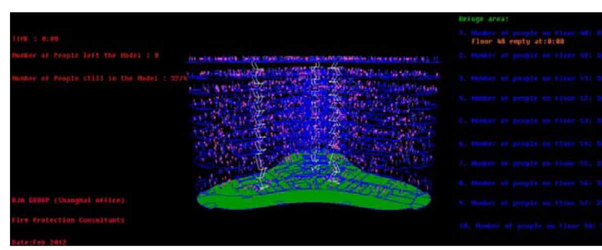

Figure 10. People in section 5 are uniformly distributed in the model.

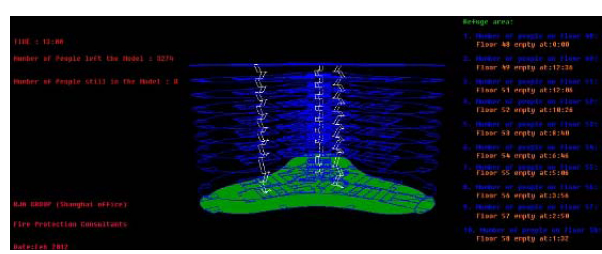

Figure 11. All people in Section 5 have evacuated to refuge floor.

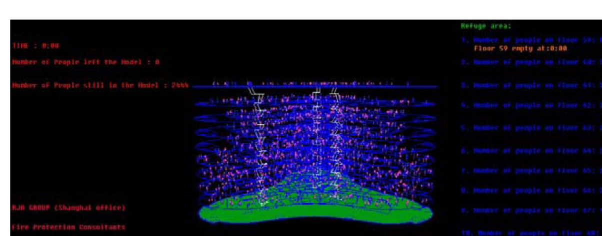

Figure 12. People in Section 6 are uniformly distributed in the model.

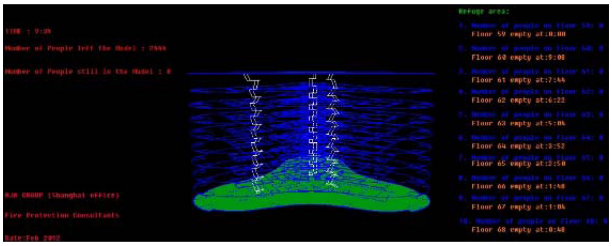

Figure 13. All people in Section 6 have evacuated to refuge floor.

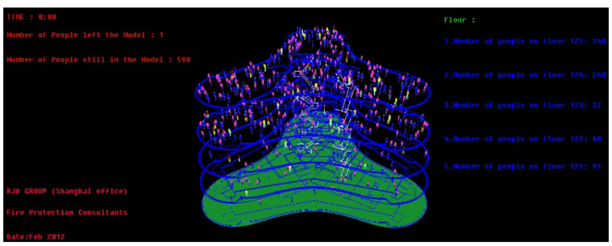

Figure 14. People in Section 11 are uniformly distributed in the model.

5. The Summary of Building Using Stair to Evacuate

This section is the evacuation summary of people in different evacuation scenes using stairs to evacuate, Table 5.

Using elevator assistant egress can save more space, an alternative to adding stairs, also provides lighting and power savings with a faster egress means. This could work out very well with the building's intelligent maintenance system and set guidance for the building's management system.

Glazing material is one of the preferred materials for introducing light to the building and for energy savings.

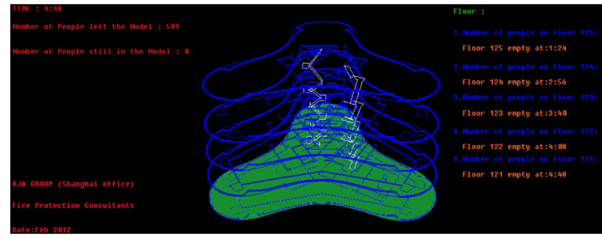

Figure 15. All people in Section 11 have evacuated to refuge floor.

However, it does create conflicts for code requirements due to fire spread concerns. In additional to the fire fighting concerns addressed by the local Shanghai FD, regulations to have a fire staging area without such massive glass façade have been proposed. Additional separation and fire related construction issues arise in large mixed-use facilities when the different usage and occupancy areas are considered separate buildings with their individual code compliance requirements for egress. Large shading structures and canopies also create code compliance issues with respect to fire resistance of these structures and fire department access to these elements.

The use of complex curtain walls can create other separation issues (O'Connor, 2011). Restriction of vertical fire spread to the floor of origin is the desired outcome. Double-skin facades for heating, cooling, sound control and lighting efficiency create challenges in preventing a breakthrough of the flame and smoke into the tall shaft-like space. The choice of fire stop materials and joint system constructions is important in achieving the necessary separations. Another challenge is the growing use of combustible insulation and finish materials for the facades.

Often the issues associated with new sustainable technologies are related to the newness of the technology itself and the lack of familiarity or lack of experience in the use of the technology in tall building design. Many times a

Table 5. The evacuation time of different floors and people using stairs to evacuate the high-rise building

Evacuation Scene	Region	Number of person	Evacuation time
Scene One	The whole building evacuates to the outdoors on the ground floor. See Figure 16.	24963	2:27:42
Scene Two	The people on the top 3 floors of the tower (F123 to F125) evacuate to the outside on the ground floor. See Figure 17.	518	52:40
Scene Three	People in Section 1 evacuate to the corresponding refuge floor (F1mez~F13)	3462	13:42
	People in Section 2 evacuate to the corresponding refuge floor (F14~F23)	3367	12:56
	People in Section 3 evacuate to the corresponding refuge floor (F24~F34)	3328	12:36
	People in Section 4 evacuate to the corresponding refuge floor (F35~F47)	3624	13:24
	People in Section 5 evacuate to the corresponding refuge floor (F48~F58)	3274	13:00
	People in Section 6 evacuate to the corresponding refuge floor (F59~F68)	2444	9:34
	People in Section 7 evacuate to the corresponding refuge floor (F69~F78)	810	3:50
	People in Section 8 evacuate to the corresponding refuge floor (F79~F89)	660	4:48
	People in Section 9 evacuate to the corresponding refuge floor (F90~F104)	869	5:34
	People in Section 10 evacuate to the corresponding refuge floor (F105~F120)	2189	9:50
	People in Section 11 evacuate to the corresponding refuge floor (F121~F125)	599	4:48

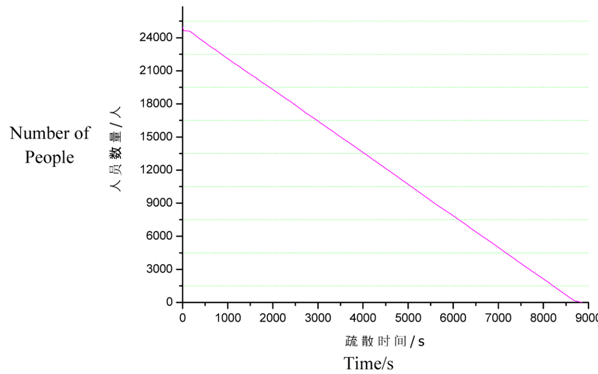

Figure 16. The comparison curve between the number of people with evacuation time in Scene one.

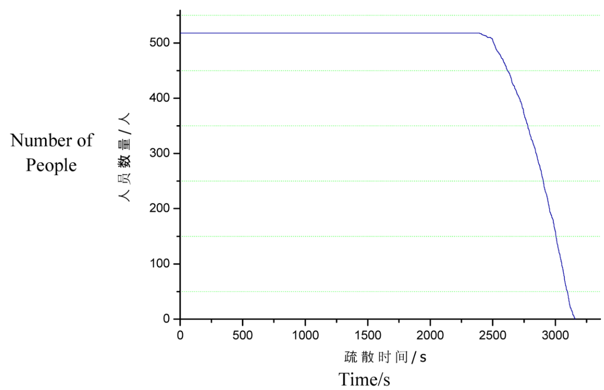

Figure 17. The comparison curve between the numbers of people with evacuation time in Scene two.

hazard analysis is needed to define the hazards associated with sustainable products or materials to quantify the hazards introduced and to determine the appropriateness for tall building design.

The energy saving exterior insulation material for the glass curtain wall requires high performance. This could conflict with fire protection performance in how to meet the objectives for achieving the design goals requiring the new technology for both product and updated testing protocol. The lessons learned from some recent fires could be the good source of best practices for updating regulations.

6. How to Work Green Building Concepts Together with Tall Buildings when Considering Fire Protection Design

6.1. Masdar Corporate Headquarters - (So called "Zero Energy Consumption Building")

This notable design, Figure 18, by Adrian Smith + Gordon Gill Architects in Abu Dhabi, United Arab Emirates.

The building includes several integral cone elements intended to moderate natural ventilation and provide natural light transfer throughout the building. The cone elements are part of the structural frame which would require a fire resistant rating based on the applicable code. Some of the cone elements are also part of the atrium spaces which would also require fire resistant rated separations.

Figure 18. MASDAR Corporate Headquarters Building (Source: AS + GG).

A performance-based approach was performed that is similar to those taken for these types of atrium issues in tall buildings in order to achieve the intent of the design. It included a review of the use, fuel loading and potential fire hazards to develop severe-case fire scenarios. Working with the structural engineering team members, various designs were fire modeled to develop the appropriate protection scheme (see Figure 19).

6.2. Fire protection system design & installation

The design and installation of fire protection systems, such as automatic sprinklers, fire alarm and smoke control are another challenge in green buildings. The challenges can range from the performance-based design of the atrium smoke control system to the placement of devices based on obstructions, local temperatures and glazing locations.

The use of fire modeling and other performance-based design tools can provide a detailed assessment of smoke movement and the impact on egress, travel distances and tenability conditions. The analysis can also provide the basis for reviewing natural smoke venting schemes.

6.3. Pearl River Tower

The Pearl River Tower in Guangzhou, China is one of

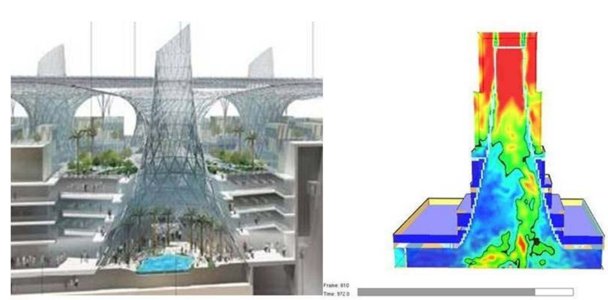

Figure 19. Fire Model Simulation for MASDAR Corporate Headquarters Building (Source: AS+GG and RJA).

Figure 20. Pearl River Tower Fire Safety Issues (Source: SOM and RJA).

the first green buildings in China. It was designed by Skidmore, Owings & Merrill, L.L.C The building is a mixed-use facility of 310 meters with 71 stories, 3 story podium and 45,000 sq. m. below grade. The fire protection issues for this building are typical of those now being addressed in many green buildings (Li et al., 2008). The features include the use of vertical axis wind turbines, photo voltaic panels, metal ceiling cooling system and a double curtain wall (see Figure 20).

One particular issue for the fire department was access to the wind turbine if the source of the fire was inside it. The detection and suppression systems for this area were also of concern to the fire department. A fire analysis by RJA used a failure mode approach provided a fire safety design and emergency response plan.

7. Fire Safety Concerns

Many decisions made by others on the design team can impact the overall fire safety of the project. They need to be understood by all of the team members.

7.1. Green Roofs

The issues of green roofs as a fire hazard have been well documented. The foliage becomes a source of combustible fuel load in drought conditions or when not properly maintained. In addition to the impact on the building roof, fire spread to other buildings in close urban areas becomes a concern. Green roof design may have an impact on airborne evacuation from the roof during fire emergencies which is a requirement in certain countries, such as China. Also starting to see more and more design to propose using the roof garden as the area of refuge to save space and meeting the requirements for serving the maximum 15 floors. If the roof is designed as a roof garden for occupant access for events or functions, then fire protection should be the key issue brought up very early in the planning phase.

Issues /concerns include:

1) Roof garden vs. refuge platform
2) Retail commercial mall street vs. atrium (20% open roof space to achievie the interim space between indoor and outdoor space to replace the mechanical smoke control system)

Highlighted new ideas /concepts:

1) Roof garden's added fuel load with the dry plant and possible fire spark
2) Roof garden counting as the AOR to save space for other functions
3) Roof garden added supplemental egress means
4) Lighting protection and other fire protection means (illumination, minimum required space size for accommodating the occupants)
5) Fire protection water tank size increase from 18 m^3 to be 100 m^3 for super high rise building over 100 meters

7.2. Sprinkler water quality & testing

Water conservation is a major part of green building design. Use of rainwater or other grey water sources as a supply for the sprinkler systems is being considered as another opportunity to conserve water. If implemented, this will increase the risk of corrosion and MIC buildup in the piping. Another consideration for conservation may be to limit or even eliminate periodic water flow testing. This could compromise the verification of system performance that is required in many codes.

7.3. Fire department access

Creative landscape design around a building is a desired feature with green buildings. This may impact the fire department access to the building or site. Large features can create vehicle obstructions and the desire to limit paving can impact fire lanes. In addition, the use of glazing on roofs can interfere with firefighter access. The glass curtain wall is the modern desired features with light weight and transparency, however, during a fire the glass could break and impact the fire operation safety. In addition, strong reflection from the glazing could negatively impact the firefighting effort and the site for fire vehicle staging.

7.4. Areas of refuge

This space is part of the culture in many Asian countries. It creates the requirement for a refuge floor every 12 to 20 floors, depending on the local codes. This requirement creates a conflict on efficient space use versus the fire service controlling the evacuation

8. Conclusion

Prevention of fire in itself is a significant green design feature. The environmental impact of a fire with the release of carbon gasses, destruction of resources and runoff of suppression products can have a greater negative impact than the actual savings in the building design. Application of today's best practices and advances in fire safety design can help to both mitigate a fire disaster from occurring and achieve the desired creative design for the building.

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