

# **TALL BUILDING FIRE SAFETY CONFERENCE 2014**

**PROCEEDINGS OF THE 2<sup>ND</sup> INTERNATIONAL TALL BUILDING  
FIRE SAFETY CONFERENCE  
GREENWICH, UK 17-20 JUNE 2014**

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**Front Cover Picture:**

View of the building EXODUS simulation of the World Trade Centre showing a Sky Lobby, Express elevators (green coloured cubes), local lifts (pink coloured cubes), the three emergency stairs packed with building occupants and building occupants who have not responded at this time. See paper by Galea these proceedings for details.

**Back Cover Picture:**

Simulation of the evacuation of the World Trade Centre North Tower with 25,500 building occupants utilising a combination of elevators and stairs. The simulation was performed using the building EXODUS evacuation model. See paper by Galea these proceedings for details.

**In memory of Dr Guylene Proulx 1960 – 2009**  
**a trusted and valued colleague**



## **THE TALL BUILDING FIRE SAFETY NETWORK**

The skylines in many cities are being populated with taller and more exotic buildings. Architects are competing with each other for singular iconic shapes and detail. Emerging economies are signifying their fiscal ascendancy with structures that are statement buildings of National intent. The challenges for fire engineers and fire risk managers are manifest given the number and extent of recent high profile fires in Tall Buildings. Tragically, there is a high casualty rate amongst firefighters responding to Tall Building fires and this has caused an urgent review of operational procedures and pre-planning.

The Tall Building Fire Safety Network (TBFSN) was founded in 2009 with the objective of promoting fire safety best practice amongst those who design, construct, manage and firefight within Tall Buildings. One early obvious question; what is a Tall Building? This led to extensive debate with several definitions developed and then rejected. Various height thresholds were also suggested as a trigger to define a Tall Building. Again, these were dismissed as too prescriptive. In the end, simplicity won the day with the following definition for a Tall Building:

‘A Tall Building is structure that has occupants above the reach of ground based rescue ladders’.

The highly concentrated nature of Tall Buildings means that potential loss consequences are very high if multiple fires, or system failures occur. Some current Tall Buildings have been described as ‘vertical villages’ with a variety of uses contained within the structure. This may include retail, office, leisure, residential accommodation and of course the obligatory viewing deck or observation area. A challenging environment for any fire safety manager in a ground based structure. Taller mixed use buildings will require new innovations in fire safety risk management.

The TBFSN has met twice a year since 2009. Recent meetings have taken place in the Shard, Canary Wharf and the BT Tower. The mission statement of the TBFSN:

“To collectively advance the understanding of fire risk management in tall buildings, during design, construction, occupation and firefighting operations. This will be achieved by group scrutiny of available research data, relevant innovative products and development of a guidance document for fire safety in tall buildings”.

Membership and attendance at the TBFSN meetings is by application and peer invitation. The TBFSN delivered the first International Tall Building Fire Safety conference in London in April 2013 and a wide range of speakers provided information, research and experiences to enhance the subject of Tall Building Fire Safety. The interest and attendance at recent conferences and training courses for Tall Building fire safety would indicate a need to advance the current knowledge, and

challenge accepted wisdoms. Unplanned simultaneous occupant evacuations, breached pressurised firefighting shafts, multiple fires on multiple floors, non-compliant 'stay put' occupants need to be considered and addressed to prevent a major loss of life tragedy.

These proceedings from the 2nd International Tall Building Fire Safety Conference, represent another significant step in the advancement of fire safety in Tall Buildings. As usual many questions will be posed as well as answered. Further academic research progress and innovation will be reported at the 3rd International Tall Building Conference to be held in Chicago, US, in 2015.

Thanks to all who have made the 2nd International Tall Building Conference in Greenwich, London, a great success.

Russ Timpson – Horizonscan  
Conference Organiser  
May 2014

## **PREFACE**

The tallest building in the world is currently under construction in Jeddah. The building, known as the Kingdom Tower, is expected to stand over 1000 m high, over 170 m taller than the current title holder, the Burj Khalifa. The 167 floor tower Kingdom Tower is expected to take 5 years to complete and will accommodate a five star hotel, apartments, office and retail space, the obligatory observatory and will be serviced by 59 lifts (elevators). The building is expected to accommodate tens of thousands of people in what will essentially be a vertical city. Considerable thought will go into ensuring that the systems and procedures within the building will be appropriate to ensure the efficient day to day operation of the building, but also how it will respond to emergency situations such as those involving fire. Tall structures pose particular fire safety challenges related to fighting fires and evacuation.

However, the drive to build ever higher structures is not new. Over the ages, humanity has strived to build taller and taller structures. For over 3,800 years, the Great Pyramid of Giza (built around 2560 BCE), at 147 m high, was the tallest man made structure. This was only surpassed in the 1300's with the building of the cathedrals, with Lincoln Cathedral in England rising to a height of 160 m. The cathedrals reigned supreme in the height stakes for the next 500 years. They were eventually surpassed in 1884 by the Washington Monument in the USA, which at 169 m was the tallest structure in the world for a brief time from 1884 to 1889. This was then dwarfed by the Eiffel Tower in France, which with a height of 301 m to its roof, held the title of tallest man made structure from 1889 to 1930. It is interesting to note that the European Union's tallest building is the Shard in London. This 87 floor, 306 m tall building, completed in 2012, while the tallest building in the European Union, is shorter than the current day Eiffel tower which today stands at 324 m to the tip of its antenna.

While tall, these structures are not what we would consider buildings in the sense of modern day high-rise buildings. For our buildings to reach for the skies we had to wait for the development of that other high-rise icon, the elevator in the 1850s. While elevators were used in the early 1800's to haul goods they were not considered appropriate for people due to safety concerns relating to the snapping of the cable used to raise and lower the elevator car. In 1852 Elisha Otis developed the safety elevator which overcame this problem. This, together with the development of electric motors paved the way for the development of the modern high-rise building.

Following these developments, high-rise buildings began to take on their familiar look which would eventually come to define the 20th century cityscape. In 1870 the first office building to operate passenger elevators was the Equitable Life Building of New York City, which was to become the home of the high-rise. At 40m high, the Equitable Life Building was a good deal shorter than the other tall structures, but was the tallest building in the world. Its pride of place was short lived with the Home Insurance Building of Chicago taking the mantle of highest building in 1884 coming in at 42 m. In the last two decades of the 19th century a tall building boom erupted in

New York City with the New York World Building jumping to 94 m in 1890 and culminating with the Park Row Building in 1899 reaching a height of 119 m.

With a new century came another tall building surge with buildings such as, The Philadelphia City Hall (167 m), Metropolitan Life Tower (213 m), Woolworth Building (241 m) and the Bank of Manhattan Building (283 m). Finally in 1930, the dizzying heights of the Eiffel Tower were finally surpassed by the Chrysler Building, coming in at 320 m. However, this was soon over taken by the Empire State Building which at 381 m held the record of highest building in the world from 1931 to 1972.

The Empire State Building was only surpassed in 1972 with the completion of the World Trade Centre (WTC) North Tower which stood at 417 m. The last US building to hold the mantle of the world's tallest is the Sears Tower in Chicago (now called the Willis Tower). With a height of 442 m it reigned supreme from 1974 to 1998. Towards the end of the twentieth century, tall buildings began springing up in Asia and the Middle East. Today there are 22 buildings around the world that are taller than the Empire State Building, three of which are located in the USA and 10 buildings taller than the Sears Tower, only one of which is located in the USA. In 1998, the Petronas Towers of Kuala Lumpur, with a height of 452 m became the first building outside the USA to hold the mantle of tallest building in the world. From 2003 to 2010 Taipei 101 claimed the title coming in at 509 m and from 2010 to the present day, the Burj Khalifa of Dubai is the world's tallest building at 828 m.

With tall buildings comes the fear of fires and the associated difficulties in; preventing fires from starting, preventing fires from spreading, manual firefighting and evacuation. A recent NFPA report suggests that from 2007 to 2011 there were an average of 15,400 structure fires in high-rise buildings in the US. These fires cause on average 46 civilian fire fatalities and 530 injuries per year<sup>1</sup>.

Right from the early days of high-rise buildings the threat of fire has been ever present. The Triangle Shirtwaist Factory fire of 1911 in New York was one of the first tragic high-rise fires, claiming the lives of 146 people. The factory was located in the 10 storey Asch building. Entrances to stairs and final exits were locked meaning that workers could not escape, with many jumping to their death. Needless to say, the building had no fire alarm or sprinkler system. The 25 floor Joelma Building in Sao Paulo experienced a fire in 1974. Of the 754 occupants in the building at the time of the fire, it is estimated that up to 189 people lost their lives. The building is reported not to have had emergency exits, fire alarms or a sprinkler system. Many people went to the roof of the building in the hope of rescue via helicopters with 40 of these falling to their deaths. It is reported that 13 people tried to evacuate using elevators and lost their lives through smoke inhalation. MGM Grand (Las Vegas, 1980, 84 killed) and Dupont Plaza (Puerto Rico, 1986, 97 killed), Nathan Street Office Building (Hong Kong, 1996, 40 killed), Garley Building (Hong Kong, 2000, 41 killed), Windsor Building Madrid (Spain, 2005, no fatalities but almost collapse of the 32 floor building), Mandarin Oriental Hotel (Beijing, 2009, 1 fire fighter killed), Shanghai Apartment Building (China, 2010, 58 killed), Torre Ejecutiva Pemex Tower (Mexico

City, 2013, 33 killed) are all examples of tragic fires or explosions in high-rise buildings around the world needlessly claiming many lives.

The most important high-rise building disaster of recent times is the World Trade Center 9/11 terrorist attack which resulted in the deaths of over 2000 people. This incident was instrumental as it raised a number of issues concerned with fire development, fire suppression, structural response to fire, firefighting and evacuation – all topics covered by this conference. Even though they manifest themselves in different ways, these issues are the same as those faced by the occupants of the first high-rise buildings over 100 years ago.

Perhaps the most fundamental question concerning safety in high-rise buildings that remains to be answered relates to how people utilise stairs. The 9/11 WTC tragedy highlighted our lack of understanding of human dynamics associated with stairs. While humanity has been using stairs for millennia (stone stairs in ancient Jericho date back 7000 years and the oldest known wooden stairs dating back 3000 years were recently unearthed in Hallstatt Austria), we do not fully understand the detailed crowd dynamics associated with stair usage. For example, while there have been several attempts at explaining merging and deference behaviour on stairs, we still do not understand it to the point that we can predict it accurately using our computer based evacuation models. Furthermore, we still cannot quantify definitively the movement speed of people of different ages (including children), gender and mobility on stairs and how this is influenced by crowd density, fatigue and a sense of urgency. With an aging and increasingly obese population, it is essential that we understand and quantify human dynamics on stairs.

Other high-rise building evacuation issues include: human behaviour associated with the use of lifts/elevators in evacuation situations, group behaviours and how these influence both the response and movement phases during evacuation, wayfinding in emergency situations, the impact of social culture on evacuation behaviour, etc. Also of great importance is the collection of appropriate human performance data that can be used for computer model validation purposes. Too often partial or incomplete data sets are collected, which allow the modeller the opportunity to tune their predictions in order to obtain the best fit to the experimental data.

What makes evacuation research both fascinating and challenging is that human behaviour and performance in evacuation is controlled by a complex combination of interacting physical and social factors. The physical factors are determined by the architectural features of the environment (e.g. door widths) and the physical attributes of the interacting population (e.g. travel speeds). The social factors relate to the psychological (e.g. motivational) and sociological (e.g. group dynamics) variables that influence the behaviour of individuals within the interacting population. To a certain extent the social influences are contextual and are governed by the nature of the triggering incident. Thus behaviour observed in a fire drill, a staged experiment, a false alarm, a real incident in which there is no sense of danger and a real incident in

which there is a real and immediate sense of danger, may lead to very different behaviours, even though the physical factors in all these incidents may be identical.

The aim of this conference was to provide an opportunity for researchers and practitioners to present the most recent developments in high-rise building fire safety research. Of the papers presented at the conference 13 complete manuscripts from Australia, Canada, Denmark, Finland, Japan, South Korea, Sweden, UK and the USA are included in these proceedings. The papers cover a range of topics including; evacuation procedures, the use of lifts for evacuation, external fire spread, firefighting, fire fighter performance, wayfinding, people with reduced mobility, timber framed buildings and issues associated with fatigue during evacuation and intervention. It is hoped that with continued discussion on these topics, during the conference question and answer sessions, panel discussions and the workshops we will stimulate new ideas and new approaches to drive discovery and address high-rise building fire safety issues.

Finally, I would like to express my gratitude to colleagues who have helped make this conference a great success, in particular Russ Timpson who brought us together in the Tall Buildings Fire Safety Network back in 2009. I would like to also thank all the authors who worked hard to get me their papers in reasonable time and to Ms Karen Judd, my personal assistant who worked so hard to pull the proceedings together.

#### **References:**

1. Hall, J.R., High-Rise Building Fires, Sept 2013, NFPA No. USS30.

Greenwich, May 2014

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