出國報告（出國類別：國際會議）

「參加 2017 火災安全亞洲研討會」報告

服務機關：內政部建築研究所

姓名職稱：雷明遠 約聘研究員

派赴國家：新加坡

出國期間：**106** 年 **11** 月 **12** 日至 **106** 年 **11** 月 **18** 日

報告日期：**107** 年 **2** 月 **7** 日

摘　要

關鍵詞：防火科技、防火安全、國際研討會

新加坡「2017 火災安全亞洲研討會(Fire Safety Asia Conference Singapore 2017)」於 2017 年 11 月 15 至 17 日舉行，內容多元豐富(包括火災風險管理、防火工程及法規發展、煙控性能設計、高樓及外牆火災、倉儲用撒水頭、製藥廠及光電板火災風險、衛生照顧設施防火及高齡、嬰幼兒場所避難安全、油槽火災應變等)，適本所刻正研擬規劃下一階段防火科技中程計畫，藉由參加會議蒐集國際研究發展動向以資參考。另於 11 月 13-14 日安排參訪新加坡民防總署轄下之民防學院訓練中心及有關機構、南洋理工大學防護科技研究中心，觀摩該國先進火災情境模擬設施、構造耐火實驗裝置等，提供本所評估未來規劃防火科技南向跨國合作可能性之參考。

目　次

壹、 目 的

本出國計畫目的之一，係藉參加新加坡「2017 火災安全亞洲研討會(Fire Safety Asia Conference Singapore 2017)」(以下簡稱 FiSAC 2017)之防火安全工程工作坊及聆聽國際級專家演講報告，廣泛蒐集國際防火災研究新知及發展動態，尤其國外有關火災風險管理、防火工程及法規發展、煙控性能設計、高樓及外牆火災、倉儲用撒水頭、衛生照顧設施防火及高齡、嬰幼兒場所避難安全等研究資料，期能提供本所規劃下一階段防火科技中程計畫之參考。其二，藉由參加會議廣泛接觸新加坡與會專家，並參訪新加坡民防總署轄下之民防學院訓練中心及相關機構、南洋理工大學防護科技研究中心，瞭解該國或東南亞近些年來建築物防火科技研究水平概況、成果應用及未來展望，提供本所防火科技計畫未來規劃防火科技南向國際合作可能性之參考。

貳、 過 程

本次出國計畫係為參加「2017 火災安全亞洲研討會(Fire Safety Asia Conference Singapore 2017)」，自 106 年 11 月 12 日至 11 月 18 日合計 7 天，行程安排如表 1 所示。本次研討會主辦單位為新加坡之民防總署(Singapore Civil Defence Force)及國家火災及緊急應變委員會(National Fire and Civil Emergency Preparedness Council)，主題為創新先端之火災安全及緊急應變(New Frontiers in Fire Safety & Emergency Response)，共同主辦單位為英國消防工程師學會新加坡分會，協辦及贊助單位有 15 家民間單位。

表 1. 本次赴新加坡計畫相關行程表

日期	活動內容	備註
11 月 12 日(日)	▪ 出發赴桃園國際機場 ▪ 搭機：台北(桃園國際機場)－新加坡	
11 月 13 日(一)	▪ 參訪觀摩新加坡民防學院相關火災防救訓練設施	
11 月 14 日(二)	▪ 參訪南洋理工大學防護科技研究中心(會見 Prof. Tan Kang Hai)	
11 月 15 日(三)	▪參加 2017 火災安全亞洲研討會(防火安全工程工作坊)	新加坡濱海賓樂雅酒店(Parkroyal on Beach Road, Singapore)
11 月 16 日(四)	▪參加 2017 火災安全亞洲研討會	同上
11 月 17 日(五)	▪參加 2017 火災安全亞洲研討會	同上
11 月 18 日(六)	▪赴樟宜國際機場 ▪搭機：新加坡－台北(桃園國際機場)	

一、參訪觀摩新加坡民防學院相關火災防救訓練設施

新加坡民防學院具有先進完善之訓練場地與設施，包括火災搶救模擬燃燒設施、高樓搶救、倒塌建築物模擬場、坑道搜救模擬場、化學災害救援場地等。新加坡民防學院指導教官均曾有多次國外救災經驗，例如南亞大海嘯及印度尼西亞尼亞斯島地震救災，甚至是中國四川大地震時，另外，民國88 年9 月21 日921 大地震造成我國重大人命傷亡及財產損失，新加坡民防部隊亦曾派出專業的搜救隊來台協助。早年我國尚未建立消防署竹山訓練中心之前，國內各地方政府概多選派人員前往該學院受訓，因此我國與新加坡之間消防官員的交流可謂密切頻繁。民防學院將於2018至2022年進行一項重大重建計畫，將使得民防學院之緊急應變訓練邁入嶄新的空前水準。特別是, 將在新建建築物內設立國家緊急醫療服務(EMS)培訓中心和災害管理領導中心。以下簡介目前相關設施：

(一)室外火患與拯救模擬設施

編號	設施說明	圖片
1	變壓器火患模擬設施 (Transformer Fire Simulator)	

2	液化石油氣筒(子彈型)火患模擬設施(LPG Bullet Tank Fire Simulator)	
3	液化石油氣管火患模擬設施(LPG flange Fire Simulator)	
4	有害化學物質洩漏與火患模擬設施 (Hazardous Material leak Simulator)	
5	汽車火患模擬設施 (Car Fire Simulator)	

6	油槽車火患模擬設施 (Road Tanker Fire Simulator)	
7	ISO油槽車洩漏模擬設施 (ISO Tank Gas Leak Simulator)	
8	120公尺搜索隧道模擬設施 (120-meters Search and Rescue Tunnel Simulator)	
9	建築物坍塌搜索模擬場地 (Collapsed Structure Ruin Area)	

10	穀倉搜索模擬設施(Silo Search and Rescue)	

(二)室內火患模擬設施 (Internal Fire Simulators) (Furnace)

此設施實際上是一座9層樓的先進建築，有地下室，且所有樓層都裝有防火和煙霧模擬器。火警由位於大廈地下的控制室透過電腦系統控制。熱顯像相機和閉路電視安裝在關鍵位置，以確保學員的安全，並監測他們在黑暗中的運動。大廈結構由耐火磚保護，並安裝熱電偶控制溫度。在點燃火焰模擬器之前，另使用安裝之氣體感應器來探測建築物內的氣體洩漏。此外，可以利用建築物外部的高度救援訓練和救援活動。建築物內設有住宅、商店、咖啡屋、歌廳、實驗室、倉庫及超市等不同火場情境，可以讓消防人員學習面對高層大火之閃燃情境及相關滅火步驟。

各式空間火災模擬訓練設施

各樓層設施說明如下：

樓層	設施說明	
9F	酒店睡房火患模擬設施(Hotel Room Fire Simulation)	
	洗衣室及煙爆火患模擬設施(Laundry Room Fire and Back Draft Simulation)	
	迷你超市火患模擬設施(Mini-mart Fire Simulation)	
8F	酒廳火患及閃燃模擬設施(Karaoke Lounge Fire and Flashover Simulation)	
	酒 廊 火 患 模 擬 設 施 (Bar Fire Simulation)	
	廚房火患模擬設施(Kitchen Fire Simulation)	
7F	化 學 物 質 儲 藏 室 物 資 火 患 模 擬 設 施 (Hazmat Store Fire Simulation)	
	包裝室機器與電箱火患模擬設施(Packing Room and Electrical Fire Simulation)	
6F	設備層	
5F	住宅火患閃燃模擬設施(Residential Fire Simulation)	
	易燃物質儲藏室火患設施 (Flammable Storage Warehouse Fire	

	Simulation)	
4F	船艦休息室火患模擬設施	
3F	船艦引擎火患類比設施(Ship Engine Fire Simulation)	
2F	設備層	
1F	生化物質保護配備信心訓練室(Chemical Agent Suit Confident Training Room)	
地下層	地下層廢物火患模擬設施 Basement Fire Simulation	

二、參訪南洋理工大學防護科技研究中心(NTU-PTRC)

(一)PTRC 歷史沿革

防護技術研究中心(PTRC)是在 1998 年 9 月 29 日南洋理工大學與該國國防部(MINDEF)簽署諒解備忘錄後聯合出資成立的一個跨學科

研究中心。該中心創設於土木工程和環境工程學院，特別聚焦於動力學和保護性工程方面的聯合研發工作。PTRC 還能提供了一個可整合南洋理工大學各應用科學和工程科系的研發專案的平臺。PTRC 的大多數聯合研發專案都得到了國防部國防科技局(DSTA)的支援。PTRC 與 DSTA 開發民用和軍用地下空間的研發專案，是與工業界或政府機構聯合研發專案的最成功例子之一。

該專案支援國家努力在花崗岩及沉積岩中建造洞穴和隧道以儲存戰略材料。多年來，土木工程和環境工程學院一直與過去被稱為國防部土地和財產組織的國防科技局保護基礎設施和房地產部門緊密合作。其中建造裕廊岩洞的成功案例顯示，PTRC 成功地將技術從與 DSTA 合作軍事用途轉移到民用，其中 PTRC 和 DSTA 擔任裕廊集團(JTC)的顧問建造裕廊岩洞，成為新加坡和東南亞地區首座地下儲油設施。除 DSTA 外，PTRC 還與國家發展部公共工程局和內政部民防總署合作，開展了若干項聯合研究專案。其中一些專案是關於防爆門、民防庇護所、地下設施和地面結構的動力、爆炸或爆發荷載的影響。這些研究專案包括數值模擬和實驗研究，探討高強度瞬態動態荷載對土壤和岩石介質以及結構構件和系統的影響。

(二)PTRC 研究能量

為實現 PTRC 的任務，確定了三項主要功能，包括(1)研究和發展、(2)教育和培訓、(3)技術移轉。依此開展以下活動：(1) 對基礎設施和設施進行動態和武器影響方面的重點研究方案、(2)與當地和國外的大學、研究中心和行業建立合作、(3)具體落實技術移轉、(4)維持資源中心、(5)提供專業的諮詢顧問服務。

PTRC 的研究領域概可分成 3 方面：(1)鋼結構與鋼筋混凝土的漸進倒塌分析與模擬、(2)地下空間發展、(3)先進材料之發展及模擬。目前主要研究成果可分為 4 方面：(1)地下彈藥設施(UAF), (2)對地下爆炸的結構保護、(3)保護空間用輕型防爆門、(4)模擬鋼筋混凝土版的穿透行為。

(三)**防火研究課題及設施**

1. 研究課題

(1)地下結構體之先進防火及避難研究

(2)碳纖管強化高性能水泥基質材料之耐火性能

2. 防火實驗設施

(1)水平500噸油壓伺服電動加載系統(組合式電爐)

由左右兩側可移動式(1.2m 高×2m 寬)電爐各兩片組合而成，加熱曝火段住長可達3.8m，爐溫部份可符合BS-476之標準升溫曲線規定。加載系統則由水平施力，柱兩端可採鉸接或固定模式，搭配水平反力框架而成，整體系統最大可施加500噸軸力。據Prof. Tan Kang Hai表示，該中心試驗爐設計之初，因考慮新加坡嚴格知環保規定，所以捨棄使用油或氣體燃料做為加熱源。

	
水平式加熱電爐搭配水平加載系統	雙軸向加載加熱後柱試體

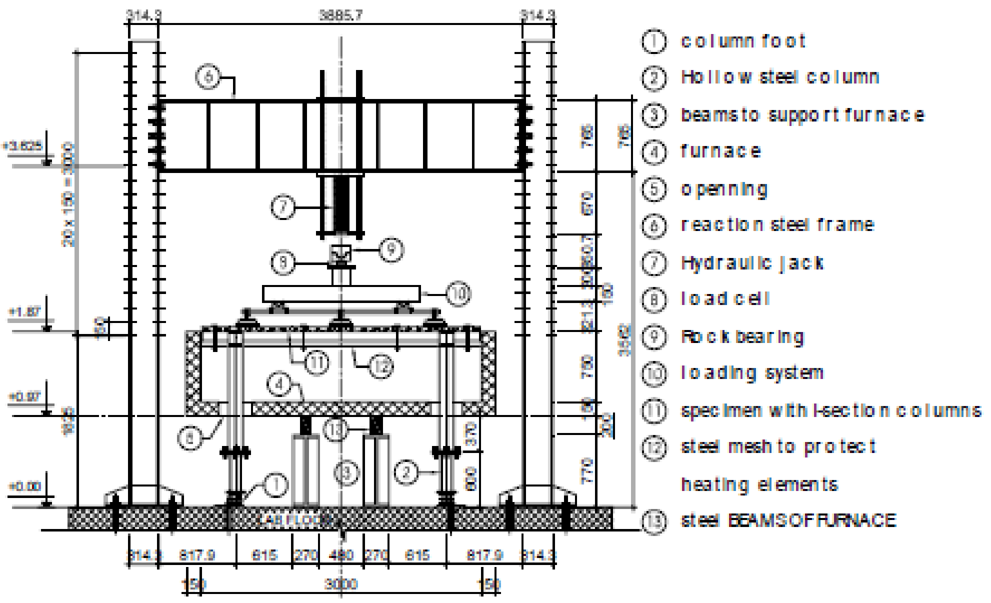
(2)梁柱複合接頭火害試驗設備

對建築結構梁柱系統而言，當火災發生於某一防火區劃內，如防火設備功能正常發揮而將其限制在該區劃內時，非火場外之梁柱結構將提供不同束制能力來支撐因高溫軟化或變形之火場內梁柱構架。對於梁構件而言，其軸向束制行為於相關結構火害研究中被廣為探討與分析。據Prof. Tan Kang Hai表示，該中心於建立設備之初，不僅考慮需可於常溫下進行梁柱接頭遲滯圈消能試驗，也考慮搭配一爐體(加熱尺度1.8m×1.5m×1.5m)與反力框架，以測試單一構件梁或柱、T 型梁柱接頭或十字梁柱構架接頭火害實驗，其水平與垂直加載油壓系統可施以250 噸外力。由於該系統於水平方向可設置反力支撐架，於加熱過程中探討梁軸向束制行為所造成之影響，其最大特色在於水平軸向束制行為之研究，即可考慮火場外其餘結構梁柱系統所提供之束制效應。

	
梁柱接頭複合火害試驗設備	RC 柱加載加熱試驗

(3)樓板加熱試驗電爐

加熱尺度為長2.3m×寬2.3m，爐溫能符合ISO 834 標準升溫曲線進行加熱試驗，搭配反力框架及外力傳遞系統可進行加載加熱試驗。



樓板試驗加載系統示意圖

	
可移動式水平電爐搭配強力地板與反力框架	水平爐內配置電熱線圈

三、參加 2017 火災安全亞洲研討會(FiSAC 2017)

本次研討會包括 2 天的火災安全及緊急應變課題研討會及 1 天的工作坊(Workshop)，均邀請國際或新加坡專家演講。開幕式邀請到新加坡總理辦公室部長(Minister in the Prime Minister’s Office)、人力部及

內政部次長(Second Minister for Manpower and Home Affair) Mrs Josephine Teo 擔任貴賓致詞，接著由大會主席新加坡國家火災及緊急應變委員會主任委員 Mr. Alan Loh Peng Leong 致詞。Mrs Josephine Teo 致詞中提到新加坡將自 2018 年 7 月 1 日起實施住宅用警報器規定，所有新建住宅建築均須要安裝，既有住宅則不須要，有變更設計涉及火災安全時才需要。我國雖然早已有住宅用警報器規定，但並未強制要求實施，近來老舊住宅建築火災頻傳，尤其是違章違建的住宅空間，因此部分地方政府已開始要求違建住宅須安裝住宅用警報器，否則將優先拆除。為提升住宅建築之公共安全，期待我國能夠早日全面實施全面安裝住宅用警報器規定。

	
Mrs Josephine Teo 開幕式剪綵	開幕式主辦單位等各代表合影

(一)防火安全工程工作坊

由美國 Fire Planning Associates, Inc.的負責人兼總工程師 Mr. Gregory Jakubowski 主講「良好的火災事前規劃的核心及和細節(The Nuts & Bolts of Good Pre-Fire Planning)」。

所謂事前規劃或預備計畫係指提供"內部資訊”給某一財產或特定事件的所有利害關係人，以利於更加有效率且有時序的反

應，此將有助於拯救生命、財產、金錢及管理風險。依據美國消防協會規範"NFPA 1620 事故事前規劃之建議實務"，火災事件事前預備計畫乃是整合相關資訊，包括物質和現場考慮、收容人員考慮、水供應、消防系統、特殊危險、緊急行動和事故前計畫測試和維護。該計畫提供建築物的各熟悉事項，對於消防員、警務人員、醫務技術員、環境衛生及安全人員及設施管理等的協助，沒有比這個是更好的。

事前規劃基本上包括了幾項重點：(1)要熟悉問題，了解問題所在，(2)管理組織，單位內部要有一個由上而下的動員組織去專責事故處理，(3)教育，員工需要教育訓練，適時教導預防、應變等做為及措施，(4)預防，應用各項設備、器材等防範災害、事故發生，並應用管理手法找出可能造成事故的風險，且予以排除，(5)防護，萬一事故或意外發生，應有萬全準備可以保護設施、人員、財產的安全，(6)緊急應變組織，事故或意外發生後，依據事前規劃的預備方案成立緊急應變組織或指揮系統，相關人員按照分組分工投入救災或處理意外工作。

(二)研討會相關報告

日期	主講人	主題/摘要
11 月 16 日	**Neil Gibbins** Chief Executive Officer and Company Secretary The Institution of Fire Engineers	**Keynote：火災及相關風險之全球管理** 本報告從全球各國之火災統計數據探討各地區之文化、氣候、財力等因素造成火災風險差異化。另以英國為例，說明消防反應、防護、

		預防等法規，並探討全球各地的防火安全系統可以從建築管理、營建過程、建造材料、人員使用、建築物管理、消防反應等方面選擇傳統或創新方式，其導致之風險亦不同。
	COL Alan Chow Mun Keong Commander, 1ST SCDF Division HQ	**油槽火災：新加坡民防總署之應變架構及策略** 本報告以發生於 1988 年的新加坡煉油公司(SRC)油槽大火為例，說明事後迄今該國民防總署針對石化火災所擬定的消防救災策略、應變佈署計畫等。
	Dr. Peter Wilkinson Director, The Institution of Fire Engineers	**防火安全工程標準 BS7974 之過去、現在及未來** 本報告探討英國防火安全工程標準 BS7974 的歷史沿革，該標準為全球最早有關於防火安全工程的規範之一。
	Henry Ho Managing Director, IGnesis Consultants Pte Ltd	**JEWEL-性能設計手法的應用** 本報告探討新加坡第 3 期航站新建工程因為造型特殊，外型呈半圓形、外覆玻璃，夜間宛如璀璨寶石，故稱為”JEWEL”。該建築內有植物公園、立體空中廊道等設計，因此應用防火性能設計手法，以達到消防安全、節能、智能化要求。

	Dr. Amer Magrabi Principal - Fire Engineering, Lote Consulting	**Lacrosse ACP 大樓外牆火災-事後分析(PIA)、建築法規變動及新澳洲外牆防火試驗標準** 本報告以澳洲墨爾本市一棟高層住宅大樓在2014年11月24日火災為例，說明該建築外牆材料為鋁複合板材料(Aluminium Composite Panels)所導致的外牆火災風險，並介紹澳洲參考英國、美國所發展之外牆防火試驗標準。
	Ron Diaper Technical Director, Colt Ventilation East Asia Pte Ltd	**煙控系統之性能設計應用** 本報告說明規格式及性能式煙控設計的差異分析，並舉一棟工業建築物之煙控設計為例介紹性能式煙控設計所採用之方法。
	Brian Davey Immediate Past International President (2016-17) The Institution of Fire Engineers	**太陽光電板危險及風險移除** 本報告介紹太陽光電板發生火災時搶救的危險，如電擊。另介紹各類型光電板的特性差異及應注意事項，並提出消防救災時如何避免人員受傷的方式。
11 月 17 日	Prof. Brian Jay Meacham Associate Professor Worcester Polytechnic Institute	**Keynote：促進新世代性能建築法規之架構** 本報告在倡議新的法規架構，即所謂社會-技術系統(socio-technical systems)，該系統包括組織面、技術面及人員面，其在法規目標、性能要求及性能基準上更加廣泛，包含健康、安全使用、危害、

		福利、永續及韌性。
	Tay Hao Giang Past International and a Trustee and Board of Directors The Institution of Fire Engineers (IFE)	**衛生照顧設施之火災安全策略** 本報告針對醫院火災風險進行探討，並依據新加坡法規提出減低或排除火災風險的具體作法。
	Richard Fowler Director, The Institution of Fire Engineers (IFE)	**高齡及嬰幼住民之避難及行為課題** 本報告介紹幾件火災之人員避難行為的特性，並說明收容高齡者人員場所避難所面臨之困難問題，同時提出解決問題建議。
	Gregory Jakubowski Principal and Chief Engineer, Fire Planning Associates, Inc	**製藥廠及研究設施內易燃液體相關火災風險移除** 本報告介紹美國 NFPA 有關易燃液體危險物品規範，並說明若干主要移除這類物品的火災風險。
	Dr. Louis A. Gritzo Vice President, Research, FM Globa	**高挑戰性倉儲風險之撒水頭研究** 本報告介紹自動倉儲應用撒水設備的最新發展，依據美國工廠互助保險集團(FM)進行之全尺度倉儲貨架火災實驗及 CFD 電腦模擬結果，提出同時在天花板置頂式及貨架內設置撒水頭設計，將能突破貨架高度限制。另外，因應物流業快速發展，貨架及取貨系統更加緊密，提出新的撒水頭設置規範，以確

		保倉儲貨物防火安全。
	Neil Gibbins Chief Executive Officer and Company Secretary, The Institution of Fire Engineers (IFE)	**消防隊員致死原因探究** 本報告以近年發生於英國曼徹斯特的 2 件火災中消防人員喪生事件為例，探討事後調查及法院審理的觀點。
	Chao Kang(趙鋼/中華消防安全中心基金會董事長) Chief Executive Officer & President Chinese Fire Protection Center Foundation	**台灣八仙樂園粉塵爆發燃燒事件之緊急應變** 本報告介紹我國 2015 年 6 月 27 日發生八仙樂園粉塵爆發燃燒事件之原因調查、緊急應變、緊急醫療救助等積極作為。
	David Larsen Director, International Sales	**使用水平橫拉門作為逃生設施** 本報告介紹新型水平橫拉門(折疊式)加設可重複開關的觸控開關，成為符合美國IBC的產品，

叁、心得及建議

一、 心得

(一) 國際研討會議所揭露之最新消防或建築防火實務，值得本所防火科技計畫研究方向研修之參考

從本次研討會所透露之國際趨勢，以下幾項值得參考：(1)建築法規因應全球性或社會問題的調整，如氣候變遷調適、建築物永續性調和、社會高齡化需求等；(2)防火性能化設計之應用；(3)建築物火災風險(人命安全風險、財產及企業持續性風險)及評估技術；(4)新型建築設備(光電板)衍生新型態火災的預防及搶救對策；(5)醫療機構等收容行動不便者之避難安全及緊急應變；(6)高層建築物防火安全；(7)建築物外牆立面火災延燒風險及防範；(11)特殊建築空間之防火安全（如儲放危險物品之工廠、研發實驗室等）。

(二) 新加坡對於安全科學研究的投入，從政府至民間均展現積極企圖心

從本次研討會議由新加坡之民防總署(Singapore Civil Defence Force)及國家火災及緊急應變委員會(National Fire and Civil Emergency Preparedness Council)共同主辦，主題定為創新先端之火災安全及緊急應變(New Frontiers in Fire Safety & Emergency Response)，可知該國主管消防及災害緊急應變業務的兩大機關的企圖心。此外，高層長官新加坡總理辦公室部長(Minister in the Prime Minister’s Office)、人力部及內政部次長

(Second Minister for Manpower and Home Affair) Mrs Josephine Teo 蒞臨致詞，顯示其政府對於類似科研活動相當重視。加上參觀了民防學院知道未來將增設國家緊急醫療服務(EMS)培訓中心和災害管理領導中心，以及參訪南洋理工大學防護科技研究中心了解到與新加坡政府多項合作計畫，在在顯示出該國在災害防治、應變及安全科技上的投入，可說是國家級資源。

(三) 積極參與國際會議並發表研究成果，方能有效提升國際能見度

本次會議為新加坡固定定期舉辦之國際性研討活動，本所首次參加，雖未受邀發表報告，但與會期間與許多當地政府部門人員、大學學者、民間專業人士廣泛交流，間接地介紹本所在建築防火科技領域歷年的成果，引起不少人高度興趣，或許未來有機會邀請本所人員前往發表。此外，與會中不少來自東南亞、國家的代表，如香港、越南、柬埔寨、泰國、印尼、馬來西亞等，本次研討會中我國有中華消防安全中心基金會趙鋼董事長發表關於八仙樂園事件的始末，引起與會人士的高度興趣，因此如能透過國際研討會發表將本所有關建築結構耐火、防火避難設計、創新防火設備技術等方面的豐碩研發成果加以介紹，相信對於上述國家必有相當吸引力。

二、 建議

(一) 建議參考國際防火研究趨勢，本所建築防火科技計畫導入前瞻防火技術研發

如本報告前節所述若干國際趨勢，將可配合本所目前刻正籌畫明（108）年度建築防火科技發展計畫，建議將上述研究

方向納入未來4年中長程研究規劃，不僅僅具有延續精神，更增添前瞻性及創新性。

(二) 建議加強我國對於安全防災及緊急應變有關科研工作的力度，有助於提升我國都市及建築之災害韌性

政府目前雖然在內政部消防署轄下設有竹山消防訓練中心，統籌國內消防人員及民間義消人員的訓練，但該中心人員編制、種子教官人才、設備維護及更新等，皆顯得短絀不足。此外，國內對於地震等天災之研發經費向來不少，但相對而言，火災等人為災害的研究資源卻逐年下降，以上顯示出我國對於安全防災的重視有所偏頗，為全面性兼顧到消防、建築防火領域，比照新加坡的重視及肯定，建議應加強我國對於安全防災及緊急應變有關科研工作的投入力度。

Global Management of Fire and Associated Risks

Neil Gibbins QFSM FIFireE

Chief Executive Officer and Past President of The Institution of Fire Engineers

Paper for presentation as key note address – FISAC Nov 2017 (delivery may vary from this paper)

1 Introduction

I am delighted to have been invited by the organising committee to deliver a key note speech to this conference. I am joined by a number of fellow trustees of the Institution of Fire Engineers (IFE), from the UK and from around the World, we are pleased to have the opportunity to spend time with so many of you who share our interest in making the World safer from fire. The conference and the associated social events give us the opportunity to share thoughts and ideas, with knowledge that we share a common motivator.

My fire journey started over 40 years ago, when I commenced a career in a UK fire brigade. I spent seven years “at the sharp end” as a firefighter responding to incidents. I remember too well some of those events, I am sure they have motivated me to get involved in taking action to help reduce the suffering from fire and associated emergencies.

The career journey took me from firefighting, through fire law enforcement, fire investigation, fire prevention and training. As the time spent in the firefighting role reduced, as I progressed through various roles and ranks, the time spent managing the organisation or the delivery of protective measures increased. My skills set increased to build on the knowledge required for fire fighting, behaviour of fire and buildings on fire to include areas such as human behaviour, risk analysis and fire safety systems.

At the very end of my career, when I reached the level of Deputy Chief Fire Officer, I was elected to the role of International President of the IFE. I relished the opportunity to engage with IFE branches and members in the UK and across the World, learning all of the time about similarities and differences in approaches to dealing with fire and associated risks, comparing and contrasting the frameworks deployed.

Fire is a difficult phenomena to manage. It can be our friend, providing heat, light or other positive, managed output. It can also take lives, ruin businesses, destroy natural or historic treasures. People should be able to sleep, work or enjoy themselves without concern as to their safety from fire. When I took up the invitation to speak here I would have been saying that the greatest challenge to keeping people safe in the UK was complacency. We had seen fire deaths reducing year after year, from over 1000 in the 1980’s to around 300 in recent years. No other public service in the UK is able to demonstrate such success.

On June 14th fire broke out in residential tower block in London. At least 83 people lost their lives, hundreds more lost their homes and all their belongings. The government has commenced a Public Inquiry, a review of Building Regulations and Fire Safety, the Metropolitan Police are investigating and at some point there will be Coroner's inquests into the deaths. I am also aware of a large number of fatalities due to wild fires in Portugal and other significant incidents around the World. As the CEO of the IFE I will not enter into conjecture or make assumptions. I will however draw attention to the UK fire safety framework and explore different approaches to managing the risk from fire and associated emergencies, to try to identify- What works?

2 The World's fire statistics

A number of organisations very helpfully gather data regarding fire deaths in different countries. The inputs may vary depending on the definitions applied, but comparison of three key tables reveals a level of consistency in terms of higher and lower rates.

Source 1 CTIF (International Association of Fire and Rescue Service).

"CTIF was founded in 1900 in Paris for encouraging and promoting co-operation among fire fighters and other experts in fire and rescue throughout the world."

The CTIF produces World fire statistics, the most current being published in 2016 giving data for 2014.

CTIF Table 2 (reproduced below) gives (incomplete) data from 32 countries which includes fire deaths per 100,000 inhabitants and fire deaths per 100 fires. Of these 32, the highest numbers of deaths by population are shown for Russia and Belarus. These two counties also show the highest numbers of fatalities per 100 fires.

Table/Таблица/Tabelle 2

Common indicators of fire statistics in the countries of the World in 2014
Укрупненные показатели объема работы и обстановки с пожарами в странах мира в 2014 г.
Verdichtete Kennzahlen der Brandsituation in den Staaten für das Jahr 2014

N	Country	Population, thous.inh.	Number of				Average number:					
			calls	fires	fire deaths	fire injuries	per 1000 inh.:		of fire deaths per:		of fire injuries per:	
							calls	fires	100000 inh.	100 fires	100000 inh.	100 fires
	Страна	Население, тыс.чел.	Число				Среднее число:					
			выездов	пожаров	погибших	травмиро-ванных	на 1000 чел.:		погибших на:		травмированных на:	
							выездов	пожаров	100000 чел.	100 пожаров	100000 чел.	100 пожаров
	Staat	Einwohner, in 1.000	Anzahl der ...				Mittelwerte:					
			Einsätze	Brände	Brand-toten	Verletzten	je 1.000 Einw.		Brandtotenzahl je:		Verletztenzahl je:	
							Einsätze	Brände	100.000 Einw.	100 Brände	100.000 Einw.	100 Brände
1	USA	318 907	31 644 500	1 298 000	3 275	15 775	99,2	4,1	1,0	0,3	4,9	1,2
2	Russia	144 000	1 801 991	150 437	10 068	10 951	12,5	1,0	7,0	6,7	7,6	7,3
3	Japan	128 130	8 415 385	43 741	1 678	6 560	65,7	0,3	1,3	3,8	5,1	15,0
4	Vietnam	93 000	-	2 375	90	143	-	0,0	0,1	3,8	0,2	6,0
5	France	66 030	4 294 400	270 900	280	13 703	65,0	4,1	0,4	0,1	20,8	5,1
6	Great Britain	61 370	505 600	212 500	322	9 748	8,2	3,5	0,5	0,2	15,9	4,6
7	Italy	61 000	730 471	189 375	-	-	12,0	3,1	-	-	-	-
8	Ukraine	43 001	175 649	68 879	2 246	1 450	4,1	1,6	5,2	3,3	3,4	2,1
9	Poland	39 492	419 264	145 237	493	-	10,6	3,7	1,2	0,3	-	-
10	Kazachstan	17 000	-	14 471	401	1 011	-	0,9	2,4	2,8	5,9	7,0
11	Netherlands	16 829	150 080	91 160	75	-	8,9	5,4	0,4	0,1	-	-
12	Czech Republic	10 505	100 776	17 388	114	1 179	9,6	1,7	1,1	0,7	11,2	6,8
13	Hungary	9 877	57 265	19 536	94	729	5,8	2,0	1,0	0,5	7,4	3,7
14	Belarus	9 481	61 087	7 489	737	421	6,4	0,8	7,8	9,8	4,4	5,6
15	Austria	8 544	228 080	43 336	-	-	26,7	5,1	-	-	-	-
16	Switzerland	8 238	47 461	11 658	-	-	5,8	1,4	-	-	-	-
17	Bulgaria	7 245	50 127	23 199	103	263	6,9	3,2	1,4	0,4	3,6	1,1
18	Serbia	7 187	27 641	16 805	73	338	3,8	2,3	1,0	0,4	4,7	2,0
19	Kyrgyzstan	5 522	-	3 991	70	48	-	0,7	1,3	1,8	0,9	1,2
20	Finland	5 398	99 074	14 027	86	851	18,4	2,6	1,6	0,6	15,8	6,1
21	Norway	5 109	18 577	8 672	54	284	3,6	1,7	1,1	0,6	5,6	3,3
22	Singapore	5 000	160 482	4 724	8	111	32,1	0,9	0,2	0,2	2,2	2,3
23	New Zealand	4 596	73 464	10 245	-	-	16,0	2,2	-	-	-	-
24	Croatia	4 290	-	7 317	21	71	-	1,7	0,5	0,3	1,7	1,0
25	Moldova	3 553	-	1 890	107	45	-	0,5	3,0	5,7		
26	Armenia	3 017	16 319	6 202	-	-	5,4	2,1	-	-	-	-
27	Mongolia	2 997	-	4 222	59	-	-	1,4	2,0	1,4	-	-
28	Lithuania	2 943	28 429	13 324	125	193	9,7	4,5	4,2	0,9	6,6	1,4
29	Slovenia	2 063	-	5 917	0	53	-	2,9	0,0	0,0	2,6	0,9
30	Latvia	2 001	21 688	12 875	94	283	-	6,4	4,7	0,7	14,1	2,2
31	Estonia	1 313	23 371	6 871	54	61	17,8	5,2	4,1	0,8	4,6	0,9
32	Liechtenstein	37	-	24	0	-	-	0,6	0,0	0,0	-	-
Total/Итого/Gesamt		**1 097 675**	**49 151 181**	**2 726 787**	**20 727**	**64 271**	**44,8**	**2,5**	**1,9**	**0,8**	**5,9**	**2,4**

CTIF Table 2 showing death rates.

Source 2 - Geneva Association

"The Geneva Association is an international think tank for strategically important insurance and risk management issues. The Geneva Association identifies fundamental trends and strategic issues where insurance plays a substantial role or which influence the insurance sector."

The Geneva Association (International Association for the Study of Insurance Economics) publishes World Fire Statistics. The most recent found is No 29, April 2014.

Table 6 gives deaths per 100,000 population, for 28 countries. Highest figures are for Finland and Romania.

Table 6: Adjustments to published figures (deaths) and population comparisons

Taking even the higher of the above sets of figures, additions need in most cases to be made for fire deaths unknown to the fire brigades or not recorded on death certificates.

Country	Addition (%)	Adjusted Figures (Fire Deaths) 2008	2009	2010	Deaths Per 100,000 Population (2008-2010)	
Singapore	10	1	1	1	0.02	
Switzerland	15	30	25	25	0.34	
Italy	25	285	285	240	0.45	
Netherlands	5	100	60	70	0.46	
Austria	5	55	40		0.47	[2007-2009]
Slovenia	5	10	10	10	0.49	
Spain	25	270	205	235	0.52	
Portugal	Nil.	65	55	60	0.57	
Germany	25	500	540	465	0.60	
Australia	Nil.	120	270	90	0.73	
United Kingdom	5	475	460	445	0.75	
Canada	10	295	240		0.77	[2007-2009]
New Zealand	Nil.	35	40	25	0.77	
France	25	595	595		0.96	[2007-2009]
Greece	25	130	110	110	1.05	
United States	6.4	3,650	3,300	3,400	1.11	
Norway	0.5	70	55	40	1.14	
Ireland	25	45	55	55	1.17	
Belgium	25				1.21	[2004]
Czech Republic	10	150	130	145	1.35	
Denmark	Nil.	90	70	65	1.36	
Sweden	12.5	130	140	145	1.49	
Japan	2	2,000	1,950	1,800	1.51	
Poland	5	585	565	595	1.52	
Hungary	Nil.	180	140	140	1.53	
Barbados	Nil.	5			1.65	[2007-2008]
Romania	Nil.	410	355	395	1.76	
Finland	5	110	120	95	2.03	

Geneva Association

https://www.genevaassociation.org/media/874729/ga2014-wfs29.pdf

Accessed 13 April 2017.

Source 3 - FEMA

The Federal Emergency Management Agency (FEMA) is an agency of the United States Department of Homeland Security. In July 2011, FEMA published Fire Death Rate Trends: An International Perspective.

Fire death rates for 23 countries are given.

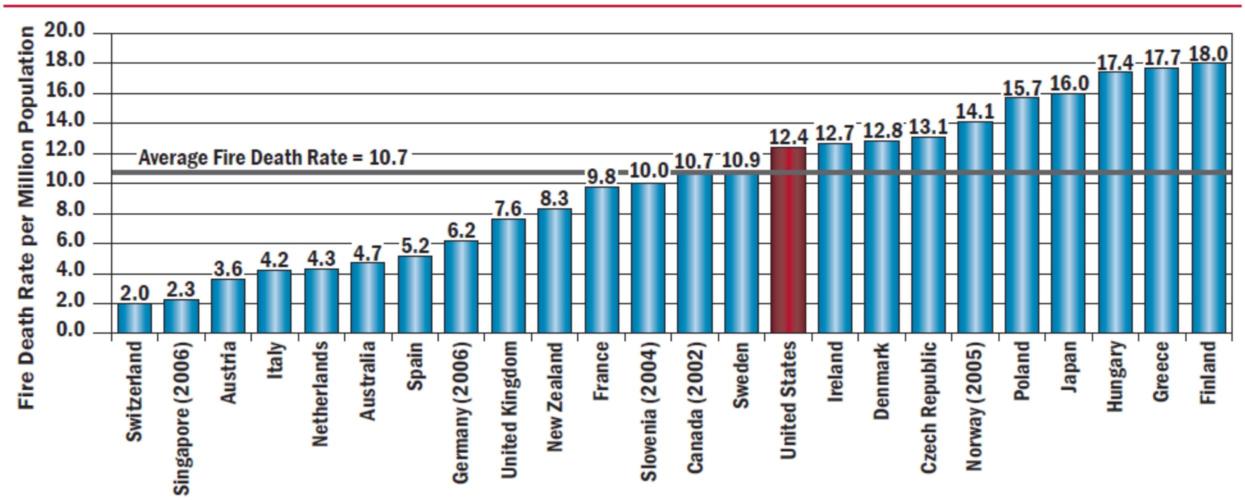
Its findings were:

- *From 1979 to 2007, fire death rates per million population have consistently fallen throughout the industrialized world. The North American and Eastern European regions' fire death rates have fallen faster than other regions.*

- *From 1979 to 2007, the fire death rate in the United States declined by 66 percent. Today, the United States still has one of the higher fire death rates in the industrialized world, however, its standing has greatly improved.*

- *Japan, a leader in fire safety, shows a slight worsening of fire death rates over the years studied.*

Figure 1. 2007 International Fire Death Rates per Million Population



Sources: World Fire Statistics Centre fire death data and the United Nations (U.N.) Demographic Yearbook population estimate data.
Note: Where 2007 data were unavailable, the death rate for the most recent year available is shown.

FEMA Figure 1. (Note: given per million population)

Ref 2.3.1.

https://www.usfa.fema.gov/downloads/pdf/statistics/v12i8.pdf

Accessed 13 April 2017.

Comment

It has to be mentioned that our hosts, Singapore, are shown consistently to have very low levels of deaths from fire, in terms of proportion of the population. Taking the CTIF table, they indicate that Singapore had a rate per 100 000 of 0.02, or 8 lost lives per year. From the same source, Russia had a rate of 7 deaths per 100 000, with a population of 144 million, 10 068 lives lost. Statistically, if Russia could achieve Singapore's fire death rate, their losses could fall from over 10 000 to under 300.

So what is the difference?

3 The Fire Safety System

3.1 In my opinion, it is probably safe to say that if you live in a country that knows how many people die from fire every year, then you are likely to be safer than in if you are in a country that does not have the infrastructure to gather such data.

3.2 Variations amongst those countries that produce statistics, as per the example above, are quite stark, and are worthy of examination to see if the differences reflect geographical variations, for instance climate or terrain, or are there human differences- Political, cultural or other variables? However, that is not the aim of my input today. I want to draw your attention to the fire safety "variables", to the standards for construction of buildings, management of buildings and response to emergencies, with intent to encourage thoughts about how the variables interact, and what we can learn from the varying systems.

3.3 I am most familiar with the UK systems. Until a few months ago I regularly quoted the significant change in numbers of fire deaths over the last four decades- from around 1000 deaths per year in the 1980's to around 300 in our most recent reports. We have recently suffered the largest single loss of life in a building fire, in peace time, since the Exeter Theatre Royal fire in the 1890's, with the loss of at least 83 people in the Grenfell Tower.

3.4 The UK has had a fire service system mandated by national legislation since the 1940's. The 1947 Fire Services Act required local authorities to set up fire services and set requirements for the service to be organised to respond and deal with fires and other emergencies.

3.5 Whilst the 1947 Act mentioned, almost in passing, that the fire service should give advice, the control of fire safety in buildings sat with local health inspectors, and then only in limited circumstances. Fire certificates for means of escape were issued in the 1950's, the first national building regulations came in during the 1960's.

3.6 The fire service took the lead role for fire safety in occupied buildings when the Fire Precautions Act 1971 (FP Act) became law. Initially applying to certain hotels, and then to places of work, the FP Act resulted in thousands of buildings being inspected by fire service officers, and when deemed satisfactory, a fire certificate was issued.

3.7 The 1980's saw a revamp of the Building Regulations, and the production of supporting documents giving descriptions of the outcomes required for safety from various risks including fire. The Approved Document B provides guidance for meeting five defined requirements including the means of warning and escape, restricting fire spread and facilities for the fire service.

3.8 Initially as a consequence of European law, the FP Act was replaced by other legislation, today occupied buildings are encompassed by the Regulatory Reform (Fire Safety) Order 2005, couched in a similar vein to the Building Regulations, focussed on outcomes rather than prescription.

3.9 A similar thread can be identified in respect of the UK arrangements for fire cover or response. The 1947 Act was supported by Government decreed “standards of fire cover”, detailing response standards based on speed and weight of attack. The Fire and Rescue Services Act 2006 removed those standards and replaced them with a requirement for FRS to produce “integrated risk management plans” (IRMP’s). The government influences the content of the plans through a National Framework document, setting out expectations for arrangements to prevent, protect and respond to fires and other emergencies. There is now no national standard for attendance time.

3.10 To summarise the above, the UK moved from a centrally directed system controlling construction and emergency response, to a locally determined, outcome focused process, allowing innovation, incorporating reliance on self- compliance and a light touch by enforcers.

3.11 Discussions with IFE members from around the World reveal many differing approaches, from strict central control of the fire service and fire safety in construction, to decentralised, market/industry led, self compliance.

4 Fire Profession, Professionals and Professional Body

4.1 I have touched on the UK journey, moving from central prescription to a goal based outcomes approach. I see nothing wrong with the intent of this journey, all I want to see is that we do all we can to reduce the risk from fire and other emergencies, to a point that is as low as reasonably practicable. In our health and safety regime, that is often shortened to “alarp”.

4.2 Prescription provides a level of certainty and surety, but can increase cost and restrict innovation. A refined fire safety system should deliver the public’s expected level of safety for the minimum cost.

4.3 Safe buildings need to be constructed and managed to reflect their use, and we have no shortage of well developed guidance documents that help define how this can be achieved.

4.4 The intervention of the emergency services should be a last resort. Prevention is better than cure, no system should rely on people awaiting rescue by the fire service. The public services should exert their influence and energy by advising and if necessary enforcing.

4.5 The construction process has to take the responsibility for keeping people safe. It is for the construction industry to apply the knowledge set out in guidance and standards, to create the safety envelope.

4.6 Once completed and handed over, it is for the managers of buildings, and any employers, to ensure that the fire safety design is maintained and functions in a manner that meets the actual needs of the occupied building at all times.

4.7 In a fire safety management system that adopts a functional or goal based approach, it is absolutely crucial that critical elements of design are approved by competent persons, that critical construction elements are approved by competent persons. It also then follows that, where fire safety systems require a high level of management, then the managers need a high level of competence.

4.8 In an effective fire safety management system, if there is freedom in the means of achieving safety, there has to be a balance, a means of ensuring that the “reasonably practicable” has been achieved and is being maintained. This is the constituency of the fire profession.

4.9 The notion or concept of “fire engineering” is seen as relatively new. In 1918 a group of UK chief fire officers recognised that a body was required to help pull together the thoughts and knowledge about fire prevention, protection and response. They formed the Institution of Fire Engineers, effectively defining “fire engineering” as a distinct discipline.

4.10 An underpinning expectation of a member of a professional body is that they adhere to the expected ethical standards and only operate within their own competency.

4.11 The key components of the professional body appear to me to be

- the promotion of ethical practice,
- the oversight of qualifications and competence frameworks,
- development of the body of knowledge,
- supporting continuous professional development,

All underpinned by science.

5 Conclusions

5.1 Countries take differing approaches to addressing fire safety, for reasons including Politics, Culture, Geography, economics. Rates of fire deaths, being a broad indicator of fire safety performance vary widely.

5.2 Decentralised, performance based systems place a high level of reliance on human analysis. The people involved must be competent and practice ethically.

5.3 The global fire community is relatively small, so fire professionals need a means to access a professional network.

5.4 Continuous improvement, in whatever fire safety system is applied, requires the support of networking opportunities to help identify developing challenges and potential solutions

6 Thank you to the organising committee, the supporting organisations and you for attending and listening.

Neil Gibbins QFSM FIFireE

Neil.gibbins@ife.org.uk

10/09/17

SOLAR PANEL HAZARDS & MITIGATING THE RISKS
(Photovoltaic Panels)

Brian Davey, CFIFireE
Immediate Past International President Institution of Fire Engineers

INTRODUCTION

For consistency during my presentation, reference to solar panel systems generally means photo voltaic solar panel systems that are systems that rely on light to generate electricity.

Why do we need to talk about solar energy? It is because of the rapid growth in the production and use of this renewable energy source. It is because of the increasing number of manufacturers. It is because of the increasing number of incidents involving solar panels. In the future as the systems get older, the ripple of incidents may turn into a wave. To this we can add electrical storage systems.

As the world demand for electricity increases, the market will continually seek lower cost and cleaner energy generation options, Solar systems will fill that option.

In 2000, 8 companies were making solar panels, in 2005 there were 20, in 2007 there were 846 in China alone. This has resulted in some cases of poor quality and has caused roofs and guttering to liven and people getting electric shocks when putting ladders up to the roofs.

In Singapore, the Energy Market Authority prepared a report in 2016 that looked at the growing interest in Singapore of PV (solar) systems and provided information to help interested parties better understand the characteristics of the system outputs.

New developments that may increase the identified hazards from solar panels are the developments in building solar components into roofing components such as roofing tiles and structural or decorative cladding. The use of these building components will add another difficulty for emergency responders in identifying solar arrays that are not obvious.

Solar systems that are already in use are not well understood. There are varying standards for installations and locations of various components that make up the system.

My presentation will cover some of the basics around these systems and provide examples of incidents that have occurred in various locations around the world, and finally, how emerge

This will then take us through a little on electricity then focus on the hazards associated with the use of solar arrays, and finally, how emergency services currently deal with incidents involving solar panels.

HOW DO SOLAR PANEL SYSTEMS WORK

Photovoltaic cells (PV) generate electricity from light, typically, sunlight. Each cell is capable of generating 0.6v of direct current (DC).

Solar power systems utilise a number of solar cells connected in series, (a string) to make up a solar panel. A number of panels are connected in series/ parallel to make up a solar array. The number of panels in an array determines the output power, in watts of the system.

The panel runs at around 45-50 Volts. An average roof panel is 250W. All panels are then run in series to increase the voltage. The commercial ones are then paralleled up to increase the amperage. Solar arrays can't work at anything higher than 1000V as it burns everything out. This is because you then have to buy 1000V circuit breakers and isolators which then cost significantly more and the contacts are large. Knife switches have been replaced with small isolators. Theoretically circuit inn the system you break a DC switch you should replace it because it pits it or marks reducing effectiveness.

Electricity

AC

- AC is alternating current, which is created by a rotary alternator.
- Electron flow vibrates backwards and forwards, at what is called the frequency.
- The frequency, or Hertz, in most countries is 50or 60 cycles per second
- When you come in contact with it. It contracts and releases your muscles, allowing you to disconnect from it more easily.

DC

- DC is Direct current, which is created by Chemical reaction, solar panels or a rotary alternator with rectifiers
- This means the electrons constantly flow in one direction
- It has no frequency
- It wants to keep flowing, in one direction, from the source to the load
- As it travels in one direction, it arcs badly when the carrier, (wire, your skin, etc), when it is disconnected
- When you come in contact with it, your muscles contract and stay contracted. It doesn't let you go

Watts

- Watts = the power unit. This is the indicator of how much power is available. How much it can hurt you.
- Power in watts is calculated by volts multiplied by the current in amps 240v x 10amps = 2400watts (2.4kw)
- Remove either volts or amps and you have no electricity. 240v x 0 amps = 0 watts.

Electrical hazard

We have just identified that electricity has an effect on the human body when it comes into contact with it. The health hazard of an electric current flowing through the body depends on the amount of current and the length of time for which it flows, not merely on the voltage.

However, a higher voltage is required to produce a current flowing through the body. The severity of an electric shock also depends on whether the path of the current includes a vital organ. Death can occur from any electric shock that carries enough sustained current to stop the heart. Low currents (70–700 mA) usually trigger fibrillation in the heart, which is reversible via defibrillator but is nearly always fatal without help. Currents as low as 30 mA AC or 300-500 mA DC applied to the body surface can cause fibrillation. Large currents (> 1 A) cause permanent damage via burns and cellular damage. The voltage necessary to create current of a given level through the body varies widely with the resistance of the skin; wet or sweaty skin or broken skin can allow a larger current to flow. Whether an electric current is fatal is also dependent on the path it takes through the body, which depends in turn on the points at which the current enters and leaves the body. The current path must usually include either the heart or the brain to be fatal.

Extract from AS/NZ 60479.1 2010: Effects of current on human beings and livestock

6.5 Description of time/current zones (see Figure 22)

Table 13 – Time/current zones for d.c. for hand to feet pathway – Summary of zones of Figure 22

Zones	Boundaries	Physiological effects
DC-1	Up to 2 mA	Slight pricking sensation possible when making, breaking or rapidly altering current flow
DC-2	200mA	Involuntary muscular contractions likely especially when making, breaking or rapidly altering current flow but usually no harmful electrical physiological effects
DC-3	200MA 500MA	Strong involuntary muscular reactions and reversible disturbances of formation and conduction of impulses in the heart may occur, increasing with current magnitude and time. Usually no organic damage to be expected
DC-4 [1)]	Above curve c_1 Above 500 MA	Patho-physiological effects may occur such as cardiac arrest, breathing arrest, and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time
	c_1-c_2	DC-4.1 Probability of ventricular fibrillation increasing up to about 5 %
	c_2-c_3	DC-4.2 Probability of ventricular fibrillation up to about 50 %
	Beyond curve c_3	DC-4.3 Probability of ventricular fibrillation above 50 %

[1)] For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation this figure relates to the effects of current which flows in the path left hand to feet and for upward current. For other current paths the heart current factor has to be considered.

We have now identified some basic facts about the generation of electricity by solar panels, the presence of electricity and its effects on the human body, so the next step is to investigate the linkages between solar panel systems, injuries and fires.

DIFFERENT TYPES OF SOLAR POWER SYSTEMS AND COMPONENTS

Typically, there are three main types of solar power systems;

1. Off grid systems. These supply electricity to the user/user's premise. There is no other source of electricity. They may have a battery supply, charged by the solar system and inverter to convert the battery power to a useable mains AC voltage.
2. Grid interactive systems. Most commonly seen in domestic homes, factories and solar farms.
3. Grid connected, battery back-up, (also known as a hybrid) system. This type of system is becoming increasingly popular.

Off Grid System

An off-grid system is a solar panel system that is not connected to the utility grid, (although the load, house building etc, may have an alternate connection to the grid). An off-grid system requires a number of additional components (compared to a grid interactive system) such as a battery storage system to store excess power, a regulator, a mains disconnect device (if the installation is also connected to the grid) and a generator to support the system if power is depleted from the battery storage system.

Grid Interactive System

A grid interactive system is a solar panel system that is connected to the utility grid. The load can be supplied by either the solar panel array or the main distribution system. There is no battery supply to provide generation when there is no light. Any excess power that is produced beyond the consumption of the connected load (ie household usage) is fed/sold back to the utility grid. This allows the property owner the ability to earn feed-in tariff credits from the utility grid provider.

Hybrid System

This third (and most recent) solar panel system provides the best elements of both the grid interactive system and the off-grid system. The convenience of a grid connected system, including the ability to earn feed in tariff credits with the extra flexibility of a battery storage system. This means that even during a power blackout, you still have electricity (more on the implications of this later). There is also a growing financial incentive; the ability to store your own power (through the battery storage system) and relying much less on the utility grid. In effect the utility grid adopts the function of the generator in the off-grid system. Power from the utility grid is only utilized when power is depleted from the battery storage system.

THE BATTERY STORAGE REVOLUTION (ENERGY STORAGE SYSTEMS – ESS)

With the "best of both worlds" scenario that hybrid solar panel systems offer, virtually every grid interactive solar panel system currently installed will adopt a battery storage system within the next 5 to 10 years. According to studies in Australia, it is forecast that up to half of all electricity generated will be on site (homes, businesses and communities) within the next few decades. These battery storage systems (or energy storage systems, ESS) will use lithium ion batteries, made up of hundreds or thousands of individual cells and hold the same amount of potential energy as a 200 litre drum of fuel. They will be mounted within garages, next to normal household possessions, next to parked cars (many of which will have similar battery storage systems as well). They will not always be easily accessible and currently there is little or no legislation around the location, installation or signage of the mains disconnect device. A further problem is that some installers/suppliers are recommending re-purposed electric vehicle batteries in these installations. These re-purposed batteries have not been approved or tested for this type of use.

Few installers/suppliers understand the need to have these ESS fitted into uninhabitable spaces with adequate ventilation and away from secondary ignition sources. A battery under fault conditions can catch fire, explode from a battery container and ignite nearby combustibles.

The implications for fire and emergency services personnel globally, are significant!

WHAT CAN CAUSE A FAILURE OF A SOLAR PANEL

- Physical Damage (tree branches, falling debris etc)
- Vermin Attack
- Poor workmanship/installation
- Component failure/degradation
- Lightning and Weather Events, Hail, Water ingression, etc.
- Building collapse
- Building fire
- Flooding, both building and weather event

Note – a solar panel will still produce power at a reduced rate, even if it is damaged, even when in pieces.

Installations – DC Danger Zone and ESS

Solar panel arrays are mounted in a variety of ways; at ground level, on the roof, or other suitable locations on buildings, and increasingly, as part of any suitable feature. With all installations, there is a high hazard area known as the DC danger zone. This is the wiring area between the solar array and the inverter. As solar panels cannot be switched off, they continue to generate electricity when-ever they are exposed to light. This means that should any fault occur, current will continue to flow between the panels and the inverter. There is the potential for fires to occur and/or electric shock, if people come into contact with any part of the system that has been damaged. This can also extend to “live” areas that may be in contact with the damaged array.

Although some countries have required isolators to be fitted in the DC danger zone, due to the large currents from some arrays, the isolators can malfunction and over heat, often causing fire. In 2014 in Queensland, Australia, there were 167 solar panel related fires caused by malfunctioning isolators. If the sun is shining, power is still going into the malfunctioning isolator!

In a further attempt to improve safety, Standards have now incorporated anti arcing devices in all newly installed inverters. This standard solves one problem in that it shuts down the inverter and disconnects the load from the solar panels, allowing the panel wiring to enter into open circuit voltage, extinguishing any "series arcing" occurring. But in the case of a parallel arcing fault, it can allow the full amount of the power available to be poured into the fault, fuelling the arc and making the arcing fault much worse!

Anti-arcing means that if there is an arc in the circuit prior to the invertor it will shut down the invertor. However, the DC circuit is still live and is now an open circuit which increases the voltage as there is no load on it. If there is a small problem it will terminate it, however if it is a parallel arc – the touching of the + and - wires i.e. by vermin chewing it, it now turns the small parallel arc into a large arc.

Rapid Shutdown/Micro-inverter Panels

Micro-inverters are a hot topic, especially in the United States where there has been a legislative push to make micro-inverter solar panels the standard (over string panels). Micro-inverter solar panels are being marketed as a safer alternative to string array solar PV panels as a small (micro) inverter is installed directly underneath each individual (or small group) panel, converting the DC electricity to AC electricity directly under panel and allowing electricity to be shut down directly below the panel. Note however, that the panel itself can still not be shut down when exposed to light and still has the potential to arc lethal DC voltage directly onto the panel frame, metal roof and guttering.

This is not a new technology; micro-inverter panels have been around for over 20 years. Apart from the perceived safety improvement versus string array panels, micro-inverter panels also have the advantage of having better shade tolerant properties than string array panels. The disadvantages of micro-inverter solar panels is that they are very expensive, up to three times the cost of a standard string array solar panel. Also, inverters are sensitive and delicate electronic components and do not like heat. This is why standard inverters are generally installed inside garages or on the shady sides of properties. By miniaturizing the inverter and installing them directly onto the back of each solar panel, micro-inverters are being exposed directly to the elements and high operating temperatures. As a result, the life expectancy of micro-inverter solar panels is greatly reduced versus standard string array solar panel panels.

Finally, we have noticed recently that in order to reduce the price of micro-inverter solar panel systems, manufacturers have started designing “micro-inverter” systems with 1 inverter to every 2 panels and even 1 inverter to every 4 panels. In essence these are now micro-string arrays rather than true 1 to 1 micro-inverter arrays. Micro-inverters are another step towards improved solar panel system safety, however they are not financially viable for most applications, are prone to failure and because of the prohibitive cost are now being watered down to a less than ideal solution.

Risks associated with the danger zone

- Wiring from the solar panel to the inverter is still live and can electrify iron roofing structures
- Potential for electric shock, fire, secondary ignition) and electrocution
- No method of isolating the electricity from the solar panel, unlike typical electrical circuits
- Collapsed buildings can still have solar panel systems generating electricity
- Water ingress due flooding, (internal or external) and rain can cause short circuits anywhere in the danger zone
- Fire damaged buildings can still have solar panel systems generating electricity
- Damage by rodents or other animals can cause short circuits or over heating

Reasons for and Incidents involving solar panels

(Video files) Hail damage, water in isolator, fire involving isolator, BP solar panel factory 2009, Taunton, Sommerset UK, San Francisco firefighter, news reports, electrical arcing water conductivity,

SHUTTING DOWN SOLAR PANEL ARRAYS

Covering solar panels to prevent light from generating electricity is theoretically an effective method of controlling the electrical hazard from a solar panel array.

Completing this operation should incorporate:

- Safe systems of work to allow the process to be undertaken safely by addressing relevant risks (working at heights, electrical etc),
- Use of covering materials that block light completely – firefighting foam is not suitable, and salvage tarpaulins may not block light completely.

In addition to electrical hazards, solar panel systems also pose the following hazards:

- Working at heights and slip and trip hazards when personnel access or work on a roof.
- Inhalation hazards, from glass or other system materials following mechanical or other damage. Collapse hazard, when weakened roof or support structures fail to hold the system components, allowing them to fall on personnel below.

CURRENT TACTICS IN USE BY FIRE SERVICES

Common emergency response agency protocol is to cover or destroy panel during the emergency.

Current tactics include use of:

- CAFS foam
- Fog nozzles from a distance
- Straight jets from a further distance
- Putting a fire fighter on the roof to cover the panels with black PVC or thick cloths

These tactics however these carry more risks especially when deploying fire fighters to the roofs.

None of these are certain to eliminate the risk of DC current and in New Zealand with the new work place health and safety laws it makes it even more difficult to justify putting the fire fighters at risk.

In Australasia, research has been conducted on a product to cover the solar panel from a place of safety to eliminate the risks of putting fire fighters on the roofs or in hazardous positions. It prevents light from reaching the panels.

Press release from London Fire Brigade 26 September 2017

Brigade trials light blocking solution for solar panel fires

26 September 2017

The Brigade is the first fire service in the world to trial a specially designed light blocking coating to tackle emergencies involving solar panels.

Incidents such as fire, floods and collapsed buildings, involving solar panels, are especially dangerous as it's very difficult to isolate the electrical current they generate if they are damaged or involved in a fire. When tackling fire involving solar panels, crews run the risk of receiving electric shocks as the current can travel down water jets and hoses.

PVStop, is a black liquid polymer coating designed to cover solar panels like a liquid tarpaulin. Stored in an extinguisher, it's sprayed onto solar panels, or from the head of one of the Brigade's aerial appliances which are often used in high-rise fires and for aerial water dousing.

There are almost a million solar panel installations in the UK. PVStop works by blocking the sunlight that powers solar panels, so the process of converting light into electricity is stopped. The panels are then de-energised and the risk of electrocution is greatly reduced so crews can get closer and prevent fire spreading from a roof to the rest of the building.

The environmentally-friendly and non-toxic solution is being distributed to all eleven of the Brigade's aerial appliances.

Fire crews in London have been called to seven fires involving solar panels this year with just over 55 fire incidents recorded in the UK since records began.

PV Stop can be sprayed on to both wet and dry panels that are alight, or arcing. Once discharged, the coating solidifies and becomes water resistant and waterproof in minutes. Waterproofing ensures it doesn't get washed away by water from hoses when extinguishing a fire. After an incident is resolved the coating can be peeled off the solar panels without damaging the panels.

The Brigade's Group Manager for Operational Policy, Tom Goodall said: "It's exciting to be the first fire Brigade in in the world to trial this new technology. We are always looking for new ways to keep London safe.

"As people become more aware of the benefits of using green energy, this solution is a welcome addition to our resources. As well as fires there are also dangers during freak weather conditions where hail, lightening and heavy rainfall can damage panels.

"Damaged solar panels on a rooftop can increase the risk of electrocution to firefighters and members of the public. For example, firefighters pitching a metal ladder to a roof may come into contact with a live current from solar panels. We need to react quickly at incidents and this helps us to quickly manage and reduce the hazards presented by solar panels."

After each use of PVStop the Brigade's fire crews will be provide feedback. If it proves effective and practical for operational use, the Brigade will be looking to include it as a permanent firefighting resource.

Fire Safety Engineering Standards: BS7974, Past, Present, Future

Peter Wilkinson BEng(Hons) MSc EngD CEng FIFireE
Institution of Fire Engineers
IFE House, 64-66 Cygnet Court, Timothy's Bridge Road, Stratford-upon-Avon, CV37 9NW, United Kingdom

INTRODUCTION

BS7974 is a code of practice that outlines a process for the application of fire safety engineering to the design of buildings. Developed by the British Standards Institution, it is used widely around the world- especially in jurisdictions where performance-based methods are used to meet functional requirements of National Building Regulations.

This paper explains the origins of the standard, describing how fire safety provision developed in the UK throughout the 20th century, the development of prescriptive regulations, and the architectural and process drivers for a new approach. It sets out how the standard was originally drafted as a developmental document, and then converted into a suite of published documents.

At a time where the committee responsible for the standard is currently in the midst of an ambitious revision of all part of the standard, this paper explains how the evolution of the standard continues, and what the user can expect when the new documents are published in 2018.

Definition

The term fire engineering is often misused and not well understood by those outside the construction profession. It is the opinion of some that fire engineering involves manual fire-fighting, whilst of others it is prescriptive fire safety code enforcement, as suggested by Lataille (1), whilst others think that fire engineering is the calculation of pipe sizing for fire sprinkler systems, or the completion of fire risk assessments using simple techniques or checklists.

The Institution of Fire Engineers defines fire engineering as ‘the application of scientific and engineering principles, rules [Codes], and expert judgement, based on an understanding of the phenomena and effects of fire and of the reaction and behaviour of people to fire, to protect people, property and the environment from the destructive effects of fire’ (2)

The Chartered Institution of Building Services Engineers cites two types fire engineering (3):

- fire protection engineering: where the engineer is responsible for design of fire systems such as automatic fire suppression and fire detection systems, and,
- fire safety engineering: where the engineer is responsible for design of fire strategies including location and number of stairs, design of smoke control regimes and designed structural fire protection measures.

It is the latter of these two types which is most appropriate for this paper, but it is interesting to examine these definitions further.

The word 'safety' is often added to create the term fire safety engineering in the United Kingdom. Anecdotal evidence attributes this to the late Professor David Rasbash, the first Professor of Fire Engineering at the University of Edinburgh who observed that at least one university official said that fire engineering sounded like a course in arson (4).

Fire protection engineering is a term more often used in the United States. According to the Society of Fire Protection Engineers, fire protection engineering is the application of science, engineering principles and experience to protect people and their environments from the destructive effects of fire. (5).

The International Standards Organisation Technical Report ISO/TR 13387-1:1999 defines fire engineering as the application of engineering principles, rules and expert judgement based on scientific appreciation of the fire phenomena, of the effects of fire, and the reaction and behaviour of people, in order to;

- save life, protect property and preserve the environment and heritage;
- quantify the hazards and risk of fire and its effects;
- evaluate analytically the optimum protective and preventative measures necessary to limit, within prescribed levels, the consequences of fire (6).

Fire safety engineering is the design and construction process which, by consideration of the hazards and risks involved and the precautions, which are possible, achieves a balanced and acceptable level of fire safety (7).

FIRE SAFETY ENGINEERING ORIGINS

Development of prescriptive guidance

Fire safety within the built environment has been a subject of concern for thousands of years. More than 2000 years ago, fires in Rome lead to the development of rules governing the minimum width of roads in order to facilitate fire brigade access and reduce the likelihood of fire spread (8).

Statutory fire safety provision within the UK has evolved slowly over many centuries, largely driven in reaction to major disasters.

In the 19th century, after disastrous industrial fires killed fire fighters and gave major financial losses, further regulations were developed. In the 20th century, experiences of fires during the Second World War were incorporated into the Post-war Building Studies on Fire Grading of Buildings. Malhotra, et al. (9) suggests that these were seen as landmark documents of their day influencing the technical content of the subsequent Building Regulations. By the time further amendments were made by 1976, the regulations comprised 307 pages, were highly prescriptive, and, in Law's (10) opinion, understood only by lawyers.

Ferguson and Charters (11) describe how even traditional prescriptive building regulation systems had procedures to oversee significant departures from the standard solution, albeit cumbersome in nature. In England and Wales such relaxations were at one time granted only by central Government, although this process was devolved to local Government.

Despite criticism, prescriptive building regulations have been an important component in the evolution of fire safety in buildings. It is acknowledged that (12) prescriptive design has resulted in the achievement of safety levels which the community appears to accept.

Drivers for a new approach

As a result of the large and rapid increase in innovative and diversified building design, including the expansion of air travel in the early 1970s, prescriptive regulations became demonstrably restrictive and inflexible. By way of example, air travel required airports to start handling large numbers of people, who were unfamiliar with the building, in a pleasant and efficient way. Designs based on the prescriptive standards of the time simply couldn't cope with this new design requirement. Some engineers and scientists saw the possibility of applying scientific research directly to the design of individual buildings (13). These issues were discussed at the time of the design of Stansted Airport by Law (14). One important issue relating to this airport design was the need for large compartment volumes, not permitted under Building Regulations without obtaining a relaxation. Law collected a range of data from experiments, surveys and fire statistics to illustrate how various measures could compensate for lack of fire resisting construction, known as compartmentation.

The commitment of UK Government to deregulation and to reduce the burden on industry led, in 1985, to the introduction of new functional building regulations, i.e. the Building Regulations 1985 (15).

The requirements for fire safety of buildings given in the 1985 regulations were set out in four functional requirements. Deakin (16) described the regime as thus. Designers were free to provide any solution that could be shown, to the satisfaction of the regulatory enforcement authority, to fulfill the functional requirements. Technical support to the regulations set out traditional approaches that were 'approved' by the Secretary of State as one way of satisfying the requirements. However, the functional nature of the regulations provided greater opportunities for the adoption of fire engineered approaches to fire safety design.

Interestingly, Billington, Ferguson et al. (6) reported that, with the introduction of the 1985 regulations, the property protection issue was deliberately set aside because the legislators' role has been seen as being in life safety matters only.

THE DEVELOPMENT OF FIRE SAFETY ENGINEERING

A fire engineering code

Whilst formal recognition and acceptance of the use of fire engineering had been given in England and Wales within Approved Document B, no guidance was given. The pressure for guidance and a structure for the application of fire engineering principles to the design of buildings came from designers and an initiative by the British Standards Institution (BSI) to provide a Code of Practice on the subject.

In 1989 a format and list of contents for a comprehensive Code of Practice on the application of fire engineering principles to fire safety of buildings was presented to BSI. As described by Cooke (17), it was intended that the proposed code would cover general principles, life safety considerations, property safety considerations, mitigation of socially unacceptable events and reduction of economic loss.

By the end of 1990, a small panel of fire safety engineers was formed with the support of Warrington Fire Research Centre, to undertake a three year contract, administered by BSI, which would culminate in a Code of Practice giving a framework for the fire engineering design of buildings. The panel first met in March 1991 and decided the following objectives for the code;

- The code should be analytical, with the acceptance that design could not always proceed entirely by quantification because some intuitive judgement might be necessary.
- The code should state acceptable levels of life loss.
- The code would be aimed principally at fire engineers. Whilst this means that only suitably qualified and experienced individuals might be able to undertake the analytical work, it would not necessarily mean that other members of the design, construction and building approval team would not be able to use the code.
- The code would identify, allow and encourage the use of appropriate zone and field models.
- Data and the methodology should have a high degree of transparency, i.e. the ability to trace where all the information came from.
- The principles and methodology should ideally be applicable to 'any bounded space in which people might be present or nearby and where a fire might occur'.

Deakin (16) described the resulting draft Code of Practice as the most important document produced in the UK in support of the use of more fundamental approaches to fire safety design. It provided the designer and the regulatory enforcement authorities with an overview of what was considered to be necessary. Deakin attempts to simplify the very complex design process and describes the way the code is divided into sub-systems. Importantly, it indicates that there are gaps in the knowledge, and that much has still to be achieved by the use of engineering judgment.

Deakin comments that the ability to trace where the information within the code has come from, as described in the objectives above, focused an unjustified emphasis on requiring demonstration of the validity and scope of the application of the relationships cited. Interestingly, he concludes that the document has been viewed in a prescriptive manner, with focus on the theory rather than the framework for design.

The draft Code of Practice was published as a Draft for development DD240 by BSI in 1997 (6). Since the publication of DD240, under the direction of the Standards Policy and Strategy Committee, FSH/24 remains the Technical Committee responsible for the development of standards for fire safety engineering in buildings. It draws representatives from a wide range of stakeholder organisations, and practicing fire engineers. FSH/24 is the national committee for Fire Safety Engineering, mirroring CEN/TC 127/WG 8 Fire Safety Engineering; and many of the working groups in ISO/TC 92.

The format and content of DD240 were reviewed leading to, in 2001, BS7974 Code of Practice on the Application of Fire engineering Principles to the design of Buildings being published. This code is supported by eight Published Documents, replicating the sub-systems defined in the draft, which contain detailed technical guidance on different aspects of fire engineering from background information to quantitative risk assessment (13).

The Published Documents include;

- PD 0: Design framework
- PD 1: Initiation and development of fire within the enclosure of origin;
- PD 2: Spread of smoke within and beyond the enclosure of origin;
- PD 3: Structural response;
- PD 4: Detection of fire and activation of fire protection systems;
- PD 5: Fire service intervention;
- PD 6: Evacuation;
- PD 7: Probabilistic fire risk assessment;
- PD 8: Property protection, business and mission continuity, and resilience.

A framework of the application of engineering approaches to fire safety in buildings is provided in BS79794.

It is defined in the standard, and PD0 with a flowchart. Essentially, it comprises three stages;

- Qualitative design review (QDR); where the scope and the objectives of the fire safety design are defined, the performance criteria are established and acceptance criteria set;
- Quantitative analysis; where engineering methods are used to evaluate potential solutions; and
- Assessment against criteria; where the results of the quantitative analysis are compared against the acceptance criteria.

The quantitative part is divided is divided into a number of separate parts, or sub-systems. Each sub-system can be used in isolation when analysing a particular aspect of design, or they can all be used in combination, as part of an overall fire safety engineering evaluation of a building.

The work of FSH/24 is continuous. The last part to be added to the suite of documents was PD8, which was published in 2012, and the last revision was PD5 which was renewed in 2014.

PD8 (18) is an interesting document, because it describes the use of an established business continuity management too in a novel way. It introduces the concept of using an organisation's Business Impact Analysis to inform the fire safety objective setting, right at the start of the QDR process, ensuring the design team meet the specific resilience objectives important to the client.

PD5 underwent a substantial revision of the sub-system that looks at fire service intervention. It reflects new methods in calculating fire-fighting water provision, as well as some other major new concepts.

THE FUTURE

Within the British Standards Institution, here is an established process for instigating a review, which operates on a five-year cycle. The committee is informed of the impending review, after which a voting booth is created on the online communications and file-sharing tool known as eCommittees for members to submit their views. There is a default course of action allocated to each standard and it's usually to re-confirm for a further 5 years. The voting booth closes and if any votes have been submitted in conflict with the proposed default action, the standard is referred back to the Secretary to confirm with the committee. After consultation within the committee, the standard is either re-confirmed, withdrawn, or a business case is drafted to revise the standard.

A standard can be changed in one of three ways:

- Revision – the entire text is reviewed and changed in line with current industry practises and technology.
- Amendment - alteration and/or addition to previously agreed technical or editorial provisions of a standard (as outlined in 3.1 of BS 0:2011). Where amendments introduce technical changes (which will be most, if not all, of them) they must go to public consultation (known as Draft for Public Comment (DPC) for a 2 month period.
- New edition - If many technical changes are introduced that affect a large proportion of the text of a standard, thus making it unsuitable for an amendment, but a full revision is not considered appropriate, a new edition of the standard may be produced to incorporate the changes. This might happen if, for example, the committee does not have sufficient resources to commit to the amount of work that would be needed to undertake a full revision. A new edition should also be produced where an amendment is proposed to a standard that has had two amendments already, if a full revision is not considered appropriate. New editions take a new publication date.

During 2016, the technical committee that oversees and maintains the Standard BS7974, and associated documents, reviewed the suite. It was decided that decided that each required Revision. Panels of volunteer experts were formed and the revision process began. The Panels are a substantial way through their work, and it is anticipated that the revised document suite will be available for public consultation as a Draft for Public Comment early in 2018, with publication during early summer, 2018.

CONCLUSIONS

Fire safety engineering remains an important element in ensuring buildings are conceived, designed, constructed and operated in a way that provides an agreed level of safety of life, and protection of assets.

BS7974 is a key process for facilitating design freedoms, whilst giving a robust methodology for ensuring adequate levels of safety and resilience are provided.

That's why we are working hard on a revision programme, to ensure the standard, and all supporting documents, remain relevant, current and useful.

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The Lacrosse ACP Façade Fire – Post Incident Analysis, Building Code Changes and the New Australian Façade Fire Test Standard

Dr Amer Magrabi and Dhanya Sasikumar
Lote Consulting – Fire I Risk I Security
Sydney, NSW, Australia
amer@loteconsulting.com

Benjamin Hughes-Brown
Ignis Solutions
Canberra, ACT, Australia
benjamin@ignissolutions.com.au

The Metropolitan Fire Brigades (MFB) in Melbourne responded to a high rise apartment fire in the early hours of 24 November 2014. When the first MFB crew arrived on scene at 02:29 hours, they observed that the fire had propagated over roughly 6 levels along the external façade and balconies. Subsequently at 02.35 hours (~ 6 minutes later), fire crews reported that the fire had reached the building roof at Level 21. Named as the 'Lacrosse Apartment Fire', this was Australia's first fire involving a building façade with combustible Aluminium Composite Panels (ACP). Since this fire, there have been numerous other ACP fires in the other parts of the including the tragic Grenfell Fire on 14 June 2017.

This paper sheds light on the MFB's post incident analysis of the Lacrosse Fire and the related regulatory changes in Australia. Key MFB findings on the building approval process, fire services design, fire-fighting operations and occupant evacuation are presented. The new Australian Standard, AS 5113:2016 for fire propagation testing and classification of external wall assemblies is introduced and discussed in the context of other international façade test standards for external wall assemblies such as ISO 13785-2, BS 8414.1:2015 and NFPA 285:2012. The paper concludes by briefly presenting a methodology for assessing external ACP applications in an Australian context.

1.0 INTRODUCTION

1.1 Aluminium Composite Panels

Aluminium Composite Panels (ACPs) are used widely in Australia for the construction of external walls, such as façade cladding, for a number of building classes (Webb & White, 2016) (Adamson, 2009). Their popularity stems from their ability to improve energy performance, reduce water and air infiltration, and allow for aesthetic design flexibility (White, et al., 2013). ACPs are flat composite panels which generally consist of a combustible internal core sandwiched between and bonded to two aluminium skins. The internal core is usually made of polyethylene or another similar material. As the internal core of the ACPs are generally combustible, when they are exposed to an ignition source, it can result in rapid fire spread which can compromise the occupant life safety and fire brigade personnel. It is highlighted that ACPs with mineral cores are also available which have better fire performance. However, they would still be considered combustible unless they have been tested and proven to be non-combustible as per AS 1530.1 referenced in the Building Code of Australia [BCA] (NSW Government Planning & Environment, 2015).

The core materials of composite panels vary in their composition from highly combustible (PE) to non-combustible (NC). Four general categories are defined below. These categories are commonly applied by panel manufacturers.

1. PE – Polyethylene
2. FR – Majority mineral 70% mineral – 30% Polyethylene binder

3. A2 – As per EN 13501 – 90% mineral – 10% Polyethylene binder
4. NC – Non-combustible – metal core or inorganic mineral.

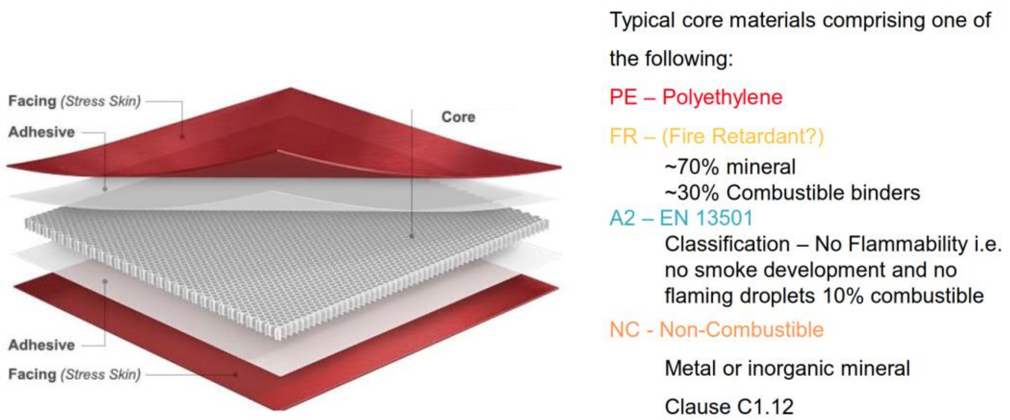


Figure 1 – Schematic showing general makeup of an Aluminium Composite Panel (ACP)

PE based cores present the greatest fire threat to external wall constructions. As there are no industry manufacturing standards or controls on product mixtures, FR and A2 cores vary in their combustible components and their ability to mitigate fire spread. Therefore, the only way to validate their fire safety is through various forms of material and installation testing.

A number of small scale material tests are permitted within Australia and provide a general indication of a materials reaction to fire. These tests do not provide an indication of fire spread via the façade. Small scale material tests include:

1. Standards Australia, AS/NZS 3837:1998 Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter.
2. Standards Australia, AS 1530.3:1999 Simultaneous determination of Ignitability, Flame Propagation, Heat Release and Smoke Release.

Within Building Code of Australia, ISO 9705 is the only referenced full scale fire test. This test represents internal applications and is not an indication of how the panels will react when installed on external walls.

1. AS ISO 9705:2003 – Fire tests – Full-scale room test for surface products.

External fire tests are currently not referenced within the Building Code of Australia. However, an out of cycle amendment is proposed to be adopted in March 2018 which will reference the new Australian Standard, AS 5113:2016 for Fire Propagation Testing and Classification of External Wall Assemblies

As such external applications are required to be evaluated on an absolute performance basis including a new verification method CV3. Generally, there are two construction applications for ACPs as follows:

- Application 1 - The ACP Panel can be fitted to a fire rated external wall structure for decorative purposes; or;
- Application 2 - The ACP Panel forms part of the external wall structure.

When used in Application 1, the ACP Panel is considered a decorative external lining to a compliant wall where the ACP Panel does not contribute to the walls compliance with respect to insulation, weatherproofing, acoustics or fire resistance. When used in Application 2, the ACP Panel typically acts as a rain screen and contributes to the walls weatherproofing. In this situation if the ACP Panel is removed the internal elements of the wall become exposed.

1.2 The Lacrosse Fire

The Metropolitan Fire Brigades (MFB) in Melbourne responded to a high rise apartment fire in the early hours of 24 November 2014 as reported in the MFB Incident Report (Metropolitan Fire Brigades, 2015). When the first MFB crew arrived on scene at 02:29 hours, they observed that the fire had propagated over roughly 6 levels along the external façade and balconies. Subsequently at 02.35 hours (~ 6 minutes later), fire crews reported that the fire had reached the building roof at Level 21.

The fire behaviour and flame spread encountered by the MFB was unusual in many respects. The fire was characterised by rapid flame propagation along the external building façade as opposed to internal flame spread associated with the building fuel load. The rapid external flame spread and subsequent internal penetration caused the entire building of more than 400 occupants to be evacuated. At the height of the fire, MFB committed 122 personnel, 22 appliances, 3 aerial appliances and 4 specialist vehicles to tackle the blaze. Named as the ‘Lacrosse Apartment Fire’, this was Australia’s first fire involving a building façade with combustible Aluminium Composite Panels (ACP). Since this fire, there have been numerous other ACP fires in the other parts of the including the tragic Grenfell Fire on 14 June 2017.

Numerous ACP façade fires have been reported around the world (White & Delichatsios, 2014) prior to the above incidents. This has resulted in a generic concern for ACP use in high rise buildings around the world as the intent of many building codes is to mitigate fire spread via the building façade. It is highlighted that some of the above façade fires involved highly combustible Exterior Insulation Finish Systems (EIFS) or Polyethylene core (PE) Metal Composite Panels (MCP). The most commonly used ACP panels in high rise construction in Australia have a Fire Resistant (FR) classification (i.e. mixture of mineral and polyethylene cores) as opposed to 100% polyethylene core.

1.3 Lacrosse Fire Post-Incident Findings

Post-Incident findings by the MFB (Metropolitan Fire Brigades, 2015) and the Victorian Building Authority (VBA) (Victorian Building Authority [VBA], 2016) point to a combination of factors that contributed to the fire including ambiguous Building Code of Australia (BCA) requirements in relation to external walls, suitability of materials and compliant building products. The main conclusions by the MFB are summarised below:

1.3.1 Rapid Fire Spread & Combustible External Wall Cladding

The events timeline described by MFB indicated that fire spread externally along 13 floor levels (i.e. Level 8 to of Level 21 roof) in a span of 10 to 15 minutes, resulting in internal ignition on the respective floors. The speed and intensity of the fire spread demonstrated that the construction adopted in the building did not meet BCA Performance Requirements, CP2 that relates to avoidance of fire spread. Additionally, the BCA requires the external wall of a Type A building such as The Lacrosse Apartment Building to be of non-combustible construction, notwithstanding any requirement for fire rating.

The combustibility of ACPs and the non-compliance associated with their use as an external wall cladding is discussed in Section 1.1 of this paper.

1.3.2 Building Material Design, Selection and Installation

The MFB post incident investigation recounts the following findings for the Lacrosse Building in relation to material selection, approval and installation design:

- The building approval documentation available at the Authority Having Jurisdiction (AHJ) Offices were incomplete making it difficult to verify if combustible ACPs were documented in the approved drawings. Documentation substantiating evidence of suitability and mode of installation of the used combustible ACPs were also unavailable.
- The Occupancy Permit documentation for the Lacrosse Building did not include adoption of a Performance Solution for the use of combustible cladding on the external building façade.
- In addition to combustible ACP cladding, the external walls on the balconies included combustible PVC storm water down pipes and associated lagging protected with incompatible fire collars that failed to operate during the fire. The downpipes were connected to the drains housed in the balcony floors presenting an additional pathway for fire spread between floor levels. The MFB concluded that the above material application and installation were unlikely to be identical with the approved tested prototype.

1.3.3 Sprinkler System Exceeds Design Capability

The Lacrosse Building was equipped with an AS 2118.6 combined fire hydrant/fire sprinkler system designed to simultaneously operate four (4) sprinkler heads and two (2) fire hydrants. During the incident, the accelerated vertical fire propagation and subsequent internal ignition across multiple floor levels activated the internal apartment sprinklers. This placed a significant demand on the building's installed sprinkler system and associated water supply. A total of twenty-six (26) sprinkler heads over 16 floors were reported to have been activated during the fire. Additionally, two (2) internal fire hydrants were used by fire-fighters to extinguish fire not controlled by the sprinklers.

Considering the narrow time-line of the events, the MFB concluded that the building's combined sprinkler-hydrant system had outperformed its designed capability. Furthermore, the water supply in a similar building with an identical sprinkler design would be inadequate for managing a similar fire situation.

The extraordinary performance of the fire sprinkler system in this instance is considered to have mitigated the following consequences:

- Internal fire spread and development within, and between adjoining apartments and public corridors;
- Delayed / obstructed total occupant evacuation leading to serious injuries and/or loss of lives;
- Extremely hazardous conditions for fire-fighter rescue and intervention operations;
- Significantly increased property damage and loss;
- Adverse social impact on displaced occupants, community amenity, infrastructure and emergency service/recovery agency resources.

1.3.4 High Occupancy Rate, Increased Storage and Un-sprinklered Balconies

The MFB post incident investigation uncovered that several apartments in the Lacrosse Building accommodated occupant numbers that exceeded the building's design capacity. Many of the two (2) bedroom apartments had sleeping arrangements for up to eight (8) people in the form of temporary partition structures installed around the beds. These temporary lightweight structures, along with additional furnishings/contents can potentially impede timely and safe occupant egress from the apartments.

The impact of high occupant numbers is two-fold. Apart from increasing the building's fuel load via greater storage of personal belongings within the apartment. It promotes occupant reliance on apartments balconies and other common areas for additional storage space. Additionally, the egress strategy for the building did not account for occupant numbers beyond the design capacity.

The post incident investigation reported that apartment balconies in the building housed a range of combustible materials such as clothing, bedding, furnishings, electrical appliances and other combustibles, notwithstanding the Air-Conditioning (A/C) compressor units. Unauthorized storage of combustible goods within the fire extinguisher enclosures located on the public corridors were also observed. The MFB findings attributed the increased combustibles encountered in the apartment balconies to have contributed to the intensity of fire spread.

The fire first broke out in an apartment balcony on Level 8 due to the disposal of cigarette butt into a plastic container located atop a timber topped outdoor table. The fire eventually consumed the table and spread onto the A/C compressor unit located in close proximity on the balcony wall structure comprising the combustible ACP.

It is noted that the sprinkler system in the Lacrosse Building did not extend into the apartment balconies due to the following reasons:

- Some of the balconies did not require sprinkler coverage under BCA Deemed-to- Satisfy Provisions based on their sizes; and
- A Performance Solution was undertaken for the deletion of sprinklers to the rest of the apartment balconies based on low fuel loads. However, storage limitations for the apartment balconies were not observed in the subject building.

As mentioned earlier, the sprinklers within the apartments prevented fire from spreading internally between apartments and public corridors despite exposure to the balcony fire. It is highly likely that sprinkler extension to the balcony areas could have confined the fire to the level of fire origin.

1.3.5 Mass Evacuation and Social Impact

Contrary to the staged evacuation procedure generally executed in high rise buildings, the entire building was evacuated since the fire covered a large portion of the building in a short time. The high occupancy rates for the Lacrosse Building translated to over 400 occupants being evacuated who began assembling immediately outside the building while the fire-fighters fought the fire. Typically, the surrounding areas of a building engulfed in flames, is likely to be blanketed with flying fire embers, intense smoke, dust, and falling debris, necessitating safe relocation of evacuees and in some instances evacuation of surrounding buildings.

The care and management of the displaced occupants presented a challenge for the MFB and other agencies involved. The large evacuee group was escorted from the immediate building vicinity to a safe area of temporary refuge located approximately 900 m to 1 km away.

Although the extent of collateral damage resulting from the fire was largely minimised due to the high performing sprinkler system and timely response of the MFB and other emergency personnel, the social impact of the fire remained considerable. All occupants were displaced for some days and some for a much-extended time period while the building underwent structural repair, refurbishment and reinstatement of operable fire safety systems.

1.3.6 Compromised Emergency Warning and Intercommunication System (EWIS)

Witness statements following the fire incident reported that none of the occupants had heard the evacuation announcement made by the fire fighters using the EWIS PA facility. Additionally, majority of the occupants reported not hearing any alarms but being awoken by ‘’screaming, banging or other loud noises’’ and some others remarked that the alarms came on for a few seconds before discontinuing. A few others heard the alarms and evacuated.

The Lacrosse Building was installed with a compliant AS 1670.4 EWIS system requiring all wiring between the EWIS main panel and the evacuation zones (i.e. individual residential floor levels) to be fire rated. However, the wiring connecting the individual EWIS sound speakers and associated fire detection and warning systems on each floor level is not required to be fire rated. Further, these speakers and detections units are generally connected in series on a given floor level.

The apartment balconies located on the building frontage that were consumed by the fire included a metal exhaust grill that connected to an exhaust collection box situated in the ceiling space of the adjoining bedroom. The EWIS sounders were located in the same ceiling space directly adjacent to the exhaust collection box.

When the fire broke out in the apartment balcony on Level 8, hot gases entered the ceiling space of the adjoining bedroom via the external exhaust grill and compromised the wiring and sounder of the EWIS. This resulted in a fault in the speaker loop and subsequent failure of the entire sound system on Level 8.

The initial FIP transmission from the activated detector system is considered to have activated the EWIS on Level 8 and 9 for a few seconds before the system was eventually compromised. As a result, some occupants heard the alarms system come on for a few seconds. Since the fire quickly spread upwards along the building facade it is considered to have caused the EWIS system to fail on most levels ahead of the evacuation announcement. The occupants who heard the alarm and evacuated were considered to be located below Level 9.

The MFB findings concluded that the complete failure of the EWIS system could have been avoided if adequate redundancies were built into a building’s fire safety system in the form of:

- Provision of two independent sounder loops throughout the floor level; one serving the sounders in the sole-occupancy units (when required by an Alternative Solution) and the other serving the sounders in the public corridors/ common areas; Or
- Provision of fire-rated wiring throughout the system; and/or to have all the speakers connected in parallel as opposed to series. This will ensure operation is not compromised if a section of the wiring or an individual sounder is lost.

1.3.7 Maintenance Issues relating to Installed Fire Services

Inaccessible Fire Extinguishers

The MFB findings identified that the two fire extinguisher enclosures located on the residential public corridors were used as storage spaces by building occupants on several floor levels. This not only blocked access for occupants or fire-fighters during a fire emergency but presents as an additional fire hazard. Note that despite the provision of sprinklers and hydrants, numerous on-site fire extinguishers were used by the fire-fighters during the Lacrosse fire.

The dry chemical powder extinguishers located on all residential levels were locked within a service room leaving it inaccessible to occupants or fire-fighters. Contrary to AS 2444 requirements, none of the enclosures accommodating the fire extinguishers were provided with a “Location Sign” on the outside.

Tampering of Apartment Smoke Alarms

The MFB findings reported that smoke alarms within several apartments had their battery removed or had been covered making them inoperable. Tampering with smoke alarms can delay detection of a fire emergency and adversely impact timely occupant notification and evacuation.

Emergency Exits

The emergency exits in the building were provided in accordance with BCA requirements. Break glass re-entry was provided within the fire-isolated stairs from every fourth level. Upon activation of the general fire alarm, electronic locks dis-engage and allow access out of the fire-isolated stairs on all levels. During the fire incident, the electronic lock on Level 9 failed to disengage necessitating fire-fighters to make a forcible entry into the corridor.

2.0 FAÇADE FIRE TESTS

This section introduces the New Australian Standard AS 5113:2016 - Fire Propagation Testing and Classification of External Walls of Buildings. As a background to its development, key features of other international facade test standards such as ISO 13785-2, BS 8414 and NFPA 285 are also discussed to highlight some of the differences.

2.1 ISO 13785-2, BS 8414 and NFPA 285

2.1.1 ISO 13785-2

The International Standard ISO 13785 -2 tests the façade with a re-entrant corner "L" arrangement or wing wall as shown by the figure below. The fire source is flames emerging from a compartment fire via a window. The height of the tested façade is at least 4 m above the window lintel. The main façade is at least 3 m wide and the wing façade is at least 1.2 m wide. The window is on the main wall with one edge at the wing wall and is 2 m wide x 1.2 m high. The façade is installed around the window down to the bottom of the window.

2.1.2 BS 8414

The British Standard BS 8414-1:2002 is a large scale test method for non-loadbearing external cladding systems applied to the face of a building and exposed to external fire under controlled conditions. This fire performance test was developed to address systems installed to masonry structures (Colwell, 2014) (Macdonald & Jones, 2012).

The test specimen is installed on the main face of the test rig, which is to have a minimum height of 8 m from the ground level and is subjected to an ignition of a timber crib in a combustion chamber at the base of the main test wall. The duration of the fire load is 30 minutes, however the test may run up to 60 minutes should the sample still be burning. (Colwell, 2014) (Macdonald & Jones, 2012).

The following the test information is evaluated during the test detachment (Macdonald & Jones, 2012):

- flame spread over the external face (pass/fail);
- flame spread internally within the system (pass/fail); and
- the mechanical response in terms of façade damage or detachment.

The British Standard BS 8414-2:2002 is generally the same as the Part 1 test however the substrate wall is steel framed instead of masonry.

As the BS 8414 test standards are large scale tests, these closely reflect the application of the external cladding systems application on a building and thus would give a good indication of the overall fire performance (Colwell, 2014).

2.2 NFPA 285

National Fire Protection Association (NFPA) 285 is a large scale American standardised fire test procedure utilised for evaluating the suitability of exterior assemblies and panel building materials, which comprise combustible components. The intent of the test is to evaluate the fire propagation characteristics of exterior non-load-bearing wall assemblies (NPFA 285, 2012).

This test incorporates a two (2) storey test rig construction which is clad in the product being tested. The test rig is subjected to a fire source of two (2) gas burners over a time period of 30 minutes. One gas burner is positioned inside the lower storey room while the other burner is at the top edge of the opening of the lower storey room.

The flame propagation vertically and laterally across the material is measured and observed. A pass / fail criteria is determined based on this (NPFA 285, 2012). As the NFPA 285 standard essentially replicates the as-installed external cladding in a fire, the results from this test is considered to be a good indication of the fire performance of the material.

Although NFPA 285 is a standard for the United States of America, this method has been determined as an acceptable testing method for external cladding in several countries, including New Zealand.

2.3 Australian Standard AS 5113:2016

Australian Standard AS 5113 - Fire Propagation Testing and Classification of External Walls of Buildings was released by Standards Australia in July 2016. It was based on international best practice and integrates the testing criteria specified in ISO 13785.2 and BS 8414 Part 1 and Part 2. AS 5113 was developed in order to provide procedures for the fire propagation testing of both wall cladding and wall assemblies and to classify their fire performance according to their tendency to limit the spread of fire via the external wall and between adjoining buildings (ABCB, 2016).

External fire tests are currently not referenced within the Building Code of Australia (BCA). However, an out of cycle amendment is proposed to be adopted in March 2018, which will reference AS 5113:2016 in a new BCA Verification Method CV3.

2.4 AS 5113 Overview

There are two (2) classification tests which need to be performed under AS 5113 (AS5113, 2016), namely:

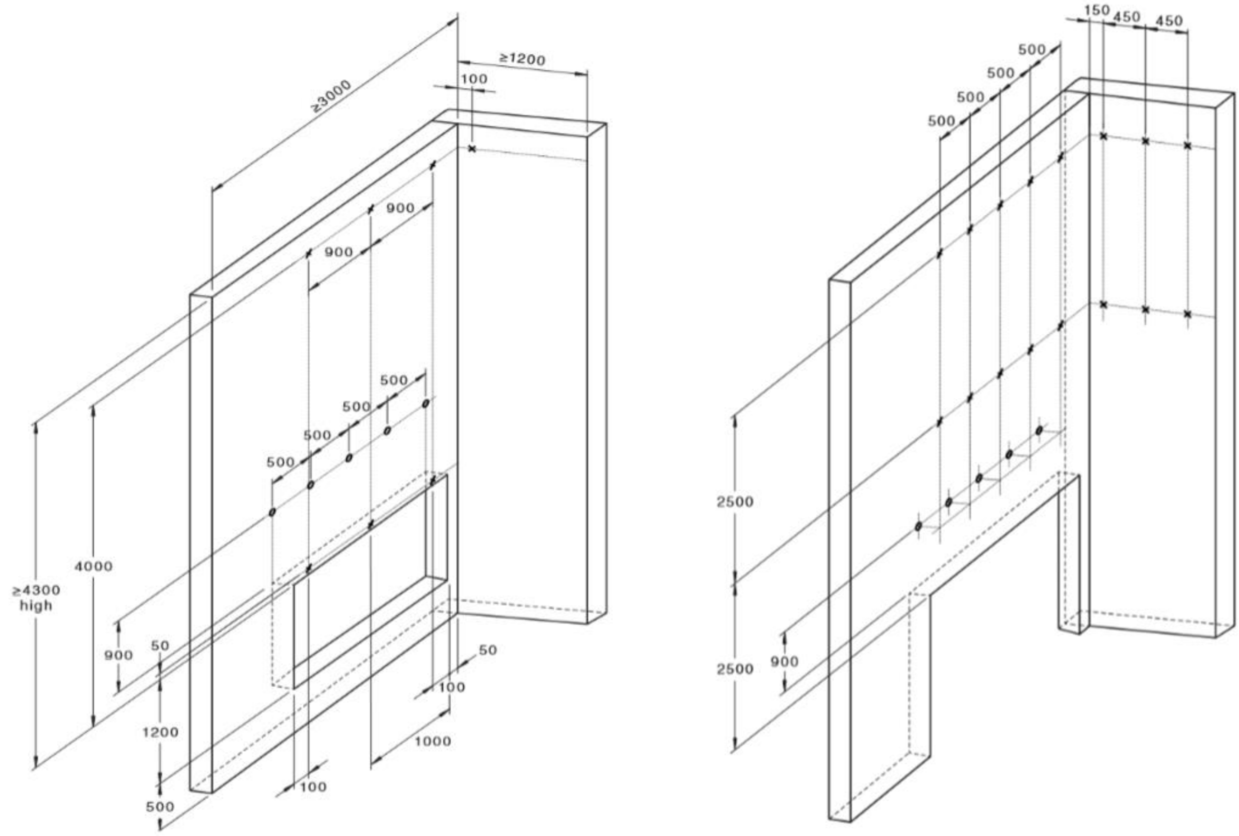
1. External wall fire test; and
2. Building-to-building fire test.

These tests are detailed in the following sections.

2.4.1 External Wall Fire Test

The external wall fire test is carried out in accordance with one of the following large scale external wall test methods: ISO 13785-2 or BS 8414. These tests apply to relatively high risk applications for Type A (i.e. buildings with a rise in storeys of more than three) and Type B Construction (i.e. buildings with a rise in storeys of more than two).

ISO 13785-2 has been specified in AS 5113 as it incorporates the following:



(A) (B)

Figure 2 – A) ISO 13785 test wall with thermocouple locations; B) BS 8414 test wall with thermocouple locations

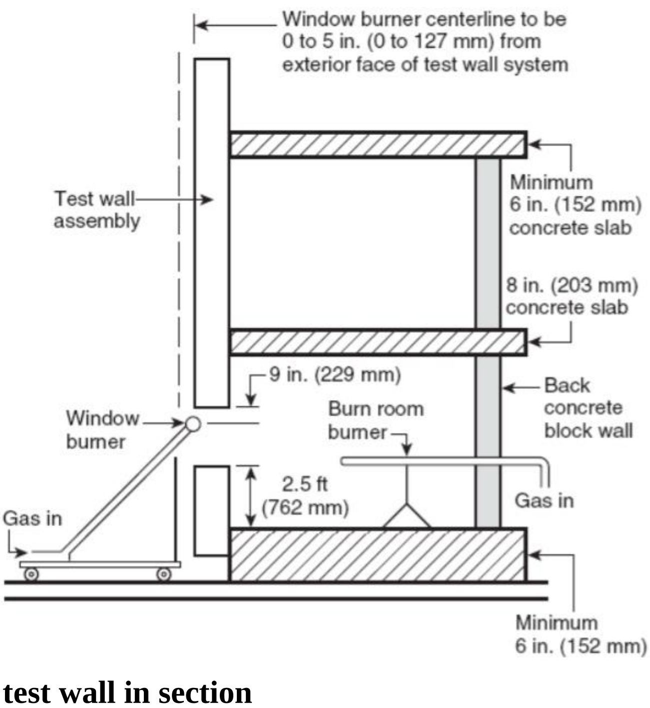


Figure 3 – NFPA 285 test wall in section

i. A wing wall;
ii. It is able to test full sized panels; and
iii. It is able to simulate the exposure of the façade to a building fire while using a reasonably sized specimen.

BS 8414, being similar to the ISO 13785-2 test setup, is also permitted under the external wall fire test.

2.4.2 Building-to-Building Fire Test

The building-to-building fire test has four (4) classifications for external walls, as follows: BB80, BB40, BB20 and BB10. The BB levels are based on BCA Verification Methods CV1 and CV2 heat flux levels and reflect that the building-to-building classification (BBnn) is met when exposed to nn kW/m^2 incident radiation for 30 minutes.

For this test method, the wall elements are exposed to various levels of radiant heat via a 3 m x 3 m furnace. Observations are recorded in relation to the following:

i. Temperature and radiant heat flux data;
ii. Duration and extent of flaming of the specimen on the side which is exposed to radiant heat flux;
iii. Flaming or openings which form on the unexposed face, if any;
iv. Debris or material release, if any;
v. Continuous flaming on the ground for > 20 s for any debris or material released from specimen, if any.

The detailed applicable procedure for this test is outlined in Appendix C of the AS 5113.

2.4.3 Fire Performance Classification

The classification of the fire performance of the specimen is based upon the external fire wall spread and building-to-building fire spread, as detailed below. It is classified in the following format:

$$FP: [External\ wall\ performance]/[Building - to - building\ performance]$$

Should the external wall performance be achieved, it is represented by 'EW'. The building-to-building performance is represented by BB classification BBnn. For example, if the external wall system is satisfied to either ISO 13785-2 or BS 8414 and it satisfies the requirements when subjected to an incident heat flux of 80 kW/m^2, it would be classified as follows:

$$FP: EW/BB80$$

The determination of the classifications is made via Table A1 and A2 of AS 5113. These tables are detailed below.

TABLE A1
CLASSIFICATION OF EXTERNAL WALLS

Class	Application	Combustible option	
		External wall fire spread requirement	Additional building requirements
A100 plus	Type A construction, greater than 100 m effective height	No combustible option	None
A100	Type A construction, greater than 25 m but less than or equal to 100 m effective height	EW	Automatic sprinklers system with balcony protection
A25	Type A construction, less than or equal to effective height of 25 m	EW	Automatic sprinklers system with balcony protection
B	Type B construction	EW	Spandrels/horizontal projections

TABLE A2
CLASSIFICATION OF EXTERNAL WALLS—BUILDING-TO-BUILDING SPREAD

Minimum distance from boundary or adjacent building	Combustible option	
	Façade fire requirement	Additional building requirements
On boundary or no distance between buildings	BB80	Nil
1 m from boundary or 2 m between buildings	BB40	Nil
3 m from boundary or 6 m between buildings	BB20	Nil
6 m from boundary or 12 m between buildings	BB10	Nil

Figure 4 – AS 5113 classification tables

In summary, AS 5113 is essentially a classification standard which nominates test methods and acceptance criteria. The standard allows both ISO 13785-2 and BS 8414 methods to be used for façade testing. Neither of these standards have pass / fail criteria. The pass / fail criteria is specified in AS 5113 for each test method and vary slightly to reflect the differences in fire exposure. The standard provides a more accurate indication of the combustibility of wall assemblies including ACP and clearer pass/fail criteria in comparison to existing façade tests.

3.0 ASSESSMENT OF EXTERNAL ACP APPLICATIONS

The methodology for assessing external ACP applications in an Australian context involves three steps as shown below.

I. Step 1 – Evaluating installation detail and combustibility
II. Step 2 – Determining if a prescriptive Deemed-to-Satisfy Solution can be adopted.
III. Step 3 – Developing a Performance Solution

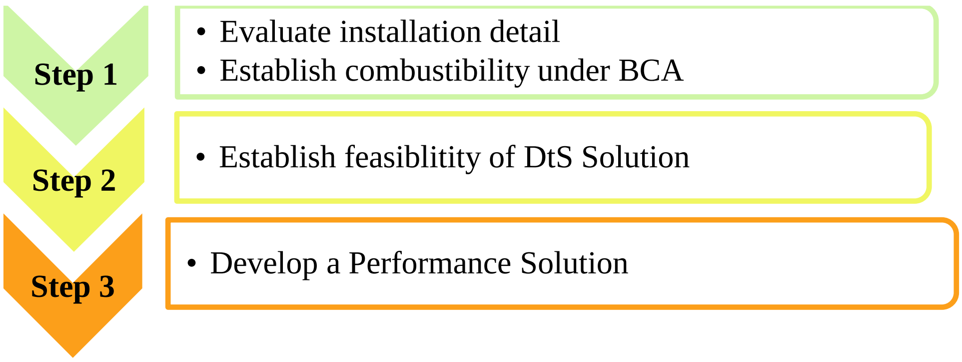


Figure 5 – Three step process to assess external ACP applications in an Australia.

The above three steps are further detailed elsewhere (Magrabi, et al., 2016).

4.0 CONCLUSION

The paper presented key findings from the Metropolitan Fire Brigades' (MFB) post incident analysis of the Lacrosse Fire and the related regulatory changes in Australia. The findings covered a review of building approval process, fire services design, fire-fighting operations and occupant evacuation. The new Australian Standard, AS 5113:2016 for fire propagation testing and classification of external wall assemblies was introduced and discussed in the context of other international façade test standards for external wall assemblies such as ISO 13785-2, BS 8414.1:2015 and NFPA 285:2012. AS 5113 provides a more accurate indication of the combustibility of wall assemblies including ACP and clearer pass/fail criteria in comparison to existing façade tests. The paper concluded by briefly presenting a methodology for assessing external ACP applications in an Australian context.

5.0 ACKNOWLEDGEMENTS

The authors wish to acknowledge Mr Paul England from EFT Consult for discussions on the fire behaviour of composite panels and the development of the new Australian Standard AS 5113.

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The Use of Performance Based Designs for Smoke Control Systems

Ron Diaper
Technical Director
Colt Ventilation East Asia Pte Ltd

INTRODUCTION

Since its introduction in the middle of the last century, the science of smoke movement in large buildings has become more understood, whilst advances in technology have allowed ever greater analysis of the behaviour of smoke in a building.

Even for a simple warehouse, using a basic zone model for the determination of the ventilation requirement can involve the use of calculations that can seem complex to those not using them on a regular basis.

Modern buildings now often require sophisticated design approaches either to meet the requirements of the national codes or to provide a cost effective solution for the fire safety requirements. This can be by the use of computer modelling systems that enable us to construct extremely detailed building geometries and analyse smoke movement in these structures that enable us to have a high degree of confidence that the results of the modelling are comparable to the likely outcome in the event of a fire.

PRESCRIPTIVE AND PERFORMANCE BASED SYSTEMS

In the modern day, designing a smoke control system for a building is often the most engineered part of the fire safety in the building. The approaches taken can be prescriptive, following standard equations and rules, or performance based, using an analytical approach for a specific situation and building geometry.

The use of prescriptive solutions for designing smoke control systems is something that is well documented and the parameters are detailed in the Code of Practice for Fire Precautions in Buildings 2013" (hereinafter referred to as the Code). The guidance, although often built on limited data, has been widely accepted throughout the world and provides a relatively simple calculation method for determining the ventilation requirements for a building. The approach allows for easy confirmation of the design and changes to the building layout can be quickly accommodated following the parameters given in the Code.

A performance-based approach to fire safety design relies on the use of fire engineering principles, calculations and/or appropriate CFD modelling tools to satisfy and comply with the Code. This approach can provide a value-added means of meeting the intentions of the Code without compromising safety. Engineers have greater flexibility in their approach to get the best performance and cost effectiveness for their building.

The availability of choice of the performance-based approach, the prescriptive approach or a combination of both gives flexibility so that the design is the best fit for the building.

Prescriptive codes and requirements specify exactly how the design should be applied – for example smoke zones must be no more than 60m long - whereas performance based designs take a much more analytical approach and set a specific performance for the system – for example the smoke must be maintained above the heads of occupants and tenable conditions must be maintained throughout the evacuation period. This approach allows the designer great flexibility to give the most suitable design solution for the building.

This can be extremely useful when working on buildings where the standard approaches do not fit in with the building architecture. The desire to create large and open spaces without any form of barrier to the spread of smoke in the building can create both a challenge and an opportunity to the engineer to be more creative in their approach. The use of performance based approaches can also provide a significant reduction in the total cost of the fire safety measures.

However, it must be recognised that with this approach there are restrictions and there is a cost of its own. This is in the time taken to confirm any system before any work can be done on site. Understandably, when using approaches that do not 'follow the rules' there is a requirement for the design to be verified and validated by one's peers and the authorities to ensure that any proposal will provide a safe building in the event of a fire. Typically, the verification of the design approach can take 6 to 9 months.

The use of such an individualised design approach for the building also has implications on any future modifications to the building. The design can be considered to be the equivalent of a made to measure suit. It will fit the body when made, but if the body shape changes alterations may be required. So it can be with performance based systems. Building changes can result in a long process of re-validation of the altered design.

Notwithstanding the above, there are many situations where performance based systems can provide a highly effective solution to the fire safety requirements in the building.

In retail establishments, where there is fairly constant stream of alterations, additions and tenant changes, this approach would not be practical due to the time required for approval of the changes, but an example where it has been used increasingly as a design approach is in multi-storey industrial buildings which shall be considered later.

THE USE OF NATURAL VENTILATION IN SMOKE CONTROL SYSTEMS

Natural ventilation is a method of ventilation that can be used in any building type. Buildings particularly suited for natural ventilation is any building where cooling of the air is not required as the natural ventilation system can be used for he dual purpose of smoke and general ventilation. Warehouses and industrial units are particularity suitable for this.

However natural smoke and general ventilation are not limited to these. Recent demands for greater environmental efficiency has led to natural ventilation being provided for many building types. A television studio and a shopping centre in the UK have both been provided with natural ventilation. Bluewater Shopping Centre in the UK is an example where wind catchers were used to introduce fresh air. In Singapore, The Star Vista Mall is another example where natural ventilation can be made to work for general ventilation.

Despite being used as a method of ventilation from man's earliest days, natural ventilation is often considered to be ineffective or inefficient and that a fan is always better. However, a correctly applied natural ventilation system can be just as effective and has been used in many types of building.

Natural ventilation is a method of ventilation that can work without electricity or moving parts. Natural forces produced by the wind or temperature variations can drive outdoor air through a building. Purpose-built openings including ventilators, windows, doors, solar chimneys, wind towers and trickle ventilators can then be used to control this ventilation.

The use of natural ventilation in fires to exhaust the smoke from a building is a method that has been demonstrated to be effective since it was first introduced in large buildings back in the 1950s following a fire at a General Motors plant in the United States.

When used for the removal of smoke, the advantages of natural ventilation are clear. Natural ventilation is a hole in the building. It is not subject to any time or temperature limits and all the time there is hot smoke in the building, the opening will allow the smoke to escape. Even in the event of other fire safety systems failing, causing temperatures to increase beyond any design or prescribed limit, natural ventilators will still allow the smoke to escape. The use of aluminium means that the ventilator louvres or flaps will not warp and block the opening when hot, but will disintegrate and a hole will be left. Aluminium also makes the ventilator lightweight and highly corrosion resistant.

Natural systems are also quiet in operation. Fire strategies in modern buildings often rely on the use of phased evacuation to minimise the number and size of escape routes, making it essential that broadcast messages during the evacuation period are not only audible, but that there is also speech intelligibility; i.e. the message can be heard, not just the sound of an alarm. Whilst fans can be attenuated to achieve acceptable noise levels, natural ventilators achieve the same result without the need for the additional space, weight and cost of attenuators on the roof.

One concern with natural ventilators is the possibility of them opening when there is not a fire and the subsequent water damage that can occur. Natural ventilators have moved on significantly in recent years. EN 12101-2 “Smoke and heat control systems — Part 2: Specification for natural smoke and heat exhaust ventilators” ensures that ventilators are reliable whilst also minimising the potential for ventilators opening unexpectedly. The mechanisms used are highly reliable and have undergone of thousands of cycles in testing to ensure this. It is also common to use motors that drive open and drive closed with a localised battery back-up to prevent opening on loss of power thus removing the concern of power cuts causing the vents to spring open unexpectedly.

Natural ventilation also has the ability to compensate for situations where the fire does not behave in the expected manner. The fire used in any smoke control design will be based upon the assumption that there will be a fire and this fire will behave in a certain manner.

Traditionally, for prescriptive systems. This has been a “steady state” fire, where it is assumed that the fire will not grow beyond a certain size. With performance based systems, it is more common to consider growing fires typically using a t^2-fire where the fire growth rate is a function of the time elapsed.

Except for highly specialised situations where there is a fixed fire load, any selection of fire size or fire growth rate is an assessment often based upon limited and fairly historic data. Sensitivity analyses can mitigate the effects of any unexpected fire behaviour, but with mechanical ventilation systems, the system will always have a fixed extract rate, so regardless of the amount of smoke produced, the amount removed will be constant.

As natural ventilation is reliant on the buoyancy of the smoke to operate, the effects of any unexpected acceleration in the fire growth is minimised as the increase in temperature or the increase in smoke depth will enable the system to operate more efficiently, as the buoyancy pressure forcing the smoke out through the vent is increased by hotter and/or deeper smoke.

Natural ventilation can also provide sustainable and energy efficient general ventilation in a building. No-one can deny that there is a general drive throughout the world to create a greener environment and so it can be used as an alternative to mechanical ventilation when cooling is not required. In these situations it can provide points for the BCA Green Mark rating of the building.

APPLICATIONS OF PERFORMANCE BASED DESIGN IN INDUSTRIAL BUILDINGS

The growth in the construction of multi-storey industrial buildings has been an area where significant use of performance based design has taken place. The layout of the building is substantially fixed from an early stage, making the use of performance based design particularly suitable and allows the designer great flexibility in many aspects of the fire safety in these buildings.

One area is zones sizes. The prescriptive zone sizes used in smoke control systems have remained unchanged. Their basis can be traced back to full scale tests carried out in a 20,000 square foot building where it was found that smoke cooling was not an issue and the smoke remained at high level. This was subsequently converted to 2000m^2 and due to its commercial and practical suitability, was universally accepted as the standard zone size for the design of smoke control systems. This was then increased to 2600m^2 for mechanically ventilated systems recognising that these systems did not rely on the buoyancy of the smoke to function and any additional cooling that may occur due to the increased area would not have a significant impact on the performance.

Further refinements when considering smoke spilling out from a compartment into a common space lead to these areas being split and it became 1000m^2 (1300m^2 if mechanical) in the compartment and 1000m^2 (1300m^2) in the common space.

These restrictions form a major part of prescriptive designs and it is the removal of these limits that is one of the most significant impacts.

The benefits of using a prescriptive design approach is shown in the following example.

The building is a 4 storey factory building. Level 2 is typical storey and is shown on Figure 1. The total area of the common areas that are part of the smoke control zones is approximately 6250m^2.

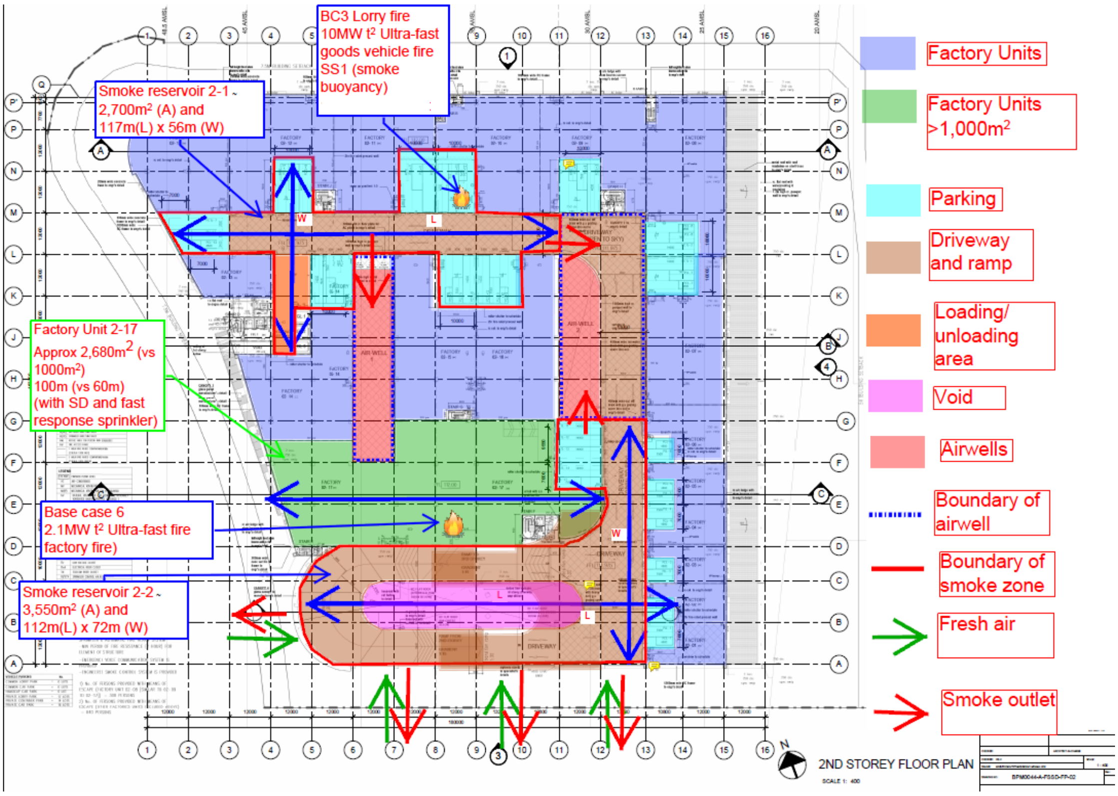


Figure 1

Using a prescriptive approach there would be at least 5 zones of smoke extract in the common area that is the driveway, each being no more than 1300m^2 and each zone would need to be a mechanical ventilation system. The use of a performance based system allows this to be reduced to 2.

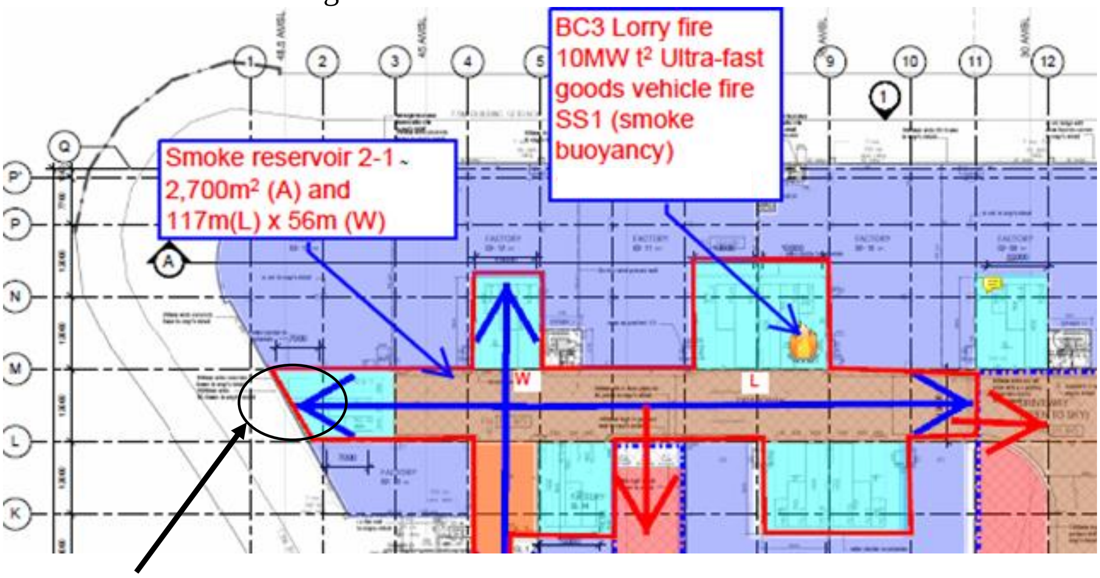
However, the use of a performance based approach does introduce other requirements. No longer when we perform the calculations do we assume that the smoke will stay at high level and that everyone will escape, but we have to consider the number of people in the building and their response to the fire alarm being activated.

The activation of the alarm will initiate the evacuation period which was calculated to be 761 seconds in the above example. It is a requirement that when considering the required safe evacuation time, the period during which tenable conditions is maintained is double the calculated period. This builds in a significant factor of safety as the engineer has to demonstrate that tenable conditions are maintain for 1600 seconds.

This is proven by the use computational fluid dynamics modelling (CFD). CFD is a very robust tool that can be used to predict smoke behaviour by solving conservation equations for mass, momentum, energy and species concentration together with a turbulence hypothesis. It therefore operates at a more fundamental level than the simple zone models used in prescriptive design solutions.

In a performance based design, a number of different fire scenarios are considered along with sensitivity analyses to ensure that the design has an acceptable level of robustness.

In this case, 7 cases were considered and 2 sensitivity analyses carried out. One fire scenario considered is shown in figure 2.



Proposed inlet

Figure 2

The fire modelled is a 10MW ultra-fast growing fire which is selected to represent a large burning vehicle.

Figures 3 shows results of the CFD modelling.

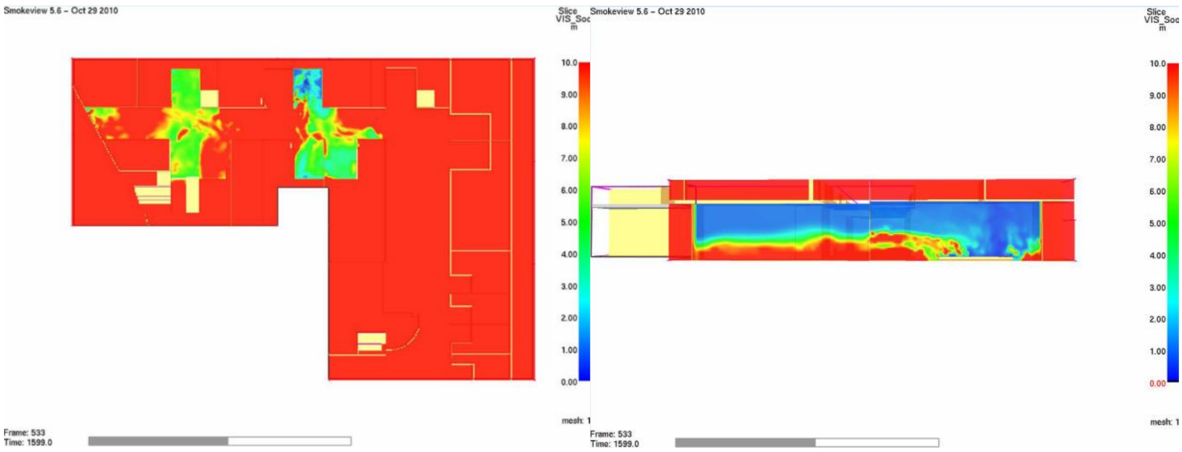


Figure 3 – Plan and section though the CFD model

The design process highlighted how what, at first sight, appeared to be a minor change resulted in a major change. Circled on the left in figure 2 is an area of proposed inlet. During the design development, it was discovered that the window in this area could not be used for inlet and as a result an extensive mechanical ventilation system has to be provided in this area as it had suddenly become a 'dead end'.

The result of this change was the installation of a costly ducted extract system which highlights the bespoke nature of these systems and the effect of what could be considered a minor change in the requirements. It also demonstrates the importance of recognising the details of the system and their significance.

The use of prescriptive and performance based systems can also introduce conflicts in their approach. When considering a multi-storey warehouse with connecting voids that are open to the atmosphere, when using a prescriptive approach it is acceptable to allow the smoke to spill into the void and rise up past the upper levels through the void and out of the building. Taking the same approach using a performance based system one would then have consider the smoke spilling out from the void and affecting the upper levels. The result would be the need for extensive mechanical extract. Thus in this situation, a prescriptive solution is cheaper and simpler than a performance based system.

CONCLUSION

Performance based systems provide the designer with a large amount of flexibility in their approach in the design of the smoke control system in a building. Selecting the right approach van provide a highly cost effective and the use of natural ventilation to go with it can ensure that the building is safe comfortable and help to limit the impact on the environment in the years ahead.

Framework for Facilitating Next Generation Performance-Based Building Regulations

Brian J. Meacham, Ph.D., P.E., CEng., FIFireE, FSFPE
Associate Professor, Fire Protection Engineering
Worcester Polytechnic Institute, 50 Prescott Street, Worcester, MA 01609, USA

ABSTRACT

In recent years, new societal and policy objectives have been introduced into the building regulatory system. In some cases, these have resulted in 'competing objectives,' which have resulted in failures within building regulatory systems. Going forward, building regulatory systems need to evolve in such a way that they can better identify and respond to new and potentially competing policy objectives, reflect quantitative performance objectives benchmarked against a unifying measure, and do a better job at balancing market approaches with the required regulatory infrastructure to assure competency and accountability of the various actors. Among the mechanisms being explored to facilitate a managed evolution that encompasses these concepts are the framing of the building regulatory system as a socio-technical system (STS), the integration of risk as a basis for performance, and the establishment of regulatory infrastructure to enable the new approach. It is suggested that framing the building regulatory system as socio-technical systems (STS) will highlight the complex interactions that exist between regulators and the market, the roles stakeholders play in defining building regulatory objectives. An STS approach will also highlight the technical knowledge and data needed for using risk as a basis of performance, and the steps that are required to shift to a risk-informed performance-based building regulatory system, taking into account different legal structures and regulatory approaches that exist between jurisdictions. This paper introduces a framework for considering building regulations as a complex socio-technical system and a set of recommended step to help facilitate a move in this direction.

KEYWORDS: Performance-based; building regulatory systems; socio-technical systems

INTRODUCTION[1]

Building regulatory systems are complex 'systems of systems.' They typically include legislative mandate for building regulation and control (laws, acts, decrees, ordinances), a building regulation (code, standard), reference standards which address testing, design, installation and maintenance of products, systems and components, product certification (listing, approval), and some type of building control and permitting system (e.g., see ICC, 2007; Meacham, 2009, 2016a; Moullier, 2016). Many also have mechanisms to assess and license (register) practitioners, which may include minimum education and competency requirements, means to demonstrate this, and codes of practice which establish the standard of care. Closely linked are regulatory or voluntary systems related to consumer protection, property insurance, and professional liability insurance, as well as zoning, planning and resource management. In some cases, market-based mechanisms, such as 'private certification' may exist, as might voluntary standards and performance rating schemes (e.g., LEED).

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From the early days of building regulation, the focus has been primarily on the health, safety and welfare of the occupants of a building and of neighboring buildings (Field and Rivkin, 1975; Cobin, 1997; Meacham, 2000, 2016; Wermeil, 2000; Ben-Joseph; 2005; Imrie and Street, 2011). They emerged in response to widespread illness, death and destruction, which occurred in urban centers as a result of unsanitary conditions and significant hazard events, and the social and political mandate to mitigate these hazards as part of urban redevelopment. Building regulation addressed such issues as minimum requirements for fire separation and resistance of materials, structural resiliency to natural hazards, and safe heating and sanitation systems for occupants. Over time, needs such as standardized testing and product approvals to assure minimum performance, industry standards for demonstrating compatibility of systems and components (Hemenway, 1975; Cheit, 1990), minimum competency of practitioners, and mechanisms to assure compliance of constructed buildings with stated designs gave rise to the other components within the building regulatory system.

In the 1980s building regulatory regimes began to transition from prescriptive- to performance-based. The motivation for change included reducing regulatory burden, reducing costs to the industry and the public, increasing innovation and flexibility in design, and better positioning to address emerging issues (BRRTF, 1991; Meijer and Visscher, 1998; May, 2003; Visscher et al, 2005; Meacham et al., 2005; Meacham, 2009). All of this was to be achieved while maintain tolerable levels of safety and performance. In some cases the transition has worked reasonable well: in other cases there have been issues (May, 2003; Lundin, 2005; Mumford; 2010; Meacham, 2010). With respect to failures, contributing factors include lack of agreed performance measures (criteria) and means to predict performance in use, lack of test methods which yield data that can be used in engineering analysis, limited availability and quality of data, inadequate competency and accountability in the market and of those in oversight (compliance checking) roles, insufficient product certification / means to assure performance of products, and challenges with insurance, liability assignment and limitation, and consumer protection mechanisms (May, 2003; Lundin, 2005; Mumford; 2010; Meacham, 2010).

Increasingly, building regulations and regulatory systems have become further complicated by policy mandates and introduction of voluntary assessment instruments originating from environmental, civil rights, and other concerns which have historically been outside the realm of building regulation (Meacham et al., 2005; Meacham, 2016a). These new pressures pose a significant challenge – not just because the traditional building regulatory environment is itself undergoing change and has structural challenges to overcome – but because the success of recent governmental policies and market approaches aimed at addressing new objectives, such as sustainability of the built environment, has arguably been limited (e.g., see Van Bueren and de Jong, 2007 as related to sustainability). Whereas a robust approach to engaging stakeholders in issues of health and safety developed over decades, new stakeholders have emerged around sustainability, civil rights, and other objectives, and the different groups are fragmented and not working effectively together. In addition, the introduction of voluntary measures have resulted in inconsistent levels of performance is being realized. This is particularly true around sustainability issues (Newsham et al., 2009; Scofield, 2009), in part because voluntary approaches lie outside the realm of regulatory oversight. The situation is further complicated because there are incomplete building performance measures, monitoring and enforcement mechanisms (Van Bueren and de Jong, 2007), increasing liability concerns (Brinson and Dolan, 2008), concerns about competency, engineering tools and methods, data and more (e.g., Meacham, 2010; 2016b; 2017; 2017a).

This fragmented regulatory approach and introduction of competing objectives has led to unintended consequences being introduced, some of which present considerable risk to building occupants (Meacham, 2014; 2016a). This includes structural hazards due to moisture-related failures of enclosed structural systems (May, 2003; Mumford, 2010), health hazards related to mold and indoor air-quality due to weather-tight buildings (Jaakkola et al., 2002), fire and health hazards due to the flammability of thermal insulating materials (Simonson McNamee et al., 2011; Babrauskas et al., 2012), fire and smoke spread potential through the use of double-skinned façades (Chow et al., 2007), and fire hazards and impediments to emergency responders associated with interior and exterior use of vegetation, photovoltaic panels and other 'green' features and elements (Meacham et al., 2012). The 'competing objectives' between sustainability and fire safety are particularly complex due to the multidimensional aspects of each. Timber is 'sustainable' but also is combustible, so if not addressed appropriately can present a significant fire safety hazard (Meacham et al., 2012). High strength concrete requires less material and is more sustainable than regular strength concrete, but can be highly susceptible to spalling during a fire (Kodur and Phan, 2007). Insulation and alternative energy sources are good for sustainability, but photovoltaic panels which can cause an ignition, and flammable insulation material, can be a catastrophic combination (Meacham et al., 2012).

To better account for 'new' policy objectives, such as sustainability, resiliency to climate change, changing demographics, and access and egress for people of all abilities, as well as for future ones which have yet to be identified, it is suggested that the whole of the building regulatory system needs to adapt (Meacham, 2014a). This is particularly important with the shift to performance-based approaches in a number of countries. It is suggested that framing the building regulatory system as socio-technical systems (STS) will highlight the complex interactions which exist between regulators and the market, the roles stakeholders play in defining building regulatory objectives. An STS approach will also highlight the technical knowledge and data needed for using risk as a basis of performance, and the steps that are required to shift to a risk-informed performance-based building regulatory system, taking into account different legal structures and regulatory approaches that exist between jurisdictions.

BUILDING REGULATORY SYSTEMS AS SOCIO-TECHNICAL SYSTEMS

Building regulatory systems are complex socio-technical systems (STS). In brief, STS theory considers the interaction of organizational or institutional components, technological components, and the actors within the organization or institution, with the explicit realization that they are integrally linked (Trist and Murray, 1993; Meacham and van Straalen, 2017). One representation of the STS concept is illustrated in Figure 1 (Meacham and van Straalen, 2017).

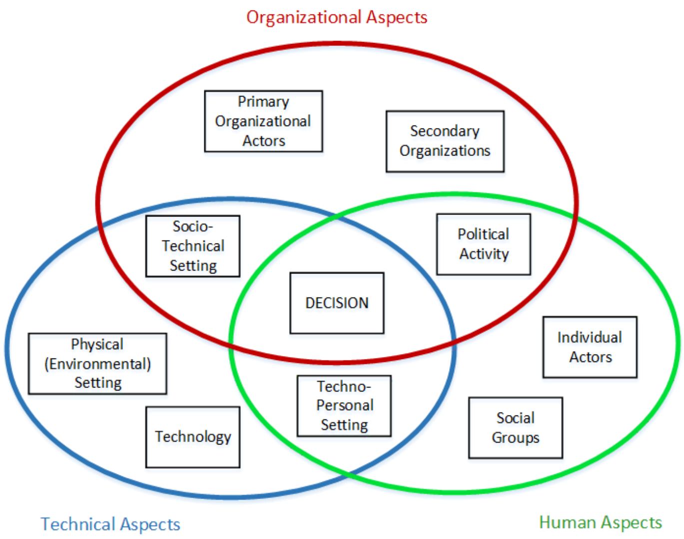

Figure 1. Framework for socio-technical decision making (Meacham and van Straalen, 2017).

There are three levels of STS: primary work systems, whole organization systems, and macrosocial systems, which include systems in communities and industrial sectors, and institutions operating at the overall level of society (Trist, 1993). It is in from the latter perspective that the building regulatory system can be viewed as a STS, considering the interaction of actors (stakeholders), institutions and technology within regulatory and market environments (Meacham and van Straalen, 2017). The STS model developed by Petak (2002) has been modified by Meacham and van Straalen (2017) and adopted as a suitable framework for incorporating risk as the basis for performance requirements in next-generation performance-based building regulation. In the original form, the model used fire as a hazard of concern. As presented here, the framework, referred to as the Socio-Technical Building Regulatory System (STBRS) framework, has been expanded to illustrate better how to address multiple objectives. In the STBRS framework there are two operational environments, 'Legal and Regulatory' and 'Market', along with an 'interactions' environment within which decisions are made. Within each environment are subsystems: Built Environment (BESS), Regulatory Objectives (ROSS) Design, Construction and Evaluation (DCESS), Political, Economic and Societal (PESSS), Policy Formulation, Implementation and Adoption (PFIASS), and Organizational Implementation Decision-Making (OIDMSS). Figure 2 illustrates the high-level interactions between the sub-systems.

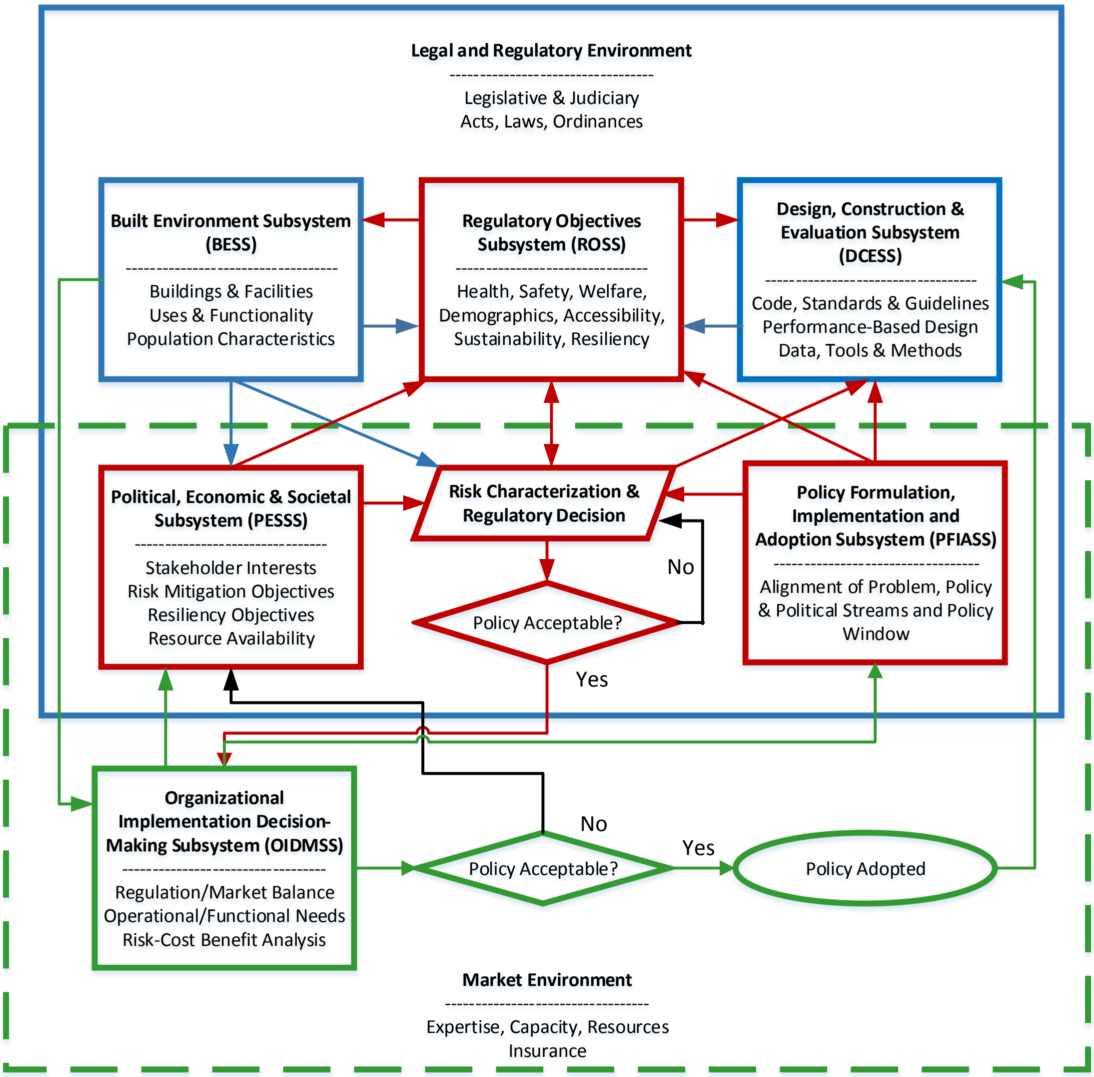

Figure 2. Socio-Technical Building Regulatory System (adapted from Meacham and van Straalen, 2017).

There are many interactions between the subsystems, a few of which are described here to help better envision how the framework can be used. The ROSS, PESSS and PFIASS interact with each other to describe/define regulatory objectives, facilitate risk characterization and develop regulatory decision, taking account of political, economic and social influences. The ROSS, BESS and DCESS interact to describe how regulatory objectives are translated into such aspects as building use classifications, population characteristics, and such within the regulations, codes, standards and guidelines used to design buildings. The policy decisions and supporting regulatory instruments are vetted and balanced with market options in the OIDMSS. Each of the subsystems is itself a socio-technical system. Some of these are described below. It is recognized that standards are developed in the private sector, and may or may not become part of the regulatory environment, as they may be used on a voluntary basis. However, the placement of standards within the DCESS reflects the role they play within the regulatory environment, and how their development is influenced by other subsystems. If one considers next the ROSS, one can envision both the diversity in regulatory objectives, and the need for these objectives to be considered holistically. This is shown in Figure 3.

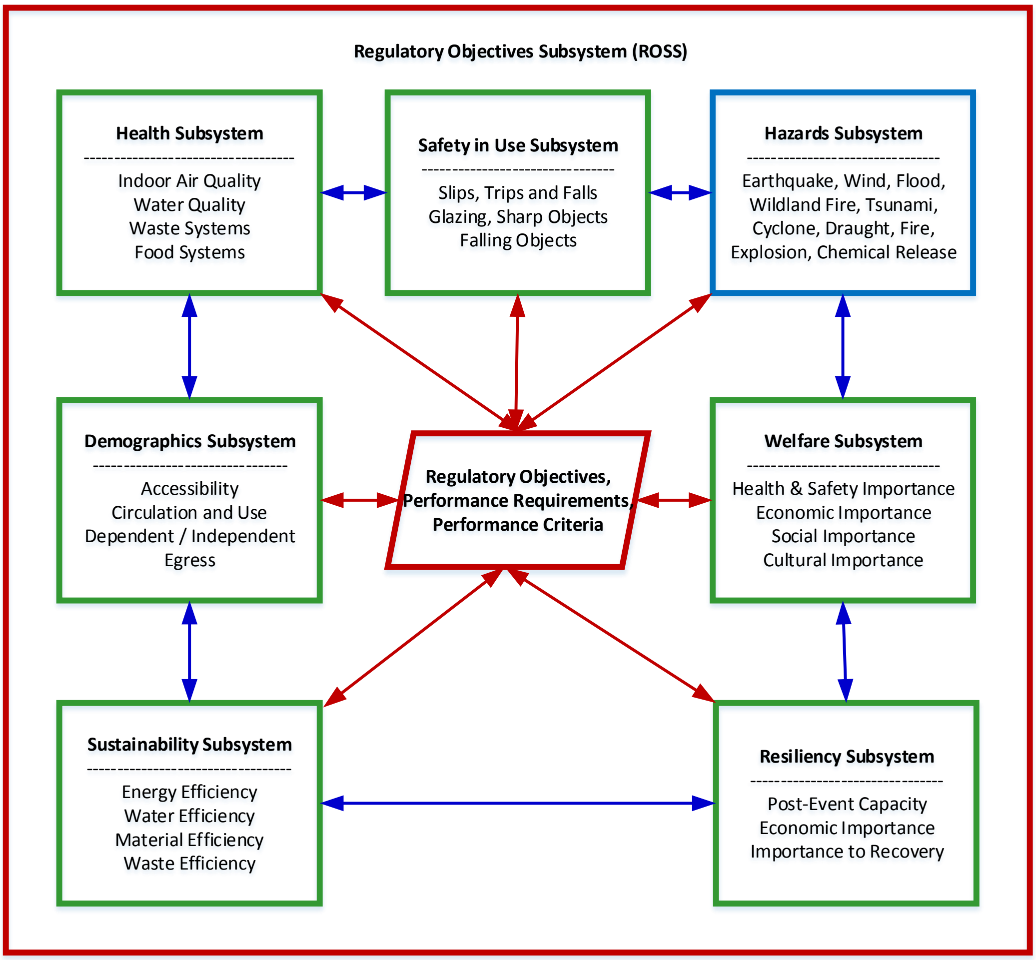

Figure 3. Regulatory Objectives Subsystem (ROSS)

In brief, while regulatory objectives are nominally focused on diverse areas, such as health, safety and sustainability, they must be considered together, so as not to create 'competing' objectives, such as combustible thermal insulation for energy efficiency resulting in an increased fire hazard. This requires that the objectives, performance requirements and criteria be developed in an integrative and comparative manner. There will be need for iteration, and for interaction with PESSS and PFIASS as well, as illustrated in Figure 2.

Each of these subsystems is again a STS as well. In Figure 4 below, the Hazards Subsystem (HSS) is considered. As with the ROSS above, there are numerous interactions between the individual hazard subsystems, which again need to be considered as integrated components, so as to assess interactions and impacts between systems and hazards, such as earthquake and fire, or fire and health effects, or demographics and stair safety. One might question why there is a Demographics Subsystem; however, the risks associated with the various hazards is impacted by the population characteristics. This is important, since risk characterization is a core objective of considering the various hazard subsections, as building regulations are significantly concerned with who is at risk from what.

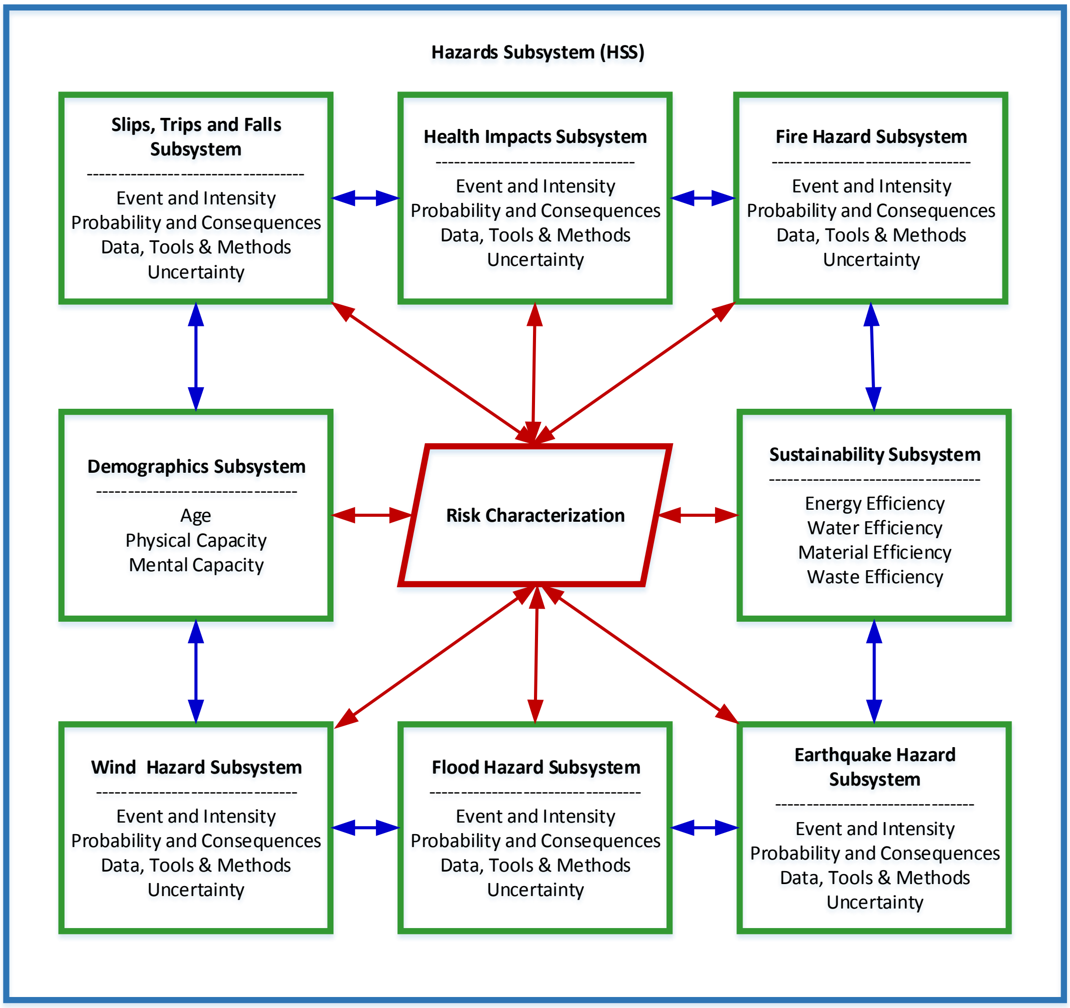

Figure 3. Hazards Subsystem (HSS)

The risk characterization process, at the core, brings one full circle to the interactions with PESSS and PFIASS, since risk characterization is influenced by the perceptions and views of the diversity of stakeholders involved, as well as the political perspectives on risk. The risk characterization process is illustrated in Figure 4 and described in detail in other publications (e.g., Stern and Fineberg, 1996; Meacham, 2004; Meacham, 2010; Meacham and van Straalen, 2017).

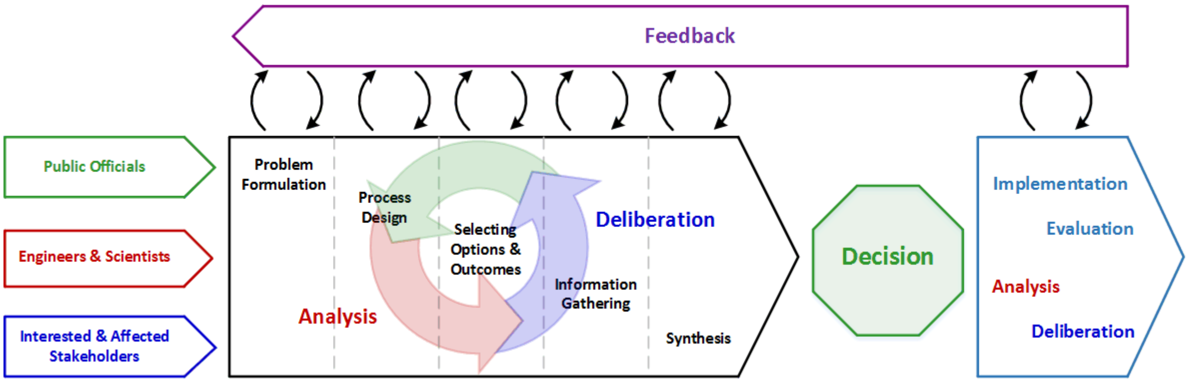

Figure 4. Risk Characterization Process (Meacham and van Straalen, 2017)

USE OF RISK AS BASIS FOR PERFORMANCE CRITERIA

It is suggested that future generations of building regulations can become more risk-informed and performance based, and that development of the regulations and the risk bases that underpin them should occur within a socio-technical systems framework. To facilitate this, it is important for regulators and the market to understand and agree the risk measure(s) that will be used to define the risks, the specific risk criteria that will be used in the evaluation of the risks, and the analysis and design approaches that will be used to demonstrate that building design solutions can be verified as meeting the risk criteria and measures. A 'roadmap' for use by regulators in achieving these objectives has been developed (Meacham and van Straalen, 2017a). The main components of the roadmap are briefly overviewed here.

The roadmap has five fundamental elements (Meacham and van Straalen, 2017a):

- Guidance on how to identify and gain agreement on a risk measure (or set of risk measures) for use in building regulation,
- Guidance on how to identify and gain agreement of risk criteria, which reflect the risk measures, that will be used for verifying compliance of designs against the established risk measures,
- Discussion on various levels and types of risk analysis approaches, which may be appropriate for addressing different types of health and safety objectives in building regulations, and recommendations on an appropriate level of risk-informed design methods for use in quantifying risk and in verifying design compliance,
- Discussion on how the application of comprehensive risk-based analysis and design methods can facilitate development of simplified, risk-informed engineering methods and solutions, that are appropriate for use in practice, and
- Presentation of various examples of the coupling between risk criteria, analysis approaches, and design methods based on the selected risk measure.

The steps are illustrated in Figure 5 below. The first major challenge is selecting a risk measure and associated risk criteria. The choice of a risk measure can make a big difference in a risk analysis, especially when one risk is compared with another, and in whether interested and affected parties see the analysis as legitimate and informative (Stern and Fineberg, 1996). Every way of characterizing risk requires value judgments. Ultimately, risk decisions are significantly policy decisions – whether in government or private-sector entity – that are informed by analytical data and stakeholder deliberation regarding the hazards of concern and the values of the society or entity (i.e., outcomes of the risk characterization process).

However, once risk measures and criteria are agreed, and appropriate risk analysis methods are agreed, it can be relatively straightforward to assess risks associated with the built environment, and develop appropriate simplified solutions, mitigation measures and the like.

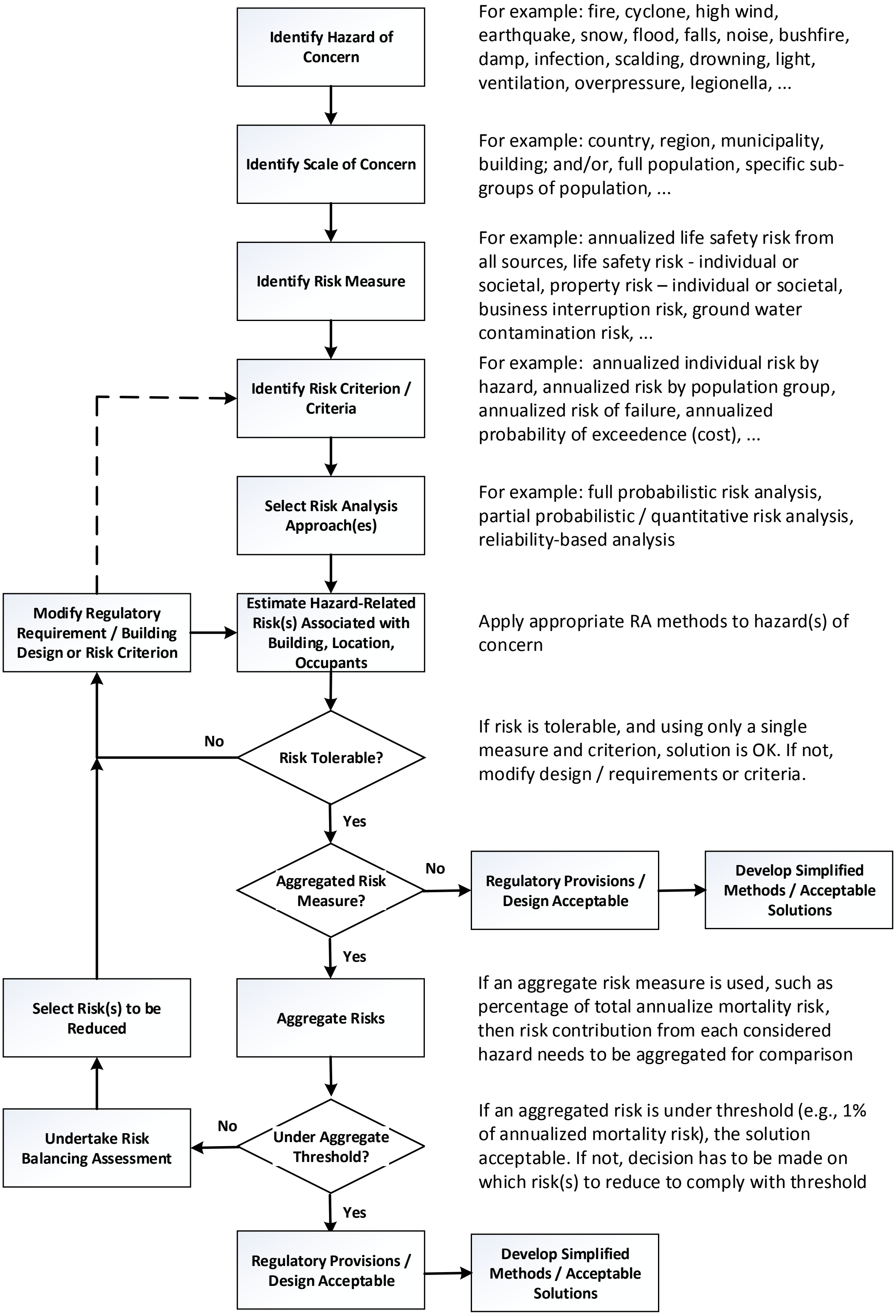

Figure 5. Risk Quantification Roadmap (Meacham and van Straalen, 2017a)

SUMMARY AND CONCLUSIONS

As the building regulatory environment becomes more complex, building regulatory systems need to evolve. They need to do so in such a way that they can better identify and respond to new and potentially competing policy objectives, reflect quantitative performance objectives benchmarked against a unifying measure, and do a better job at balancing market approaches with the required regulatory infrastructure to assure competency and accountability of the various actors. To move forward, several steps are needed.

First, there needs to be a shift in thinking from viewing buildings as a collection of independent systems, to viewing buildings – and building regulatory systems – as complex socio-technical 'systems of systems' with strong interrelationships between subsystems and overall building performance (Meacham and van Straalen, 2017). Increasing energy performance should not be considered without assessing impacts to structural performance, indoor air quality, fire performance or other attributes. Reducing material should not just be viewed as a cost savings or sustainability measure, but resulting structural performance, fire performance and related factors need to be considered. The 'silo' based approach to regulatory development and implementation is creating new hazards and risks as it tries to mitigate others, and this needs to stop (Meacham 2014a; 2016a). The socio-technical building regulatory system (STBRS) framework can help facilitate this.

Second, the basis for performance requirements in building regulations should be made common, to the extent practicable. It is suggested that risk should be the basis (Meacham, 2010; 2016c; Meacham and van Straalen, 2017; 2017a), with some measure of individual or societal risk-to-life being the measure (Meacham, 2016a). Once societal expectations are identified, and risk targets are set, performance requirements can be determined, and tools, mechanisms and criteria that are necessary to define, measure, calculate, estimate, and predict performance must be developed. The right balance of regulatory and market mechanisms are needed for optimization of the system (Meacham and van Straalen, 2017; 2017a).

Third, to adequately characterize risks and establish performance measures within the STBRS framework, a broader set of stakeholders is required to feed into the regulatory development and control process to help assure the key societal and policy objectives are met (Meacham, 2014; 2016; Meacham and van Straalen, 2017).

Fourth, through deliberation within the STBRS framework, changes which may be required to the supporting regulatory infrastructure, which are necessary to assure the successful incorporation of the new regulatory objectives, need to be identified, evaluated and implemented. This includes minimum qualifications, competency criteria, licensing, product testing, certification and conformity assessment systems, on-site inspections, assessment of installed performance, potential changes to liability systems, and so forth (e.g., see Meacham 2010; 2016b; 2017; 2017a).

Fifth, while not discussed in detail in the body of this paper, future building regulatory systems need to do a better job at addressing existing buildings. In most countries, building regulations do not address existing buildings, except when significant renovation or change of use occurs, and in some cases it is unclear as to when and to what level compliance with codes for new buildings is required. Given the significant policy focus on sustainability and resiliency, aging in place, and access for all, existing buildings must be addressed (Meacham, 2014a; 2016a).

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Sprinkler Research for High Challenge Storage Risk

Dr. Louis A Gritzo
FM Global Research
1151 Boston-Providence Turnpike, Norwood, MA 02062

INTRODUCTION

Modern storage facilities are posing increased challenges for fire protection. The combustible loading continues to rise, with more widespread use of plastics in both stored materials and in storage containers. Driven by the cost of real estate, modern warehouses are also becoming taller and more densely packed with equipment and materials. Newer designs are increasingly using robotic automated storage and retrieval systems that allow for smaller aisles and spaces between storage. Furthermore, these warehouses are becoming increasingly less isolated, with storage facilities located in close proximity to each other or other occupied or high value structures. Both the fire challenge, and the severity of fires that go uncontrolled, is rapidly increasing and needs new protection solutions.

DEVELOPMENT OF FIRE PROTECTION SOLUTIONS

Automatic fire sprinklers continue to be the most cost effective solution for protecting large facilities with high challenge storage. With larger orifice sizes and new spray patterns, the limit where adequate ceiling-only sprinkler protection can be provided has increased in recent years up to a range of 12 to 13.7 m depending on the material stored and the ceiling clearance. Although new designs are still being developed, current ceiling only options seem to be near a limit with current sprinkler technology. Finding new protection points has traditionally been based on full scale fire tests, where arrangements (layouts, sprinkler K-factor and pressure/flow rate) were tested under different configurations. Once fire control was achieved and either a subsequent test (or judgement) was used to show that no further reduction in the protection would be effective, the protection point was added to installation guidance, and submitted to be added to industry consensus standards. As solutions are pursued for increasing storage heights, this test and re-test approach becomes even more cost prohibitive. Furthermore, storage heights are increasing and spacing in flues and aisles are decreasing to the point where judgment alone would indicate that in-rack sprinklers will be required. The addition of in-rack sprinklers includes even more variables than ceiling-only protection, since sprinklers can be placed in the flues or at or near the face, as well as at different vertical levels and horizontal spacing. In pursuing these solutions, additional tools are required.

OPEN SOURCE FIRE MODEL AS A TOOL

In fire protection engineering, Computational Fluid Dynamics (CFD) CFD has often been used in performance-based design for life safety, for example, smoke control, detection and activation, and egress. In these applications, a design fire with a prescribed heat release rate (HRR) history is typically used as the fire source. As a result, a CFD model for these applications, such as the widely-used Fire Dynamics Simulator (FDS) from NIST [1] only needs to handle the fluid dynamics aspects of fires, e.g., plume, ceiling jet and doorway flows. If used properly, these

CFD tools can be especially effective for scenarios with nonstandard building geometries and provide useful guidance for life-safety design. However, such a tool has only limited value when it comes to modeling fire hazards related to industrial property protection. The physical processes involved in fire growth and water-based fire suppression in industrial settings are far more complicated than smoke transport. Primarily, the HRR and fire growth in time and space must be predicted, rather than simply being specified as an input to the model. Therefore, additional key physics are required in the CFD model: reaction and extinction of flames, convective and radiative heat transfer, solid fuel pyrolysis, spray atomization and transport, film flow on solid surfaces, and the complex interaction between gas, liquid and solid phases.

To enhance FM Global's technical capability to better address engineering needs in property protection, we took the grand challenge to extend CFD from typical smoke transport analysis to modeling the entire spectrum of fire growth and suppression phenomena. This endeavor was initiated in 2007. Over the last nine years, we have progressed from modeling the fundamental fire dynamics of a simple, 30 cm (11.9 in.) square methane burner with a 50-kW fire size [2] to large-scale, sprinkler-based fire suppression of realistic storage facilities [3].

FM Global's journey of fire modeling research started from choosing a right numerical platform. An open-source CFD library called OpenFOAM [4] was selected after careful evaluation of many options including commercial and in-house CFD codes [5]. The name's suffix, FOAM, stems from Field Operation and Manipulation, representing the innovative way that the numerical program is organized for mathematical operations of spatial and temporal fields, for example velocity and temperature. Our fire modeling software, named FireFOAM [6], builds from the OpenFOAM libraries and focuses on fire-modeling applications. OpenFOAM's capabilities of handling complexed geometry with arbitrarily unstructured mesh and highly efficient parallel computing make FireFOAM suitable for analyzing very large-scale and complex scenarios typically found in industrial facilities.

Developing the predictive capability for fire growth was the first step in creating FireFOAM. The initial key sub-models developed were gas-phase combustion, solid-fuel pyrolysis and flame heat transfer. The parallel-panel test with corrugated cardboard was the first target to evaluate the integrated fire growth model. Later, we extended the pyrolysis model to handle wood pallets and rack-storage fire growth in Class 2 commodity representing non-combustible contents in a combustible cardboard box (Fig. 1).

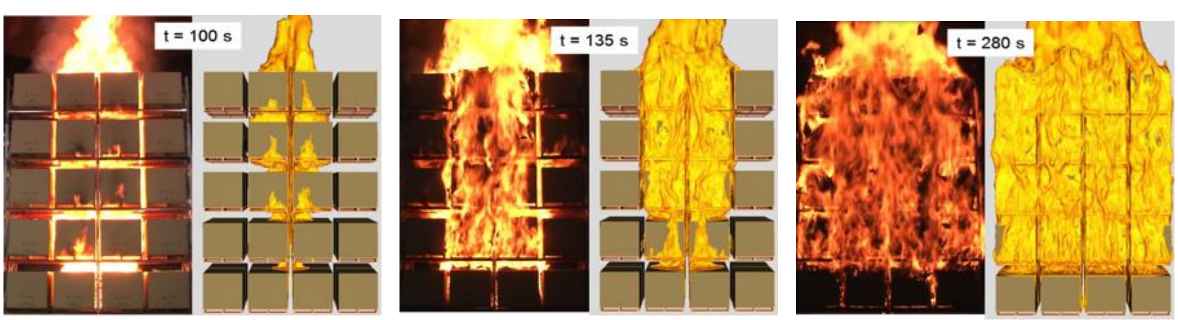

Figure 1: Fire tests and model predictions

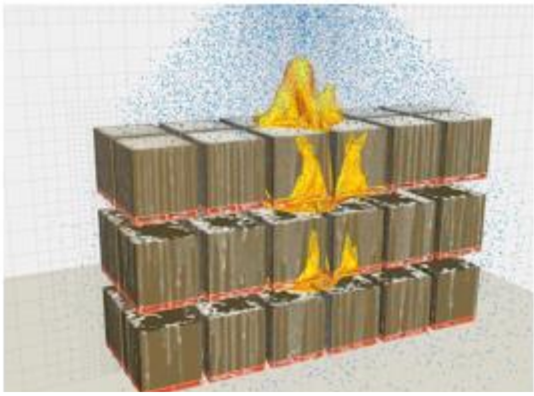

Figure 2: Calculated Suppression of Class 2 Storage

The model validation process included comparing HRR and vertical/lateral flame-spread patterns against experiments. With the extensive, individual component validation exercises, we are now confident to apply the model to different storage heights and array sizes for this commodity. The fire-spread models were recently extended to Cartoned Unexpanded Plastics (CUP) and Class 3 (cartons with paper contents) commodities, as well as roll-paper storage. Similar rigorous validations were conducted for all fuel types with different heights and configurations.

In parallel with the flame-spread model development, key suppression models were also incorporated into FireFOAM: spray injection and transport, water film flow, as well as their interactions with fires, as illustrated in Fig 2. The water film flow on solid surfaces is the key model to couple all the suppression-related physics, especially solid-fuel prewetting and water interactions with burning surfaces [7]. Similar to the fire-growth capability, fire-suppression models underwent extensive separate-effect validation exercises, and the full integrated model was validated for sprinkler fire tests with rack storage of Class 2.

The model formulations of many sub-models in FireFOAM are general and not particular to the protected commodity type. However, the pyrolysis and solid fuel suppression models do need separate model development for each industrial commodity type, due to the differences in material flammability and physical configurations, e.g., packing and orientation. FM Global's current focus is to develop commodity-specific models to simulate the standardized commodities typically used in developing sprinkler protection guidance. In addition to sprinkler technology, models for water mist are under development in FireFOAM. In the future, FireFOAM will also be extended to handle ignitable-liquid fires. FM Global releases FireFOAM as open source, meaning that full access to the source code is available to the external community to facilitate collaboration and provide greater impact to the broader research community [6].

LATEST RESULTS

In-Rack Sprinkler Protection

The FireFOAM model, in addition to suites of small-, intermediate-, and full-scale experiments, were used to develop new guidance for in-rack sprinkler design over the period of a 3-year research program starting in 2012. This program had the goal of both developing solutions for increasing storage heights, but also developing lower cost and simpler systems for storage arrangements that could be protected with existing installation standards. Specific efforts were made to maximize vertical increments of the sprinklers to reduce cost and the likelihood of sprinkler damage, increase storage heights above the in-rack systems, and allow for independent in-rack and ceiling design to reduce water demand. Historically, in-rack sprinkler systems were designed using K80 (K5.6) or K115 (K8.0) sprinklers at vertical increments ranging from 3 to

4.6 m (10 to 15 feet) with limits on the maximum storage area above the top level of in-rack sprinklers of 3 m (10 ft.). Hence the goal was to apply the new tools to help develop an improved design, in part by using newer, larger sprinkler designs. Sizes as large as K25.2 (K360) were considered to reduce piping and sprinkler requirements.

Small scale tests of material flammability were performed using the Fire Propagation Apparatus [8]. Model calculations were performed to estimate fire growth and sprinkler activation times. Separate calculations were performed to determine water distribution and validated with flow tests. Intermediate scale fire tests were then conducted to determine the critical water fluxes for suppression within a defined zone below each row of in-rack sprinklers. This “zonal protection approach” allowed solutions for very large storage arrangements to be developed faster and with greater confidence. Using the critical water flux to the base of each zone, a suite of numerical simulations using FireFOAM were conducted to cover the large parameter space and propose the optimal placement and conditions of operation for face and flue sprinklers. Almost all successful in-rack sprinkler protection points were obtained by only one large-scale test.

The resulting guidance more than doubles the vertical increments of the sprinklers to heights of 9.1 to 12.2 m (30 to 40 ft.). As per the design, each row of in-racks creates a virtual floor since neither the rows of in-rack or ceiling sprinklers above are needed (nor will activate) for any fire that starts below the next lowest level of in-rack sprinklers. Hence the solution can provide protection for unlimited ceiling heights with the addition of the necessary levels of in-rack sprinklers. Furthermore, the amount of storage space above the top level of in-rack sprinklers is now solely based on the capacity of the ceiling sprinklers. If the ceiling sprinklers can protect 12.2 m (40 ft.) of rack storage, for example, then a warehouse could have 12.2 m (40 ft.) of storage above the top-tier level of in-rack sprinklers. These new guidelines are included in Global Property Loss Prevention Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities* [9].

A measure of potential cost savings provided by the new design was determined by estimating the difference in cost for installing sprinklers in a hypothetical 152-m x 305-m (500 ft. by 1,000 ft.) storage facility with a storage height of 23 m (75 ft.) and a ceiling height of 24.4 m (80 ft.) using the prior and new installation guidance. The total cost of the project was US$2.11 million using the new option compared to US$3.57 million under the prior guidelines, a reduction of 40 percent. Hence, warehouse owners could save at least US$0.09/$m^2$ ($2/$ft.^2$) because of the reduced equipment and installation costs. Reductions in water storage are also beneficial.

Automatic Storage and Retrieval Storage System (ASRS) Sprinkler Protection

Automatic storage and retrieval systems (ASRS) use (generally) plastic boxes tightly configured in tall racks and managed via automated systems to place boxes or remove contents. These configurations can create a unique fire hazard that can be severe compared to standard storage racks, depending on the type of ASRS structure and the containers used within them. The structural arrangement of a mini-load type ASRS unit alone is a severe challenge to sprinkler protection; the narrow transverse flue spaces increase the potential for horizontal fire spread and the mini-load’s material supporting structures divert discharged sprinkler water from the portions of the rack structure where it is needed. Also, ASRS units typically have narrow aisle widths that increase the chance for potential fire jump across the aisle from one rack to another. Since most of the containers used within ASRS units are plastic (which has a very high heat release rate and cannot be pre-wetted by discharged sprinkler water) and the units are commonly open-top which collect water, the time required for sprinkler discharge to reach the lower portions of the storage rack where the fire is typically located is significantly increased. These fire hazards can create a condition in which it is nearly impossible to protect the area with ceiling-level sprinklers unless they are supplemented with in-rack sprinklers. Finally, ASRS units can be erected to heights more than 30 m (100 ft.), thus making manual extinguishment of a fire very challenging.

A very similar approach was used to revise and improve in-rack protection for ASRS warehouse storage. The method relied even more on water distribution modeling due to the different types of plastic boxes (open/closed top, vented/solid walls, …) that can be used in these systems. The design was again driven by an objective to use larger orifice sprinklers and limit fire growth to within a region and below the next highest level of sprinklers to reduce water requirements and water damage. Eliminating the use of horizontal barriers to reduce vertical fire spread, as was present in past installation guidance and consensus standards, was also desirable.

A new solution was developed using quick-response K160 (K11.2) and larger in-rack sprinklers, with close spacing of the in-rack sprinklers and flows of 230 L/min (60 gpm) or more. This approach allows for an increased vertical distance between in-rack sprinkler levels and eliminates the need for horizontal barriers. The new solution differentiates between open-top containers that collect sprinkler water and containers that allow water to be released more quickly into the transverse flue spaces. Containers with slots, holes, hinges or other design features that allow for sprinkler water to better flow through the stored materials allow the vertical distance between in-rack sprinkler levels to be increased. Hence use of these venting-type containers will generally reduce the number of in-rack sprinkler levels needed. A summary of the changes and subsequent improvements to FM Global Property Loss Prevention Data Sheet 8-9, "*Storage of Class 1, 2, 3, 4 and Plastic Commodities*" [10] is provided in Table 1.

Table 1: Comparison of Prior and New Guidance for ASRS Protection

	Previous Data Sheet 8-34	New Data Sheet 8-34
Minimum K-factor of In-Rack Sprinkler	K80 (K5.6)	K160 (K11.2)
Minimum In-Rack Sprinkler Design Flow	115 L/min (30 gpm)	230 L/min (60 gpm)
Typical Number of In-Rack Sprinklers in Design	14 (7 on 2 levels)	6 on 1 level
Maximum Horizontal In-Rack Sprinkler Spacing	3 m (10 ft.)	1.2 m (4 ft.)
Maximum Vertical In-Rack Sprinkler Spacing	1.5 m (5 ft.)	4.5 m (15 ft.)
Horizontal Barriers	Needed above every IRAS level	Not needed
Maximum Storage Height Above Top IRAS Level	1.5 m (5 ft.)	3 m (10 ft.)
Hydraulic Balancing of Ceiling and IRAS Systems	Needed	Not needed

These requirements no include sprinklers in the flue and near the faces at each level. While the new protection recommendations result in the installation of more in-rack sprinklers at the tier levels where in-rack sprinklers are needed, there are scenarios where less in-rack sprinklers may be needed overall. The new recommendations, however, do result in less sprinkler piping and installation labor costs as well as reduce the amount of water needed for the in-rack sprinkler system.

FUTURE DEVELOPMENTS

To date, the major sprinklers and installation standards all share the common feature of using a simple and reliable fusible link or glass bulb, which, when heated (largely by convective flow) will result in individual sprinkler activation. By comparison to most other modern systems, which use sensors and logic/controls systems to improve their operation, they are overdue to make the transition to digital. An experimental study was recently conducted to demonstrate the concept of a new sprinkler protection system using Simultaneous Monitoring, Assessment and Response Technology (SMART) [11,12]. For this system, sprinkler activation is controlled using input from a series of sensors at each sprinkler location that include a smoke alarm and a ceiling temperature rise threshold. Using these variables, rather than rely on the time required to bring the sprinkler thermal element to activation levels, the system can respond much faster, and provide earlier detection. The fire location is calculated to determine the thermal centroid based on ceiling temperatures. A group of six sprinklers, closest to the calculated fire location, is activated simultaneously. Subsequent fire development was monitored through visual observation as well as ceiling temperature data. Test results show that the SMART sprinklers can provide adequate protection for the CUP commodities stored up to 7-tiers (12.2-m) high within a rack storage under the tested conditions. The water densities used in these tests were approximately 50% of those in existing protection recommendation. These results lay the foundation for exploring potential applications of the SMART sprinklers to fires that currently challenge other ceiling-only designs. Included in the description of the system is a reliability analysis, including different inspection, testing and maintenance intervals, for comparison to standard sprinkler systems [13]. The goal of making the information freely available is to stimulate development that will provide a spectrum of new products and systems in the marketplace, hence resulting in more protection options and reduced risk.

CONCLUSIONS

New options for ‘in rack protection’ have been developed that allow fewer levels of in rack protection, and, thanks to ensuring that protection is restricted to the region below each level, now offer protection for unlimited storage heights for all types of commodities in standard and ASRS configurations. These advances have been made possible by research which brings new tools to the historically test (or even judgement) –based methods for developing new protection. The largest of these tools is an open source computational fluid dynamic framework developed by FM Global in collaboration with a global team of public and academic partners. Over the past few years, this suite of tools, which is tailored for and utilizes high performance scientific computing clusters, has been used in concert with carefully designed small and intermediate scale experiments to successfully and rapidly develop new potential solutions, which in turn are validated by large scale tests. Although large scale fire testing is inherently challenging due to the hazards and high degree of non-linearity (where small changes in conditions can result in very different outcomes) key variables have been identified that strongly affect test quality and hence can be more carefully controlled resulting in improved repeatability in test results. The results from this effort have provided new solutions and less expensive options that current protection guidance. In addition, new solutions, including increasing digitally enabled systems, that advance new frontiers in fire safety are be highlighted as the potential to continue to improve the performance and reduce cost of effective fire protection.

ACKNOWLEDGEMENTS

This paper is a summary of work performed by a large number of people in the Fire Hazards and Protection Area of FM Global Research and the FM Global Research Campus. Virtually everyone in those two organizations contributed to the experiments for discovery, the model development, the use of both experiments and model results for validation, and the usage of experiments and modeling in this new way of developing loss prevention solutions.

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Mitigating Fire Risk Involving Flammable Liquids in Pharmaceutical Plants and Research Facilities

Speaker S11
Friday, November 17, 2017
1:55-2:25 pm

Gregory Jakubowski
Fire Planning Associates, Inc.
PO Box 466, Washington Crossing, PA, USA 18977

INTRODUCTION

Pharmaceutical manufacturing facilities are currently located, as well as being constructed throughout Asia. These facilities are located in many countries including Singapore, Malaysia, Indonesia, China, Japan, India, Vietnam, Russia, South Korea and Australia. Pharmaceutical manufacturing can involve the use of a variety of flammable liquids, particularly alcohols and other related solvents, used in both manufacturing and sanitization of manufacturing equipment and areas as well as in laboratory environments. The quantities used can range from a few ml, up to hundreds or thousands of liters. Common flammable liquids used in these facilities can include: methanol; ethanol; acetone; acetonitrile; toluene; isopropanol; and others.

The use of these flammable liquids can present both fire and explosion risks in these facilities. These fire and explosion risks have resulted in incidents that have resulted in significant damages, as well as casualties up to fatalities.

CLASSIFICATION OF FLAMMABLE LIQUIDS

Flammable liquids are classified as follows:

Class IA – Flash Point $<22.8^{o}$C, Boiling Point $<37.8^{o}$C
- Ethyl Ether
- Methyl Ethyl Ether
- Pentane
- Isopentane
- Petroleum Ether

Class IB – Flash Point $<22.8^{o}$C, Boiling Point $>=37.8^{o}$C
- Acetone
- Ethanol
- Methanol
- Gasoline
- Hexane

- Isopropanol
- Methyl Ethyl Ketone

Class IC – Flash Point >=22.8^{o}C and <=37.8^{o}C

- Naptha
- Turpentine
- Butyl Alcohol

Class II – Flash Point >37.8^{o}C and <60^{o}C

- Acetic Acid
- Kerosene
- Fuel Oil #1, 2, 4 & 5

Class IIIA – Flash Point >=60^{o}C and <93^{o}C

- Phenol
- Formaldehyde
- Pine Oil

Class IIIB – Flash Point >=93^{o}C

- Castor Oil
- Coconut Oil
- Fish Oil
- Olive Oil
- Ethylene Glycol
- Glycerine

It should be noted that some of these materials have other hazardous properties as well. The classification of flammable liquids helps to determine allowable quantities that can be stored, or used in open or closed systems in buildings. The lower the classification, the less quantities that may be stored or used in buildings, although codes do make allowances for larger quantities when the building they are in is sprinklered, and if the liquids are stored in approved flammable liquid storage cans/cabinets.

FIELD FINDINGS

There are regulations, guidelines, and other requirements at facilities identifying how flammable liquids should be stored and utilized. Limits are placed on quantities in storage and use, and usage quantities can be dependent upon whether the material is being used in a closed, or open system. Closed systems are considered as systems not open to the atmosphere, or essentially those that do not emit flammable vapors to the spaces around them. Open systems are systems that are not closed systems. Assessments that have been conducted in pharmaceutical facilities have found drum storage of flammable liquids being stored in production areas that are not designed for drum quantities, along with liquids being utilized in containers that are not approved for use with flammable liquids. Waste cans for flammable liquids are used extensively in HPLC (High Performance Liquid Chromatography) laboratories. The focus on saving time and money during both sanitization and production processes has resulted in employees coming up with innovative, but risky methods of working with these products. Sanitization methods may call for several 100 ml of cleaning liquids, but regulatory issues with products and sanitization in industry have increased operations personnel focus on better sanitization. This has resulted in using increased quantities of flammable sanitizers. Sanitization requirements may include total wipedown (sometimes with mops) of entire rooms or facilities, including fire protection equipment.

Quality evaluation of production rooms has resulted in specifying concealed sprinklers, which are not listed for extra hazard applications, in these spaces. In addition, concealed sprinklers have been found sealed, caulked and/or painted for Quality reasons in flammable liquids operations rooms. Isopropanol has been often found to be used to help “dry” equipment being cleaned, but the use of these liquids in the sanitization process may often be done in rooms or spaces that may not be designed for open handling of flammable liquids. Alcohols also present different properties than hydrocarbon materials, and even approved flammable liquids pumps and other materials with seals designed for hydrocarbons, require special seals if this equipment is used for alcohol-based materials as these materials can dry the seals out over time, resulting in product leaks.

PHARMACEUTICAL INDUSTRY CHALLENGES

In the pharmaceutical business, there are strict quality requirements related to sanitization of production areas and equipment. Sanitization methods are detailed in manufacturing documents, and modifying these manufacturing documents to switch to different means of cleaning can involve months or years of testing and governmental approvals, as well as potential risks to production and government licensing that most companies are not willing to pursue. Thus the use of flammable liquids (typically isopropanol), is generally “here to stay” at these facilities. It is vital that those using these flammable liquids clearly understand their hazards, as well as safety practices to follow for storage and use of these liquids. Control of quantities, area ventilation, fire protection, fire barriers/separation, and proper bonding and grounding are all safety factors that should be in place in areas where flammable liquids are used.

Besides sanitization, basic research, quality lab operations, chromatography operations, and other work with pharmaceuticals all can involve the use of flammable liquids. These liquids are used in a variety of typical sizes, from 4 liter bottles to 24,000 liter isotankers to 84,000 liter tanks. 4 liter bottles that are heavily utilized in laboratory operations with flammable liquids can be standard (brown) glass, or plastic-coated to inhibit breakage when dropped or struck. They are typically delivered in cases to the area of use, although can be transported in special holders that minimize the potential for being dropped or breakage if dropped.

A more recent innovation for the storage and dispensing of various flammable liquids has been the use of Pressurized Liquid Dispensing Containers (PLDCs), often known by their trademark names such as NowPAK®, FisherPak™, CYCLE-TAINER™, and others. These products come in containers up to 1350 liters, and there are many advantages to the users, although the quantities that may be present in labs and other pharmaceutical operations areas are likely to be greater than what would normally be expected. Fire testing was conducted on PLDCs to determine the relative risk of using these containers vs. using more traditional containers.

TESTING OF PLDCs

The test program was operated by the Fire Protection Research Foundation (FPRF), an independent nonprofit organization associated with the NFPA. The FPRF's mission is to provide practical, usable data on fire and building safety. Program testing was performed by a nationally recognized research and development laboratory using hexane-filled containers, with nominal 55-gal (208-L) capacity, to simulate realistic fire situations.

The test protocol was to expose three different container designs to both stored, no hoses connected to the containers, and in-use conditions; the containers had both a gas pressurization hose and a solvent dispense hose connected to them. The fire conditions included both a spray fire, which involved four nozzles spraying flaming hexane at the containers so that they were engulfed in a ball of fire, and a pool fire, in which containers were placed in a contained pool of 5 or 10 gal of hexane that was then ignited. Some of the tests also included an activated sprinkler system to simulate a typical laboratory sprinkler system. Data collected during the tests included container pressure, water pressure of the sprinkler system, fuel delivery pressure, fire temperature, and photographic/video. The performance of the containers was documented and compared to hexane-filled 4-L glass bottles. This included both plain glass bottles and plastic-coated (shatter-resistant) bottles, the current standards for high-purity flammable liquids in laboratories.

The project test data were analyzed, and it was found that no stainless steel container exceeded its design pressure because the pressure relief devices performed as expected. All of the bottles broke in less than 1 min 20 sec.[1]

There is one positive physical property surrounding the hazards of many of the flammable liquids used in pharmaceutical operations, and that is that many of them are water-soluble. Some of them are used in a partially diluted form, such as 70% Isopropanol/30% water. Many risk management standards consider a mixture of these liquids of 20% or less in water to no longer be flammable. This same factor can be considered during the design of fire protection systems, and area ratings. For example, in a room with a 1900 liter tank of flammable liquids, the water sprinkler density may be designed to 24.4 $L/min/m^2$). If the room is 56 square meters, and the contents of the tank spill into the room and ignite, when the sprinklers all activate in the room, the discharge will be over 1300 liters/min. Within 6 minutes of the sprinkler discharge, the amount of water discharged into the room would bring the spilled material to less than a 20% mixture, essentially rendering it no longer a flammable liquid. These concepts can be used in a performance-based manner to design and operate these facilities.

SUMMARY

The industry generally has a very good track record of working safely with these flammable liquids, but there have been a number of incidents of fires involving these liquids. Understanding actual incidents involving flammable liquids in the pharmaceutical industry, following the available codes, as well as applying practical approaches to the storage and use of flammable liquids in this industry can minimize the risks of using these materials. Implementing and enforcing various safety precautions provides realistic protection and sustainable design considerations. It is critical to take these considerations into consideration during the design, design review, operations, and inspection processes at facilities using flammable liquids to control risks to personnel, facilities, and the environment.

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Inquest into the death of a firefighter- lessons to be learned

Neil Gibbins QFSM FIFireE

Chief Executive Officer and Past President of The Institution of Fire Engineers

Paper for presentation – FISAC Nov 2017 (delivery may vary from this paper, in the time available visual aids will be relied on to convey more information)

1 Introduction

i. On June 13th 2013 On the 13 July 2013, Firefighter (FF) Stephen Hunt lost his life and FF Jeremy Jones sustained injuries whilst attending a serious building fire in a multi-occupied premise at 21-33 Oldham Street, Manchester. Greater Manchester Police (GMP), following advice from the Chief Fire and Rescue Advisor, appointed West Yorkshire Fire and Rescue Service (WYFRS) to provide them with independent support in the form of technical advice.

ii. On the 4th April 2016 Her Majesties Senior Coroner for Manchester, Mr Nigel Meadows, opened the inquest into Stephen's death. Mr Meadows appointed a legal team to support him, I was appointed to act as expert advisor to that team and the Court.

iii. An inquest is a public judicial inquiry to find the answers to a limited but important set of questions:

Who the deceased was
When and where they died
The medical cause of their death
How they came by their death

It is usually the 'how' question that is the main focus of the inquest. The Coroner cannot, in law, deal with any other matters.

It is a fact-finding process. It does not deal with issues of blame or responsibility for the death, or with issues of criminal or civil liability. These can be addressed in other courts if necessary.

iv. The inquest had a jury of eleven members of the public, they sat for five weeks, hearing evidence about the cause of the fire, the spread, the compliance of the building with fire law and the fire and rescue operational response. The verbatim record ran to over 250 000 words.

v. After hearing and considering the information given, the jury gave their findings. Mr Meadows relayed those findings and sent letters to people he felt could act to prevent future deaths of a similar nature.

2 Overview of the building, it's use and location.

Fig 1 Manchester map

Plaintree House, 21-33 Oldham Street, Manchester

Oldham Street is located in Manchester City Centre in an area known as the Northern Quarter. This is a busy area of the city, occupied by a varied mix of premises and businesses.

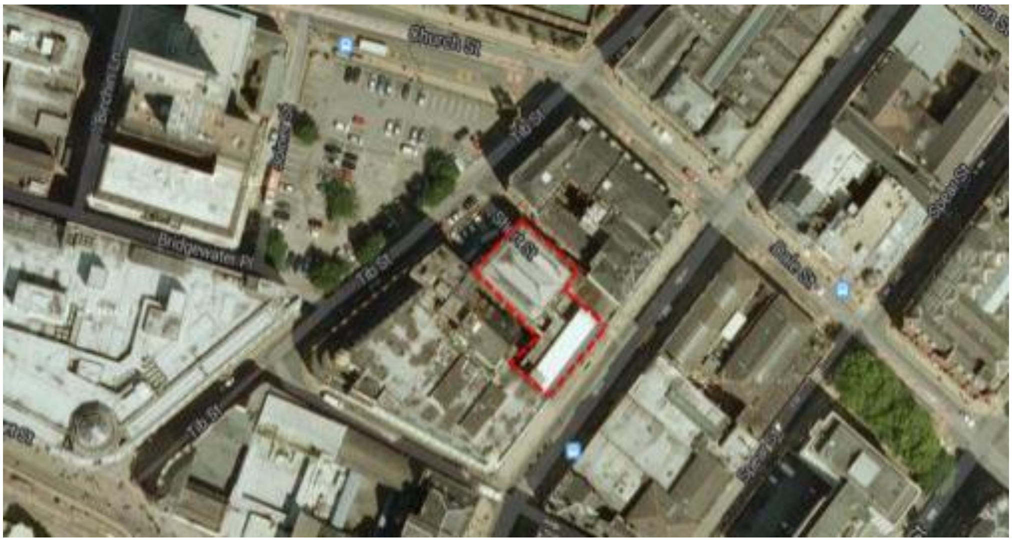


Fig 2 aerial view

The front elevation of the building is on Oldham Street and access to the rear elevation is from Tib Street (figures 4 & 5). There is a small car park area between the building and Tib Street. There is some access to the north-east side elevation of the building from Short Street, which becomes a narrow pedestrian alleyway leading back to Oldham Street. There is also an access path at the rear of the building giving limited access to the south-west side elevation of the building.

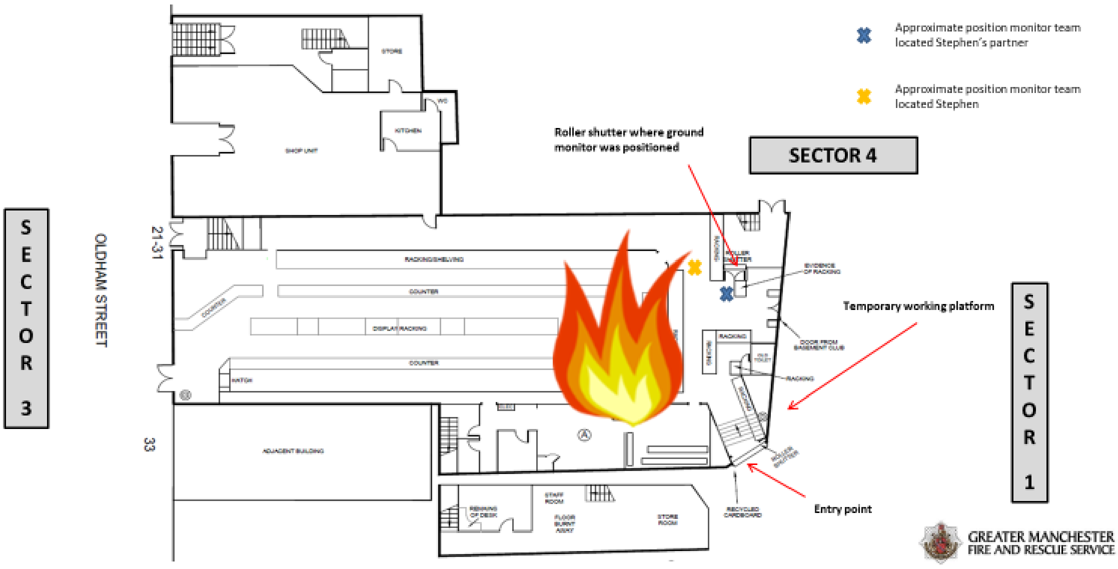
The building is adjoined on both sides. To the south-west side is Sachas Hotel and to the north-east side is The Manchester Coffee Company café. Afflecks Palace adjoins this café and is in close proximity to 21-33 Oldham Street at the rear of the premises.

Figure 4: Front elevation of Pauls Hair & Beauty World from Oldham Street.

Figure 5: Rear elevation of Pauls Hair & Beauty World from Tib Street.

The premises has four floors and a basement. Built on sloping ground, the rear is lower than the front (figure 6) giving four storeys (figure 5) at the rear and three storeys at the front (figure 4). At the rear of the premises, the ground floor is approximately six steps above the ground level and the basement is only partly below ground.

Plan of building



3 Key Points- not related to fire fighting

i. The fire was deliberately started by two juveniles.

ii. The fire spread quickly to involve stored materials

iii. Staff and fire service reacted quickly but the fire took hold

iv. Acetone and hydrogen peroxide were stored separately

v. There was no detector under mezzanine floor

vi. Risk assessment carried out by unqualified person

4 Key Points- Fire fighting

i. Initially believed to have persons missing inside

ii. Fire fighters entered building and used external jet

iii. A system of monitoring was set up and deployed throughout day shift deployment

iv. Change of shift 1900hrs

v. Stephen and Jeremy deployed to "top of stairs, turn left, look right, fight the fire from there"

vi. (BA team movements will be described assisted by use of plan)

5 Inquest findings and Coroners letter to prevent future deaths

(Direct copy of the Coroners Letter)

"Paragraph 7 of Schedule 5, Coroners and Justice Act 2009, provides coroners with the duty to make reports to a person, organisation, local authority or government department or agency where the coroner believes that action should be taken to prevent future deaths.

Greater Manchester Fire and Rescue Service (GMFRS) and the Fire Brigades Union (FBU) ask the Senior Coroner to include in any report to prevent a recurrence of the tragic death of Stephen Hunt on 13th July 2013, that the following recommendations be directed to the Secretary of State for the Home Department, the Right Honourable Theresa May MP:

1) It is recommended that all FRSs should consider the implementation of measures to reduce the risks associated with the physiological affects of working in a hot environment. In particular consideration should be given to:
   a) Duration of wears under breathing apparatus;
   b) Having regard to all relevant factors including, for example the weather, previous exertions of BA teams and individual circumstances;
   c) Training and guidance for all operational personnel to recognize the effects of heat both on themselves and on their colleagues and the appropriate steps to take upon such recognition, including withdrawal and self withdrawal.
   d) Training and guidance for all operational personnel to have the ability and confidence to ensure the withdrawal of others who may be adversely affected by heat whether by calling a BA emergency or otherwise appropriately.
   e) Training and guidance for all operational personnel to have the ability and confidence to withdraw themselves by whatever means appropriate including activating the ADSU.

2) It is recommended that all FRSs should consider the implementation of measures to reduce the risks associated with the loss of communications at operational incidents. For example, to include safety control measures to ensure BA teams can be withdrawn from the risk area if needed.

3) It is recommended that all FRSs should undertake a review to ensure the adequacy of standard operating procedures, guidance and training of the handing over and taking over of roles at incidents to ensure all the key areas of information, including safety control measures, are captured and shared.

4) It is recommended that all FRSs should ensure that significant hazards and any safety control measures are

   a) The responsibility of the incident commander and should be recorded within each sector, to ensure visibility to all on the fireground, and
   b) passed/copied for use by the the incident commander/command team to assist on the analytical risk assessment.

5) It is recommended that all FRSs should undertake a review to ensure the adequacy of standard operating procedures, guidance and training in the appropriate use of thermal imaging cameras to include the limited extent to which they can be relied upon to measure ambient temperature.

6) It is recommended that all FRSs should undertake a review to ensure the adequacy of standard operating procedures, guidance and training in the deployment of aerial monitors to ensure the safety of any personnel within the risk area is not compromised.

7) It is recommended that all FRSs should undertake a review to consider the circumstances in which inspections should be carried out under section 7(2)(d) of the Fire and Rescue Services Act 2004.

8) It is recommended the above mentioned steps be undertaken jointly by Fire and Rescue Services and the FBU or other Health and Safety Representatives on the Health and Safety Committees.

9) It is recommended that the Secretary of State for the Home Department considers measures to ensure that:

   a) fire risk assessors are adequately trained and qualified so as to be competent in the role, and
   b) the responsible person has the means to verify the competence of any person holding themselves out to be a fire risk assessor.

6 Conclusions and summary

i. Greater Manchester Fire and Rescue Service acted on the Coroners letter, having completed most actions prior to the inquest

ii. UK National Operational Guidance (NOG) has been reviewed

iii. The inquest process allowed all interested parties to hear relevant evidence regarding the circumstances of Stephen’s death. The Institution of Fire Engineers is assisting the learning process by making all information available from this and similar incidents, to support CPD and other learning events.

Additional reading-

Greater Manchester Fire Authority report-

http://authority.manchesterfire.gov.uk/documents/s50006158/Oldham%20St.%20Report%20FINAL%20low%20res%20web.pdf

Case Study of Formosa Fun Coast Dust Explosion

Kang Chao
CEO of Chinese Fire Protection Safety Center, Taiwan
5F, No. 51, Housheng Rd., Luzhu District, Taoyuan City 338, Taiwan (R.O.C)

INTRODUCTION

At 8:32 pm on June 27, 2015, The Color Play, a music party, was being held at a drained swimming pool within Formosa Fun Coast (Chinese:八仙樂園), a recreational water park in Bali, New Taipei City, Taiwan when flammable starch-based powder exploded and scorched the activity site, injuring 499 people, devastating hundreds of families, and causing substantial financial burden to the society. The dust explosion has been considered the worst incident of mass burns in Taiwanese history and a rare one among outdoor events using colored powder internationally. This case study aims to explore the course of the dust explosion incident, origin of such activities, response process and results of fire investigation as well as provides a complete explanation about subsequent care for the injured and amendments made to related regulations for similar activities.

1. VENUE INTRODUCTION

Located in the coastal area of northwestern Taiwan and in the vicinity of West Coast Expressway and Taipei Harbor, Formosa Fun Coast boasted the largest water park in northern Taiwan. With an area of 90000 square meters, Formosa Fun Coast began its operation in 1989. Its water park, equipped with tens of recreational facilities, opens to the public during the summer season starting from June to September and was one of the most popular summer amusement parks among teenagers in northern Taiwan. (See Picture 1)

Happy Great Barrier Reef, located at the end of the amusement park, was turned into the venue for the Color Play music party. The recreational facility, a large swimming pool with an area of 1800 square meters, 30 meters by 60 meters, 140 centimeters deep, is one of the most popular facility in the park during summertime. (See Picture 2) The organizer set the music stage at Happy Great Barrier Reef, at the far end to the exit of the amusement park. The distance between the exit and the stage area is 200 meters. The swimming pool, 30 meters by 60 meters, was drained and turned into the activity site, which included the dance floor, the stage, and the south and north extended platforms forming a U shape. The stage and the extended platforms surrounded the dance floor with 2-meter-high pool ends. Participants could only access the activity site through the opening of the U-shaped space. The capacity of the dance floor area was estimated to be 500 people. (See Picture 3)

2. ORIGIN OF THE ACTIVITY

The Color Play, the activity in which the dust explosion occurred, was hosted by Wan Se Chuang Yi Creative International Ltd. and Rui-bo International Integrated Marketing Ltd. The Color Play party was inspired by the colored powder used in the Hindu religious festival "Holi", also called "festival of colors", which is celebrated in India at the end of winter and the beginning of the spring, where people splash colored powder onto each other.

Every color represents a specific blessing and the ritual of splashing is used to give all kinds of good wishes to others. For example, red symbolizes marital harmony; yellow symbolizes auspiciousness and wish fulfillment; green symbolizes new beginning and abundant harvest; saffron symbolizes connection of the forces. Holi means color in Indian. Opinions about the origin of the Holi Festival vary. One of them thinks the festival originates from an Indian myth, where Krishna, an emanation of Vishnu, one of the three major deities, had a playful nature and enjoyed splashing colored powder on the Gopis. As the myth has been passed down over a thousand years, it has been turned into a local custom in India. Others say that, in ancient times, a boy who piously worshipped Vishnu, one of the three major deities in Hindu Religion, was tortured because of his unwillingness to convert his religious belief. However, his faith helped him overcome difficulties over and over again. In the end, the evil spirit of Holika tried to kill the boy and hurdled him into the flames. To Holika's surprise, the boy was totally unharmed and Holika himself was overcome by the flames. Later on, people named the festival "Holi" in order to celebrate the victory of good over evil.

Holi Festival has also inspired a carnival style marathon event, **The Color Run.** The Color Run originated in the USA in 2011 and has been called "the happiest 5 km running race". The event, stressing freedom and limitlessness, does not have ranking or time limits. Participants who completes 1 km will be splashed with colored powder by the staff as a means of blessing so as to disseminate the message of freedom, love and peace. In 2012, 50 events of The Color Run took place in the US and attracted over six hundred thousand participants. From then on, similar events have taken place around the globe. The Color Run advocates the ideas of health, happiness, and being true to oneself, and, therefore, is popular with younger generations around the world. Similar events are held every year in many cities such as those in Japan, China and Europe. There have been several such events in Taiwan and those outdoor activities were quite popular among young people.

The Color Play music party. With a theme of popular rock and roll electronic music, The Color Play music party is different from The Color Run. During the musical event, colored powder is splashed onto the stage and the proximity of the audience, creating a colorful environment while warming up the music party. It has been a great hit in younger generations. Before the dust explosion, three Color Play music parties have been held in Taiwan: September 2013 in Kaohsiung, June 2014 in Formosa Fun Coast, and September 2014 in Taichung, respectively. This was the second time for the Color Play music party to be held at Formosa Fun Coast. Previously, it was held at the bank of the swimming pool. However, the water was drained from the pool for the second event. Participants of the second event were estimated to be over 4000 people.

Other than playing deafening music that kept the crowds high, the Color Play music party splashed colored powder onto the crowds so as to create an environment of bright colors. Colored powder was contained in a gun-like device and sprayed with compressed CO_2 carried on the back. The colored powder used in this event was manufactured by a food processing factory in Taiwan. It was composed of 97% corn starch and 3% edible artificial colorings. Particles of the colored powder were 6 ~ 18µm in diameter, and majority of them were 9 ~ 14µm. The colored powder used was a running race-specified product, causing fairly low damage in terms of breathing, consuming and polluting the environment. Because such edible starch might easily cause dust explosion if misused, there were notes on both the packaging box and the factory's website to remind users **"not to spray the product in confined spaces so as to prevent dust explosion"** and **"not to use the product at fire origin so as to prevent flashover"**.

For The Color Play music party, the organizer prepared 3 tons of colored powder for the event. Every participant was given 3 packages of color powder (600g) for throwing at each other as entertainment.

3. SUMMARY OF THE PARTY

The organizer set 8 colored powder spray guns at the stage and each extended platform was equipped with 11 pray guns. During the party, there were live band performances on the stage. Color powder was sprayed occasionally to compliment the deafening music so as to encourage the participants to have more fun. (See Picture 5)

4. PROCESS OF DUST EXPLOSION INCIDENT

At around 8:30 pm, the event was approaching its end. In order to create stage effects, the staff sprayed large amount of colored powder from three sides to compliment the deafening electronic music and the audience's excitement was at all time high. The central dance floor area was covered by a high concentration of colored powder mist, with a thick layer of colored powder dust on the ground. At around 8:32pm, the northwestern side of the main stage suddenly caught fire. Because the air contained a high concentration of dust, the fire immediately spread over the central stage. The incident occurred unexpectedly, so visitors surrounding the stage thought it was merely effects caused by light and sound and didn't escape in time. Many people suffered severe burns. The dust explosion ended in mere minutes, but 499 people thereby suffered minor and severe burns.

5. EMERGENCY RESPONSE

After the incident broke out, New Taipei City Fire Department first deployed 21 ambulances and 30 response vehicles to the scene and notified the Ministry of the Interior and the Ministry of Health and Welfare to activate Multiple Casualty Incident mechanism, an emergency medical care system for mass injuries. Many patients with burns were sent to nearby medical facilities such as MacKay Memorial Hospital in Tamsui and Chang Gung Medical Hospital in Linkou.

Because of the large number of injuries, the Mayor of New Taipei City personally phoned Taipei, Keelung and Taoyuan cities to request support with ambulances. Meanwhile, the Mayor of Taipei City instructed Taipei City Fire Department and Public Health Department to provide full assistance and directed the Taipei Emergency Operation Center of the Ministry of Health and Welfare to assist with unified coordination. Keelung and Taoyuan municipalities also deployed fire fighters and medical personnel to immediately respond to the incident. Ministry of National Defense, R.O.C. also supported the response at once, and six army corps established the command post and deployed army doctors, engineers and fire engines to respond to the incident. Military police command division from Joint chiefs of staff and Guandu command division deployed personnel and vehicles to join the response efforts as well. Eventually a total of 144 ambulances, 18 vehicles for transporting minor injuries, 88 various response vehicles from New Taipei City Fire Department and 1504 responders were deployed.

Relief efforts for the injured was as follows:

(1) Disaster assessment and surgical alert activation

When the fire department was notified and assessed the disaster, they notified responsible hospitals right away to activate surgical alerts, while informing the department of public health to activate Multiple Casualty Incident mechanism and connecting with the emergency operation centers in Taipei and Northern Taiwan to follow pertinent procedures to obtain pertinent information for further decisions in transferring on-site patients to the hospitals.

(2) Mass on-site injuries operation procedures

Triage：Handle mass on-site injuries in accordance with the principal of simple triage and rapid treatment. During initial and middle stages, triage was conducted for on-site patients while search and rescue efforts for the injured, emergent treatments, transportation and congregation were all being conducted.

Transferring the patients to the hospitals: Considering the great number of on-site injuries and the massiveness of ground they spread across, the fire department and the public health department reported regularly at various stages so as to allow the incident command post to obtain information on on-site patient triage and transfer to the hospitals and thereby ensured that injured people at various stages could be further transported to appropriate hospitals responsible for emergency treatments.

6. CASUALTIES

Two days after the incident, the first death occurred. The victim was a 20-year-old woman who suffered second degree burns on 90% of her body. More deaths followed and, 3 months thereafter, a total of 12 deaths occurred and another 12 in critical conditions, 7 severely injured, and 468 with minor or mid-level injuries. Currently, there are 107 people still in the hospitals, including 19 in intensive care units. Most of the injured were young people aged 18 to 29. The majority of the injured were Taiwanese and 16 foreigners were involved in the incident. Official statistics revealed that, by July 7, the average area of burns was 44% and there were 248 patients with burns that involved over 40% of their body, with 22 among them suffering over burns that involved 80% of their body. As there were a lot of patients, they were transferred to 53 respective hospitals in other counties for treatment. In total, this dust explosion accident caused 15 deaths and 484 people with various degrees of injuries.

7. DISSCUSSIONS

In the history, particularly during the recent century, the occurrences of dust explosion have become more frequent. Statistically, those dust explosion incidents all took place in indoor or confined space. The dust explosion at Formosa Fun Coast was the only one that took place outdoors.

Table 1: well-known dust explosion incidents in the history

Time	Incident
May 2, 1878	A grain dust explosion occurred at the Washburn flour mill in Minnesota, USA, causing 22 deaths, destroying the world’s largest flour mill while collapsing another 5 flour mills.
April 26, 1942	An explosion broke out at Benxihu Colliery in the Manchurian State under Japanese regime, killing 1549 Chinese miners, about 34% of the whole miner population. It was the worst mining accident in the history.

December 22, 1977	The grain exploded in a grain storage silo located along the Mississippi River, Louisiana, USA and the explosive wave propagated as far as 16 kilometers. The explosion caused 36 deaths and 9 injuries. During the overhaul, another dust explosion occurred.
January 29, 2003	A dust explosion of rubber powder broke out at the factory of the West Pharmaceutical Service located in Kinston, North Carolina, USA.
February 7, 2008	Combustible sugar powder caught fire and exploded at the Imperial Sugar Company, Port Wentworth, Georgia, USA, killing 14 people.
August 2, 2014	A dust explosion occurred at Zhong Rong Metal Company, Kunshan, Jiangsu Province, killing 146 people and injuring 114.

Explosion at Imperial Sugar Company

On February 7, 2008, a dust explosion of sugar powder accumulated and leaked from the equipment broke out at Imperial Sugar, destroying all the packaging factory facilities, killing 14 people and injuring many. Causes of the explosion were accumulation of sugar particulate matter and powder leaked in the working environment, lack of effective monitoring system for dust and abnormalities in the environment, and lack of consideration among workers and operating procedures in terms of dust risks. A tiny fire started a chain reaction and thereby caused a devastating explosion.

Dust explosion at a metal company in Kunshan, China

On August 2, 2014, a dust explosion occurred in the car wheel hub polishing section at Zhong Rong Metal Company, Kunshan, Jiangsu Province, China, killing 146 people and injuring 114. The reason why the explosion took place was lack of effective operation control over density of metal dust, improper installment of electric equipment that didn’t comply with anti-explosion requirements, and mistakes made in safety management of personnel, items, and materials.

Discussion 1. Why did dust explode in open space?

The activity site was at the bottom of a drained swimming pool. The main “dance floor” set up for the event was 2 meters lower than the ground level. The stage and the extended platforms on both sides created a U-shaped semi-confined space with a huge basin, i.e. the central dance floor, in the center. During the event, the organizer constantly sprayed large amounts of colored powder to the center from the front of the stage as well as from the extended platforms while the participants also sprayed colored powder themselves. Due to the fact that the dance floor was a sink-in area, the atmosphere was filled with a high concentration of colored powder dust. The thick dust cloud whipped from the ground was ignited by a heat source and a dust explosion broke out. As a thick layer of powder dust covered the dance floor during the event, more dust was aroused by participants' movement. After the dust explosion, people were panicked and the disturbed crowd tried to escape from the scene. Therefore, airflow near the floor rapidly changed, causing powder dust to rise and create more flames within a short amount of time.

Discussion 2. Why were there so many severe injuries?

The front of the stage and the extended platforms were levitated, so people in the dance floor area could only evacuate through the rear exit/entrance. During the event, the dance floor was packed with participants, who failed to react to emergency situations quickly under influence of loud music, dancing, and alcohol. When the first dust explosion occurred, most participants thought it was a special effect of the program and didn't back up and evacuate. When more dust explosions caused by more powder dust coming from the spray guns followed, people started to evacuate. As a lot of people got disturbed and ran for their lives, a large amount of the powder dust on the floor was ignited and inflicted injuries on those in the central dance floor area. Even though the powder dust burned for merely a short period of time, heat radiated from the combustion caused large areas of burns on a lot of people's skins. As most participants were in their swimwear, large areas of skin were directly exposed to the flames without any insulation or protection. That was the reason why the incident caused such severe injuries.

Discussion 3: What was the cause of dust explosion at Formosa Fun Coast?

After the dust explosion at Formosa Fun Coast, the police and the fire department investigated the cause and conducted experiments respectively with cigarette butts, lighters, and lighting equipment collected on the scene (See Table 2). The findings of the experiments revealed that, based on three key factors that could play in dust explosion, inclusive of triggers such as the explosive mixture of combustible dust, sufficient air, oxidizer, fire point and static electricity, forensic agencies deduced that 4 factors might contribute to the dust explosion: burning cigarettes, open flames (lighters), static electricity, and light equipment.

From data analysis of previous studies literature review and forensic analysis, "the threshold for a dust explosion is usually 370 degrees centigrade." As the temperature of a burning cigarette, which was at merely 270 degrees, didn't reach the threshold for a dust explosion. Flames from this source were unlikely to be the cause.

In the experiments, it was assumed that the vibration caused by the sound waves from the base speakers could release a large amount of static electricity that could result in rapid combustion and incur dust explosion. However, static electricity is produced in a relatively dry environment. As Formosa Fun Coast was by the sea and humidity was reportedly high according to weather data. At the time of the fire, 7 to 9 pm, the relative humidity was around 61-67% or more, so the minimal energy release threshold for ignition and explosion was not reached. Therefore, static electricity was unlikely the cause of the incident.

Additionally, the police and the fire department repeatedly examined the video and images captured at the dust explosion and failed to identify anyone using lighters on the scene to cause the explosion, nor did they find any evidence to prove that open flames were the cause of ignition. Eventually, open flames were excluded as a contributing factor.

As the fire originated from the front of the west side of the stage, beam light equipment with heat-resistant, high ripple current ultrahigh pressure MSD light bulbs for large nighttime events was found installed at this location. After testing, it was found that the light bulbs of the light equipment could reach over 1000 degrees centigrade. The surface temperature of the light equipment reached 200 to 300 degrees in mere minutes and could reach as high as 400 degrees centigrade, hot enough to cause a dust explosion.

After repeated experiments, testing and deduction, the cigarettes, static electricity, and open flames were found unlikely to be the cause of the incident. As all of its conditions matched those for a dust explosion, the extreme heat of the light equipment at the west side of the stage, which later incurred a chain reaction for further dust explosions, was eventually identified as the cause of the tragedy.

Laboratory personnel found that, other than the light equipment, people at the scene were panicked and tried to run for their lives after the first dust explosion. The air flow was stirred rapidly and a high concentration of powder was prompted into reaction, causing extensive combustion that resembled a gas explosion. This incident turned out to be the dust explosion that caused the most deaths and injuries in Taiwan.

Discussion 4: On-site response and emergency rescue operations review

According to EMS Act in Taiwan, fire fighters' responsibilities include general EMS, conducting medical measures and then sending the patients to medical facilities. When there are over 15 people injured during a single event, it will be considered a multiple casualty incident (MCI). With the Ministry of Health and Welfare being the leading agency, the district hospitals responsible for EMS shall be notified and medical personnel shall be sent to the site to conduct rescue efforts and establish on-site medical care station. Doctors or medical personnel shall perform on-site triage, notify nearby hospital responsible for EMS to prepare for the patients, and confirm that patients have been sent to hospitals. Fire fighters shall rapidly transport the patients to the hospital for treatment.

As there were almost 500 people injured in this incident, it was a MCI and should have been responded as a MCI so that further medical care could be performed. In Taiwan, several MCI trainings are conducted annually with fire departments, medical facilities and police departments. The trainings were completed in accordance with the designated scenarios. However, during this incident, even though the fire fighters got to the site, the district medical facilities were unable to arrive at the scene to establish on-site medical care stations for performing triage and coordinating transportation of patients to the hospitals. The EMS at the site were disorganized. Some hospitals had a large number of patients within a short period of time, while a few hospitals refused to take patients. Some family members of the injured even hired ambulances themselves and sent the patients to hospitals in 2-4 hours driving distance, thereby delaying critical medical time.

In addition, due to the fact that the incident broke out unexpectedly and caused mass injuries, the traffic in the surrounding was chaotic with hundreds of EMS and rescue vehicles, preventing the EMS vehicles from immediately providing services to the patients.

8. CONCLUSION

Aftermath of the incident

(1) “One patient, one case” long term medical care

On July 14, 2015, the Taiwanese government established 27 Proprietary Managing Centers for Burnt Patients and initiated a management mechanism called “One case per patient. Long-term companionship.”, which integrates resources and provides thorough care to the injured. As of today, all of the injured have been discharged from the hospitals. (The last one was discharged on June 3, 2016). The death rate among the 499 patients with burns that involved 40% of their body in average was merely 3%, a record breaking figure.

The Ministry of the Health and Welfare has integrated resources from the Ministry of Education, the Ministry of Labor, and New Taipei City Government and established an inter-communication platform for problem solving. Cross-departmental assistance is provided to the patients in terms of recovery, schooling, working, welfare services, care and comfort as well as legal assistance so as to support the patients and their families and help them get their life back as soon as possible.

(2) Due to the incident, public events that involve use of powder and dust have been banned, and countries such as Thailand, Japan, Malaysia, China, and Hong Kong decided to

discontinue similar activities that involved colored powder.

(3) Review of application, approval, and emergency response management of large events. Organizers of any large-scaled activities shall file an application, obtain an approval and establish an emergency response plan in advance. The duration, number of participants, space and type of large events have been defined and an approval application scheme has been established so as to review and control safety measures and emergency response management of the event.

(4) Reinforcing management of the industry of tourism and entertainment and its business premises. Management and inspection of the industry of tourism and entertainment and its business premises has been reinforced. Amendments of current laws in terms of raising liability insurance coverage and fine for violation are being discussed.

The dust explosion incident at Formosa Fun Coast, Taiwan, was a rare and possibly the only dust explosion incident that occurred to outdoor events in open space, injuring hundreds of people and creating substantial burden to the society. It was a traumatizing lesson to the general public and will serve as a bitter reminder and reference for organizers of similar events in the future.

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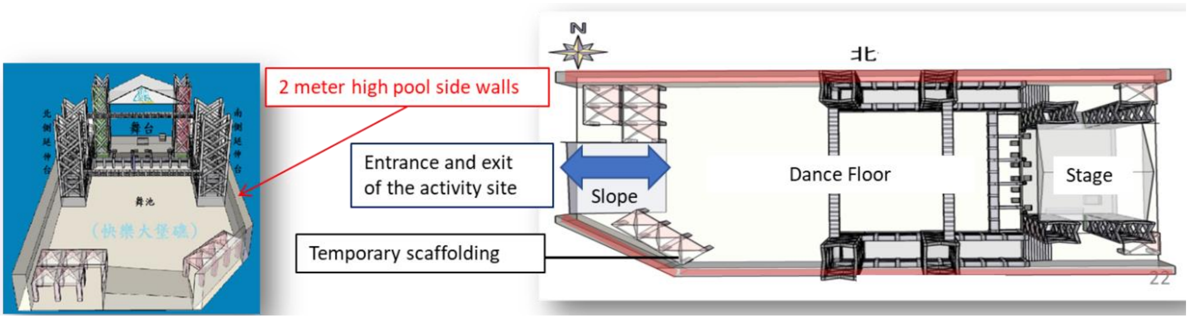
2. Wikipedia, “2015 年八仙樂園派對粉塵爆炸事故”
3. New Taipei City Government, “2016 八仙粉塵爆燃專刊”

Picture 1.

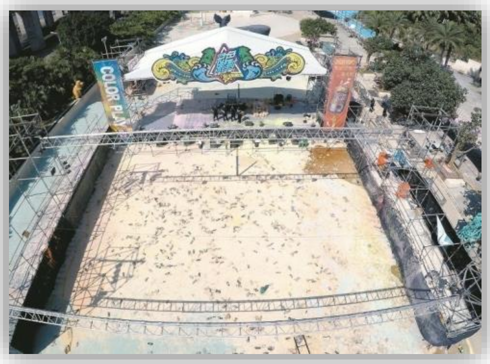
Formosa Fun Coast and incident location

Picture 2.

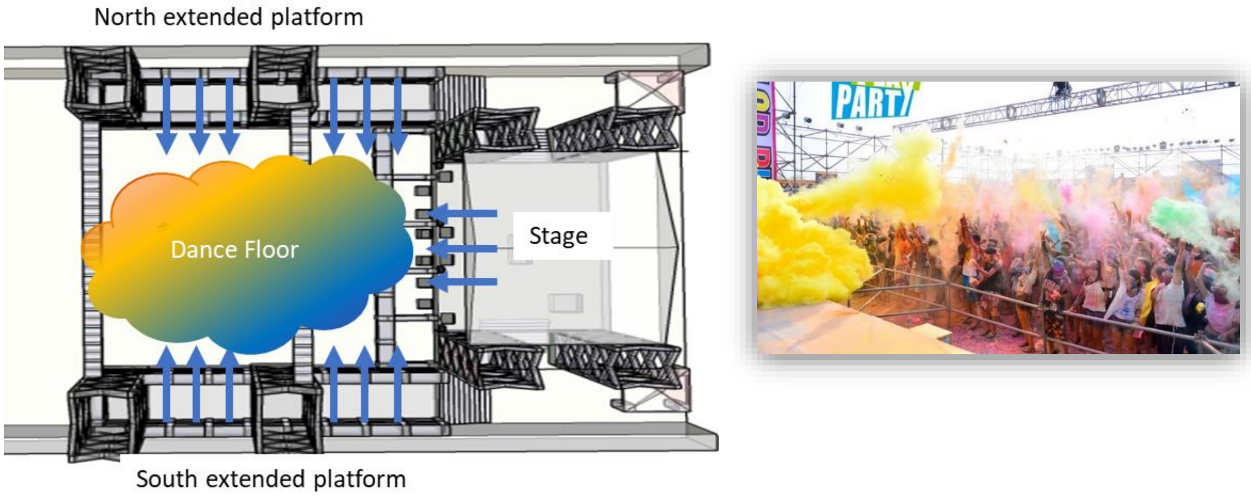
the swimming pool used as the venue



Picture 3. stage settings when the incident broke out



Picture 4. on-site aerial image



Picture 5. dust spray during The Color Play musical event

Table 2. Joint investigation conducted by prosecutors, police and fire departments

Agency	**Responsibilities**
Shilin District Prosecutors Office, R.O.C.	Coordinated and directed investigations
Criminal Investigation Bureau of the Ministry of the Interior	Measured on-site topography and collected evidence of fluorescence emulsion in the stage area.
National Fire Agency of the Ministry of the Interior	Assisted in locating fire point and origin, confirmed settings of stage lighting equipment, speakers and switches, dissembled them and conducted identification and combustion tests.
Department of Occupational Safety and Health of the Ministry of Labor	Provided advice regarding static electricity incurred fire, surface temperature of lighting equipment, and traces of combustion evenly radiated from center of lighting equipment.
Police Department of New Taipei City	Collected cigarette butts, cartons, lighters and assisted in retrieving images from devices such as on-site cell phones and Go Pro cameras and conducting frame by frame analysis
Fire Department of New Taipei City	Confirmed and identified all possible fire origins, conducted fire point & corn starch combustion tests, and further clarified contents in the images