出國報告（出國類別：考察）

考察實大規模建築複合災害驗證技術及實驗設施

服務機關：內政部建築研究所
姓名職稱：王天志 約聘研究員
派赴國家：美國
出國期間：105 年 11 月 13 日至 19 日
報告日期：106 年 2 月 10 日

摘　　要

關鍵詞：防火安全、複合災害

近來建築結構防火安全研究跨入複合式（火災與震災）災害之領域，本所科技計畫「鋼構建築複合性災害作用下耐火科技研發計畫」（104~107 年度）也於臺南防火實驗中心建置實尺寸鋼構造建置，逐年進行實尺寸鋼構造複合(及多重性)災害作用實驗。而美國國家標準技術研究所(NIST)工程實驗室防火研究部門轄下的防火研究實驗室（NFRL）參考世界各國之研究設備，首創將結構框架安置於耐震工程之反力牆及強力地板空間，配合加載系統給予側向位移，並於建築結構內施予一定之火災規模，探討火災及震災複合式災害之影響等；該項設施及研究內容與本所「鋼構複合性災害作用下耐火科技研發計畫」研究領域相關，可為我國後續科技計畫規劃與執行參考。

目　　錄

第一章　目的

第一節　緣起

近來建築結構防火安全研究跨入複合式（火災與震災）災害之領域，而美國國家標準技術研究所(NIST)工程實驗室防火研究部門轄下的防火研究實驗室（NFRL）參考世界各國之研究設備，首創將結構框架安置於耐震工程之反力牆及強力地板空間，配合加載系統給予側向位移，並於建築結構內施予一定之火災規模，探討火災及震災複合式災害之影響等；該項設施及研究內容與本所近期「鋼構複合性災害作用下耐火科技研發計畫」研究領域相關，可為我國後續科技計畫規劃與執行參考。

同時，NIST工程實驗室下另有工程防火安全、滅火技術、阻燃及材料與結構系統等研究部門，其研究內容與各項實驗設施與本所「建築防火安全工程創新科技及應用研發計畫」以及防火實驗中心實驗運作相關，本計畫藉由安排實地參訪及相互討論交流，蒐集其建築防火研究及實驗相關研究成果，可供本所對於建築防火工程技術、消防煙控科學的研究領域有所拓展與啟發，尤其可做為本所相關科技計畫內容與研究課題之研擬參考，而對於我國於進行建築防火、煙控避難、結構耐火性能及複合性災害下結構防火性能的研發，將有相當之提升效益。

第二節　與業務關係及預估效益

一、與業務關係

本所建築防火安全工程創新科技及應用研發計畫－防火安全設計及工程技術精進研發計畫與鋼構建築複合性災害作用下耐火科技研發計畫

二、預估效益

1. 蒐集建築工程防火安全、火災偵測與消防滅火技術、材料阻/耐燃性質、材料與結構系統、次系統與整體建築、建築用太陽光電系統，以及複合性災害下結構性能等之研究成果，可做為國內防火材料執行檢測以及避難煙控性能式應用之參考。

2. 瞭解 國際間對於防火材料應用、大型構造防火實驗以及複合性災害研究內容，可供本所 規劃「建築防火安全工程創新科技及應用研發計畫」與「鋼構複合性災害作用下耐火科技研發計畫」內容 之參考。同時 藉由實地參訪NIST，可增加雙方研究人員之經驗交換，有助參與國際間之交流 。

第二章　過程

本章說明本次奉派赴美國考察成員、時間、行程及內容。

第一節　考察成員、時間及行程

一、考察成員名單

姓名	職稱	專長
王天志	約聘研究員	建築防火、結構分析及設計

二、出國期間

中華民國 105 年 11 月 13 日至 11 月 19 日，共計 7 日。

三、行程

本次考察行程如下所示：

日　期	活　動　內　容	備註
11 月 13、14 日(日、一)	從台灣前往美國國家標準技術研究所(NIST)	路程
11 月 15 日(二)	參訪 NIST 工程實驗室防火研究部門，了解近期進行之研究計畫，拜訪滅火技術研究群（fire fighting technology group）負責人 Dr. Jiann C. Yang，參觀滅火技術研究群及意見交流。	

11 月 16 日(三)	參觀防火研究實驗室（National fire research laboratory, NFRL）的實大規模建築複合災害實驗設施，了解研究計畫內容、相關設施規劃配合、建置、操作訓練、實際運作與人力配置等，同時就本所「鋼構複合性災害作用下耐火科技研發計畫」與之進行意見交流及資料收集。	
11 月 17 日(四)	參訪工程防火安全及材料阻燃等研究部門，並拜訪材料與結構系統研究群負責人 Dr. Long T. Phan 及參觀該研究群實驗設施及意見交流。	
11 月 18、19 日(五、六)	從美國 NIST 返回台灣	路程

第二節　考察內容

一、美國國家標準技術研究所(National Institute of Standards and Technology, NIST)簡介

美國國家標準技術研究所，前身為國家標準局（NBS，1901 年~1988 年），該研究所的主要任務為：促進美國的創新和產業競爭力，推進度量衡學、標準、技術以提高經濟安全並改善國民的生活質量。

NIST 轄下主要實驗室及其項下分組等，如下列組織圖所示。

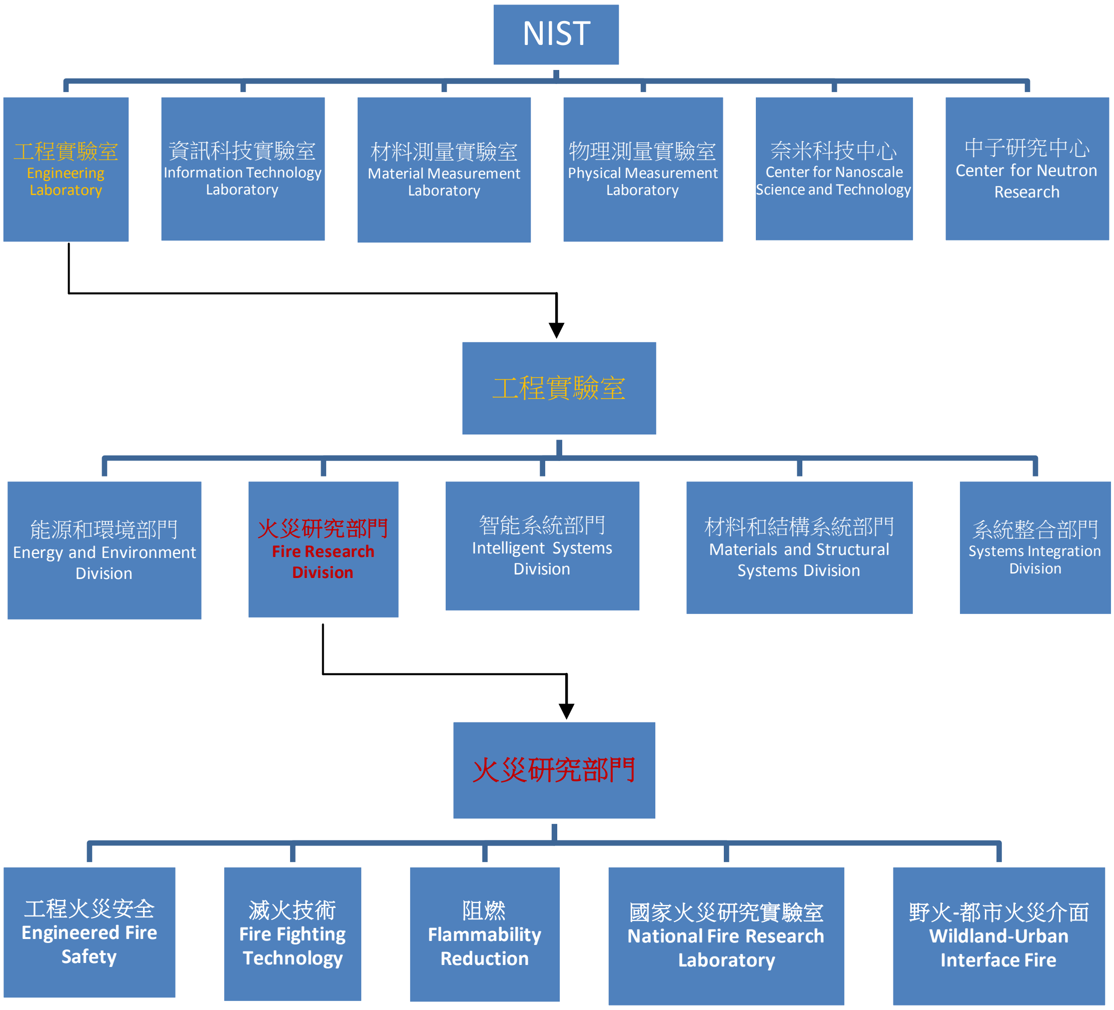


圖 1 NIST 實驗室組織圖

由上述實驗室組織圖可知，其工程實驗室的研究範圍與本所業務職掌，如環境控制、安全防災、智慧建築及工程材料等相當類似，本次考察其研究內容、設施與方向，可增進我國與國際研究機構互相交流研究成果及經驗。

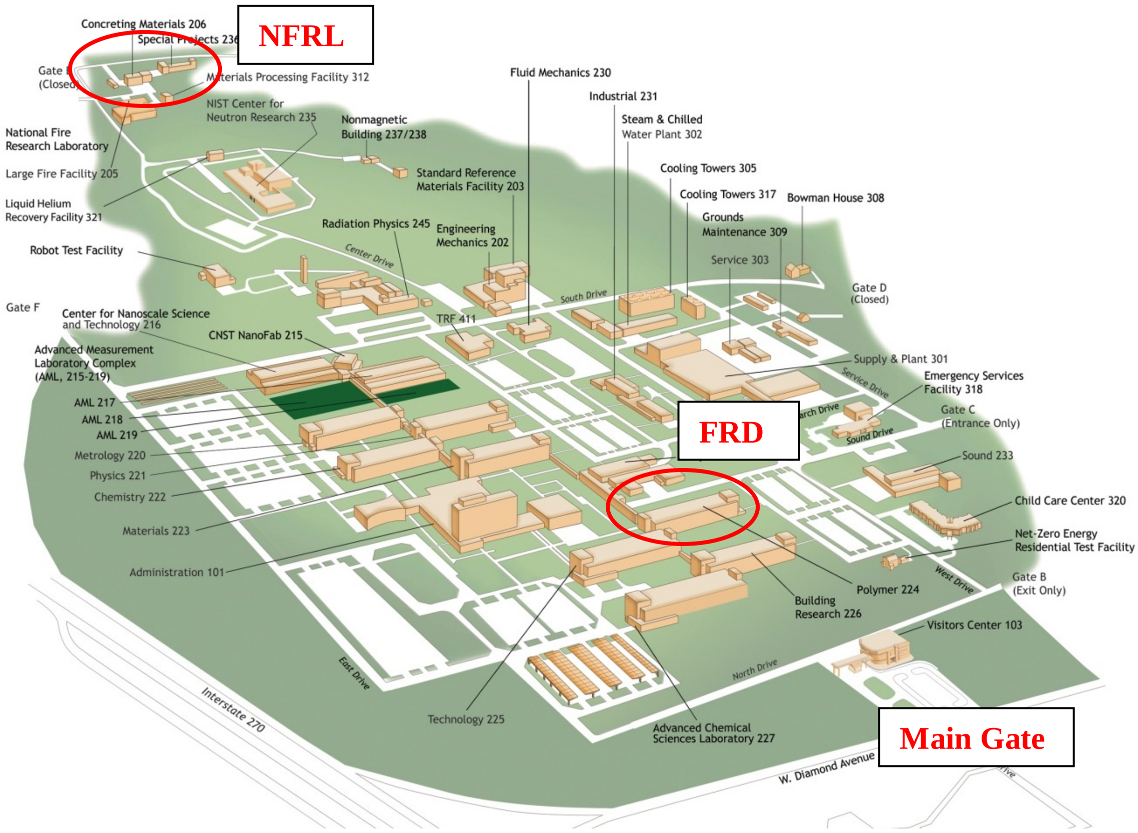


圖 2 NIST 園區圖

二、火災研究部門（工程火災安全、滅火技術、智能滅火技術）考察參訪內容：

本次主要考察火災研究部門，因 NIST 為國家級研究單位，須先取得同意方能參訪，經聯繫該部門副主管 Dr. Jiang C. Yang，於行前取得參訪同意函（附錄 1）後依預定行程前往拜訪。11 月 15 日早上抵達後，首先拜會火災研究部門主管 Mr. Nelson P. Bryner，隨後由 Dr. Jiang C. Yang 帶領導覽解說該部門主要研究內容、近期執行的相關研究及實驗設施。

（一）主要研究內容及近期執行的相關研究

在工程火災安全部分（Engineered Fire Safety Group），研究範圍包括材料、模擬、量測、調查鑑定以及標準化，主要發展具量化精度、先進的驗證模型，同時整合知識、工具和模型，以評估影響建築性能的各種因子，包括材料的著火性、火焰的成長和擴散、火災偵測和抑制、燃燒產物氣體毒性以及避難逃生出口等。目前進行的主要計畫包括家用偵煙器測試、低易燃性香菸測試、性能式設計火災模擬、提升住戶防火安全和避難逃生及交通運輸載具的防火消防安全等。

在美國，住宅火災的件數、傷亡及財損，仍佔火災事件的多數，因此如何運用創新或更有效的防火安全產品、修訂相關法規與標準和提升防火安全公共意識，為主要推動任務。

在滅火技術方面（Fire Fighting Technology Group），Dr. Jiang C. Yang 同時亦為此部門的負責人，研究內容包括發展和運用新科技、火場偵測和標準以及預防和控制火場措施，以改善消防滅火操作、設備、提升消防滅火安全以及對災害的反應，他說明目前執行的計畫包括加強消防策略的有效性、消防設備器具的高溫性能及發展智能滅火技術。

基於多數消防隊人員的滅火策略及技術，通常會有過多依循該消防隊領導階層的經驗，而忽略消防科學的基礎，有需要透過以往傷亡案例的調查分析及加強此項目的教育訓練，以提升消防策略的有效性。

另外，消防員搶救災所用設備器具除為滅火工具外，亦為消防員的安全保命工具，因此所用設備器具及穿戴用具於火場的高溫性能至關重要，目前主要針對個人揹負式呼吸系統、移動式電子通訊設備及消防衣的高溫性能進

行測試研究，用以改善相關設備製造標準。

而在智能滅火技術，藉由網路資通的革新，搜集整體性火場資訊、中央處理訊息及派送整體性指管訊息與個別救災人員的任務分配及適用設備等資訊,另外也須更新消防單位的資通訊,以與火災現場有總體性的任務掌握。此項計畫目標包括發展所需的工具和標準、智慧建築、良好有效的偵測感應技術以及智能消防單位的器材和設備，期望藉由統合水平及垂直訊息與各階層的智能管控，降低火災對建築與社會的綜合損失。

在阻燃性能技術方面（Flammability Reduction Group），利用科學研究降低家具與建築材料著火機率、抑制火災成長和擴散，以及減少對環境的衝擊影響。這個專案將推動住宅消防安全產品商品化，藉由製造低可燃性家具產品、訂定產品法規和測試標準等來達成目標。研究內容包括降低產品可燃性技術、軟墊家具類的可燃性測試、降低奈米工程發泡材的引燃和火焰擴散及發展氣相阻燃技術等。

（二）主要實驗設施

此類小型材料或器具實驗室，均多與研究人員研究室相鄰接，以方便實驗操作進行，同時因與研究室相接，實驗室均有完善的安全防護措施，如排氣措施、安全防護用具、消防滅火設備及緊急沖洗裝備等。部分實驗設施因進行實驗中以及負責人不在等因素外，其餘實驗室 Dr. Jiang C. Yang 皆予以帶領解說，主要實驗設施說明如以下圖示。

圖 3 軟式泡棉座椅家具阻燃性測試裝置

圖 4 地坪材料延燒性測試裝置

圖 5 壁裝材料延燒性測試裝置

圖 6 NIST 自製消防人員設備耐高溫性測試裝置

圖 7 圓錐量熱儀熱釋放率測試裝置

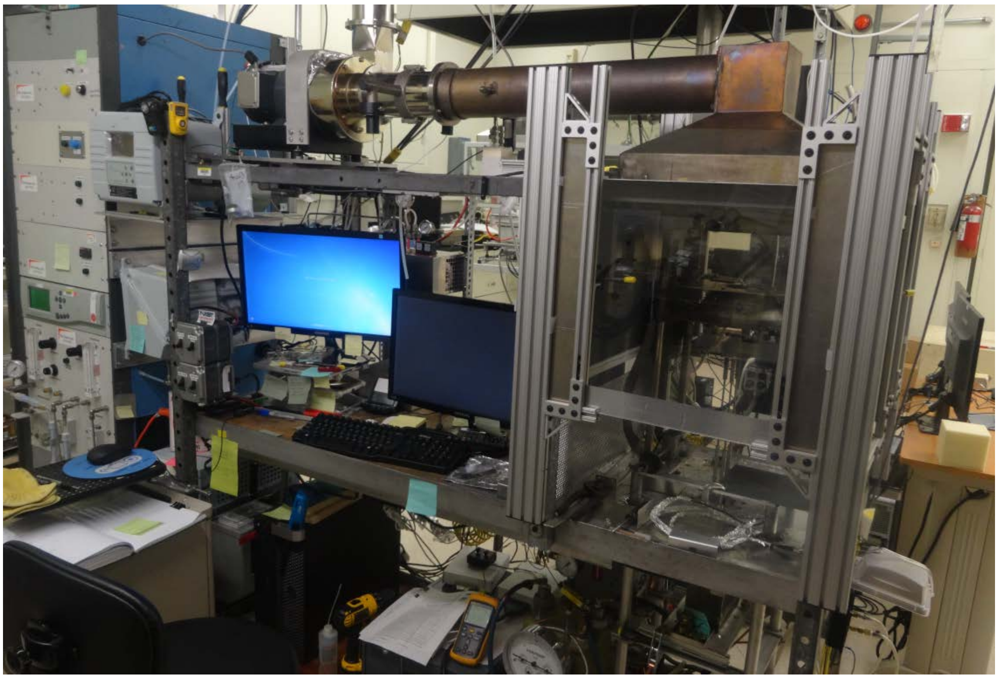
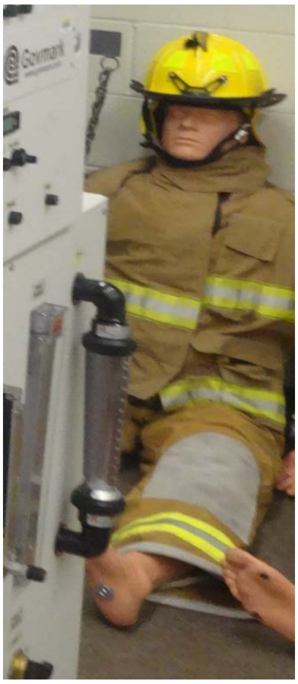


圖 8 NIST 自製圓錐量熱儀熱釋放率測試裝置

面罩

頭盔

通訊設備



消防衣

圖 9 消防員裝備用具耐高溫測試

三、火災研究部門（國家火災研究實驗室）考察參訪內容：

國家火災研究實驗室（National Fire Research Laboratory, NFRL）成立於1973年，原主要實驗設施為1、3、10 MW中大型量熱裝置，進行燃燒熱釋放率、火場模擬、燃燒模型驗證等實驗。而自從911事件後，美國政府單位隨即由NIST進行建築結構火害中及火害後行為研究，考量與世界上其他既有類型實驗設施區隔，因此於2015年擴建實驗場地並構建強力地板及反力牆，可進行實尺寸、實場火災試驗，可更精確了解火災-結構之交互作用。該設備為將結構體構築於強力地板上，加載系統安裝於強力地板及反力牆上，另於結構體內進行實際燃燒行為或可控制之燃燒條件，可在加載下，同時觀察量測燃燒從起火、成長、旺盛期直至衰退期之結構行為。

另外，該實驗室原有1、3、10 MW量熱裝置，新增20 MW量熱裝置，以量測更大規模的物體熱釋放率。

NFRL參訪，首先仍先拜會實驗室負責人Dr. Matthew F. Bundy，隨後由Dr. Jiang C. Yang及其他實驗室研究人員陪同導覽解說，實驗室相關研究領域包括火災後調查、基於物理模型的火場驗證、探討相關技術資訊以修訂防火和建築規範以及進行實尺寸結構與火災行為量測。目前進行的專案則包括結構防火性能式設計、NFRL實驗室火場標準化量測與技術開發以及含樓版系統結構耐火性能研究等。

（一）新增大型實驗室內設備規格如下：

設備：

- 天然氣燃料供應系統（可提供20 MW熱值）

- 20 MW 量熱裝置，集氣罩尺寸 13.7 m x 15.2 m，離地高 12.5 m，最大集氣流率為 5100 m^3/min
- 即時資料和影像擷取管理系統
- 2 部 20 噸橋式吊車
- 油壓供應系統（340 lpm）
- 拉壓雙向油壓致動器
  - 8 支拉力 240 kN/壓力 365 kN
  - 2 支拉力 445 kN/壓力 650 kN
  - 2 支拉力 956 kN/壓力 1470 kN
  - 作動行程為 762 mm

反力牆：

- 9.1 m 高 x 18.3 m 寬 x 1.2 m 厚
- 420 個錨定點（0.61 m x 0.61 m 網格狀分布）
- 於牆最高處可抗水平力 146 kN/m

強力地板：

- 18.3 m 寬 x 27.4 m 長 x 1.07 m 厚
- 地下室高度 2.7 m
- 1218 個錨定點（0.61 m x 0.61 m 網格狀分布）
- 每個錨定點可抗拉力 445 kN
- 每個錨定點可抗剪力 222 kN
- 每個錨定點可抗彎矩 136 kN-m

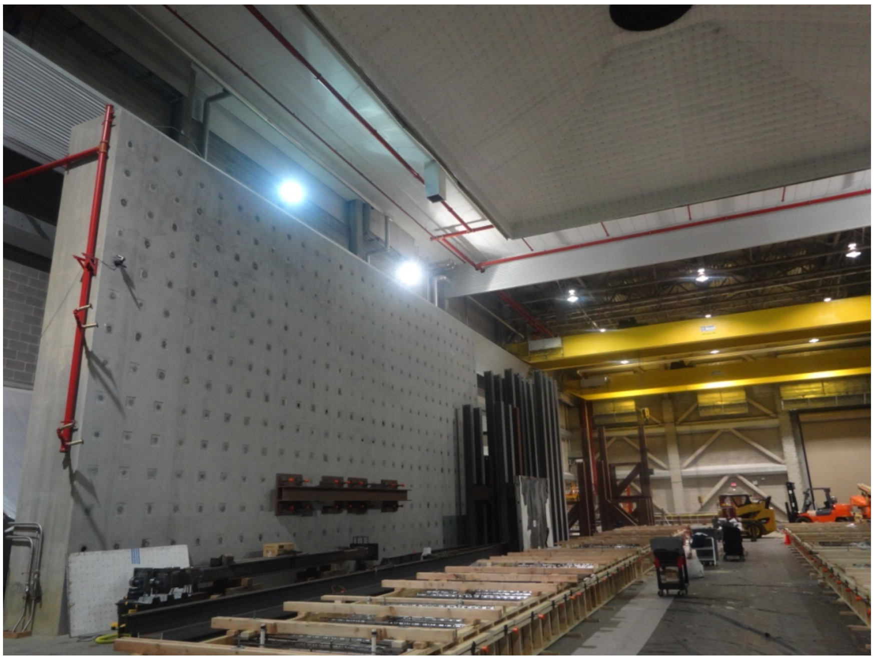


圖 10 NFRL 新建實驗室

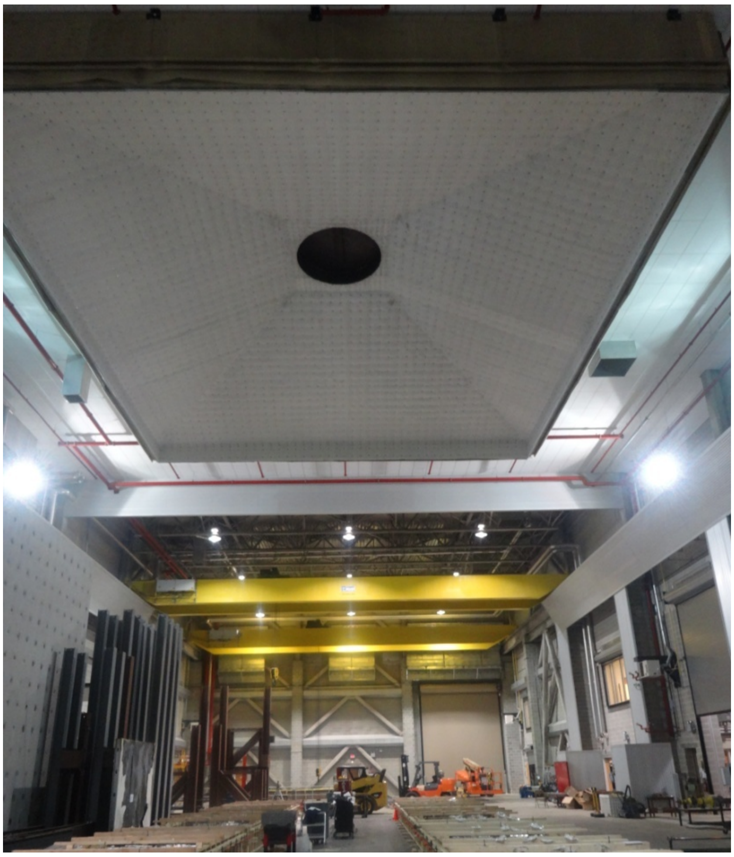


圖 11 20 MW 量熱裝置（安裝於反力牆前，可量測實尺寸建築火災時之熱釋放）

圖 12 拉壓雙向油壓制動器

圖 13 試體準備區

圖 14 安裝於強力地板地下室的油壓致動器

圖 15 強力地板地下室的消防設備

圖 16 實驗室的消防設備

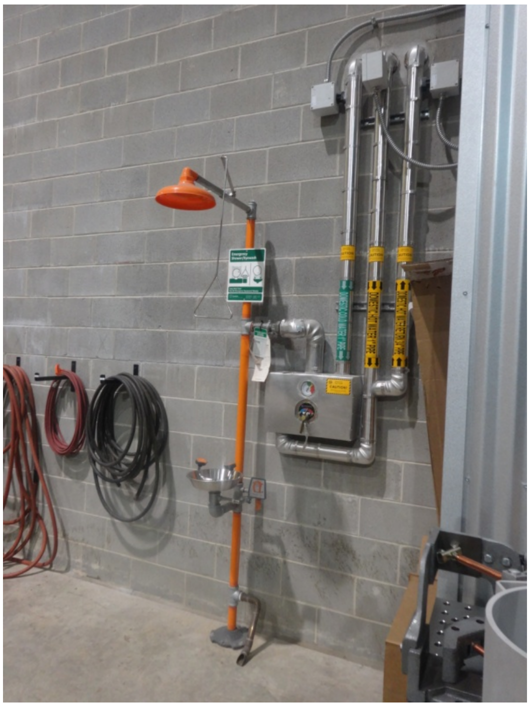


圖 17 實驗室的緊急沖洗設備

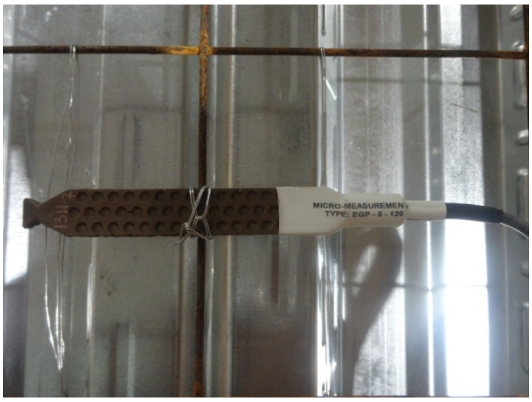


圖 18 混凝土應變計

圖 19 試體溫度量測用熱電偶

（二）結構防火性能式設計研究專案：

此專案目的為發展和發布性能式設計工具、方法和指引，並制定設計和評估結構防火性能標準。整個工作包括：

（1）建立實尺寸結構、構造連結組件及次系統構造於真實火災和荷重下，大規模的實驗紀錄資料庫，並據以進行分析模型的驗證。

（2）驗證基於火災動力學和熱學-結構行為之結構耐火性能模擬模型和工具之正確性。

（3）驗證用於預測結構溫度場和火災影響模型之風險性和可靠度。

（4）訂定運用性能式設計於結構系統火災影響性評估之設計指引。

基於前述工作項目，為實現性能式設計的本意，及考量實際火場變化，有必要進行結構承受實際火災之行為研究，而非以往規格式設計，採用單一構件於標準試驗爐之試驗結果，以反應針對不同火災時之安全性、成本及降低環保衝擊。

針對真實火災對結構之影響，NIST 近來進行鋼結構構件承受局部火災時之耐火行為研究，以往標準試驗構件係全長、4 面承受均勻之加熱，構件斷面無較大的溫度梯度產生，但在某些實際火場，如開闊的建築構造，其火災成長可能不會產生閃燃，而只產生局部加熱行為，此時構件耐火失效之挫曲行為與標準試驗有所不同，有可能造成構件提前失效，而此結果視局部加熱係為單面靠近構件或局部環繞構件而有相反的結果。

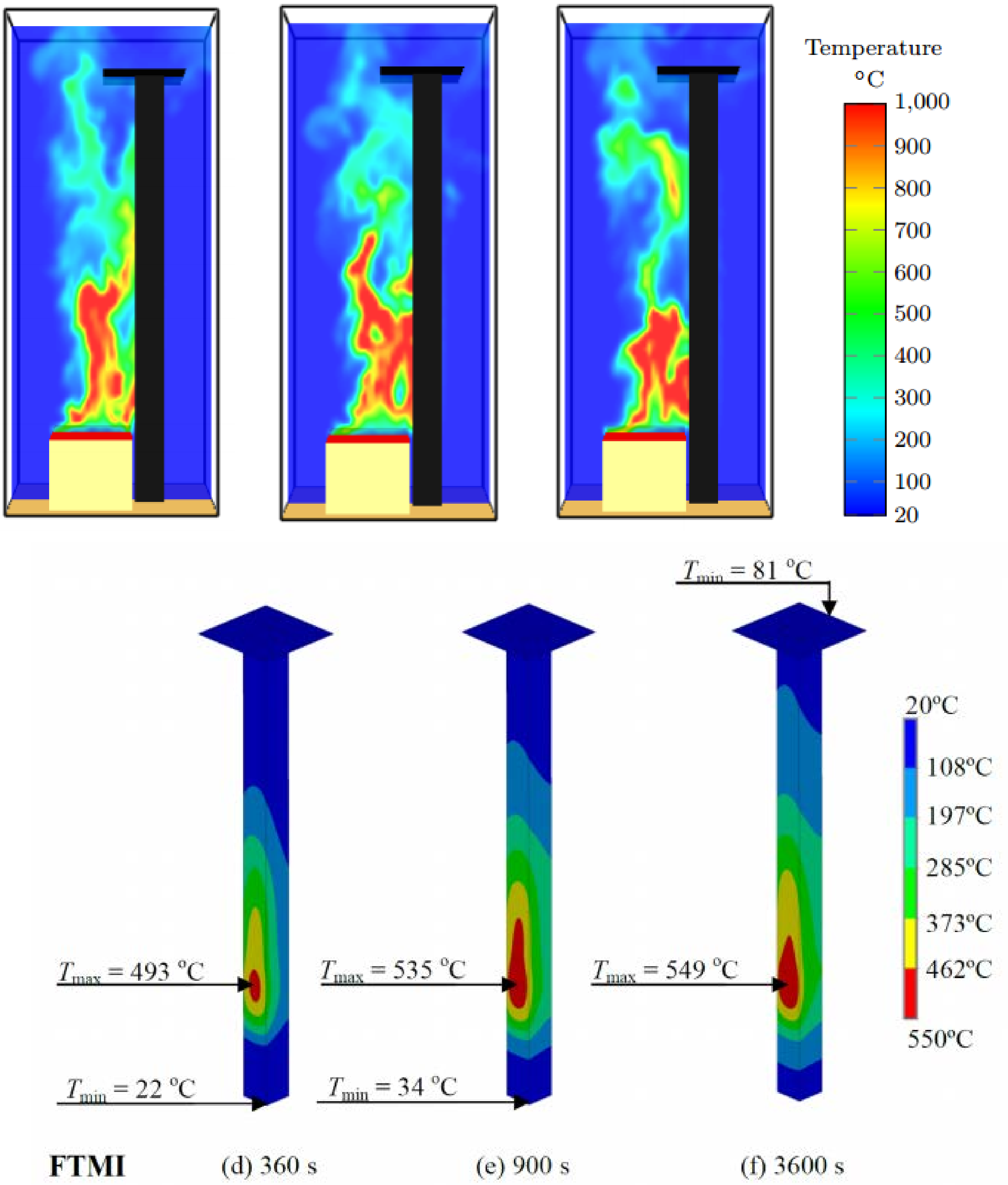


圖 20 受局部加熱，火場模擬與柱構件數值模擬（Chao Zhang 等，2016）

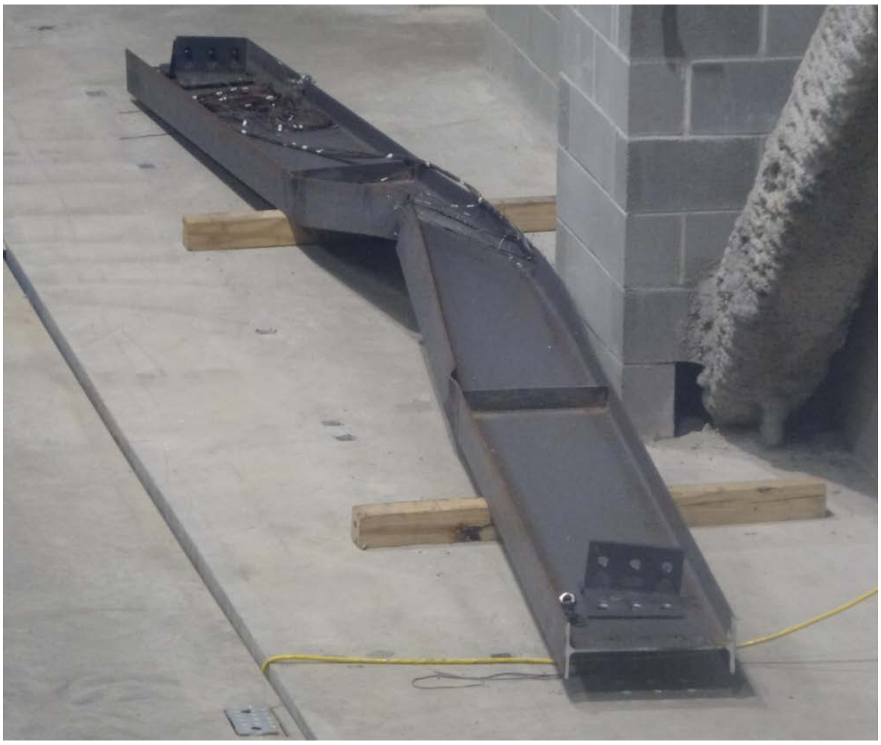


圖 21 受局部加熱後，梁構件試體破壞情形

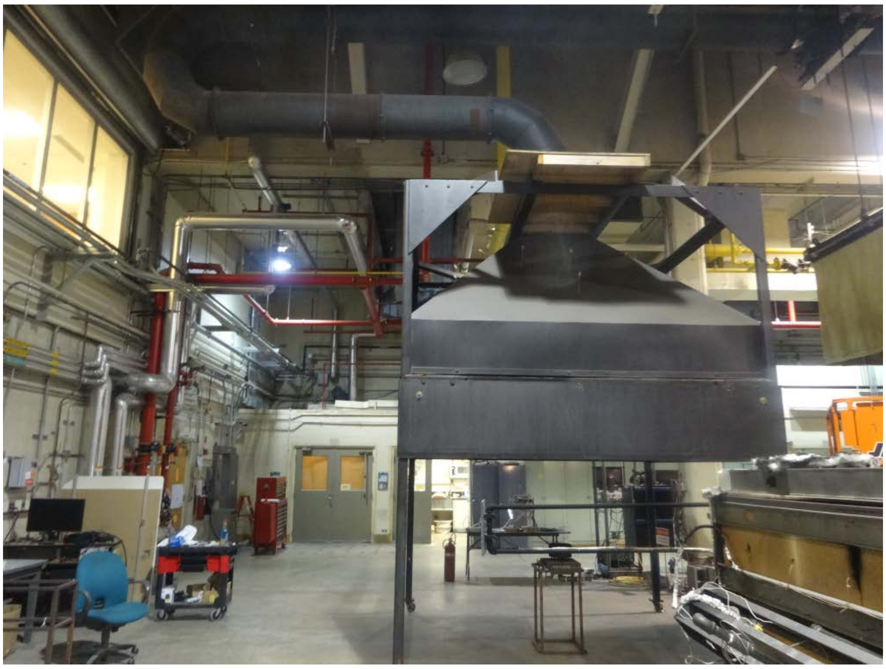


圖 22 1MW 量熱裝置

圖 23 3MW 量熱裝置

圖 24 木構造實驗屋與上方的 10MW 量熱裝置

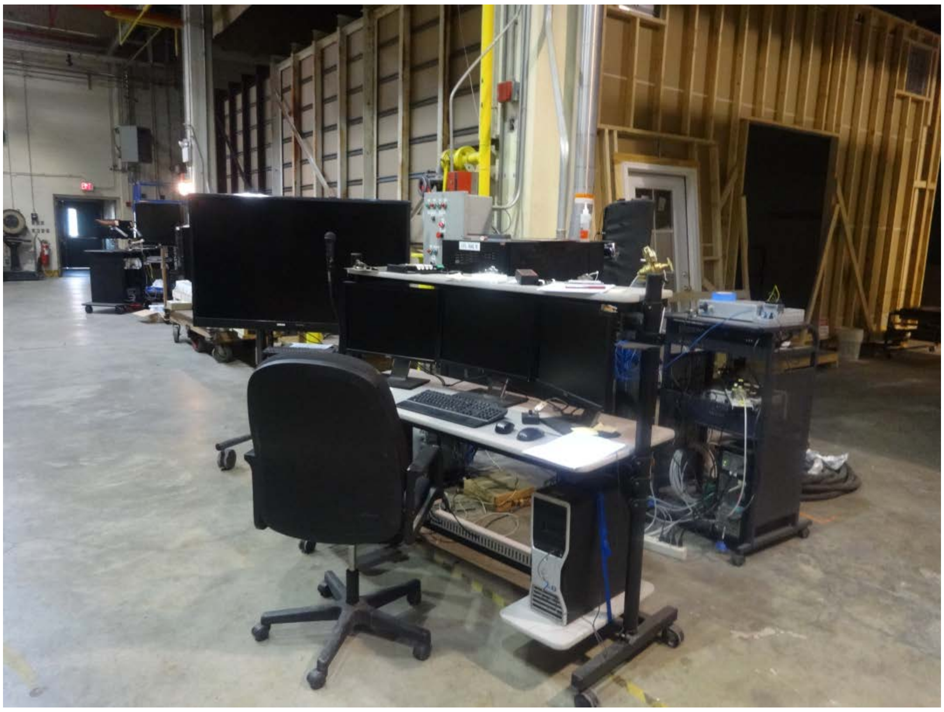


圖 25 大型化實驗監控螢幕，供不同站位人員監看觀測

圖 26 不同形式火源燃燒器

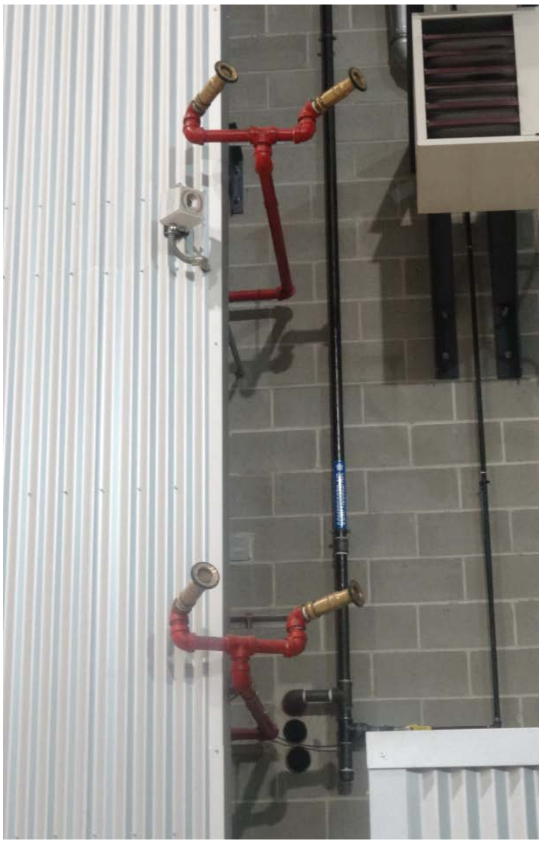


圖 27 實驗室週遭消防噴嘴　　　　圖 28 緊急沖洗裝置

圖 29 911 事件，世貿大樓鋼骨殘骸

（三）NFRL 實驗室火場標準化量測與技術開發專案

本專案主要任務目標為開發、改善和維護必要之功能，以安全地進行具足夠量化精度的大型火災行為和結構-火災反應行為等之量測。引進開發測試新型的量測設備，以盡可能的提供研究者進行實尺寸結構受載重下於火災高溫之反應行為的觀察。此量測設備系統，必須可適用於從小結構系統到實尺寸結構（2 層樓高、2 x 3 跨建築），同時安裝在 20 MW 量熱裝置下方進行加熱實驗之觀察。此系統須能精確量化結構在火災環境中的影響參數，量測儀具須能承受惡劣環境及考慮高溫對量測數值的影響。有關位移量測，目前嘗試中的研究包括機械式（點位移）、雷射（點或線位移）和成像法（場位移）；對於應變量測，主要有攝影測量和光纖應變計等。

McAllister 等人（2012）曾提出使用於高溫下量測的設備要求，包括可適用於火場溫度 20~1400 ℃、可使用 4 小時以上、量測目標（如柱構件）的溫度可達 750 ℃、在快速升降溫環境下具足夠的靈敏度以及可在有煙灰的環境中使用。

拉線式位移計為常見的位移量測設備，但在高溫下其金屬線會造成熱膨脹而使量測數值失真，NIST 嘗試利用計算熱膨脹補償來修正，或者同時利用非金屬纖維進行量測，以修正溫度的影響。

NIST 也嘗試利用藍光雷射來量測位移變形，藍光相較常見的紅光雷射於高溫下，有較不易受到熱輻射影響的優點。而評估系統的考慮原則包括需不受熱輻射影響、雷射光束不受熱氣影響以及光束不因煙灰顆粒影響而消減。

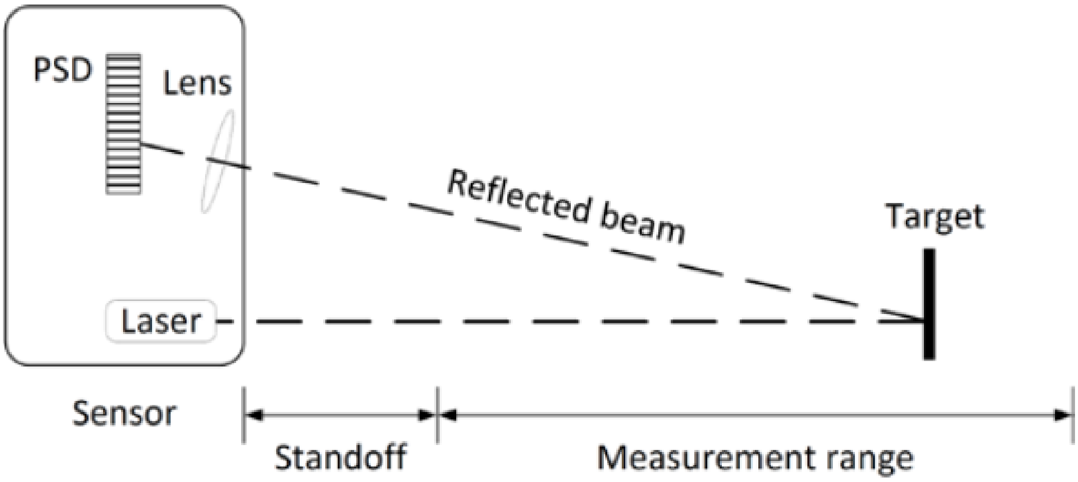


圖 30 雷射量測位移原理示意圖

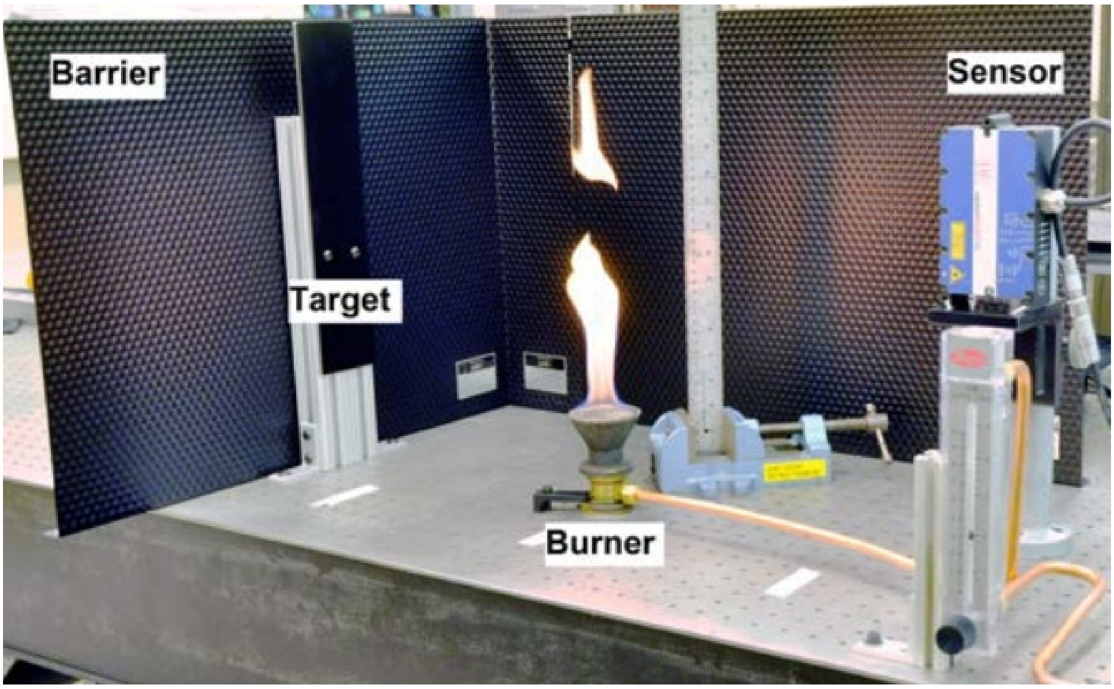


圖 31 雷射量測試驗裝置圖

光纖量測元件可在沿元件長度上，進行多點的壓力和溫度量測。光纖使用時必須固定到欲量測的物件上，其固定方式需考慮到高溫環境，為目前尚待進行研究的重點。

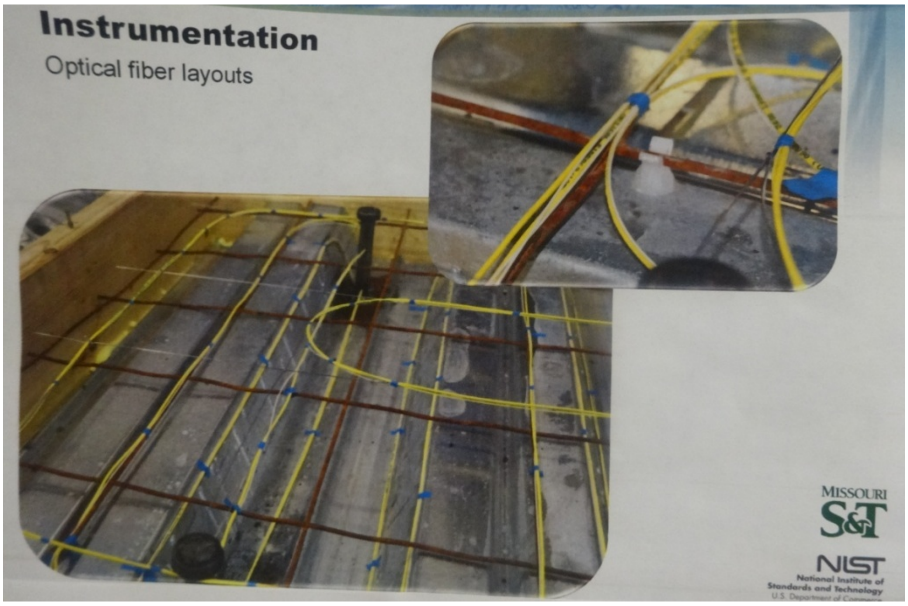


圖 32 光纖感測器佈設於版構件圖

圖 33 埋設有光纖感測器的版加熱試驗

（四）含樓版系統等複合結構耐火性能研究專案

911 事件後，調查報告指出複合樓板結構系統在特殊火場條件下，仍有許多性能漏洞存在。此專案主要執行實尺寸複合樓板多層鋼架結構系統在承載下進行實場火災實驗，以提供性能式設計執行實際火災行為分析所需之資料、驗證利用物理計算模型來預測火災性能以及評估量測實尺寸複合樓板多層鋼架結構系統結構變形的方法。

研究主要探討項目包括對稱框架的行為、樓板幾何形狀對版變形線的影響、梁版系統對剪力的傳遞、周遭結構對熱膨脹變形的束制以及整體結構在火場下的行為。

參訪 NFRL 過程，王天志研究員也同時與 NFRL 相關研究員以簡報（附錄 2）介紹本所防火實驗中心，並就各項試驗設備、功能、操作、實驗規劃、試體製作以及各式量測元件的性能等，雙方進行討論交流。

圖 34 含梁複合樓板試體製作

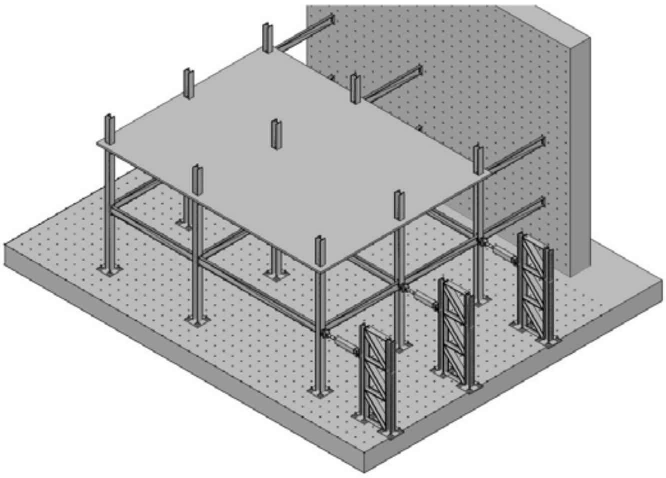


圖 35 結構框架安裝於反力牆及強力地板示意圖

圖36 牆系統受側向力實際火源加熱試驗

圖37 與NFRL研究人員經驗交流討論

四、材料和結構系統部門 （結構組）考察參訪內容：

本單位主要拜訪該組負責人Dr. Long T. Phan，並由他帶領解說，該組主要提供具可靠性及成本效益的複合災害性能預測工具，來減少建築和基礎建設受極端事件（風、火、地震、爆炸）的影響。主要任務有進行相關實驗和分析研究、制定指引（guidance）以應對各種災害情境的評估、執行災害調查分析和提供必要技術資訊以制定與建築和基礎建設相關的國家政策。

Dr. Long T. Phan近期負責執行一項運用不同材料的基礎建設受環境影響的耐久性試驗，該試驗為實尺寸試體，且全程至於可控制溫度、溼度的空間內，進行為期至少1年以上的耐久性測試，此項試驗所需的場地、長期性的環境控制以及多點資料蒐集紀錄，均是相當不容易進行的試驗要求。

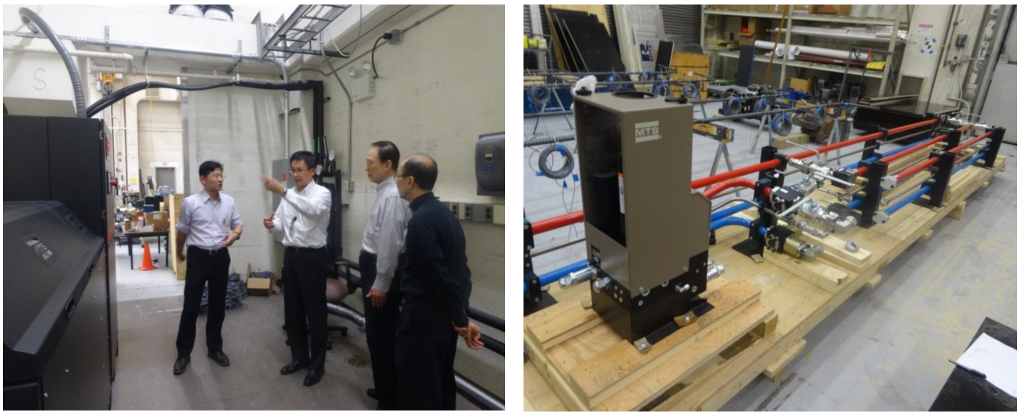


圖38 結構組所用油壓加載系統介紹

圖39 箍筋應變計施工介紹

圖40 梁試體製作

圖41 小型油壓加載系統

圖42 大型基礎試體製作

圖43 試體內部量測元件佈設

圖44 數據量測記錄處理中心

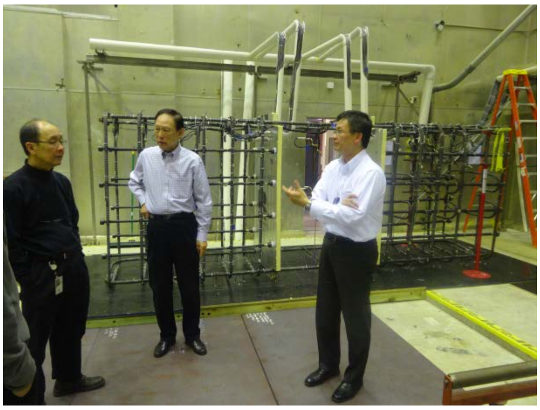


圖45 Dr. Long T. Phan耐久性試驗介紹

圖46 耐久性試驗艙

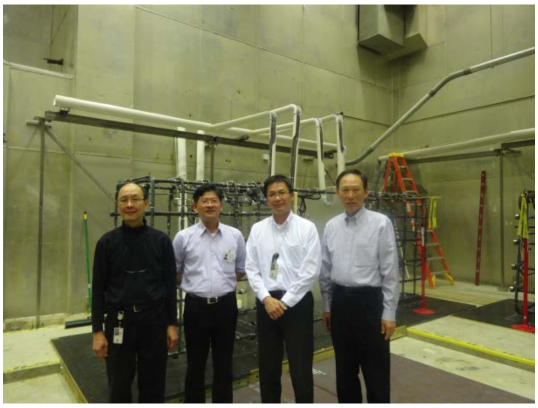


圖47 與導覽人員合影(左1為Dr. Jiang C. Yang，右2為Dr. Long T. Phan)

• 五、NFRL研究成果文宣：

NIST為國家級研究單位，非以營利為目的，其研究成果相當豐富且相關研究資料也非常的公開，供各界參考引用，各研究領域的成果報告多數均可於網頁下載，火災模擬常用的FDS軟體，亦由NIST開發並無償供各界使用。在NFRL實驗室大廳亦準備有很多該單位的研究成果光碟，供參訪者取用，對NFRL的研究成果達到良好的宣傳。所蒐集之光碟封面如附錄3所示。綜整光碟的研究內容領域包括建築因火災崩塌實驗研究及其對於消防救災人員之危害探討、於實際建築進行有無安裝撒水系統對火災危害影響性的實驗及數值模擬比較、木構造建築火災熱性質條件的評估、災後案例調查及數值模擬、精進火災動力學數值模擬、結構滅火的火災動力學模擬、Station夜店大火案例調查及實驗研究、消防滅火策略研究及運用正壓通風消防救災之實驗及模擬研究等。NFRL所提供的光碟，除了公開研究成果外，令人驚訝的是光碟所含內容相當豐富、完整及資訊呈現方式相當直覺化，讓觀看者能很快及完整的了解整個研究的資料，例如包括實驗時多鏡頭影像的對比、實驗及數值模擬影像對比、數值模擬數據輸入檔、簡報檔及成果報告檔等，均收錄於光碟內，極具參考價值。

第三章 心得與建議

透過本次考察NIST防火研究相關單位，可以了解與本所性質類似的國際一流研究組織，其組織架構、任務內容、目前執行之研究專案、實驗設施及運作等作業。參訪心得與建議可歸納如下：

1. NIST實驗室組織，其工程實驗室的研究範圍與本所業務職掌，如環境控制、安全防災、智慧建築及工程材料等相當類似，本次考察有關防火工程研究內容、設施與方向，可增進我國與國際研究機構互相交流研究及經驗，也能呈現本所的研究成果。
2. 本次參訪，藉由了解各研究群目前執行研究內容，包括建築材料與家具的阻燃、持續整合最新成果精進火災模擬、結構崩塌機制、避難逃生、實尺寸構架受實場火災行為、火災與結構複合分析、複合災害行為、智能滅火以及數值模擬等發展，此類研究方向，許多亦為本所近來科技計畫執行內容，可供本所後續規劃參考，並須持續觀注其它國際研究單位之研究，以除符合國情需求外，也能掌握國際研究趨勢。
3. 本次參訪防火研究相關實驗室，除了部分設備正進行委託測試不便參觀外，其他設備均有詳細解說，首先可見其對實驗室安全防護相當重視，因部分中小型材料實驗室，就位於研究室週遭，因此對其防火、排煙相當完善，而個人安全的安全帽、護目鏡及防噪音耳塞等均有準備，而在NFRL大型實驗室，因常有實場火災實驗，實驗室週遭更配有消防噴嘴，可直接對有失控疑慮的火源，可更快速的反應。另外現場也均有配置緊急沖洗設備，可對人員沾染危害物質時，可快速沖洗，以降低傷害。
4. 參訪NFRL實大規模建築複合災害驗證相關實驗設施，因其可將建築結構安

裝於反力牆及強力地板場地上，且置於 20 MW 量熱裝置下，因此其可對結構進行可控制、不同維度的施力，同時受實場火災侵襲，試驗過程可量測觀察整個結構承載下受火之結構行為，另外上方的量測裝置可量測確認所用之火場熱釋放量。因此設驗裝置為目前唯一，本所研究成果並無法與之直接比對，但其構想（例如實場火災標準化規定）以及現場設備安裝方式等，仍值得本所未來參考。

5. 大型實驗動輒耗費大量的人力、物力、時間及經費，在參訪過程了解 NIST 除了進行實驗驗證外，有部分研究人員係利用數值模擬來進行分析，除可降低實驗數量的需求，也可提供未來性能式設計時之分析參考，本所未來研究案除運用既有實驗設施的特點外，也可規畫數值模擬的方向進行，以探討更多的分析案例，完善整個研究。

6. NIST的研究成果之呈現相當豐富且完整，可有效且開放的呈現其研究成果，對在相關研究領域的其他研究人員有很大的幫助，各界在引用或參考 NIST 研究成果的同時，也提升了 NIST 在此領域的地位，可供本所未來在研究成果的展現上參考。

附錄

相關資料

附錄 1　NIST 參訪同意函

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

November 11, 2016

Dr. Tien-Chih Wang
Fire Experiment Center
Architecture and Building Research Institute (ABRI)
Tainan City, Taiwan

Dear Dr. Wang:

Ensuring the safety of built structures in the event of fire is of great interest to scientists and engineers in both Taiwan and the United States. We are delighted to host your visit to the National Fire Research Laboratory (NFRL) at the National Institute of Standards and Technology (NIST) from November 15 to November 17, 2016 and to discuss with you about potential future collaboration in fire-structure interaction research that is mutually beneficial to both organizations. I have also made arrangement for you to meet with Dr. Long Phan, Leader of the Structures Group in the Materials and Structural Systems Division to discuss with you the current research activities in his Group.

We look forward to your visit to NIST next week. In the meantime, please do not hesitate to contact me if I can be of any help.

Sincerely,

Jiann C. Yang, Ph.D.
Deputy Chief, Fire Research Division
Engineering Laboratory
National Institute of Standards and Technology
100 Bureau Drive
Building 224, Room B358
Gaithersburg, MD 20899
(301) 975-6662

jiann.yang@nist.gov
www.nist.gov/el

附錄 2　內政部建築研究所防火實驗中心簡介

Wall（Door, Window）Test Furnace

- Specimen size: 4300*4300 mm
- Standard test: ISO, ASTM, BS, UL…
- Loaded or Unloaded: Up to 60 t

3

Related Studies and Tests

Fire door

Rolling steel fire door

4

- Partition wall
- Loadbearing wall

5

- PV panel fire test

Smoke control performance of fire door

6

Structural Assembly Test Furnace

- Column: 4m height
- Beam: 8m long
- Floor/roof: 4m by 8m
- Loading system:
  Column: 2000t
  Beam: 200t
  Floor/roof: 70~400 kg/m^2

7

- Frame test

Column test

8

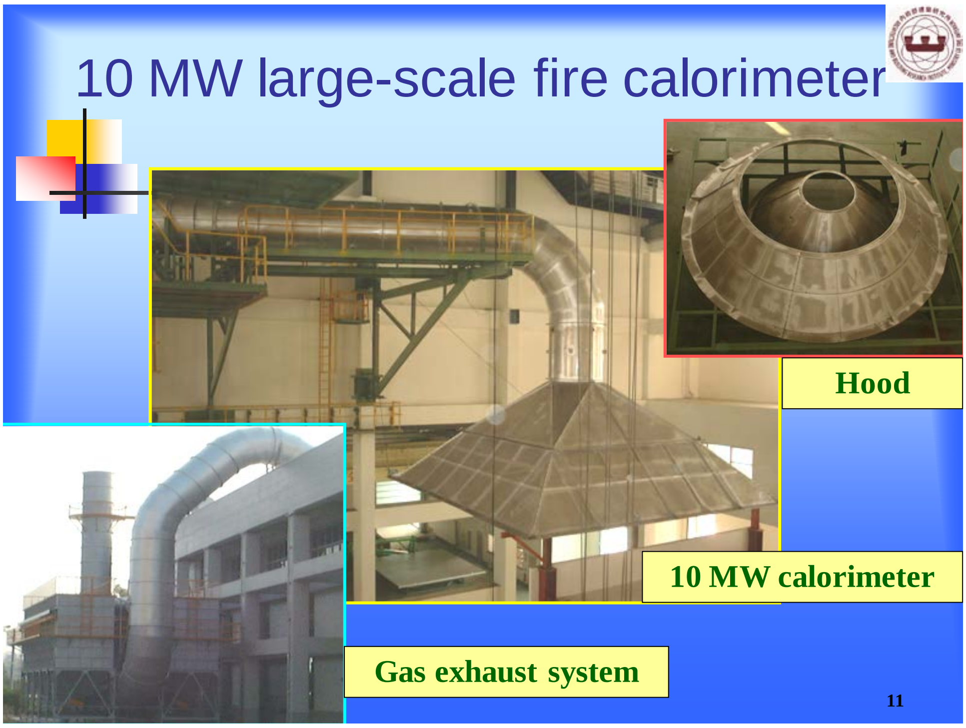
RC Beam-Column assembly test

9

Roof test

Wood slab test

10


10 MW large-scale fire calorimeter
Hood
10 MW calorimeter
Gas exhaust system
11


wood-cribs , motorcycles , seats
12

Effects of water spray on motorcycle fire

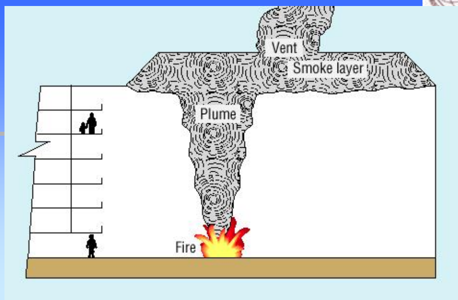
car fire

13

- Fire propagations with/without water curtain

14

Large space smoke control



15

NFPA 285 test

16

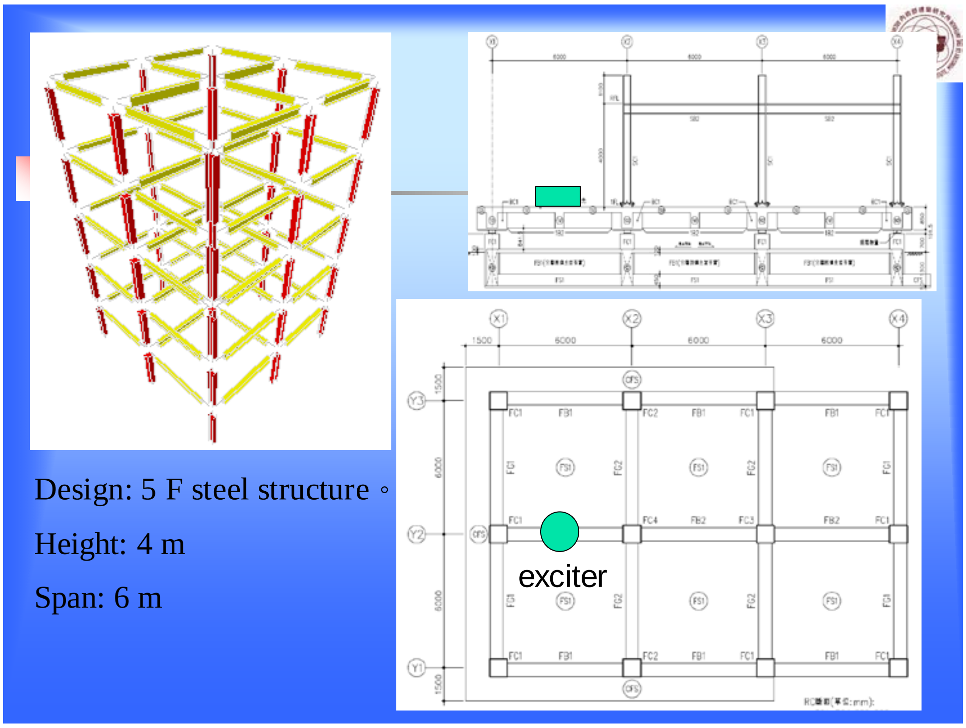
NFPA 285 test - Standard fire test method for evaluation of fire propagation characteristics of exterior non-load-bearing wall assembles containing combustible components

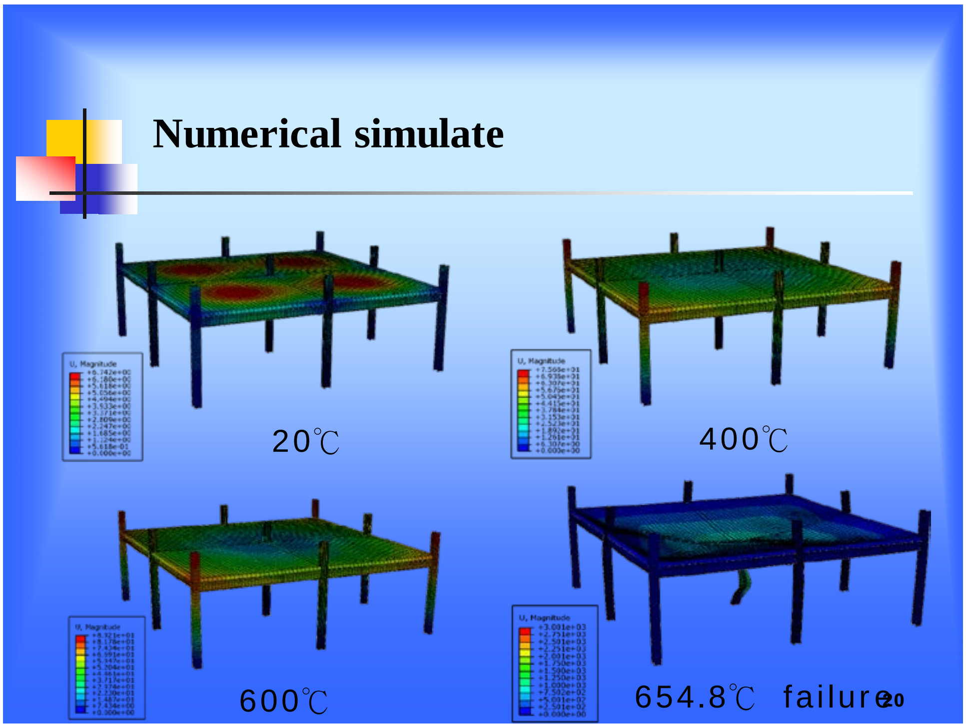
- Discussion: wrapped with ceramic fiber ?
- heat flux meter

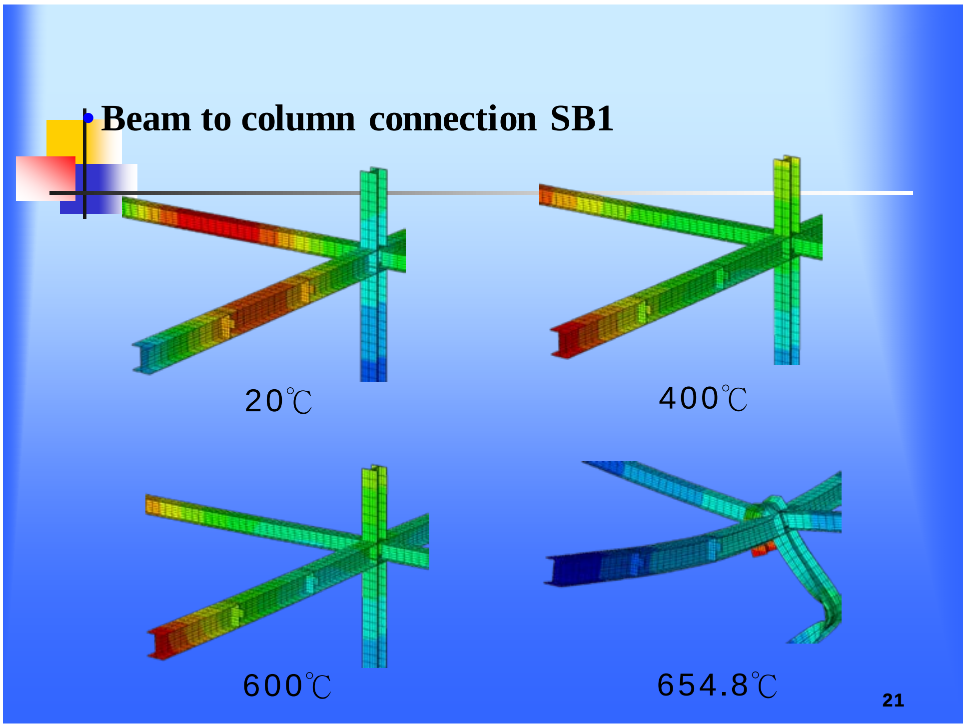
17

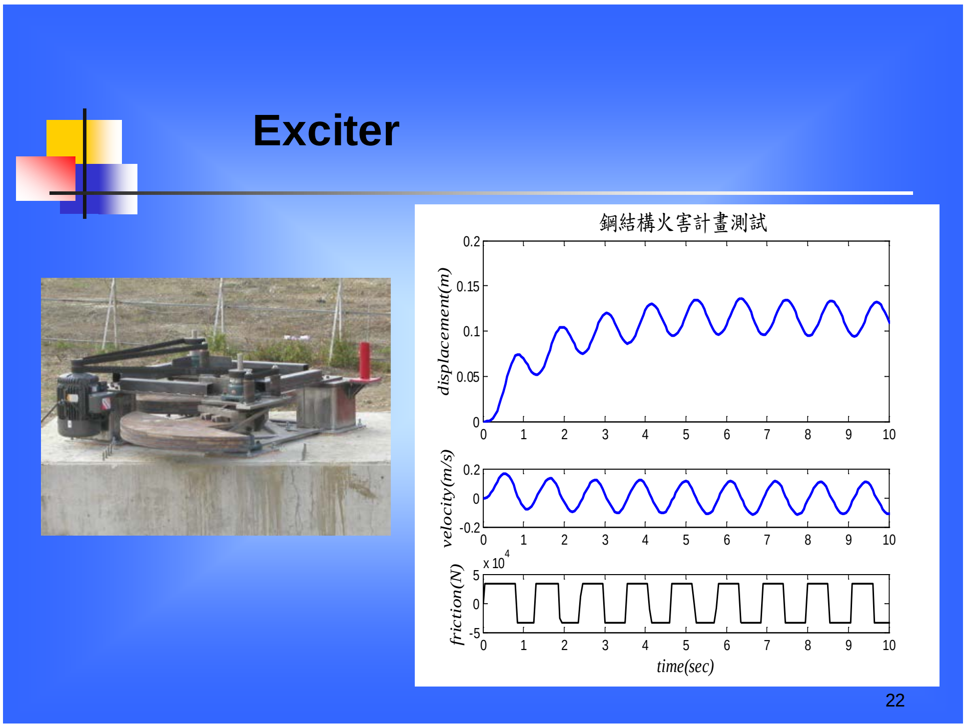
Composite disaster test – fire → earthquake

18


Design: 5 F steel structure。
Height: 4 m
Span: 6 m
exciter

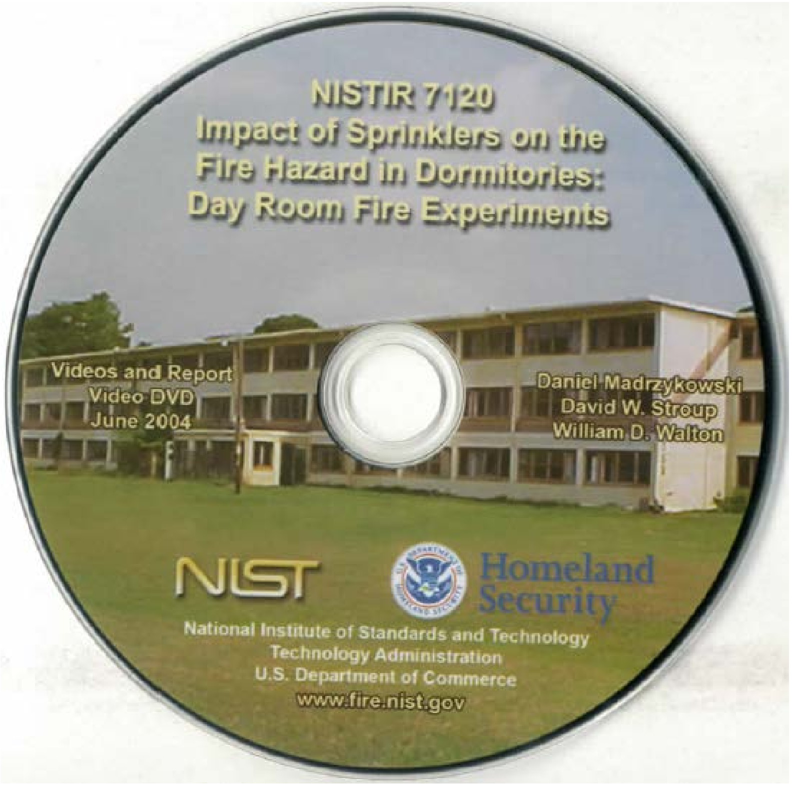

Numerical simulate
20℃
400℃
600℃
654.8℃ failure
20

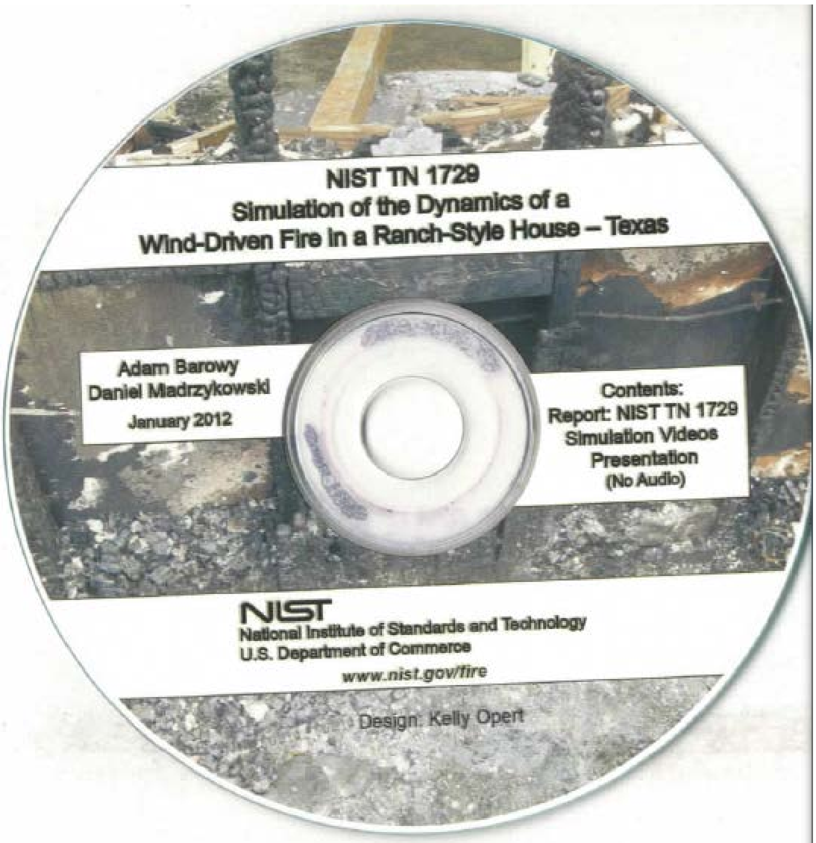

Beam to column connection SB1
20℃
400℃
600℃
654.8℃
21


Exciter
鋼結構火害計畫測試
displacement(m)
velocity(m/s)
friction(N)
x 10^4
time(sec)
22


Full view of the fire laboratory buildings
The End
24

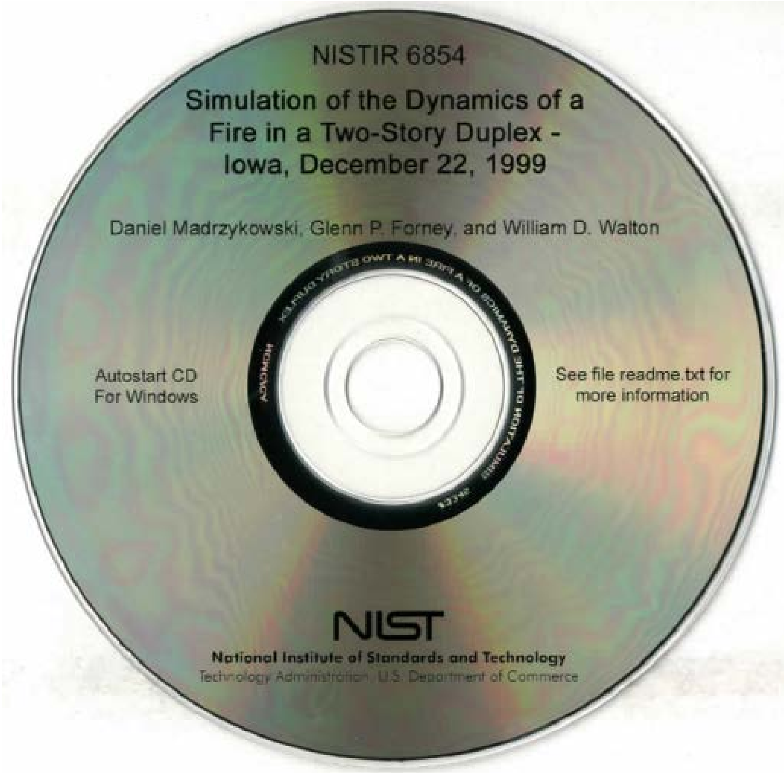
附錄 3　NIST 研究成果光碟封面

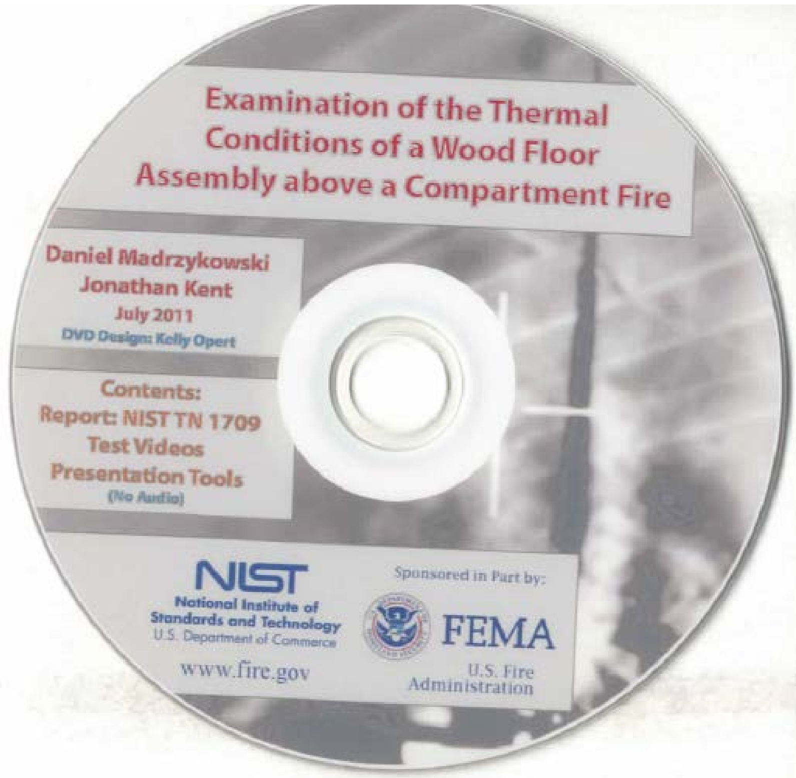





Structural Collapse DVD
Videos and Reports
Editor:
David W. Stroup
Video Production:
William D. Walton
The Phoenix Fire Department
FEMA
NIST
National Institute of Standards and Technology
U.S. Department of Commerce
www.nist.gov/fire


Report of the
Technical Investigation of
The Station Nightclub Fire
National Institute of Standards and Technology NCST Act Report - 2
William L. Grosshandler
Nelson Bryner
Daniel Madrzykowski
Kenneth Kuntz
June 2005
NIST NCSTAR-2
Volume I: Report
Volume II: Appendices
Computer Simulations
Experiment Video
Version 1.0c
NIST
National Institute of
Standards and Technology
Technology Administration
U.S. Department of Commerce
www.nist.gov/ncst


NISTIR 6854
Simulation of the Dynamics of a Fire in a Two-Story Duplex - Iowa, December 22, 1999
Daniel Madrzykowski, Glenn P. Forney, and William D. Walton
Autostart CD For Windows
See file readme.txt for more information
NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce


Examination of the Thermal Conditions of a Wood Floor Assembly above a Compartment Fire
Daniel Madrzykowski
Jonathan Kent
July 2011
DVD Design: Kelly Opert
Contents:
Report: NIST TN 1709
Test Videos
Presentation Tools
(No Audio)
NIST
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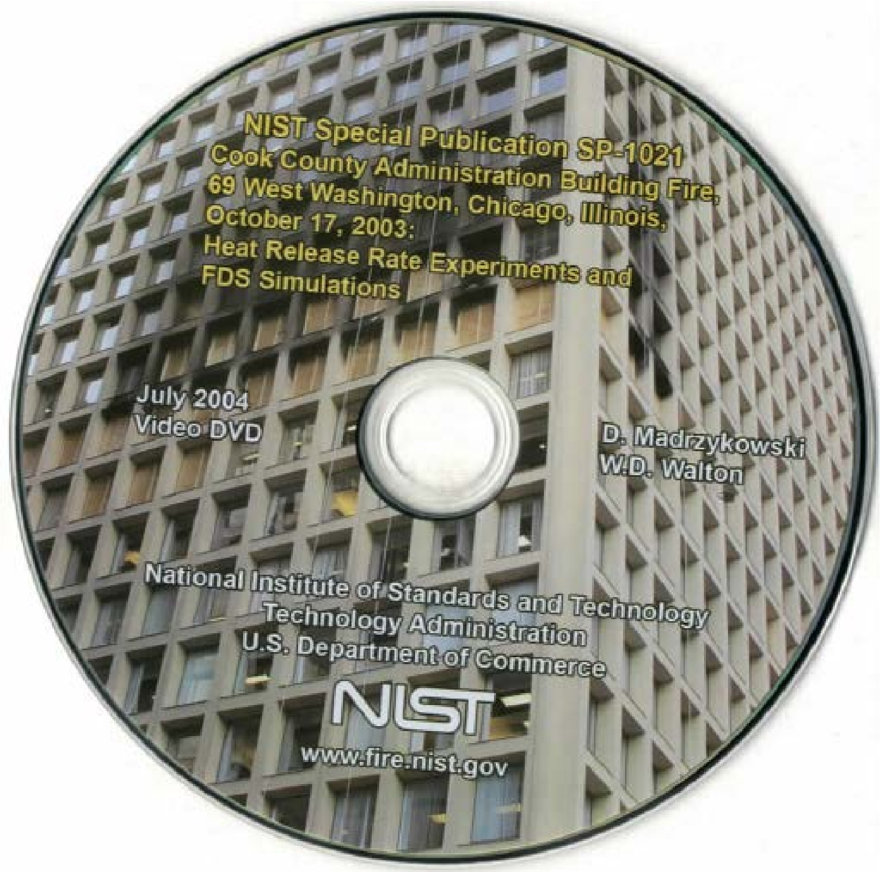
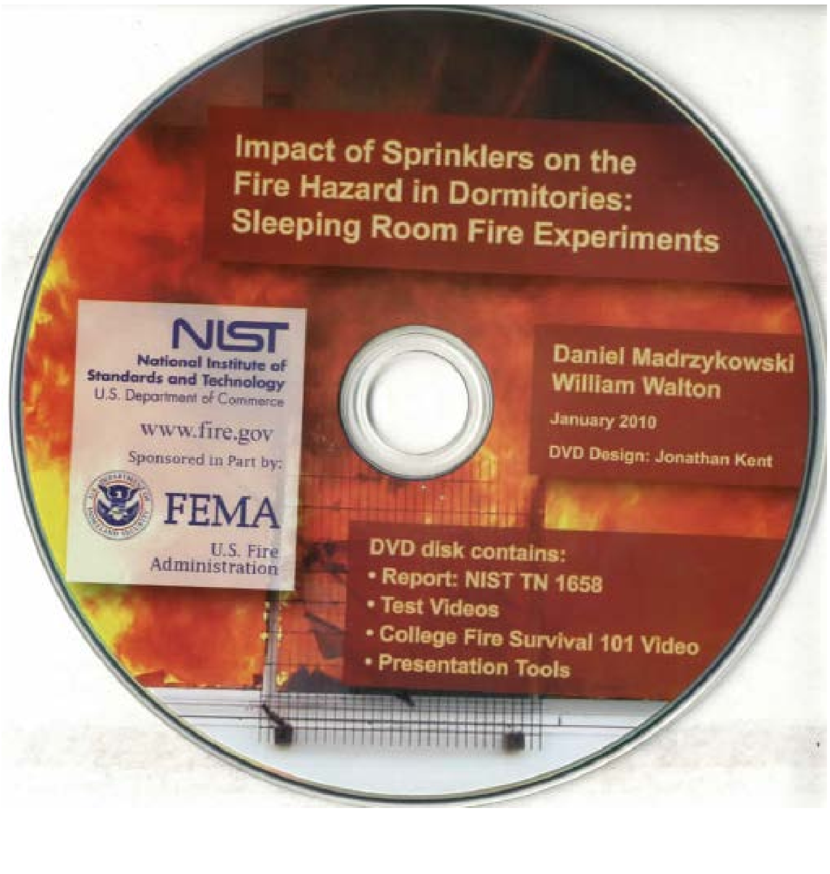
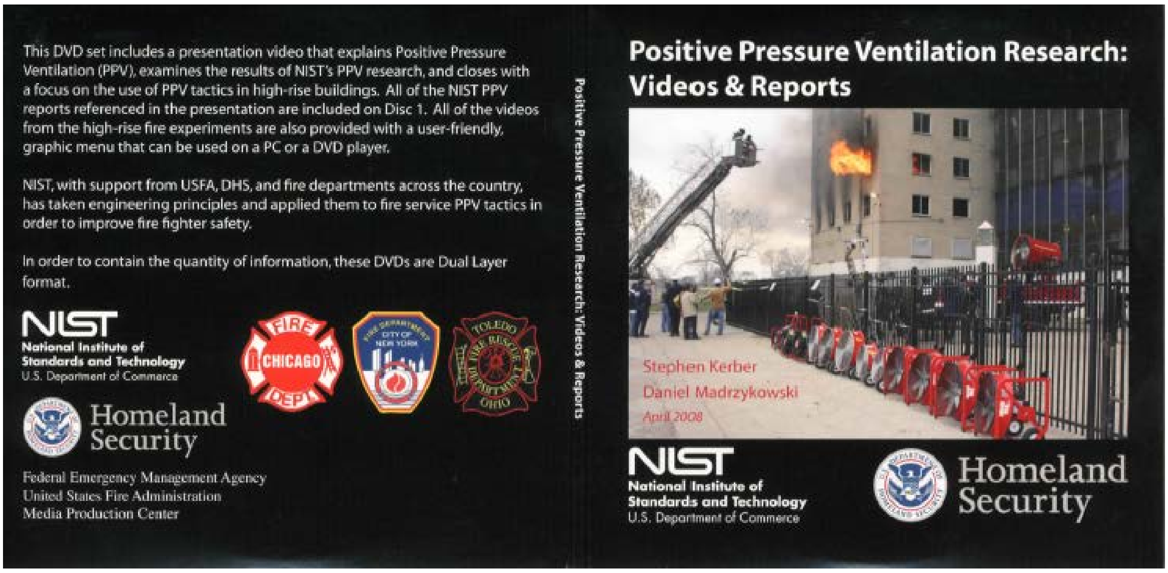
www.fire.gov
Sponsored in Part by:
FEMA
U.S. Fire Administration



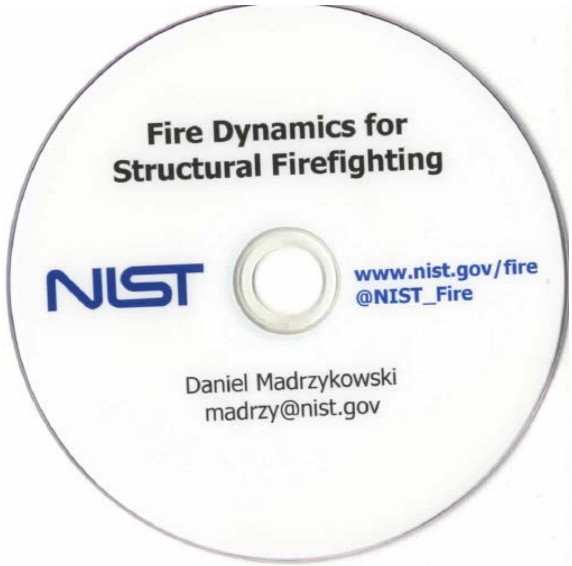
NIST Special Publication SP-1021
Cook County Administration Building Fire,
69 West Washington, Chicago, Illinois,
October 17, 2003:
Heat Release Rate Experiments and
FDS Simulations
July 2004
Video DVD
D. Madrzykowski
W.D. Walton
National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce
NIST
www.fire.nist.gov



Impact of Sprinklers on the
Fire Hazard in Dormitories:
Sleeping Room Fire Experiments
NIST
National Institute of
Standards and Technology
U.S. Department of Commerce
www.fire.gov
Sponsored in Part by:
FEMA
U.S. Fire
Administration
Daniel Madrzykowski
William Walton
January 2010
DVD Design: Jonathan Kent
DVD disk contains:
• Report: NIST TN 1658
• Test Videos
• College Fire Survival 101 Video
• Presentation Tools


This DVD set includes a presentation video that explains Positive Pressure Ventilation (PPV), examines the results of NIST's PPV research, and closes with a focus on the use of PPV tactics in high-rise buildings. All of the NIST PPV reports referenced in the presentation are included on Disc 1. All of the videos from the high-rise fire experiments are also provided with a user-friendly, graphic menu that can be used on a PC or a DVD player.
NIST, with support from USFA, DHS, and fire departments across the country, has taken engineering principles and applied them to fire service PPV tactics in order to improve fire fighter safety.
In order to contain the quantity of information, these DVDs are Dual Layer format.
NIST
National Institute of Standards and Technology
U.S. Department of Commerce
Homeland Security
Federal Emergency Management Agency
United States Fire Administration
Media Production Center
Positive Pressure Ventilation Research: Videos & Reports
Positive Pressure Ventilation Research: Videos & Reports
Stephen Kerber
Daniel Madrzykowski
April 2008
NIST
National Institute of Standards and Technology
U.S. Department of Commerce
Homeland Security


Implementing the Advances in Fire Fighting Research on the Fire Ground
NIST
Daniel Madrzykowski
madrzy@nist.gov
www.nist.gov/fire
@NIST_Fire


Fire Dynamics for Structural Firefighting
NIST
www.nist.gov/fire
@NIST_Fire
Daniel Madrzykowski
madrzy@nist.gov


Review of Modern Fire Dynamics Research
NIST
www.nist.gov/fire
http://fstartraining.org/
FSTAR
FIREFIGHTER SAFETY THROUGH ADVANCED RESEARCH

Station 夜店大火調查報告簡報

- Report on The Station Nightclub Fire

National Construction Safety Team Investigation

Report on
The Station Nightclub Fire

National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce

June, 2005

NIST

Duties of National Construction Safety Teams

To establish likely technical causes of building failure;

To evaluate technical aspects of evacuation and emergency response procedures;

To recommend specific improvements to model building standards, codes, and practices based on findings; and

To recommend research and other appropriate actions needed to improve structural safety of buildings, evacuation and emergency response procedures, based upon findings of this investigation.

NIST

Conduct of Investigation into The Station Fire

Identified technical issues through consultations with experts in fire protection engineering, emergency evacuation, and members of other investigative teams.

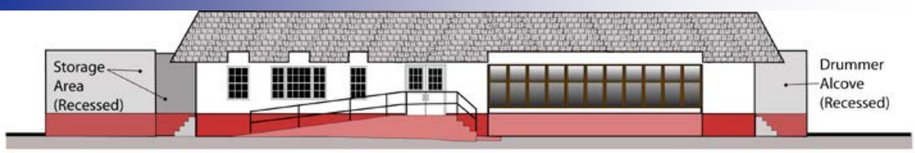
Collected data from the site, local authorities, contractors, building design documents, video/photographic data, telephone/radio transmissions, oral and written accounts.

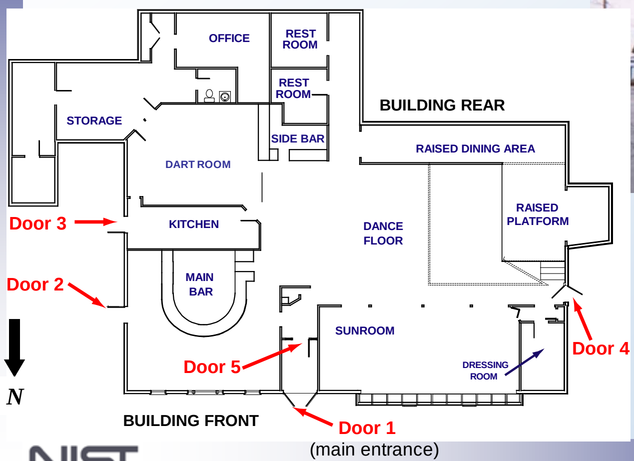
Compared model building and fire codes and practices, and reviewed practices used in operation of building.

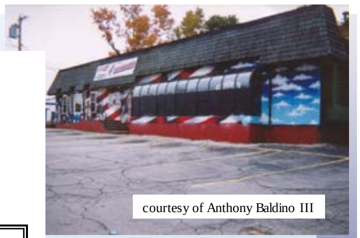
Simulated and analyzed fire spread, smoke movement, tenability, evacuation, and operation of fire protection systems.

Conducted tests to support analysis and simulation predictions.

NIST







Views of Building

NIST

Overall Timeline

Time	Event
11:08 pm	- ignition of foam by pyrotechnics
	- band stops playing, crowd begins to evacuate
11:09	- cell phone callers report fire to 911
	- fire alarm sounds and strobes begin to flash
	- report received of fire at Station nightclub; off-duty police on scene
	- people caught in doorway, smoke pouring out above
11:10	- 4 fire engines, a ladder truck and battalion chief assigned and dispatched
11:13	- Engine 4 on scene; running first hose line (1 3/4")
11:20	- master stream off Engine 2 operational
11:23	- Fire Chief 1: implement mass casualty plan
11:32	- roof over main bar appears down
12:15 am	- partial collapse of pool room area begins
~ 12:45	- State Fire Marshal on scene
~1:00	- all patients transported

NIST

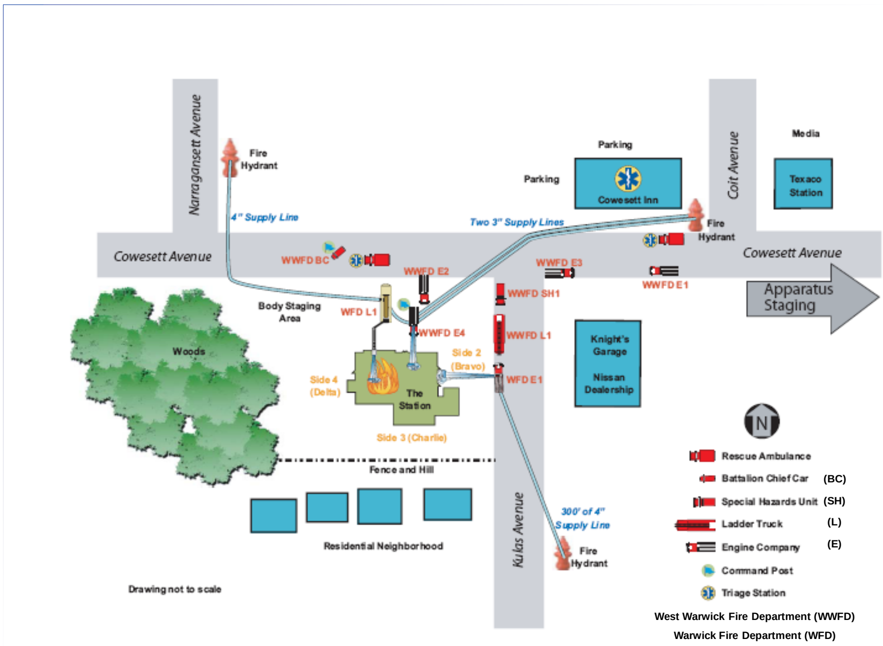
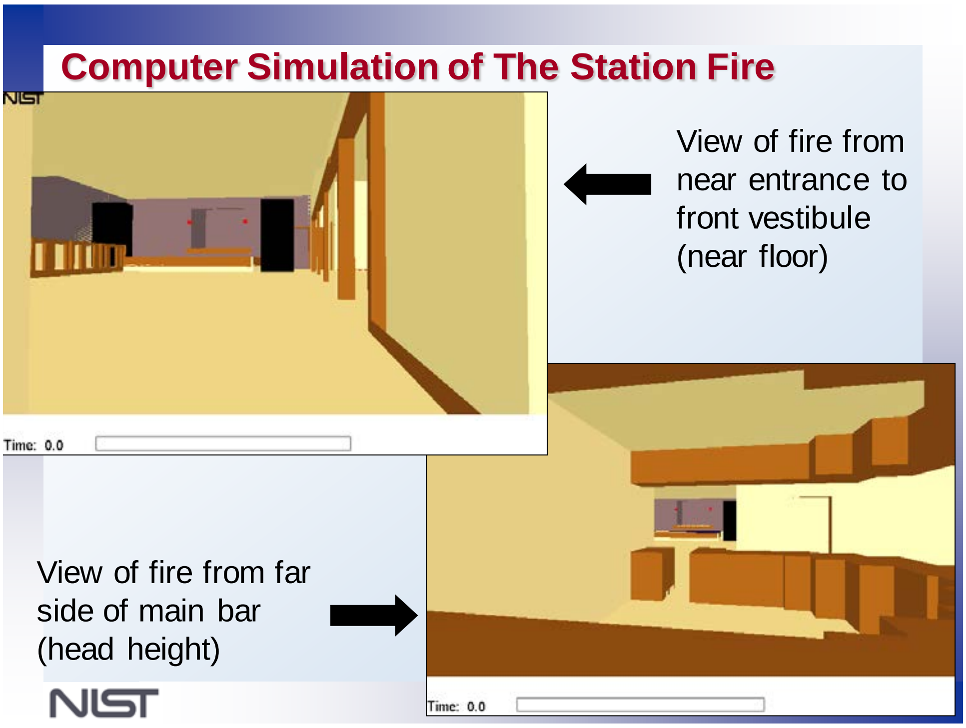
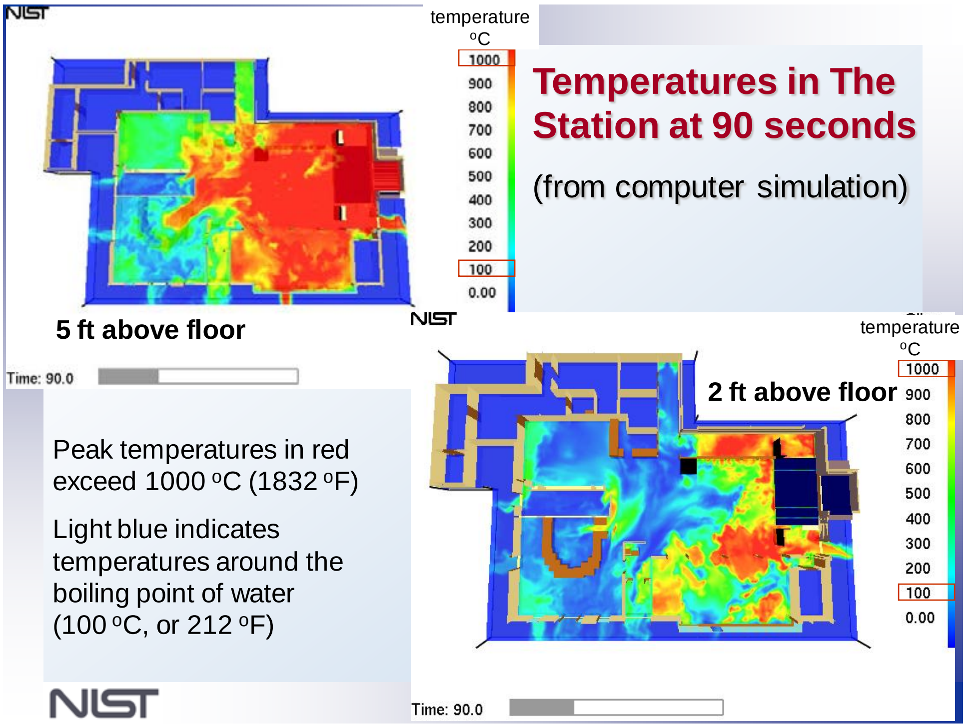


Figure 3-1. Schematic of primary apparatus deployment


Computer Simulation of The Station Fire
View of fire from near entrance to front vestibule (near floor)
Time: 0.0
View of fire from far side of main bar (head height)
Time: 0.0
NIST


Temperatures in The Station at 90 seconds
(from computer simulation)
temperature °C
1000
900
800
700
600
500
400
300
200
100
0.00
5 ft above floor
Time: 90.0
2 ft above floor
Time: 90.0
Peak temperatures in red exceed 1000 °C (1832 °F)
Light blue indicates temperatures around the boiling point of water (100 °C, or 212 °F)
NIST

Direct contributors to substantial loss of life in The Station fire

- Hazardous mix of building contents
- Inadequate capability to suppress fire during its early stage of growth
- Inability of exits to handle all of the occupants in the short time available for such a fast growing fire

NIST

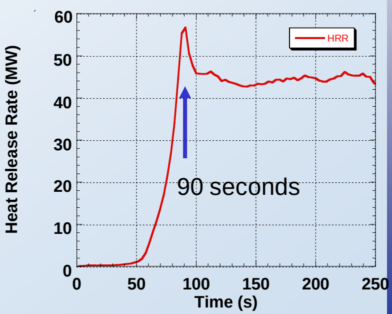
Major Conclusion

- Strict adherence to 2003 model codes available at the time of the fire would go a long way to preventing similar tragedies in future.
- Changes to codes subsequent to fire made them stronger.
- By making some additional changes – and state and local agencies adopting and enforcing them – we can strengthen occupant safety even further.

NIST

Key Findings Regarding Building Contents

- Non-fire retarded foam sample purchased by NIST ignited within 10 seconds when exposed to a pyrotechnic device; under similar condition, fire retarded foam sample did not ignite.
- Computer simulation of the nightclub fire shows that flames spread rapidly over foam finish material, igniting the wood paneling adjacent to the foam and generating intense heat in the first 90 seconds.
- Fire transitioned to more traditional, ventilation-limited wood frame building fire in about 2 minutes.



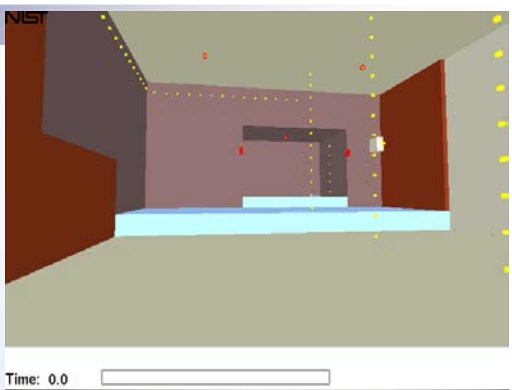
NIST

Key Findings Regarding Fire Protection Systems

- Experiments conducted at NIST demonstrated that a sprinkler system installed in test room in accordance with NFPA 13 was able to control a fire initiated in non-fire retarded polyurethane foam panels.
- Sprinklers were not installed in The Station, nor would they have been required for such existing structures under 2003 editions of the model codes
- A heat detection/fire alarm system was installed in the building and was activated (sound and strobe) by the fire 41 seconds after the fire started.

NIST

Computer simulation of platform area mock-up with sprinklers



NIST

Key findings regarding emergency egress

- First patrons recognized danger 24 seconds after ignition of foam; bulk of crowd began to evacuate around time band stopped playing (30 seconds).
- Up to 2/3 of occupants may have attempted to leave through main entrance; many were unsuccessful.
- Prior to 90 seconds, a crowd-crush occurred at main entrance which disrupted flow through front exit.
- Event precipitating crowd crush likely related to arrangement of single interior door with merging streams of traffic and pressure to escape rapidly deteriorating conditions in nightclub.

NIST

Key findings regarding emergency egress (cont.)

- Measurements in a fire test of a reconstructed portion of the platform and dance floor produced, within 90 seconds, conditions well in excess of accepted survivability limits.

- Computer simulation of the full nightclub fire suggested that conditions around the dance floor, sunroom, and assembly area behind kitchen would have led to severe incapacitation or death within about 90 seconds after ignition of the foam.

NIST

Areas of recommendations for improvements to model building & fire codes, standards and practices in nightclubs

- Adoption/enforcement by state/local jurisdictions of model codes
- Strengthening requirements for sprinklers
- Increasing factor of safety on time for occupant egress
- Tightening restriction on use of flexible polyurethane foam as an interior finish product
- Further limiting use of pyrotechnics
- Conducting research to underpin recommended changes

NIST

Recommendation 1

Model Code Adoption and Enforcement

All state and local jurisdictions

a) adopt building/fire code covering nightclubs based on model codes (as a minimum requirement) and update local codes as the model codes are revised;

b) implement aggressive and effective fire inspection and enforcement programs that address:

- (i) all aspects of those codes;
- (ii) documentation of building permits and alterations;
- (iii) means of egress inspection and record keeping;
- (iv) frequency and rigor of fire inspections, including follow-up and auditing procedures; and
- (v) guidelines on recourse available to the inspector for identified deviations from code provisions

NIST

Recommendation 1 (cont.)

All state and local jurisdictions

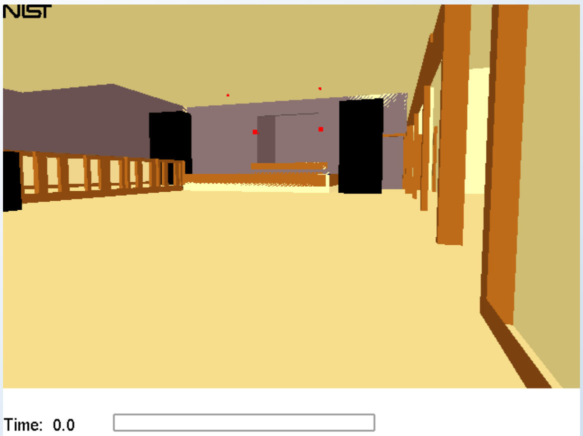
c) ensure that enough fire inspectors and building plan examiners are on staff to do the job and that they are professionally qualified to a national standard such as NFPA 1031 (*Professional Qualifications for Fire Inspector and Plan Examiner*).

NIST

Recommendation 2

Sprinklers

Require sprinkler systems for all new nightclubs regardless of size, and for existing nightclubs with occupancy limit > 100.



Computer simulation of The Station fire had sprinklers been installed

NIST

Recommendation 3

Building contents and finish materials

(a) specifically forbid non-fire retarded flexible polyurethane foam, and materials known to ignite and propagate flames as easily, from all new and existing nightclubs;

(b) provide more explicit guidance to building owners, operators, contractors, and authorities having jurisdiction for when large-scale tests that are covered in NFPA 286 are required to demonstrate that materials (other than those already forbidden above) do not pose an undue hazard for the use intended

(c) modify ASTM E-84, NFPA 255, and NFPA 286 to ensure that product classification and the pass/fail criteria for flame spread tests and large-scale tests are established using best measurement and prediction practices available.

NIST

Recommendation 4

Indoor use of pyrotechnics

(a) Ban pyrotechnic devices from indoor use in new and existing nightclubs not equipped with an NFPA 13 compliant automatic sprinkler system.

(b) Modify NFPA 1126 to include a minimum occupancy and/or area for a nightclub below which pyrotechnic devices should be banned from indoor use, irrespective of the installation of an automatic sprinkler system.

(c) Increase clearance between building contents and range of pyrotechnic device.

NIST

Recommendation 5

Occupancy Limits and Emergency Egress

Increase factor of safety on time to egress by

(a) establishing the threshold building area and occupant limits for egress provisions using best practices for estimating tenability and evacuation time; and, unless further studies indicate another value is more appropriate, use 1-1/2 minutes as the maximum permitted evacuation time for nightclubs similar to or smaller than The Station;

(b) computing number of required exits and permitted occupant loads assuming at least one exit will be inaccessible in an emergency evacuation.

NIST

Recommendation 5 (cont.)

(c) increasing minimum capacity of main entrance (for nightclubs with one clearly identifiable main entrance) to accommodate 2/3 of maximum permitted occupant level (based upon standing space or festival seating, if applicable) during an emergency;

(d) eliminating trade-offs between sprinkler installation and factors that impact the time to evacuate buildings;

(e) requiring staff training and evacuation plans for nightclubs that cannot be evacuated in less than 1-1/2 minutes; and

(f) providing improved means for occupants to locate emergency routes for when standard exit signs become obscured by smoke.

NIST

Recommendation 6

Portable Fire Extinguishers

Perform a study to determine minimum number and appropriate placement (based upon time required for access and application in fully occupied building) of portable fire extinguishers for use in new and existing nightclubs, and level of staff training required to ensure their proper use.

NIST

Recommendation 7

Emergency Response

Ensure effective response to rapidly developing mass casualty events by adopting and adhering to existing model standards on communications, mutual aid, command structure and staffing, such as NFPA 1221, NFPA 1561, NFPA 1710, and NFPA 1720

NIST

Recommendation 8

That research be conducted to **better understand human behavior in emergency situations**, and to predict impact of building design on safe egress in emergencies.

Recommendation 9

That research be conducted to **understand fire spread and suppression better** in order to provide the tools needed by the design profession to address above recommendations.

Recommendation 10

That research be conducted to **refine computer-aided decision tools for determining costs/benefits** of alternative code changes and fire safety technologies, and to **develop computer models to assist communities in allocating resources**.

NIST

Actions Already Taken by Rhode Island

- Require the use across the board of up-to-date fire safety codes (elimination of grandfather clause) and coordinated administration of fire safety building codes
- Prohibit use of pyrotechnics in places of assembly such as nightclubs, and strictly regulate use in other large venues.
- Mandate sprinklers in nightclubs with occupancy of >150 in all class A and B places of assembly, with some exceptions.
- Provide greater enforcement powers to fire marshals to ensure ability to make inspections, to require immediate abatement of threats to public safety, and to increase access.
- Establish comprehensive planning requirements to identify future weaknesses in RI's approach to fire safety.

NIST

For Further Information:

Web site to view final report: http://www.nist.gov/ncst

NIST Building and Fire Research Laboratory:
http://www.bfrl.nist.gov

NIST Fire Research – Data, Models, Reports:
http://www.fire.nist.gov

NIST

Review of Modern Fire Dynamics Research

Daniel Madrzykowski, PE, FSFPE National Institute of Standards & Technology Fire Research Division
Engineering
Laboratory madrzy@nist.gov
www.nist.gov/fire

Presentation Objectives

- Increase your knowledge of the changing fire environment.
    - Review and Expand on your understanding of Fire Dynamics
- Capabilities and Limitations of FF Safety Equipment
- The Importance of Size-Up and Choosing Tactics to fit the fire conditions to:
    - Put the fire out faster and more efficiently
    - Improve the safety of you and your crew
    - Improve your chances to save victims
- Provide you with the information for your department and how to implement change

The Firefighters' Work Place

- Houses are getting larger
    - 1973: 1,600 sq. ft. 2008: 2,500 sq. ft.
- Housing lots are getting smaller
    - 1976: 10,100 sq. ft. 2008: 8,800 sq. ft.
- During the past 50 years fuel loads have in homes have changed
    - Resulting in fuel rich fire conditions within homes
- Home designs have become more open (less compartmentation, engineered structural members) and more energy efficient (multi- pane windows, wrapped in plastic, alternate energy sources)
- Have staffing and tactics changed to adapt to these changes?

Current Reality

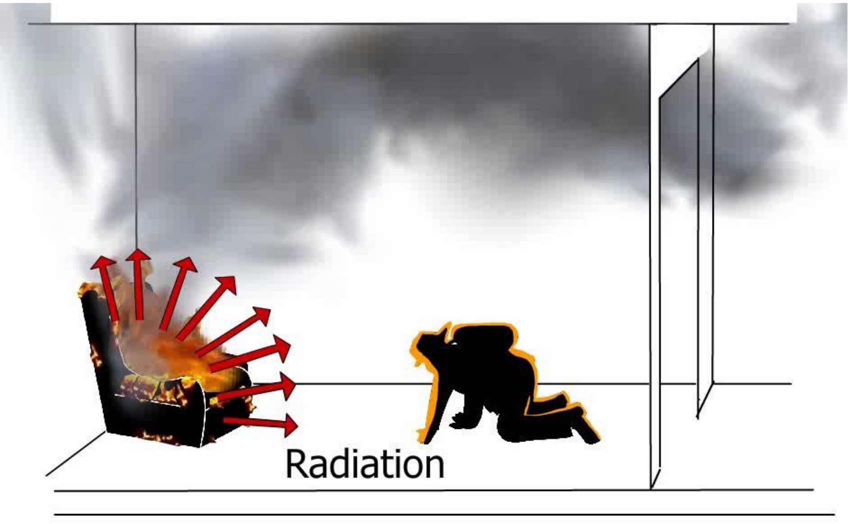
- Changes in fire environment
- Fewer fires = less experience
- Limited fire behavior training in the academy
- Equipment and building standards working to catch up to advances in technology
- No National Standards on Fire Fighting Tactics

A Disturbing Reality

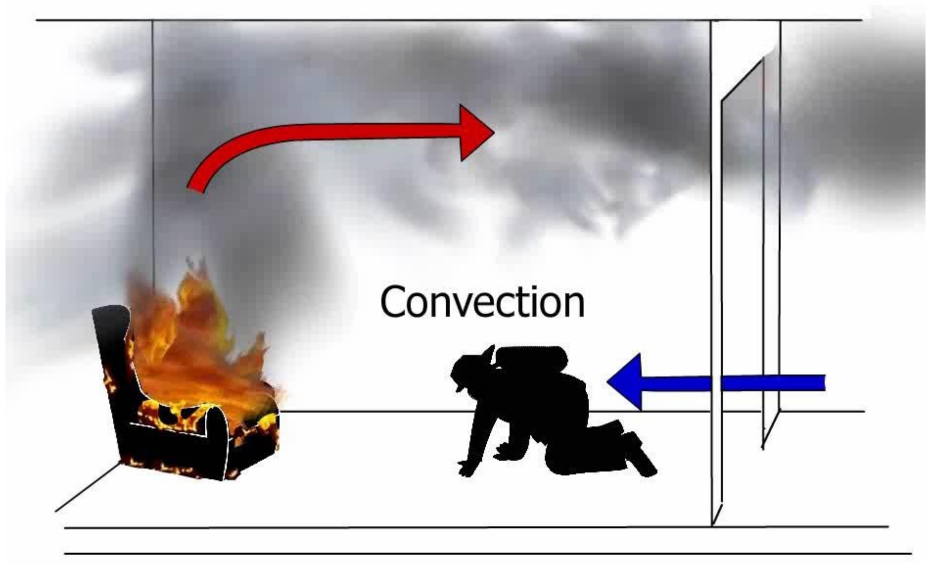
- Rate of FF deaths due to traumatic injuries
  - Late 1970s – 1.8 deaths per 100,000 fires
  - Late 2000s - 3.0 deaths per 100,000 fires
- During this same period the annual number of structures fires decreased by 53%
- Since the number of structure fires is decreasing, how do firefighters and fire officers gain the experience to understand fire progression, fire behavior, and what happens to the structural integrity of a building under fire conditions?

Ref: Fahy, Rita, F., "U.S. Fire Service Fatalities in Structure Fires, 1977-2009", NFPA, Quincy, MA., June 2010.

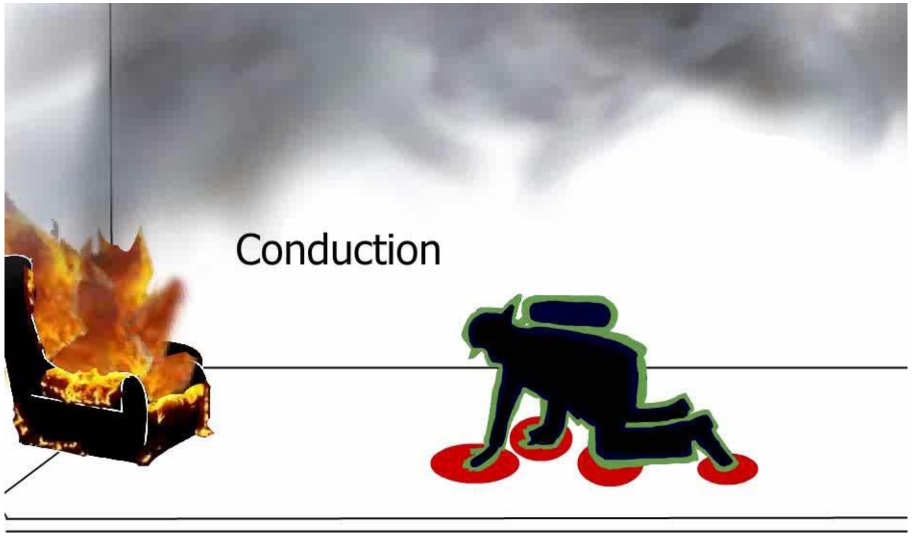
Radiation



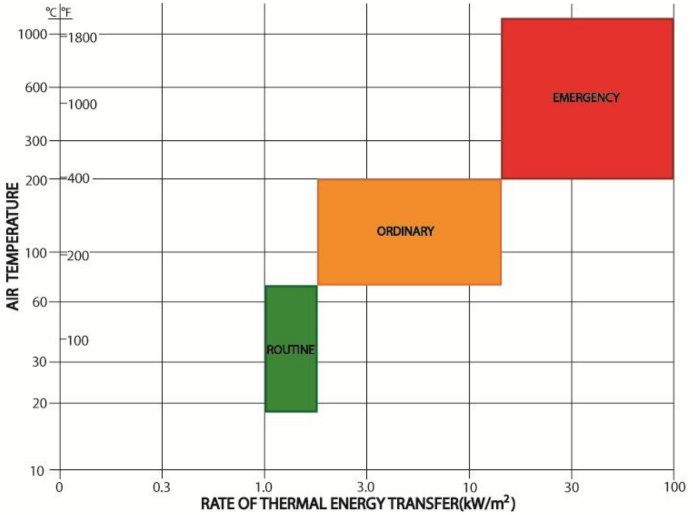
Convection



Conduction



Fire Fighting Thermal Environments



From: Utech, Status Report on (NBS) Research Programs for Firefighters Protective Clothing. FDIC 1973.

Recognition that the Face Piece is one of the weakest links of the protective ensemble

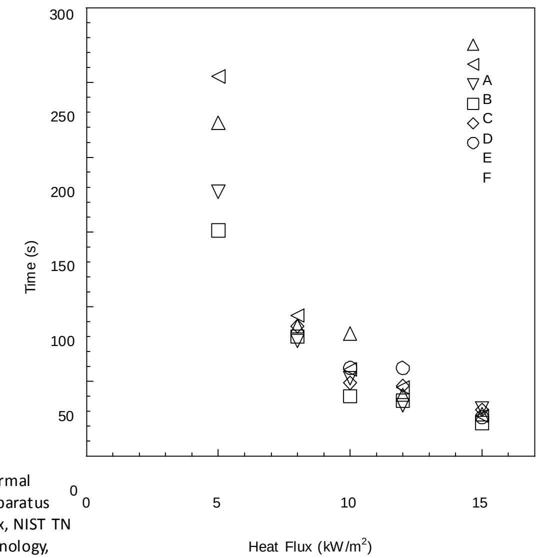
SCBA Face Piece Lens Related Incidents

- NIOSH F2002-34, "Career Lieutenant and Fire Fighter Die in a Flashover During a Live-Fire Training Evolution - Florida,"
- NIOSH F2005-31, "Career officer injured during a live fire evolution at a training academy dies two days later - Pennsylvania,"
- NIOSH F2007-12, "Career Fire Fighter Dies in Wind Driven Residential Structure Fire - Virginia,"
- NIOSH F2007-29, "A Volunteer Mutual Aid Captain and Fire Fighter Die in a Remodeled Residential Structure Fire - Texas,
- "NIOSH F2008-34, "Volunteer Fire Fighter Dies While Lost in Residential Structure Fire - Alabama,"
- NIOSH F2009-11, "Career Probationary Fire Fighter and Captain Die as a Result of Rapid Fire Progression in a Wind-Driven Residential Structure Fire - Texas,"

From: NIST-SP 1123 -Emergency Responder Respirator Thermal Characteristics Workshop, July 2010.

Time to Glass Transition Temperature

- Exterior lens TC temperature
- Time to reach 140°C (280 °F)



A. Putorti, A. Mensch, N. Bryner, G. Braga, Thermal Performance of Self-Contained Breathing Apparatus Facepiece Lenses Exposed to Radiant Heat Flux, NIST TN 1785, National Institute of Standards and Technology, Gaithersburg, MD, February 2013

12

Comparison of NFPA PPE Test Conditions

1981 – SCBA (2007 ed.)	1982 – PASS 1801 – Thermal Imager	1971 – Turnout Gear
Convective Oven 95 °C (203 °F) for 15 min	Convective Oven 95 °C (203 °F) for 15 min	
Open Flame 1000 °C (1832 °F) for 10 s	Open Flame 1000 °C (1832 °F) for 10 s	
	Convective Oven 260 °C (500 °F) for 5 min	Convective Oven 260 °C (500 °F) for 5 min
Radiative Flux 15 kW/m² for 5 minutes NEW for 2013		Convective + Radiative Flux 84 kW/m²

55 °C (131 °F) Human skin receives a second degree burn injury

5 kW/m² Pain to skin within seconds

20 kW/m² Threshold flux to floor at Rollover

A TI is not an X-ray device

Traditional Tactics

"This is how we have always fought fire."

- Whenever possible, attack from the unburned to the burned side.
- Ventilation – systematic removal and replacement of heated air, smoke and gases from a structure with cooler air. (Vent to Cool)
- The most effective and efficient fire attack is from the interior.
- Attack basement fires from the interior.
- Don't flow water from the outside – you will push fire.

Is this really how fire fighters have always fought fire?

- Whenever possible, attack from the unburned to the burned side.
- The most effective and efficient fire attack is from the interior.

IFSTA 200, 1977 Figure 6.20

ANALYSIS OF THE EXTINGUISHMENT OF A CONFINED STRUCTURAL FIRE

PHASE	CONDITIONS	REQUIREMENTS TO EXTINGUISH	METHOD
1st	Beginning fire. 20% oxygen content of atmosphere. Accelerating heat generation according to development of fire. Considerable smoke in reverse proportion to heat generation. Destruction limited to immediate fire area.	Entrance and direct application of extinguishing agent. Personal protection if needed.	Make entrance. Locate fire. Apply extinguishing agent at base of fire. Protect self with protective breathing equipment. Ventilate at natural openings if needed.
2nd	Flame production. Major involvement. Entrance difficult because of heat. Oxygen reduction 21 - 15% or less. Rapid heat generation with highest temperature at ceiling. High convection of heated gases and air. Limited smoke production, increasing as flame decreases. Increasing atmospheric pressure within space. Rapid destruction.	Reduction of room temperature to 300° F. or less. Entrance and direct application of extinguishing agent to remaining fire. Personal protection if needed.	1. Locate area of major involvement. 2. Determine point or points at which application is to be made. 3. Make opening, if needed, small as possible for application of water fog. 4. Assume position so that nozzleman will not be involved with hot smoke and condensing stream. 5. Apply fog into upper level to meet space requirements. –If applied at upper level use short-reach fog. –If applied at lower level use long-reach fog and direct into upper level. The order of expulsion due to displacement will be: 1st. Smoke 2nd. Smoke and condensing steam 3rd. Condensing steam 6. Continue application of fog without interruption until decrease of condensing steam is noticed. 7. Enter and extinguish remaining fire and spot fires. 8. Protect self if necessary with breathing equipment and heavy clothing.
3rd	Smoldering fire. Oxygen below 15%. Convection ceased and stratification of temperatures, highest at upper level. General decreasing of temperature due to lowering of heat generation and heat losses. Intense smoke production. Serious accumulation of carbon monoxide gas. Chance for atmospheric breathing. Possibility of smoke explosion if air is admitted.	Reduction of temperature. Displacement of smoke and gases with steam to make space livable and eliminate chance for explosion. Entrance and direct application of extinguishing agent. Personal protection if needed.	

ISFSI

THINKING FIREFIGHTERS

DO IT DIFFERENT

NIST

Spartanburg, SC
January 2013
May 2014

Garage Fire – Exterior Attack

Garage Fire – Interior Attack

Ventilation

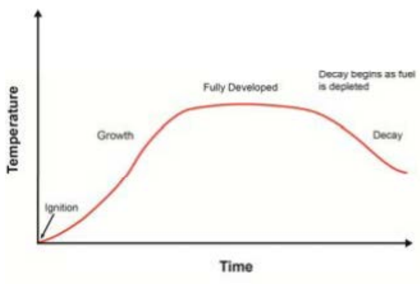
- Vent to cool?
- Ventilation must be coordinated.
- Coordinated with what?
- Is vertical ventilation better than horizontal ventilation?

Fire Dynamics

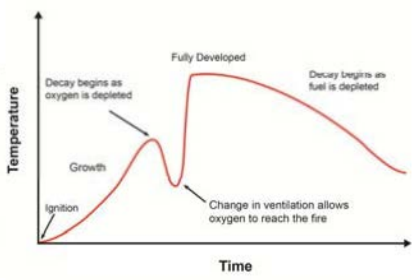
- Study of how fires start, spread and develop.
- Fire Dynamics – detailed study of how chemistry, fire science, material science and the engineering disciplines of fluid mechanics and heat transfer interact to influence fire behavior.

Recognition of Ventilation Controlled Structure Fires

Fuel Controlled Fire



Ventilation Controlled Fire



What is a fire?

- A fire is an gas phase, exothermic chemical reaction that emits heat and light
- Fire Tetrahedron
  - Fuel
  - Oxidizing Agent
  - Heat
  - Uninhibited Chemical Reactions
- Fire Tetrahedron
  - Fire triangles do not account for sustained flames or a growing fire. The self-sustained chemical reaction enables flames and fire growth.

Recognition that Smoke is Fuel

Recognition that Fuels are Different

Wood

Polystyrene

Diffusion vs Pre-mixed Flame

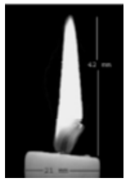
Fuel Rich

Oxygen Added

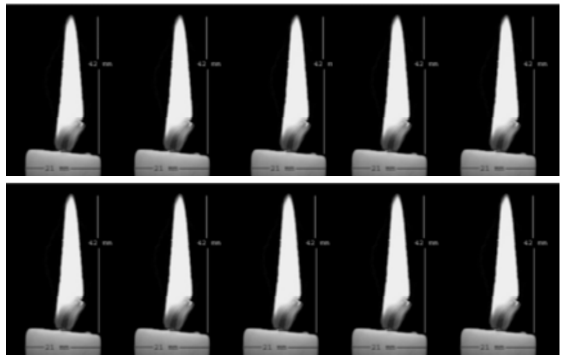
Oxygen – No Heat without it!
For each kg of O_2 consumed in a fire,
13 MJ of heat is released.

Heat Release Rate vs Temperature

- One candle vs ten candles - same flame temperature but 10 times the HRR

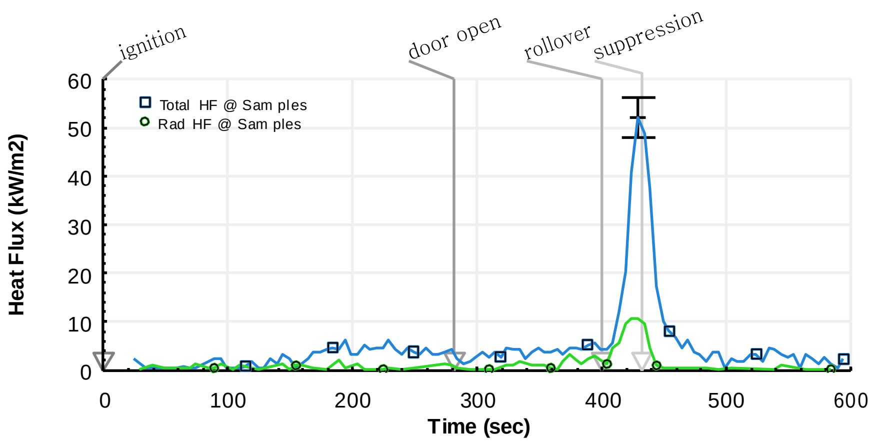


HRR:
Approx. 80 W
Temperature Range:
500 C to 1400 C
(930 F to 2500 F)

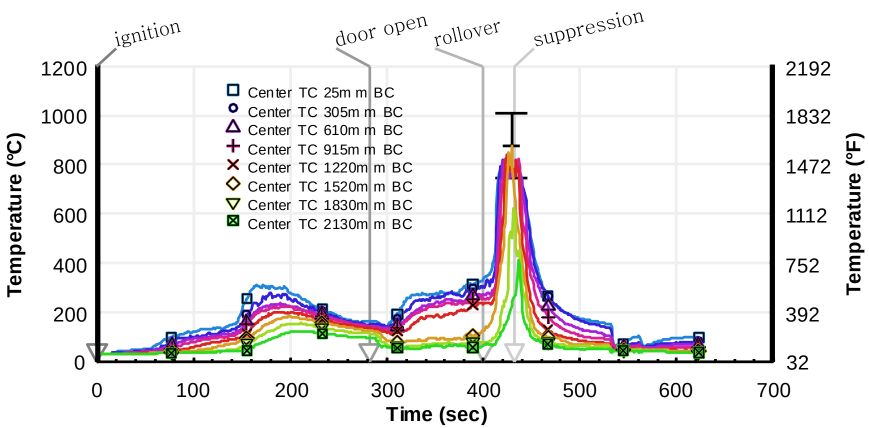


Energy: Approx. 800 W

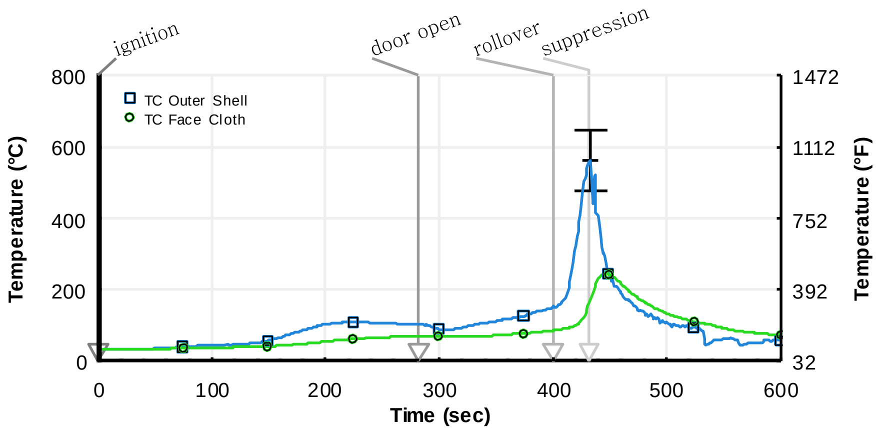
Total and Radiant Heat Flux



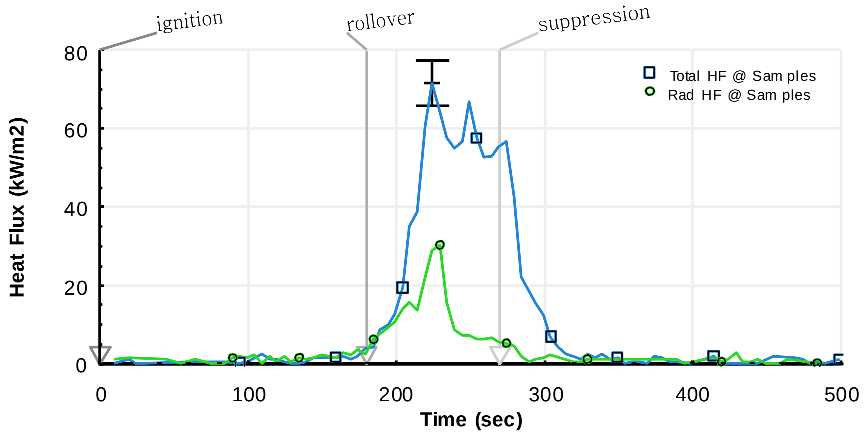
Temperature – Center of the Room



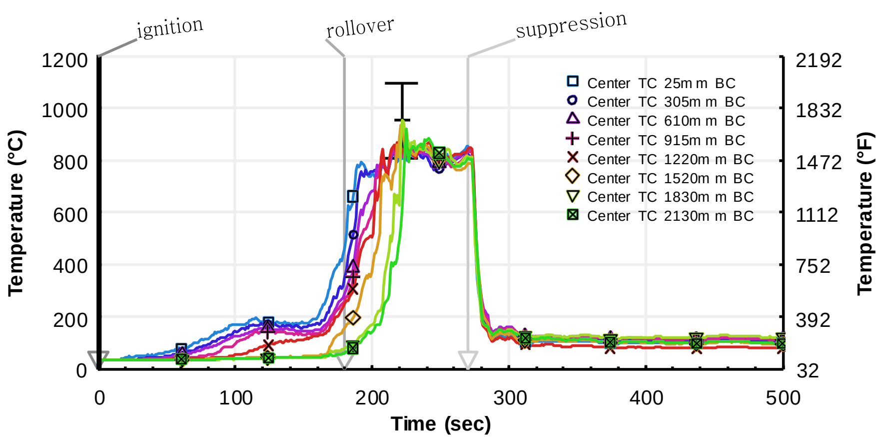
PPE Temperatures



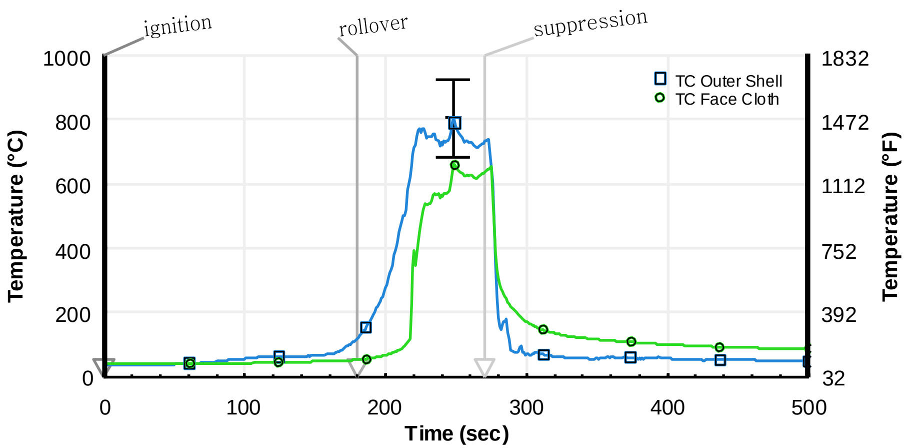
Total and Radiant Heat Flux

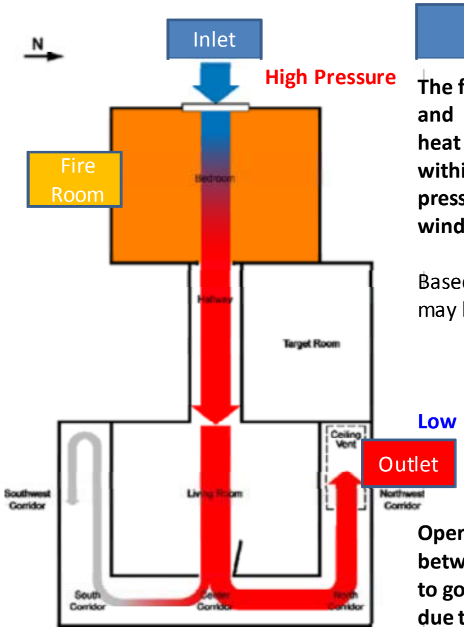


Temperature – Center of the Room



PPE Temperatures





Flow Path

The flow path is the volume between an inlet and an outlet that allows the movement of heat and smoke from the higher pressure within the fire area towards the lower pressure areas accessible via doors and window openings.

Based on varying building configurations, there may be several flow paths within a structure.

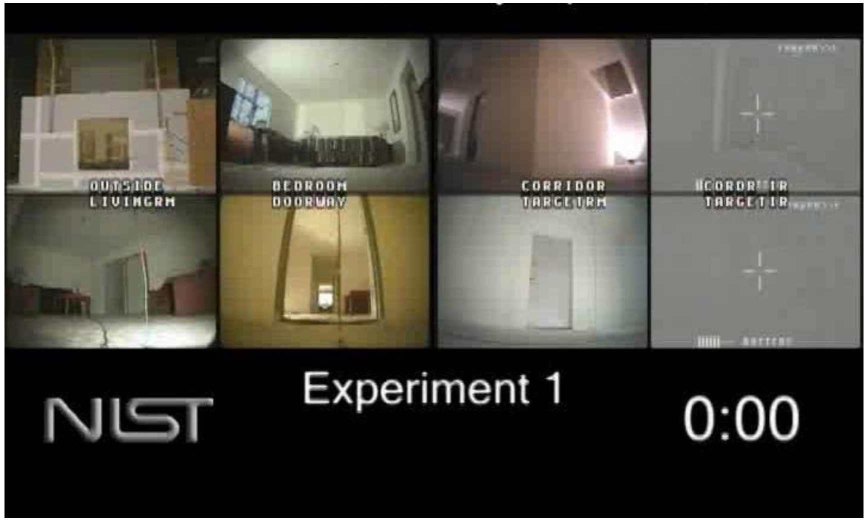
Low Pressure

Operations conducted in the flow path, between the fire and the where the fire wants to go, will place members at significant risk due to the increased flow of fire, heat and smoke toward their position.

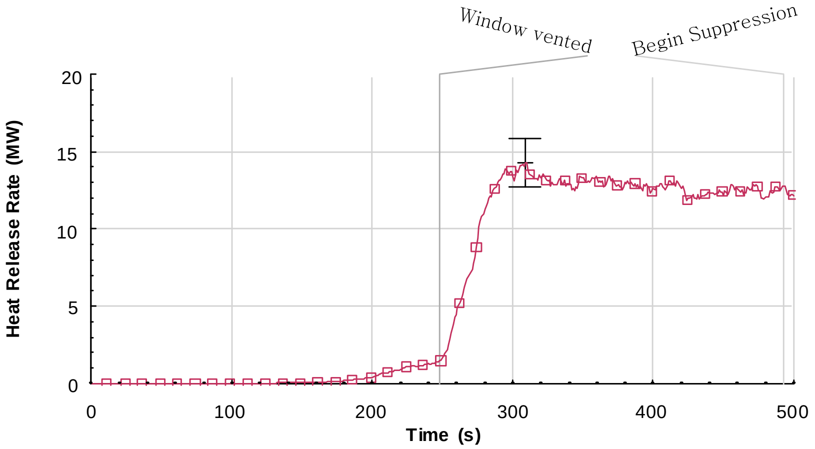
Heat Release Rates

Item	Avg. Peak HRR
Trash Container	30 kW
Chair	1.8 MW
Sofa	2.5 MW
Bed	4.3 MW

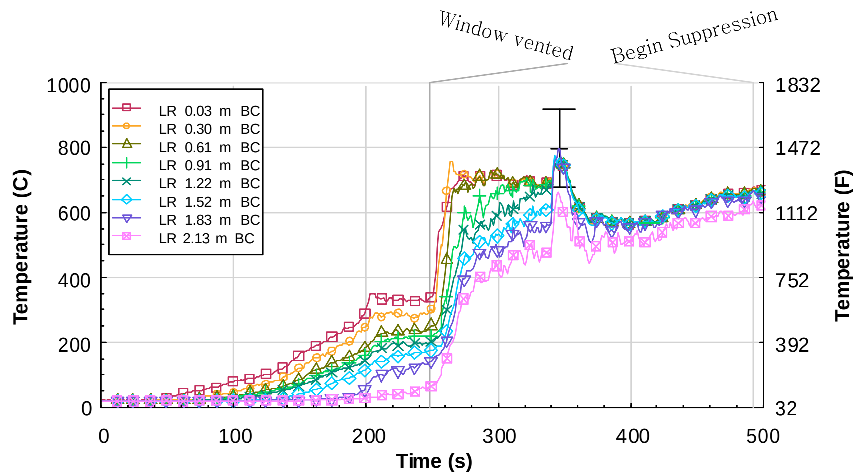
Fuel Load



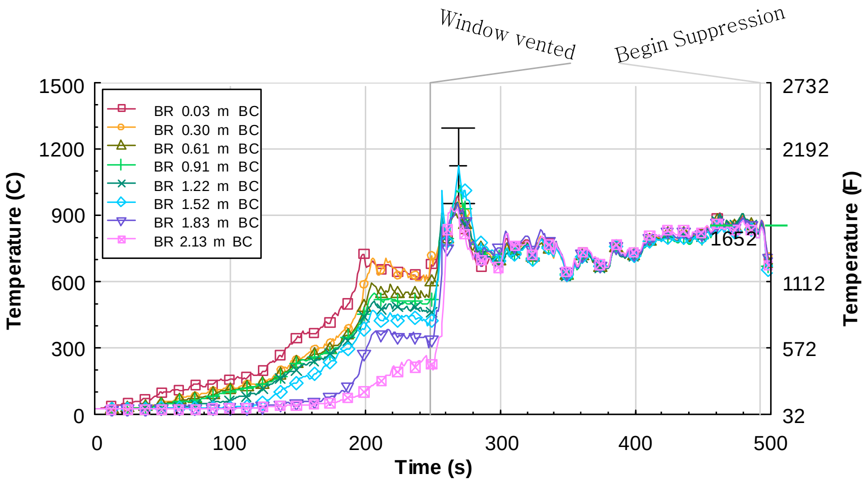
Impact of Ventilation on HRR
No Wind



Impact of Ventilation on Living Room Temperatures

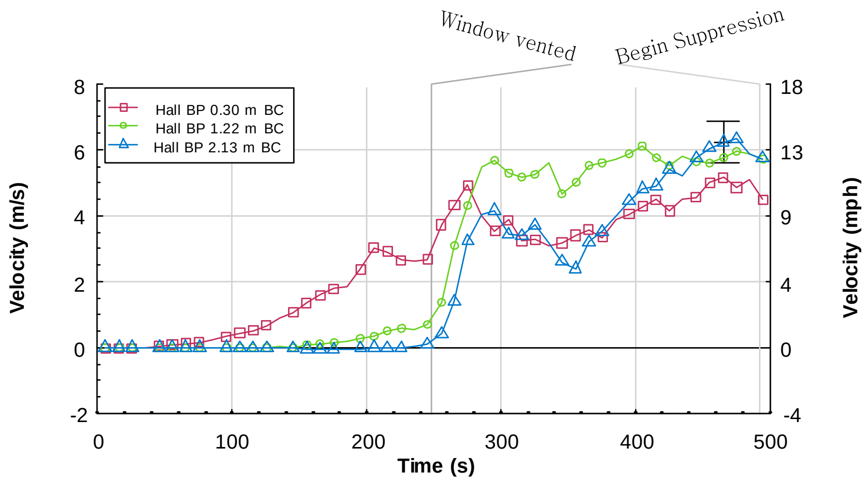


Impact of Ventilation Bedroom Temperatures

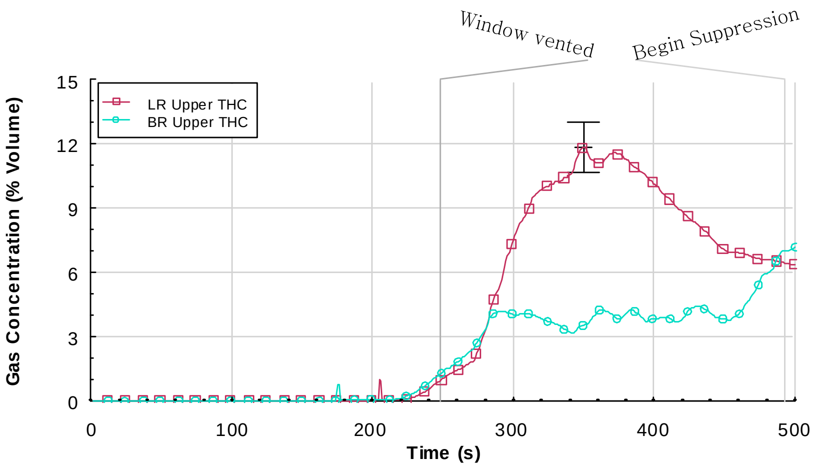


Velocity in the Hallway

This is a fire induced flow between the bedroom (room of origin) and the living room (downstream in the fire's flow path to the outlet)



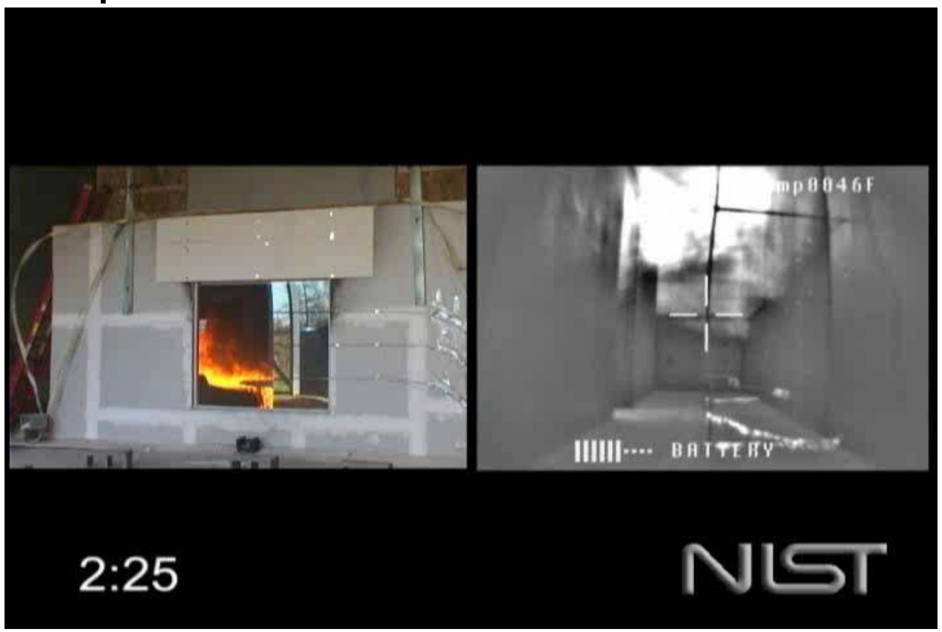
Impact of Ventilation on Total Unburned Hydrocarbon Generation



Neutral Plane

The interface at a vent, such as a doorway or a window opening, between the hot gas flowing out of a fire compartment and the cool air flowing into the compartment.

Impact of Wind on a Structure Fire



Neutral Plane

First Floor Fire **Basement Fire**

Townhouse Fires

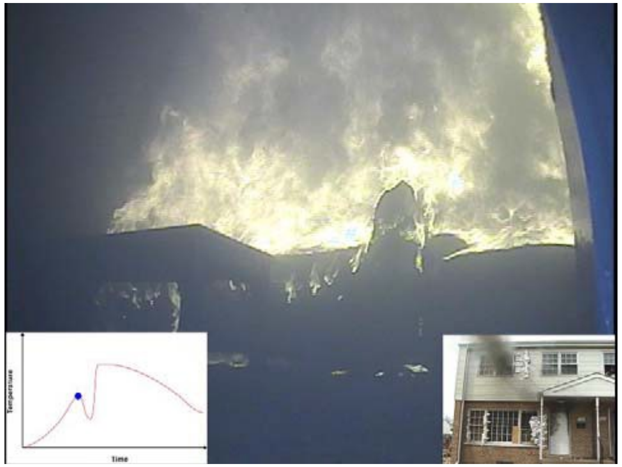
NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Venting Does Not Equal Cooling

Fire Development– Ignition

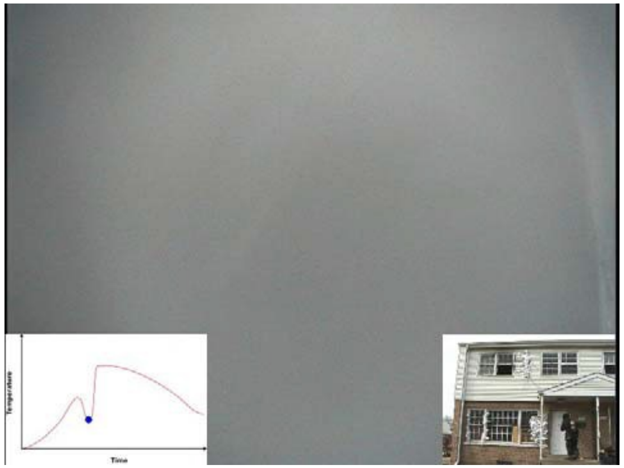
National Institute of Standards and Technology
U.S. Department of Commerce

First Fire Peak



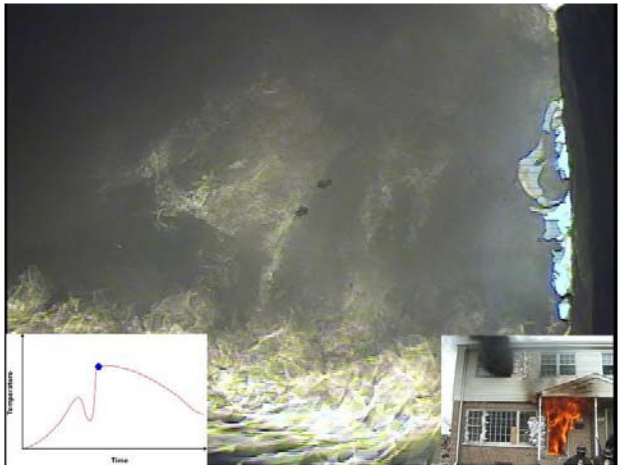
Growth

Temperatures drop more than 1000 F due to lack of oxygen.

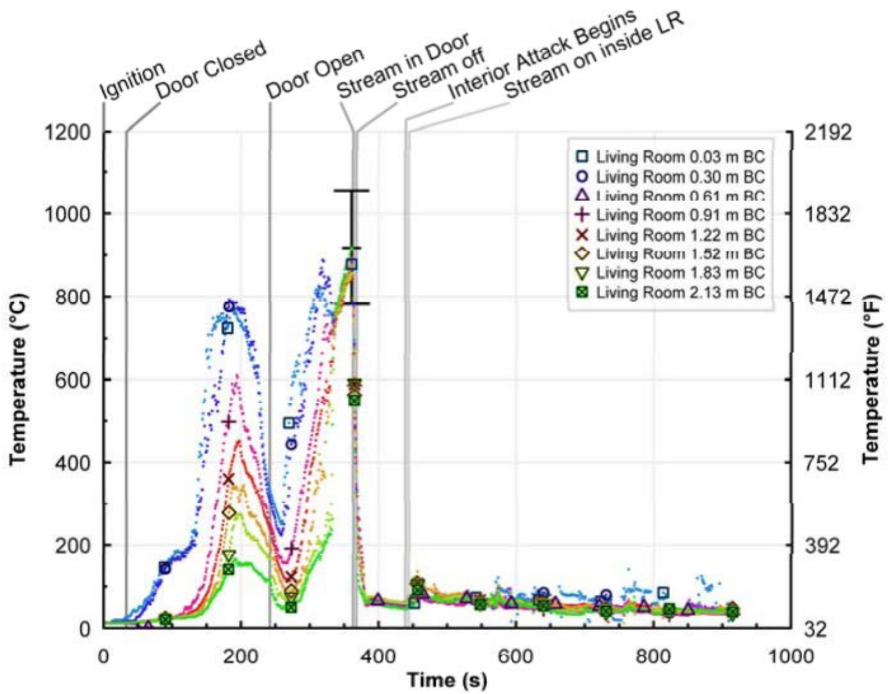


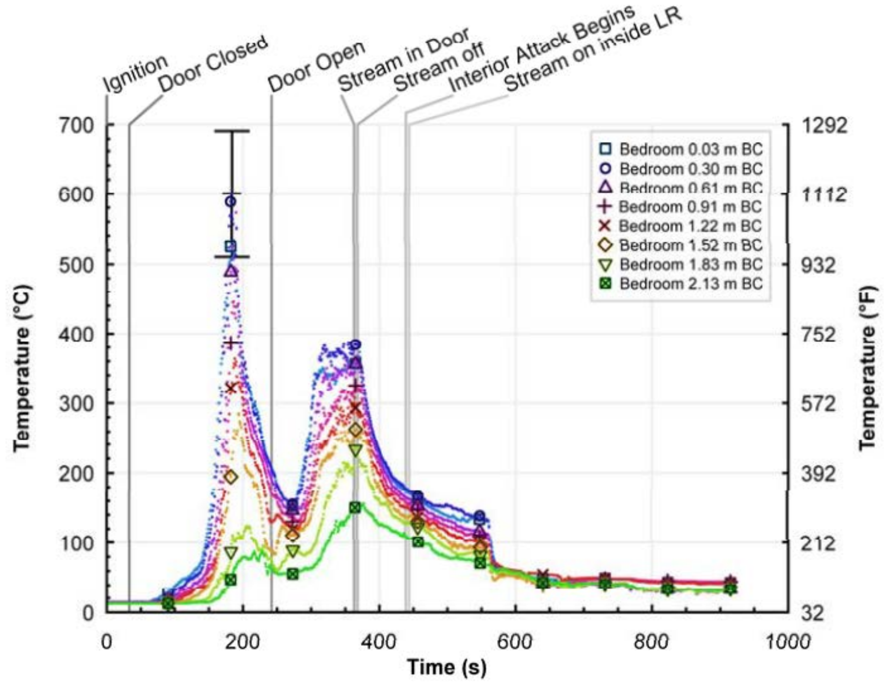
5 seconds after opening the front door

Fire fully developed 80 seconds after opening the front door



Post Fire





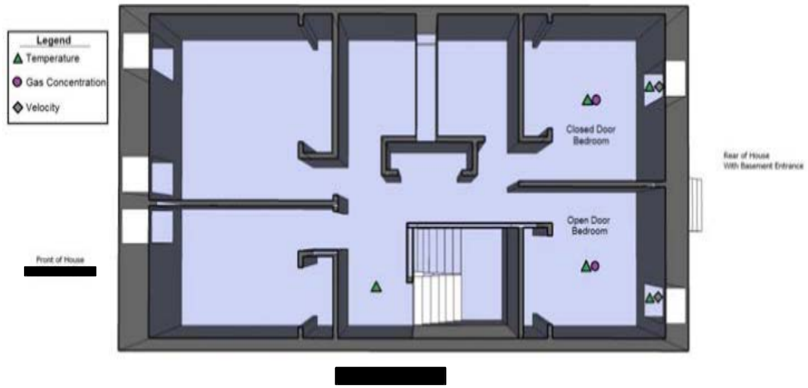
Row Homes

Scientific Research for the Development of More Effective Tactics

overnors Island Experiments July 2012

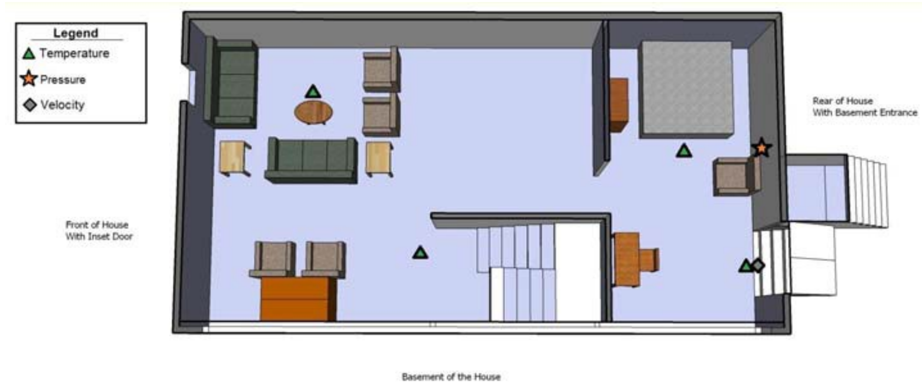
FDNY, NIST, UL

Second Floor – 4 bedroom



First Floor

Basement

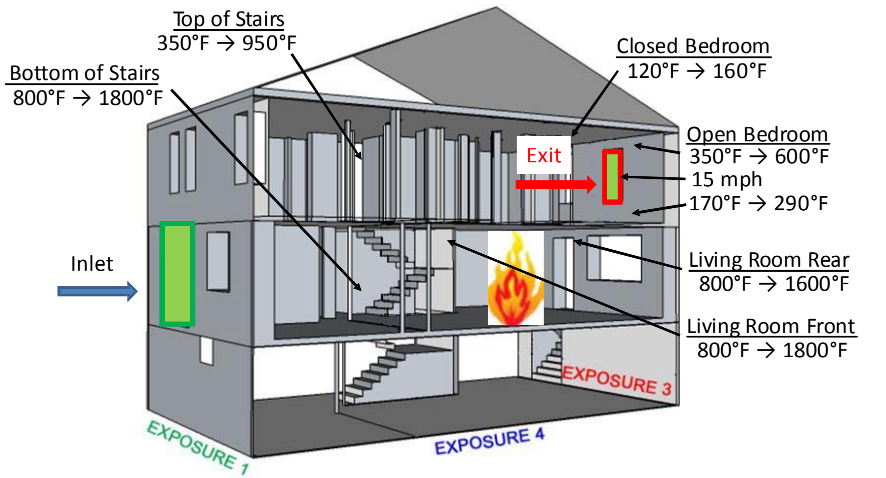


Impact of Closing Door During VEIS

Impact of flow path through Open Bedroom due to Window Ventilation

Flow Path from Open Front Door and exits through Open 2^{nd} Floor Bedroom Window
DC2 (642B)

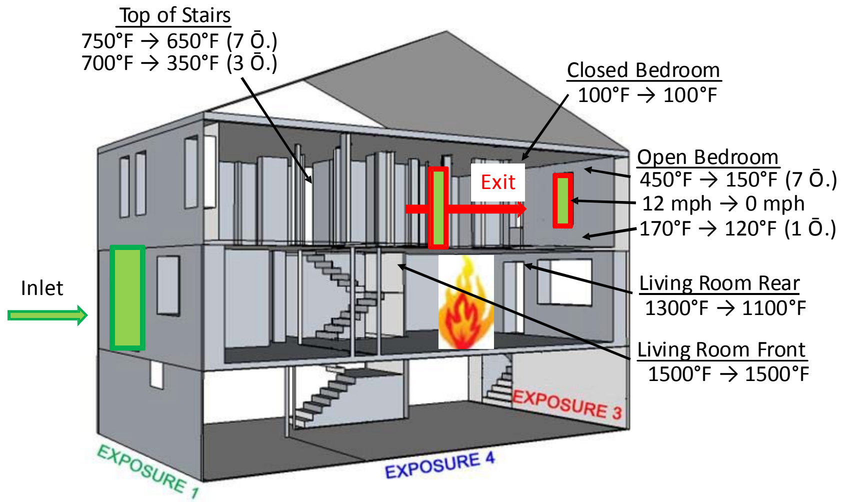
You MUST Control the Flow Path to Improve Victim Survivability



Impact of Closing Door During VEIS

Flow Path from Open Front Door and exits through Open 2^{nd} Floor Bedroom Window
DC3 (640C)

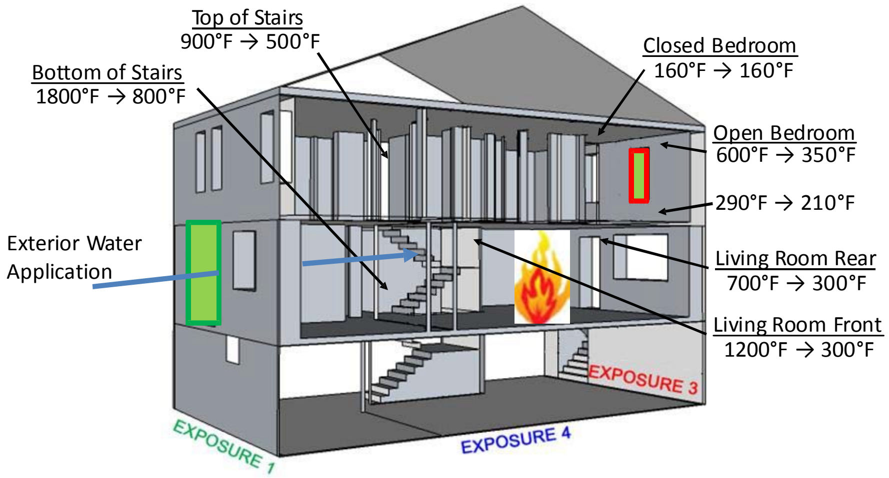
You MUST Control the Flow Path to Improve Firefighter Safety



Impact of Water through Open Front Door on Living Room Fire

DC 2 (642B) – 28 seconds of water

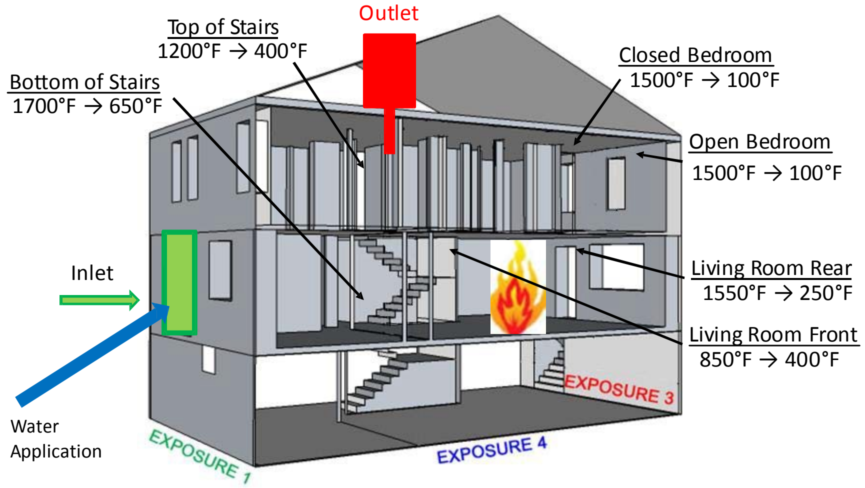
You Don't Have to be on top of the fire to flow water

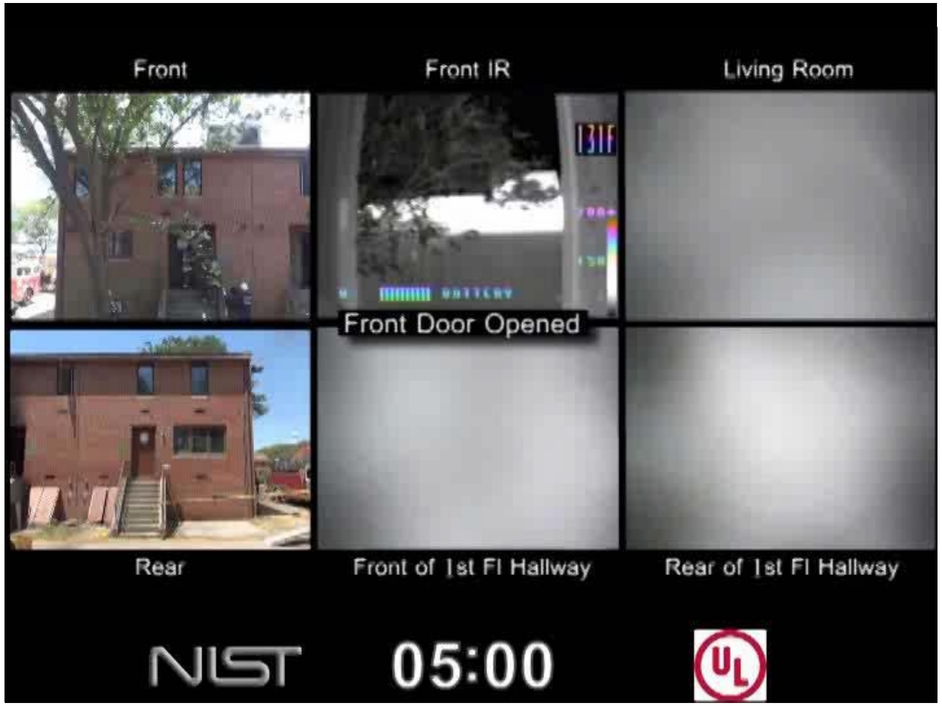


Impact of Water through Open Front Door With Vertical Vent

Scuttle (640A) – 25 seconds of water

Conditions improve everywhere from water on fire





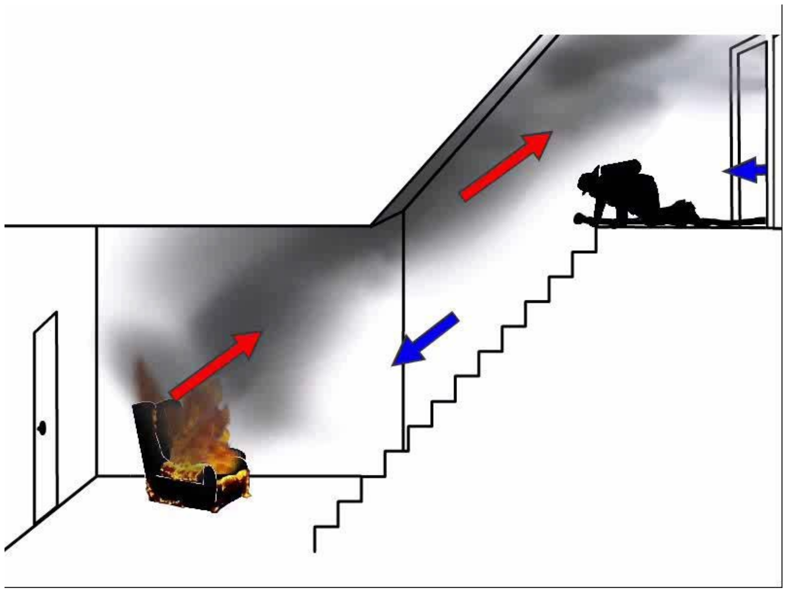
Basement Fire or Operating Above the Fire Floor

- The most effective and efficient fire attack is from the interior.
- Attack basement fires from the interior.
- Position FFs at the top of the stair to protect the search.

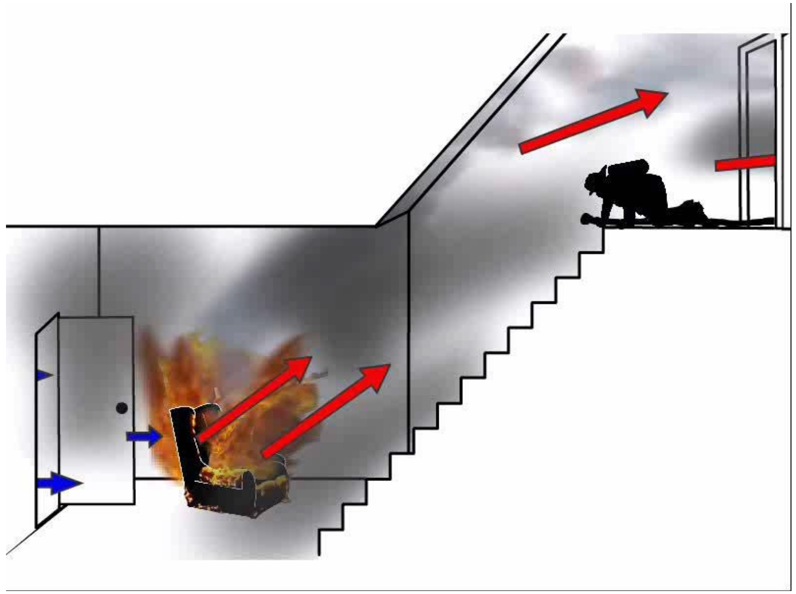
Basement Fires/Operating Above a Fire

- Why are these fires a challenge?
  - Ventilation limited with the potential for rapid change if windows/walkout door is present
  - Current SoPs, place FFs over the fire in combustible construction and position FFs in the exhaust portion of the flow path.

Basement Fire – Only vent on 1st Floor



Basement Fire – Basement and 1st Floor Vent

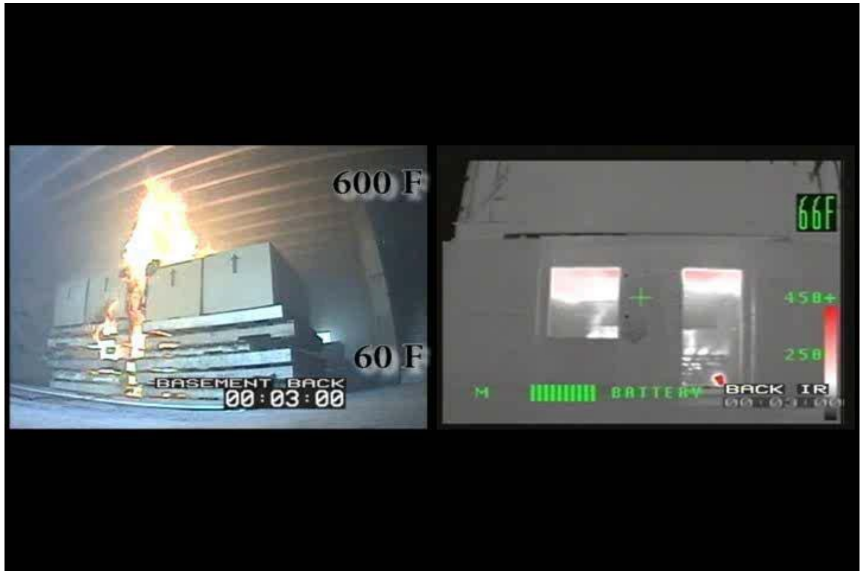


UL/NIST Basement Experiments

Front

Rear

Flooring Assemblies



Ref: Full-Scale Floor System Field and Laboratory Fire Experiments
Kerber (UL), Madrzykowski (NIST), Dalton (CFD) and Backstrom (UL)

Collapse Times

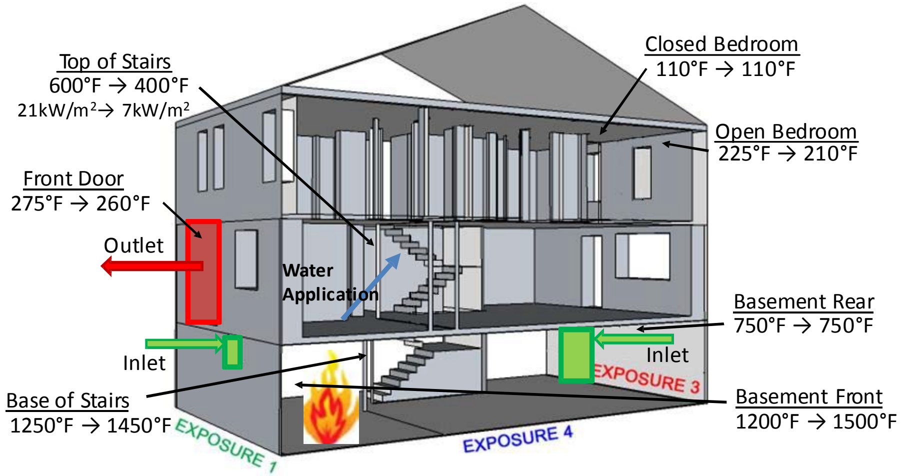
Experiment Number	Floor Support	Ventilation Description	Time from Ignition to Collapse	ΔT Time to Collapse – Time to fire spread to floor assembly.
1	Dimensional Lumber (2 x12)	Max Vent	11:09	7:11
2	Dimensional Lumber (2 x12)	Sequenced Vent	12:45	10:45
3	Engineered Wood I-Joist (12 in.)	Max Vent	6:00	2:45
4	Engineered Wood I-Joist (12 in.)	No Vent	6:49	4:06
5	Engineered Wood I-Joist (12 in.)	No Vent/No boxes	8:27	4:42
6	Engineered Wood I-Joist (12 in.)	Max Vent/Furnace DHS load	6:49	2:29
7	Steel C-Joist (12 in.)	Max Vent	8:15 (6:11 exceeds ISO 834:1)	5:15
8	Steel C-Joist (12 in.)	Sequenced Vent	14:04* (10:08 exceeds ISO 834:1)	10:32
9	Parallel Chord MPCWT	No Vent	6:08	3:42
10	Parallel Chord MPCWT	Max Vent	3:28	1:50

Post Fire Damage

Watch Your Back, Fire Extended Through the Kitchen Pipe Chases, Not the Interior Stairwell And Collapse Occurred in the Kitchen

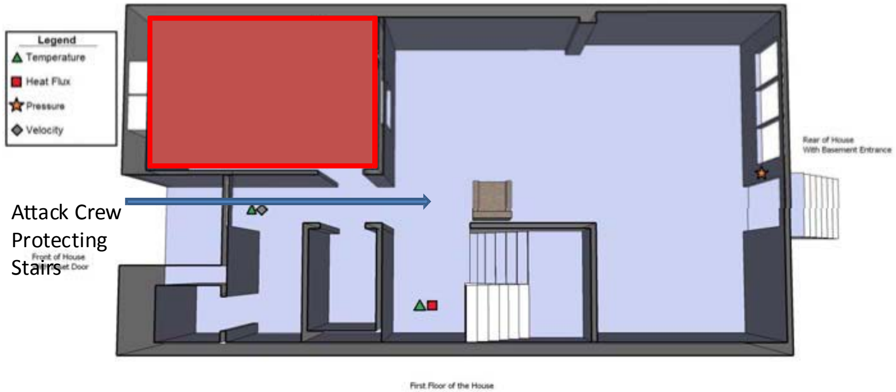
Protecting the Stairs

Flow Path from Open Front Door and exits through Open Front Door
Basement 3 (644C) – 25 seconds of water
Flowing Water into the 1st Floor Basement Door Has Little Effect



Protecting the Stairs

Flow Path from Open Front Door and exits through Open Front Door
Basement Fires (644C, 644A, 642F, 640F)
Watch Your Back, Fire Extended Through the Kitchen Pipe Chases, Not the Interior Stairwell And Collapse Occurred in the Kitchen

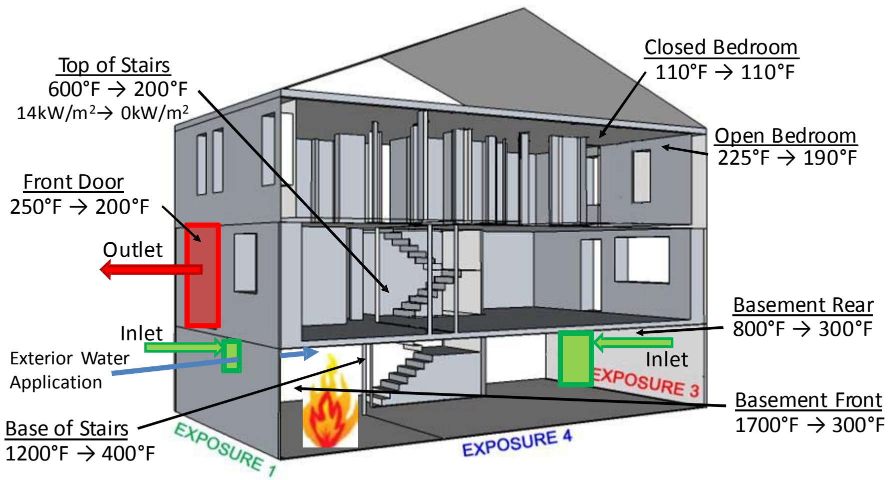


Pushing Fire

- Don't flow water from the outside – you will push fire.
- What does "pushing fire" mean?

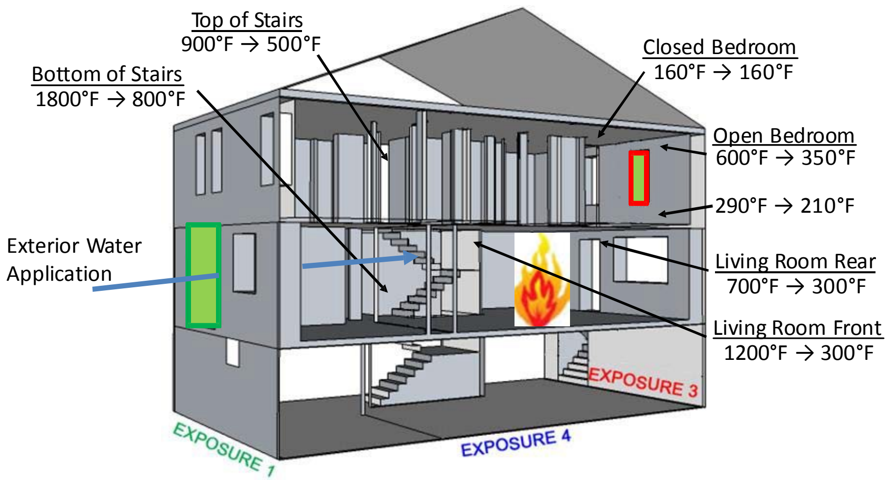
Water through the Basement Window

Flow Path from Open Basement Window and Bilco Door, exits through Open Front Door
Basement 3 (644C) – 60 seconds of water
Flowing Water on the Fire Improves Conditions Everywhere in the Structure



Impact of Water through Open Front Door on Living Room Fire

DC 2 (642B) – 28 seconds of water
You Don't Have to be on top of the fire to flow water



ISFSI THINKING FIREFIGHTERS

DO IT DIFFERENT

Spartanburg, SC
January 2013
May 2014

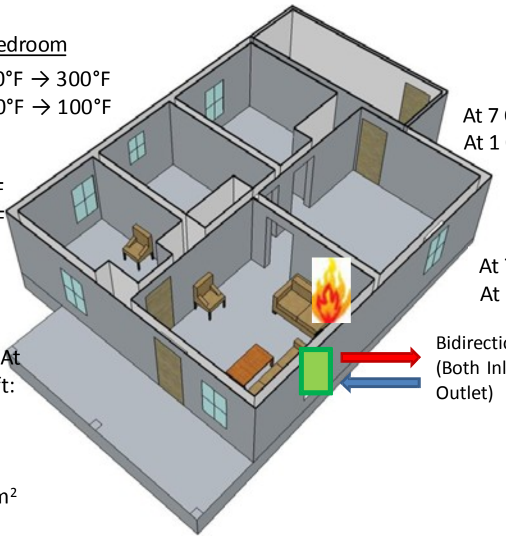
Impact of Venting the Living Room Window

214 Folsom St. Experiment 1

Rear Bedroom
At 7 Ō: 300°F → 300°F
At 1 Ō: 100°F → 100°F

Middle Bedroom
At 7 Ō: 300°F → 300°F
At 1 Ō: 100°F → 100°F
7 kW/m² → 5 kW/m²

Front Bedroom
At 7 Ō: 120°F → 120°F At 1 Ō: 70°F → 70°F At 3 ft: $20\%\ O_2 \rightarrow 20\%\ O_2$
$1\%\ CO_2 \rightarrow 1\%\ CO_2$
0% CO → 0% CO
0 kW/m² → 0 kW/m²



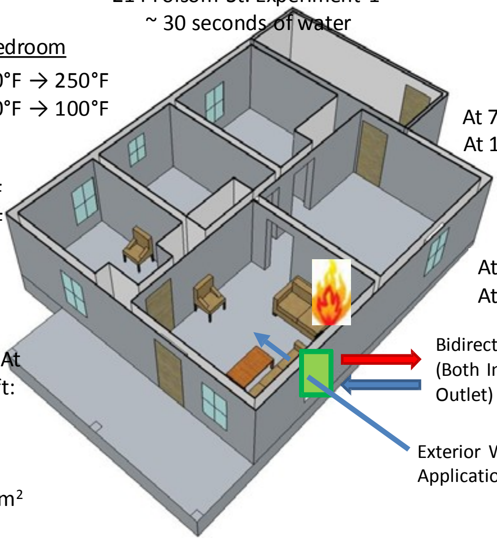
Kitchen
At 7 Ō: 400°F → 450°F
At 1 Ō: 100°F → 100°F

Living Room
At 7 Ō: 600°F → 700°F
At 1 Ō: 200°F → 200°F

Bidirectional Flow (Both Inlet and Outlet)

Impact of Exterior Attack through Living Room Window with no other Ventilation

214 Folsom St. Experiment 1
~ 30 seconds of water



Rear Bedroom
At 7 Ō: 300°F → 250°F
At 1 Ō: 100°F → 100°F

Middle Bedroom
At 7 Ō: 300°F → 250°F
At 1 Ō: 100°F → 100°F
5 kW/m² → 4 kW/m²

Front Bedroom
At 7 Ō: 120°F → 120°F At 1 Ō: 70°F → 70°F At 3 ft:
20% O_2 → 20% O_2
1% CO_2 → 1% CO_2
0% CO → 0% CO
0 kW/m² → 0 kW/m²

Kitchen
At 7 Ō: 450°F → 300°F
At 1 Ō: 100°F → 100°F

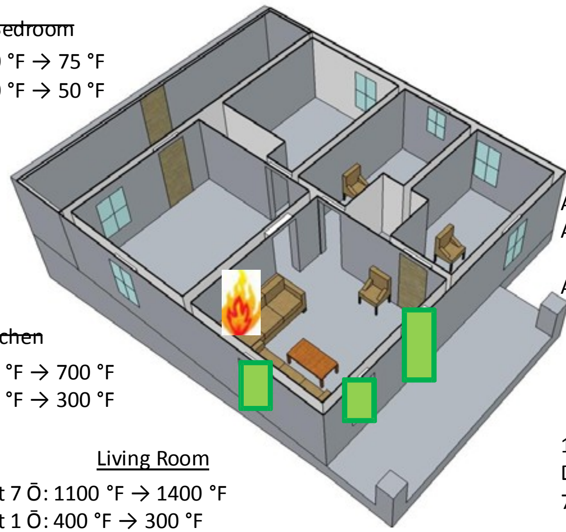
Living Room
At 7 Ō: 700°F → 100°F
At 1 Ō: 200°F → 70°F

Bidirectional Flow (Both Inlet and Outlet)

Exterior Water Application

Impact of Opening the Front Door and Windows

215 Folsom St. Experiment 1



~~Rear Bedroom~~
At 7 Ō: 70 °F → 75 °F
At 1 Ō: 50 °F → 50 °F

~~Kitchen~~
At 7 Ō: 500 °F → 700 °F
At 1 Ō: 200 °F → 300 °F

Living Room
At 7 Ō: 1100 °F → 1400 °F
At 1 Ō: 400 °F → 300 °F

Middle Bedroom
At 7 Ō: 600 °F → 700 °F
At 1 Ō: 200 °F → 300 °F
At 3 ft: 4 kW/m² → 4 kW/m²

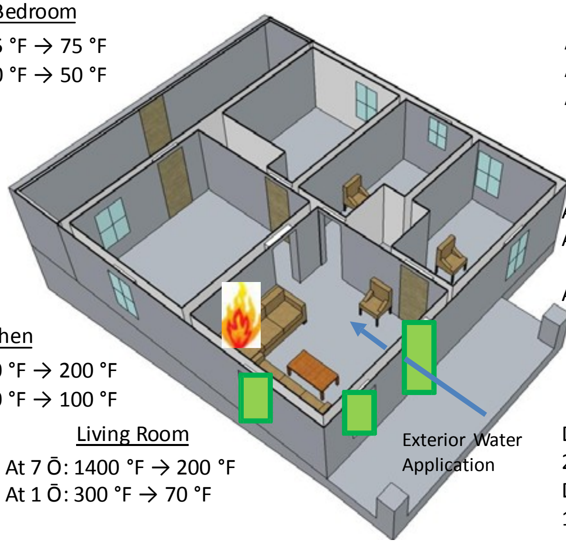
Front Bedroom
At 7 Ō: 80 °F → 90 °F
At 1 Ō: 50 °F → 50 °F

At 3 ft: 20% O_2 → 20% O_2
0% CO_2 → 0% CO_2
0% CO → 0% CO
3 kW/m² → 3 kW/m²

Door Knob Inside Room:
100 °F → 200 °F
Door Knob Exposed to Fire:
700 °F → 1200 °F

Impact of Exterior Water through the Front Door

215 Folsom St. Experiment 1
~ 75 seconds of water



Rear Bedroom
At 7 Ō: 75 °F → 75 °F
At 1 Ō: 50 °F → 50 °F

Kitchen
At 7 Ō: 700 °F → 200 °F
At 1 Ō: 300 °F → 100 °F

Living Room
At 7 Ō: 1400 °F → 200 °F
At 1 Ō: 300 °F → 70 °F

Exterior Water Application

Middle Bedroom
At 7 Ō: 700 °F → 200 °F
At 1 Ō: 300 °F → 100 °F
At 3 ft: 4 kW/m² → 1 kW/m²

Front Bedroom
At 7 Ō: 90 °F → 80 °F
At 1 Ō: 50 °F → 50 °F

At 3 ft: 20% O_2 → 20% O_2
0% CO_2 → 0% CO_2
0% CO → 0% CO
3 kW/m² → 1 kW/m²

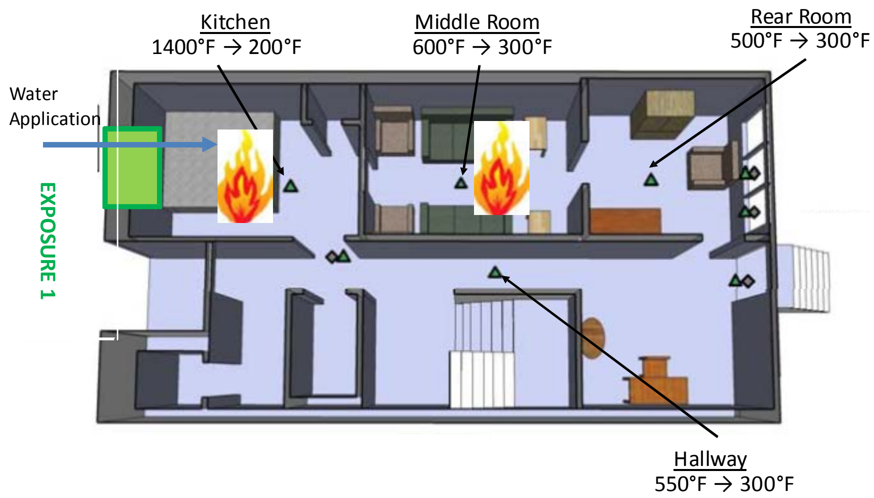
Door Knob Inside Room:
200 °F → 100 °F
Door Knob Exposed to Fire:
1200 °F → 300 °F

Single Family Home
Importance of Size-Up

- Front
- Rear

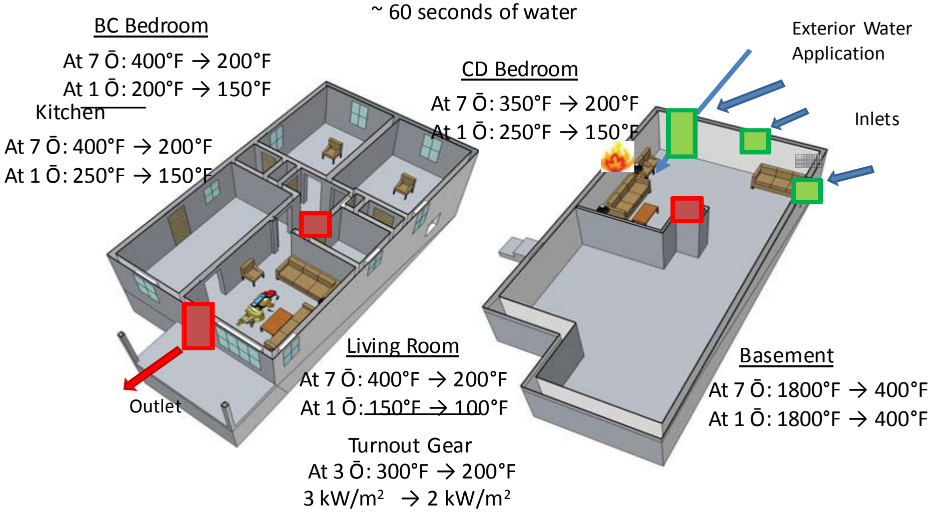
Water in a Window Does Not Push Fire

Flow Path from Kitchen Windows
Rail Road Flat 2 (642A) – 14 Seconds of Water
Fire Cannot be Pushed – No Flowpath



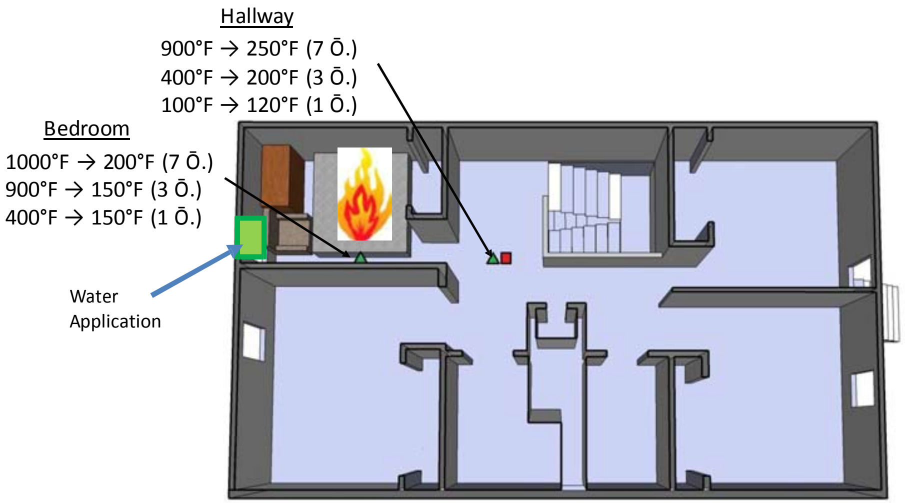
Impact of Exterior Attack through Basement Door

227 Folsom St. Experiment
~ 60 seconds of water

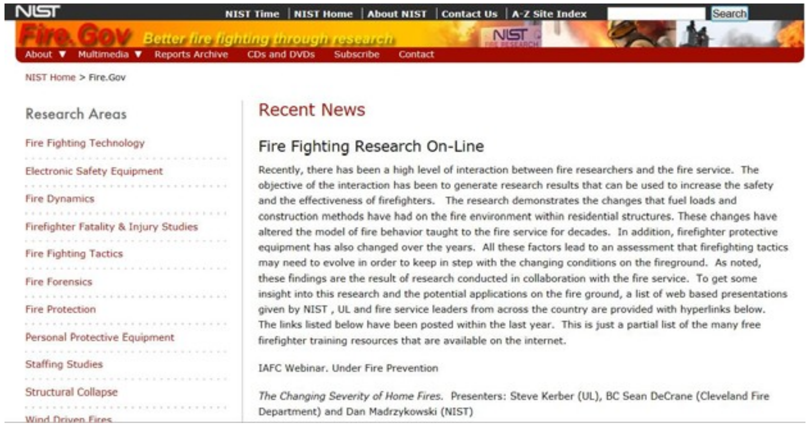


Exterior Water into 2nd Floor

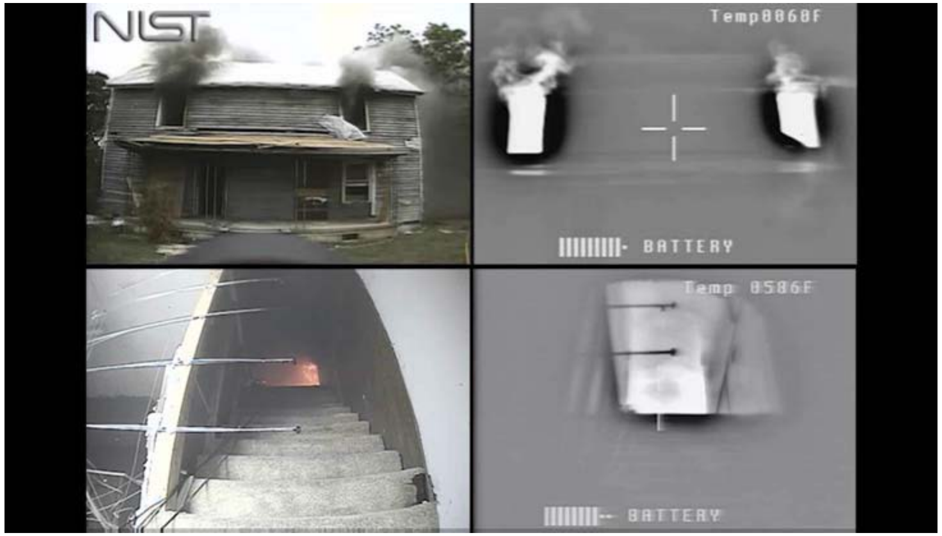
Flow Path from Bedroom Window and 1st Floor
Can Test 2 (644D) – 22 Seconds of Water



www.nist.gov/fire
Reports, Presentations and Videos



Exterior Attack - SS vs Fog



Technology Transfer - Online Training Programs

http://learn.isfsi.org/

www.ULfirefightersafety.com

CFI TRAINER.NET

Fire Dynamics
Station Night Club Fire Analysis
Super Sofa Store Fire Analysis
Thermometry – Underdevelopment

www.cfitrainer.net

YOUTUBE IAFFTV *Fire Behavior and Tactical Considerations* by NIST and UL Time to Survival, High-rise and Residential Deployment Studies

ALIVE : Web-Based and Mobile Applications

iPhone iPad Android

www.poly.edu/fire

Wind Driven High Rise Fires
Modern Residential Fires
Fire Dynamics

http://www.lacofdturnout.com/

www.FSTARtraining.org

www.modernfirebehavior.com

Questions

www.nist.gov/fire

Follow the Fire Fighting Technology Group on Twitter
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madrzy@nist.gov

NISTIR 6510

Simulation of the Dynamics of the Fire at 3146 Cherry Road NE, Washington D.C., May 30, 1999

Daniel Madrzykowski and Robert L. Vettori

CD Version prepared by:
William D. Walton and Glenn P. Forney

April 2000

Fire Safety Engineering Division
Building and Fire Research Laboratory
National Institute of Standards and Technology

Learning Objectives:
1)Ventilation Induced Flashover
2) Flow Path
3)Speed of transition to flashover

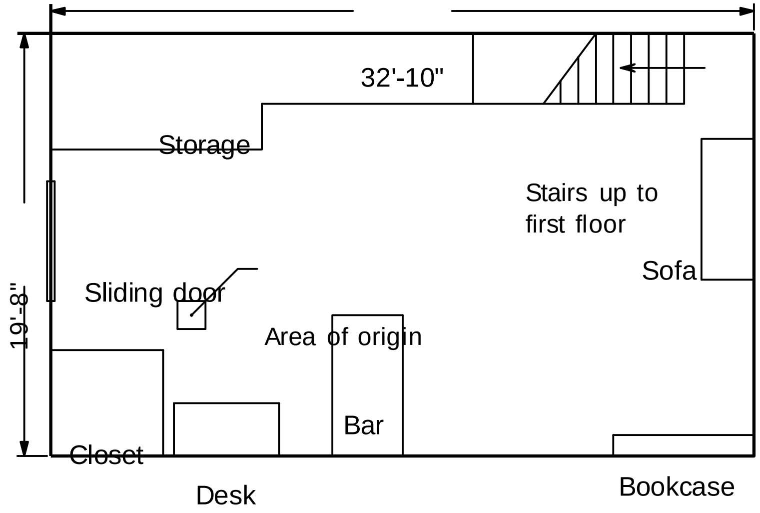
Front View

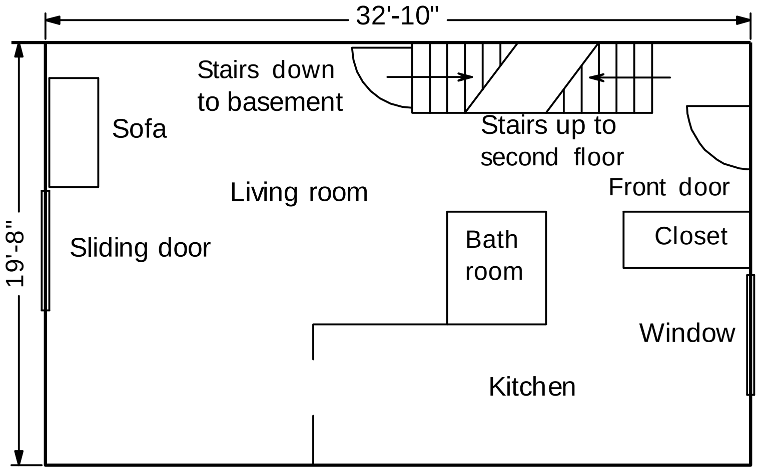
Rear View

First Floor Hallway

Stairway to Second Floor

Living room

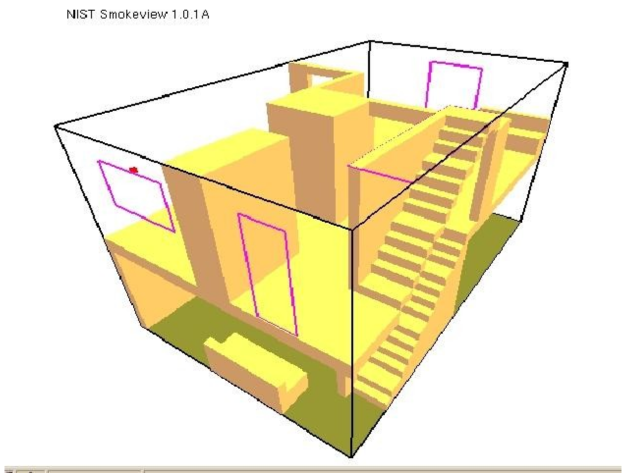




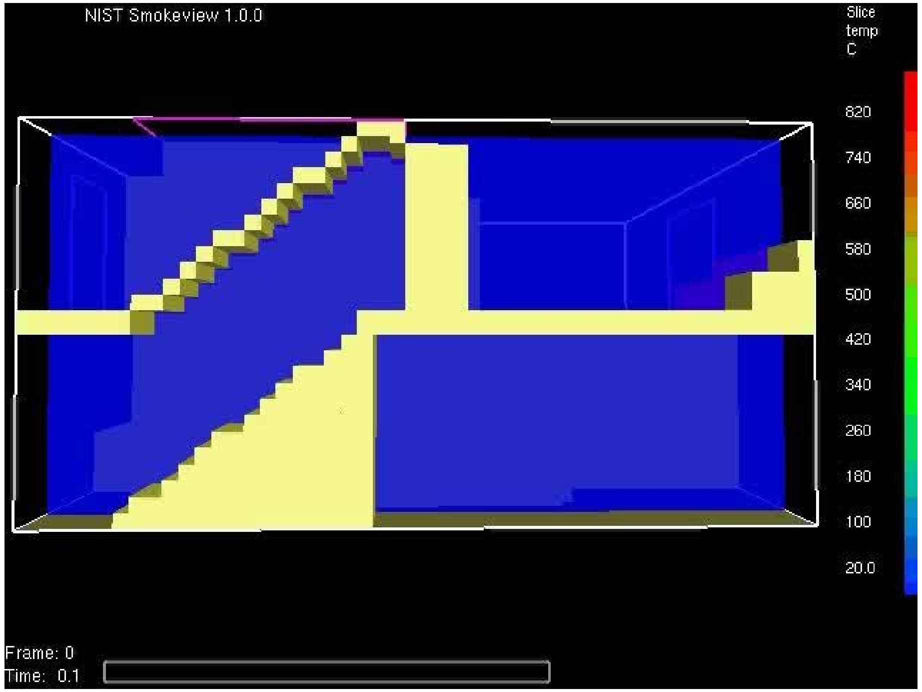
Reconstruction Committee

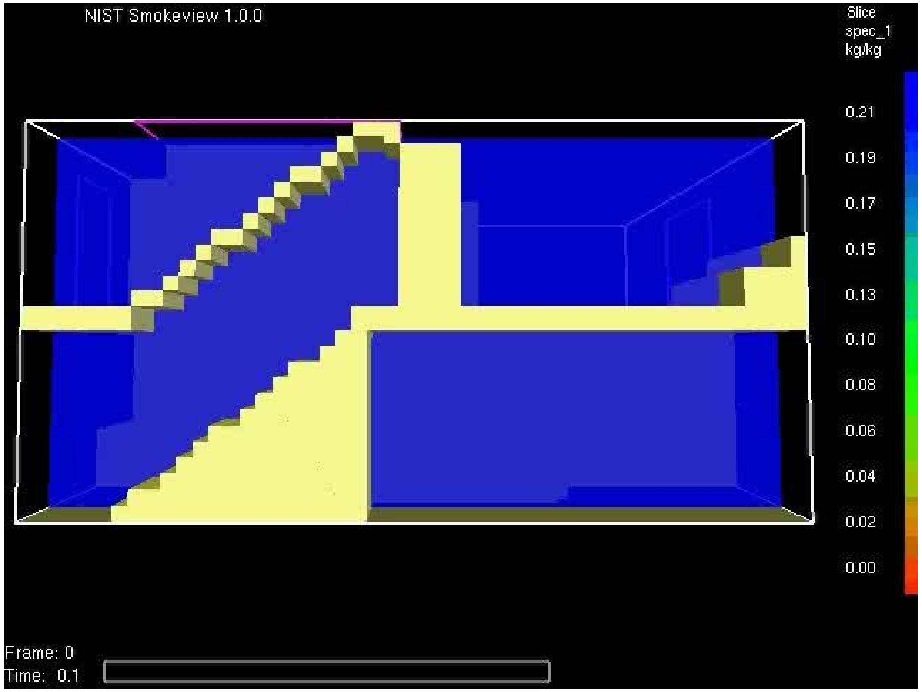
- 5 FFs on 1st floor – significantly different injuries
- Room where LODDs occurred had limited thermal damage
- Both fatalities had charged lines – never opened them

3-D Geometry



Incident Time		Simulation Time
00:17:00	First call reporting fire	
00:24:00	FFs enter front door	0 s
00:26:00	1st Flr Front Window open	120 s
00:26:20	Basement door half open	140 s
00:26:40	Basement door fully open	160 s
00:27:00	Basement “fully involved”	200 s
00:28:00	FFs on 1st flr injured	240 s
00:28:40	Fire extending to 1st flr	280 s
00:29:00	(End of simulation)	300 s





Simulation of the Fire at 1100 Prospect Place
12-19-2011
Can You Vent Enough?

Adam Barowy
Daniel Madrzykowski
NIST- Fire Research

National Institute of Standards and Technology
U.S. Department of Commerce

Prospect Place

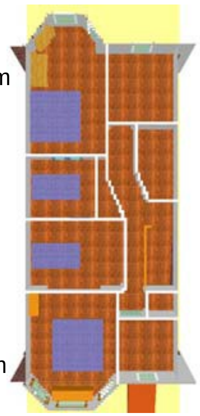
0904: 911 call received

0911: Flames observed extending from
Two rear window on the top floor
Front Window , top floor, exp 2 side,
Vented
Stairwell skylight vented
Scuttle opened

0912: Front Window , top floor, center, vented.
Bathroom skylight vented
Bedroom skylight vented

0913: Firefighter bailing out of front Window, top floor, exp 4 side.

Floor plan



Rear Room
(Room of fire origin)

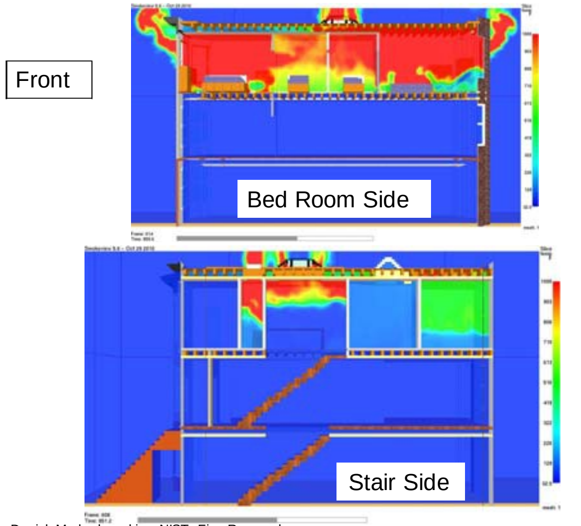
Front Room
(Room where firefighters were burned)

Model Timeline

(min:sec)

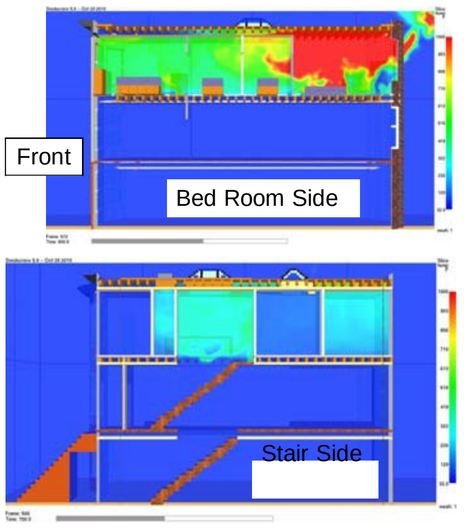
- 3:40 – Front Door Open
- 5:50 – Rear windows start to fail
- 11:40 – Luan Door opened
- 12:40 – Front Window, Bottom Pane – Exp 2 side
- 12:55 – Stairwell Skylight
- 13:05 – Front Window Top Pane – Exp 2 side
- 13:20 – Scuttle opened
- 13:50 – Center Window, Bottom pane opened
- 13:50 - Bedroom skylight
- 14:10 – Center Window, Top pane opened
- 14:10 – Bathroom Skylight opened
- 14:35 – Front Window, Exp 4 side opened

After Roof (44 sq ft) and Window (3 in Front, 2 in Rear) Ventilation



Adam Barowy, Daniel Madrzykowski, NIST- Fire Research

Before Tactical Roof and Window Ventilation

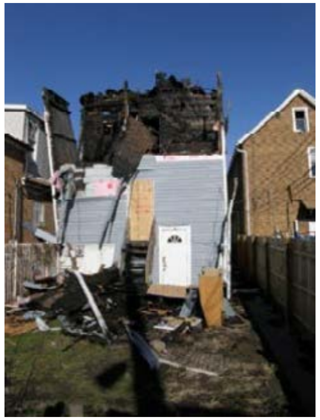


Adam Barowy, Daniel Madrzykowski, NIST- Fire Research

High Pressure to Low Pressure Chicago, IL November 2, 2012

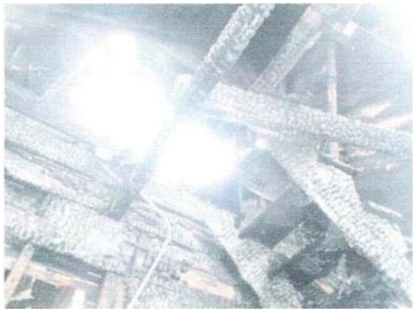
Side A

Side C



Porch Stairway

2nd Floor to Attic

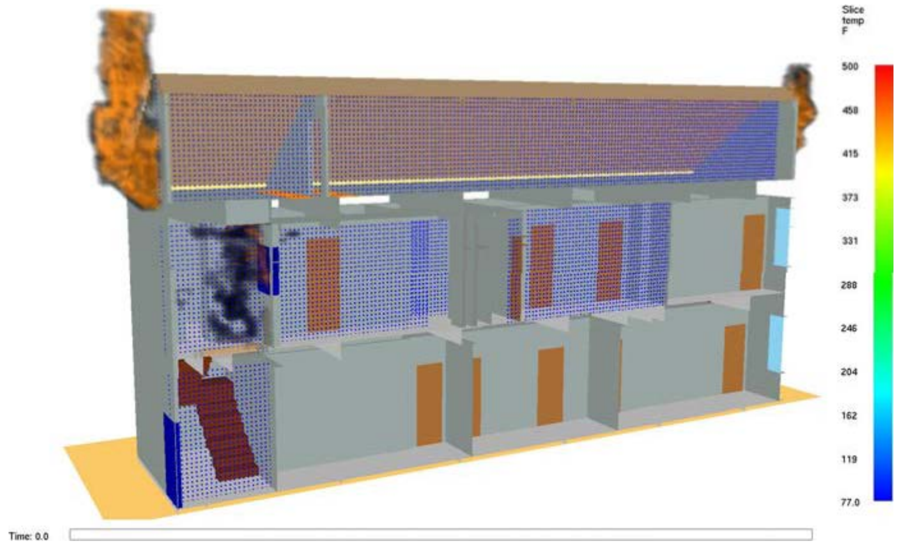


1 St Floor

Attic

Hallway

Doorway to Porch

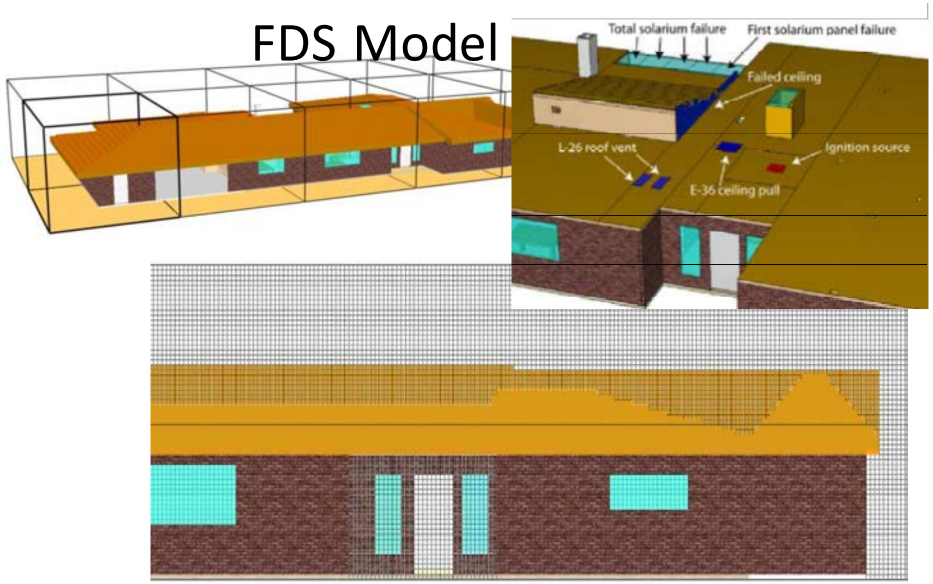


Limited Thermal Damage in Kitchen

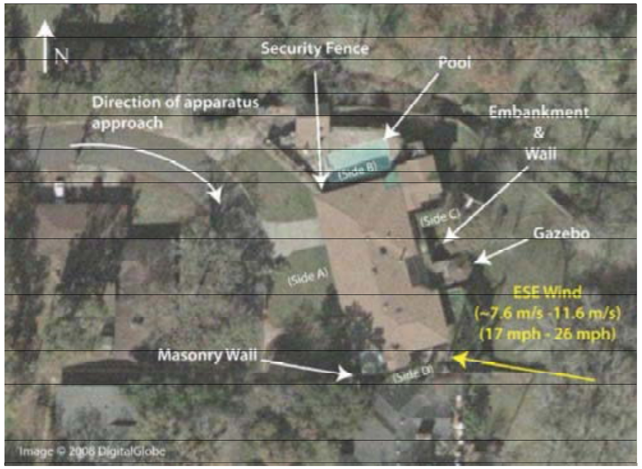
Spartanburg Doors

Spartanburg Doors

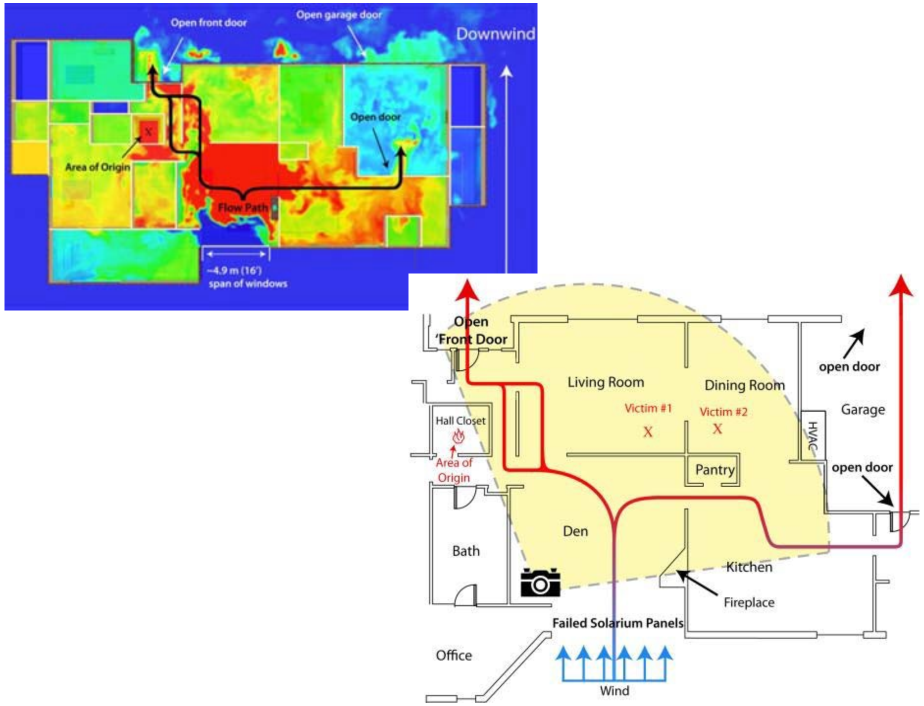
FDS Model



Single Family Home – Houston Wind Driven Fire

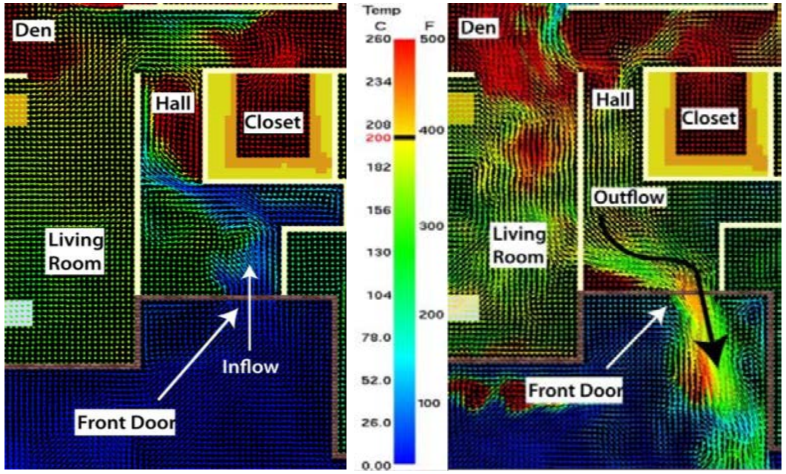


Reference: Barowy, A., and Madrzykowski, D., Simulation of the Dynamics of a Wind-Driven Fire in a Ranch-Style House – Texas, NIST-2011.

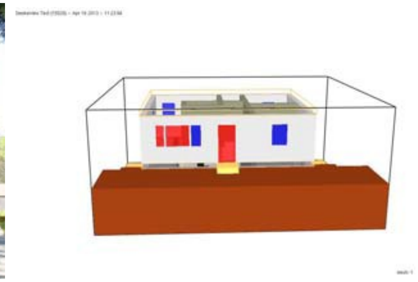


Flow reversal at the front door

10 s before glass failure **10 s after glass failure**



Side A

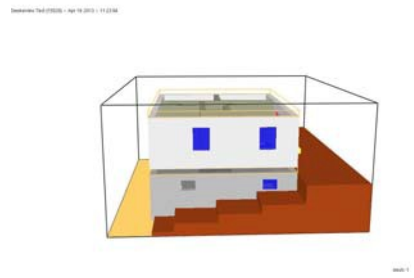


57th Ave Fire - Fire Dynamic Simulator (FDS) Model

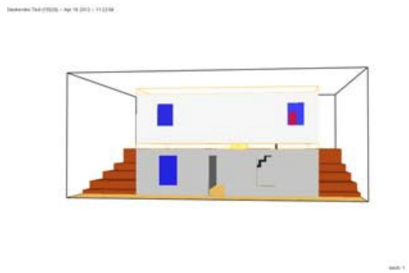
Focus on the formation of the flow path between the openings in the basement on upwind side (inlet) and the front door on the downwind side (exhaust).

Craig Weinschenk
Daniel Madrzykowski
NIST

Side B



Side C



Wood Floor Assembly

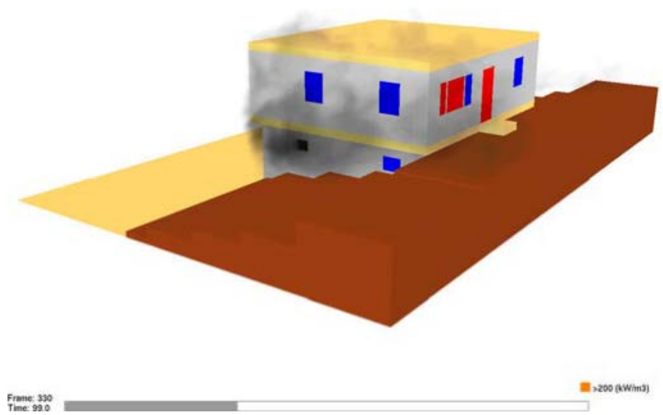
Basement – Area of Origin

Wood Stairs

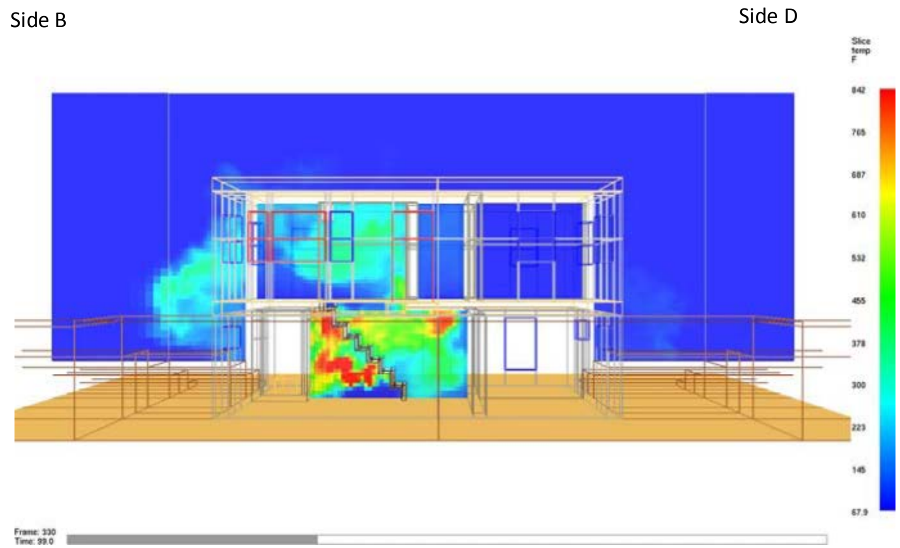
Wood Cabinets in Bathroom and Basement Kitchen

1st Floor Living Room

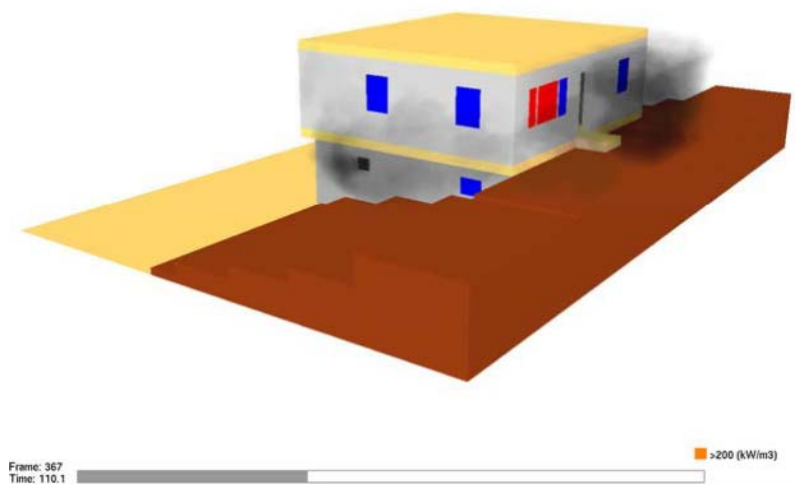
AB Corner View, 1 s before front door opened



Side A, 1 s before front door opened



AB Corner View, 10 s after front door opened



Side A, 10 s after front door opened