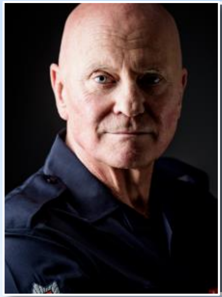
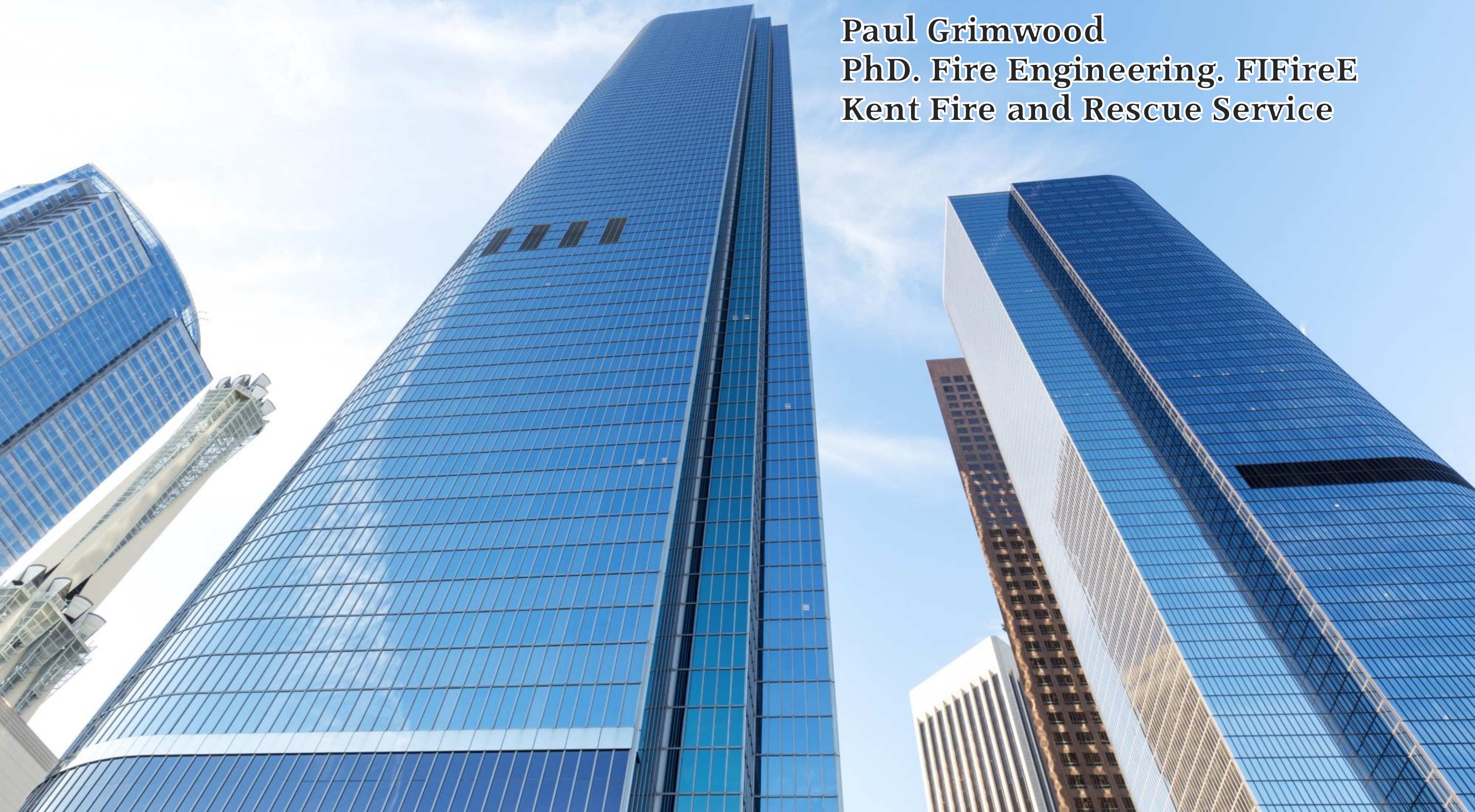


HIGH-RISE FIREFIGHTING

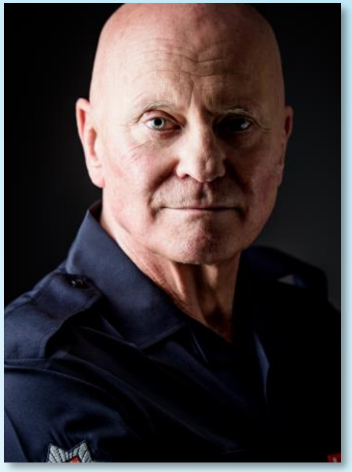
Evidence based Research 1990-2019

Paul Grimwood
PhD. Fire Engineering. FIFireE
Kent Fire and Rescue Service



"If history repeats itself, and the unexpected always happens, how incapable must humankind be of learning from experience"

George Bernard Shaw



"The instance when one of our high-rise buildings is engulfed in flames may never present itself. However, as the metropolitan skyline forms, the skyscraper effect becomes more prominent and the chances of such a conflagration increases.

It is important that we learn from those who have experienced such fires so that our attack plan is capable of functioning to effect.

If we do not act to rectifying our failings, then only a disaster will teach us our wrongs".

Paul Grimwood
Fire Magazine
November 1990

RESCUE 1 MANHATTAN NEW YORK CITY 1990

In the summer of 1990 I was detached for several weeks from London Fire Brigade to work with Rescue 1 in New York City, Task Force 3 in Los Angeles and Squad 1 in Chicago, to study high-rise firefighting. I worked at close quarters with several highly specialist and knowledgeable firefighters on R1 in NYC who later tragically died in the collapses of the WTC in 2001.

These firefighters taught me a lot and I feel greatly indebted to them. In fact I learned so much that I wrote several books and articles about the knowledge they handed down. There is still so much to learn, in particular the ability to establish a functional command structure from the arrival of first on-scene firefighters through to a working fire, coupled with their ability to deal with information overload and make tactical decisions based on pre-determined triggers and an improved level of situational awareness.

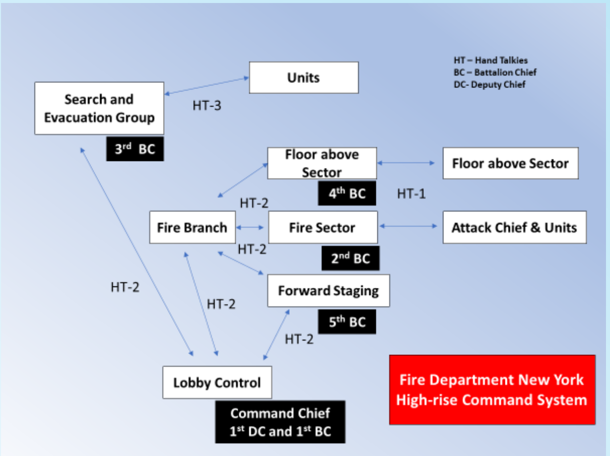
Further, the ability to protect egress and access routes from smoke infiltration; to transport adequate amounts of firefighting water to upper levels and to communicate more effectively by optimising clear and precise information exchange.

The research remains ongoing @ 2019 LinkedIn
Paul Grimwood – Kent Fire and Rescue Service

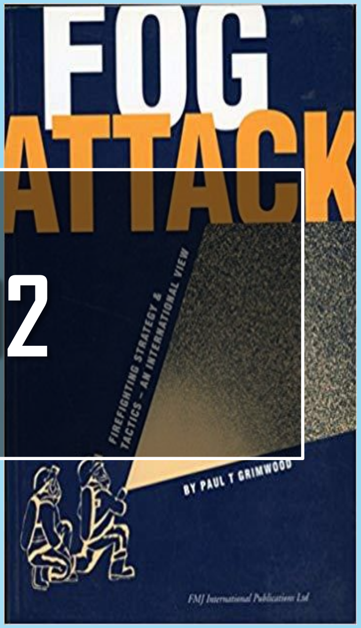
HIGH-RISE FIREFIGHTING 2019

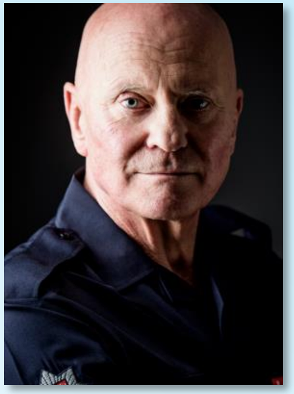
1. INCIDENT COMMAND FUNCTIONS
2. R.I.C.E COMMAND DECISION TOOL
3. STAIRWELL PROTECTION
4. ADEQUATE FIREFIGHTING WATER
5. 150mm RISING FIRE MAINS
6. 51mm FIREFIGHTING HOSE
7. MSVS SMOKE SHAFT HAZARDS

INCIDENT COMMAND FUNCTIONS



HIGH-RISE INCIDENT COMMAND 1992





"The Incident Command System (ICS) is a fireground management system that has evolved in the USA over several years. In high-rise firefighting the basic command functions of Lobby Control; staging; operations command, fire attack and search and rescue are described here in detail"

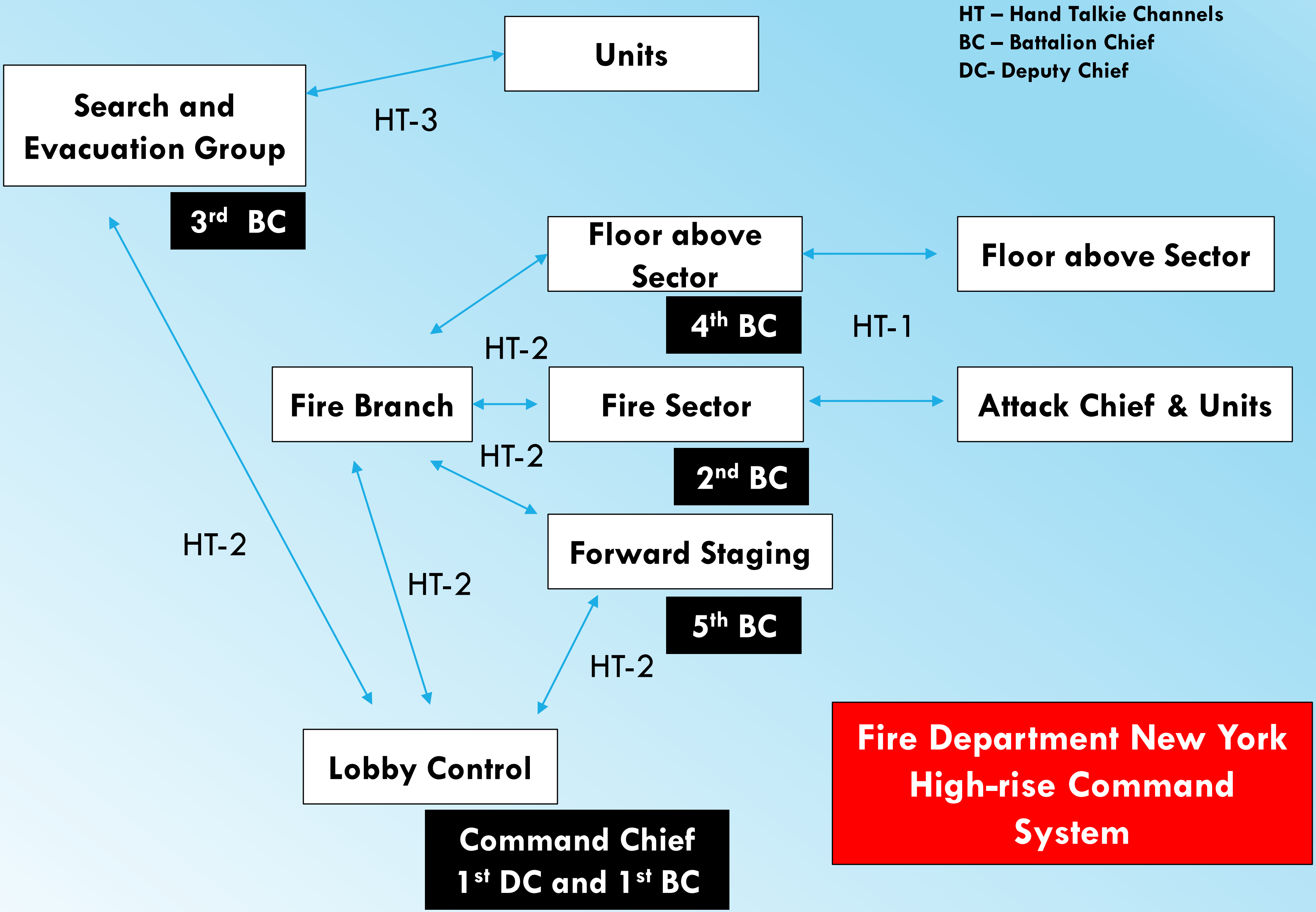
Fog Attack p274-277
1992

NEW YORK FIRE DEPARTMENT HIGH-RISE COMMAND PROCEDURE

FDNY High-rise command procedures are very structured and precise from the moment of arrival on-scene. The role of lobby sector is implemented almost immediately on arrival of the first Battalion Chief. From here there is complete assignment accountability within the building.

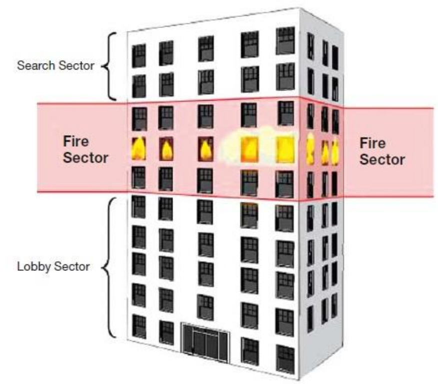
Another functional command role seen as critical is the assignment of a search and evacuation commander, usually at a very early stage and taken by the third arriving Battalion Chief.

In all, there are five Battalion Chiefs (Station Commanders UK) assigned roles in the command structure as soon as a working fire is confirmed.


HT – Hand Talkie Channels
BC – Battalion Chief
DC- Deputy Chief
Units
Search and Evacuation Group
HT-3
3rd BC
Floor above Sector
Floor above Sector
4th BC
HT-1
HT-2
Fire Branch
Fire Sector
Attack Chief & Units
HT-2
2nd BC
HT-2
Forward Staging
HT-2
5th BC
HT-2
Lobby Control
Command Chief
1st DC and 1st BC
Fire Department New York High-rise Command System

At what stage do you establish this role?

Stair Protection Teams



Search and Evacuation Sector

Bridgehead

Fire Sector

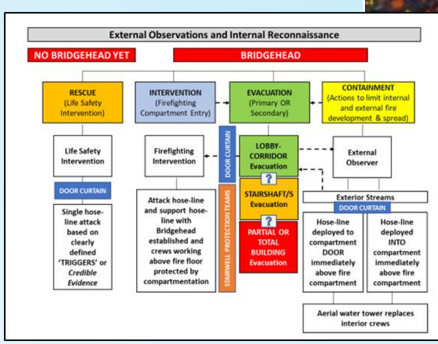
Forward Staging

?

Lobby Control

Where does YOUR system fit in?

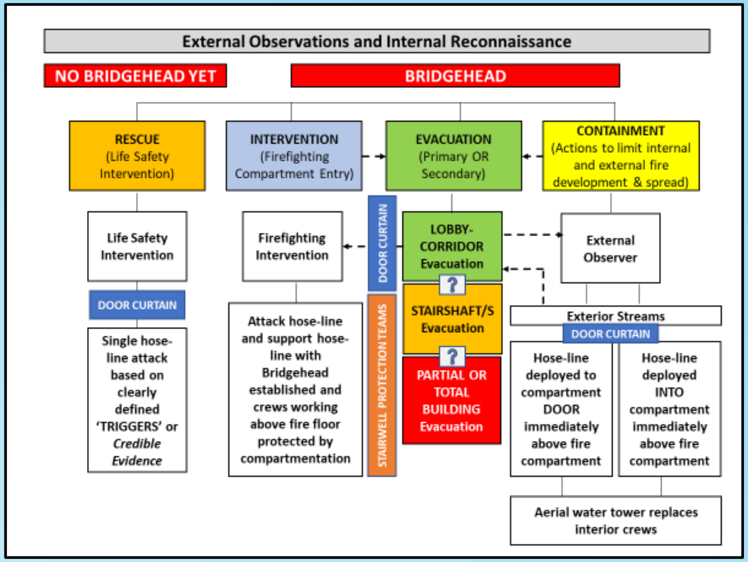
R.I.C.E COMMAND DECISION TOOL



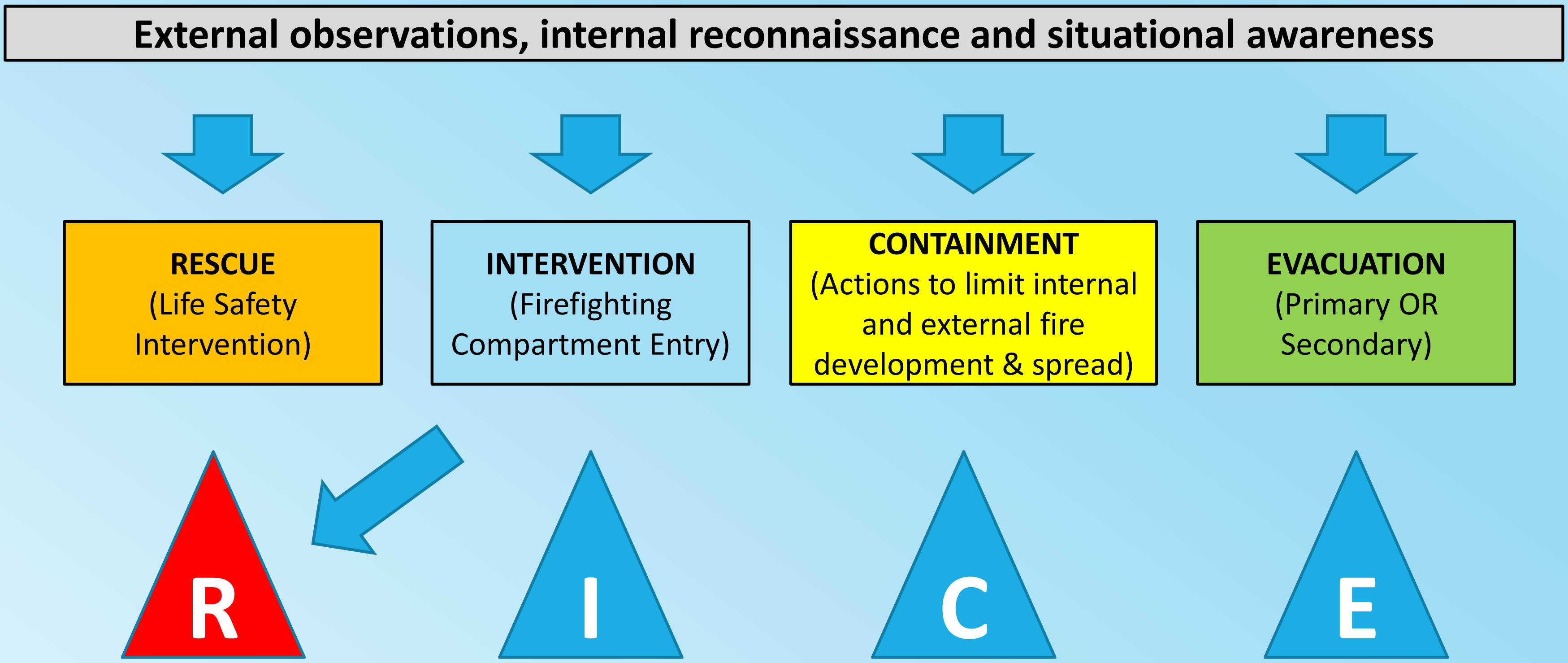
Developed whilst training high-rise firefighters in the city of Kuala Lumpar in 2008
As reported by Paul Grimwood in the Journal Gulf Fire 12/2015

RESCUE-INTERVENTION-CONTAIN-EVACUATE

R.I.C.E Tactical Command Tool: In support of stairway protection and to rapidly analyse strategic options, challenging firefighting intervention as not always the being first option, the RICE analytical command decision tool was introduced to assist first arriving commanders. This provides a simple mnemonic by which first-arriving incident commanders can promptly question why their initial chosen strategy may or may not be the best one and how such decisions may impact either positively or negatively on self-evacuating residents.



This tool was seen to increase situational awareness amongst 97 KFRS officers by 33% in exercises, when compared to not using the tool.



Initially called 'ICE' where RESCUE was a branch off the INTERVENTION header

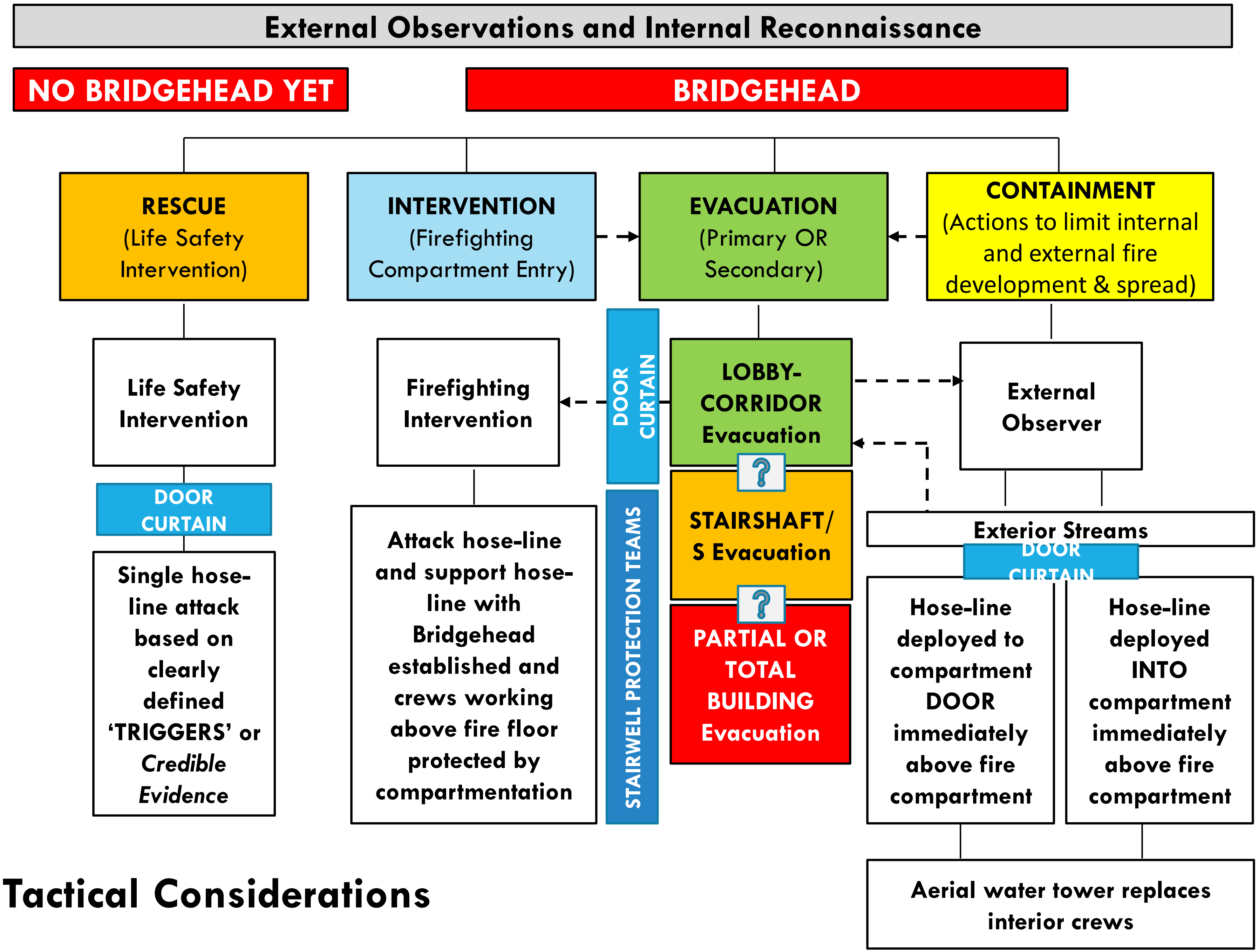
“The overriding objective is to maintain vertical escape routes for occupants clear of smoke”.........

KFRS ‘ICE’ Training 2010

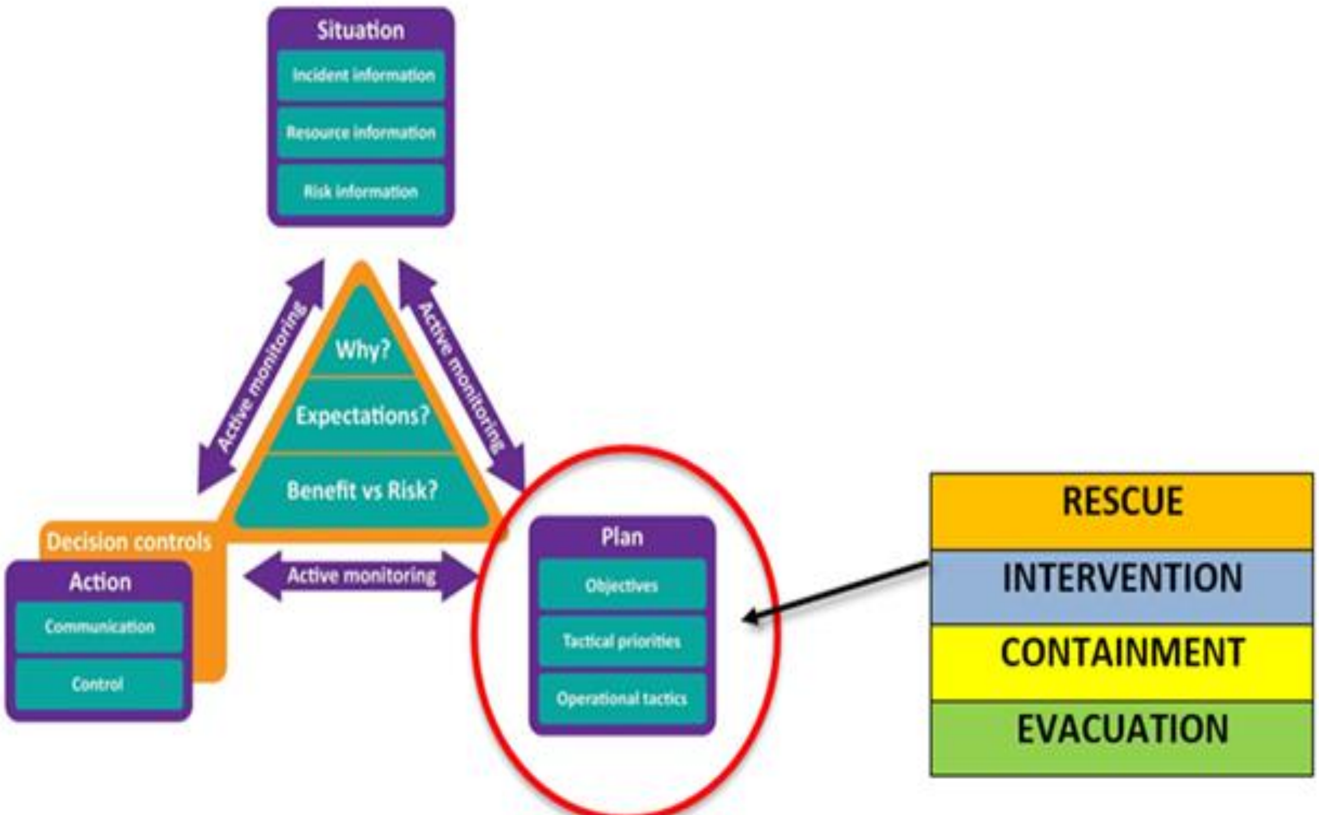
"In situations where single exit stairs may become compromised by smoke as firefighters open up the fire compartment, the evacuation of the entire building above the fire floor, and possibly below it, may need to be controlled".

KFRS 'ICE' Training 2010

Tactical Considerations



RICE AS AN ANALYTICAL COMMAND MNEMONIC



FAILING DESIGN FACTORS

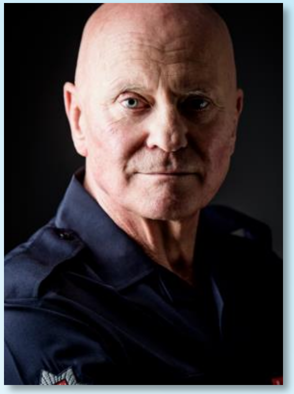
AT WHAT POINT IS THE 'FIRE SAFETY DESIGN' OF A RESIDENTIAL BUILDING FAILING?

- Internal failure of compartmentation – 60 minute 'boxes' 30 minute escape routes
- Failure of smoke control systems
- Failure of firefighting lifts or water standpipes/risers
- **External fire spread beyond two storeys (three storeys or more)**

EVACUATE

‘Following introduction of the **R.I.C.E. Primary Command Decision Tool,** KFRS Officers demonstrated a dramatic 33% increase in situational awareness in exercise scenarios where trigger based decisions had been pre-defined’.

PROTECTING THE STAIRS FROM SMOKE 2008



"A prompt fire suppression action may save lives. However stair-shaft integrity should be maintained as far as possible. Whilst it is recognised that building design may, in some situations, place the rising main outlets in the stair-shaft, every effort should be made to keep the stair doors closed as much as possible.

Prior to opening a door into the stairs from the fire floor, a check should be made for occupants in the stair for at least five floors above the fire. Any stair-shaft contaminated by smoke should be prioritised for secondary search undertaken by the second arriving response firefighters".

EuroFirefighter 2008
p331

The prediction of human behaviour during a fire emergency is one of the most challenging areas of fire safety engineering. In recent years we have witnessed clear patterns emerging in how human behaviour impacts on firefighting operations and occupant evacuation, particularly in tall residential buildings with single stairs. Past fire experience around the world has received much media coverage and this has been reflected in how people now respond to fires.

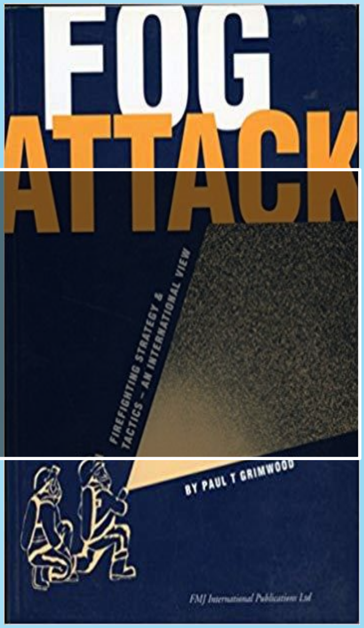
Since 1962 it is the case in most tall residential buildings in the UK that a **'stay put'** strategy is generally dictated by 60 minute compartment design, whereby simultaneous evacuation of all residents together is likely to be problematic due to limited stair escape capacity, building height and lack of general fire alarm provisions. Many of the buildings still around today, constructed in the 1960s and 1970s, originally incorporated a **'stay or go'** approach, stating that '*the possibility that individuals may seek to leave the building cannot be overlooked and provision should therefore be made for the occupant of any dwelling to do so by his own unaided efforts, using adequately protected escape routes within the building without outside assistance'.*

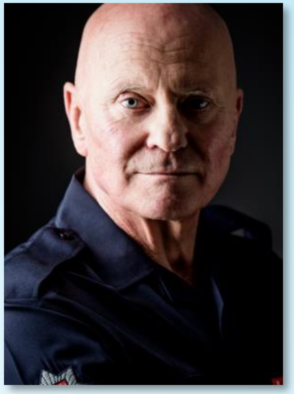
Kent Fire and Rescue Service have raised concerns nationally over the past decade in relation to the clear disconnect between operational firefighting objectives, regulatory building design and human behaviour.

The importance of protecting vertical egress routes from smoke infiltration is already acknowledged in existing operational firefighting guidance and building design guidance – however, the disconnect between the two prevents this in practice.

(ADB; BS 9999; BS 9991)

FDNY STAIR SEARCH TEAMS 1992





"Battalion Chief Glenn Dinger of the Los Angeles Fire Department felt strongly that any pre-plan should account for a team of firefighters to be despatched into the stairs above the fire floor on the initial response, but it was surprising to find that few fire departments actually do this [1990]. However, FDNY do deploy a two-man scout and search team above the fire floor on arrival. They will search stairs, lifts shafts and report smoke conditions in egress routes. The FDNY stair protection procedure is coordinated by a designated Search and Rescue Commander"

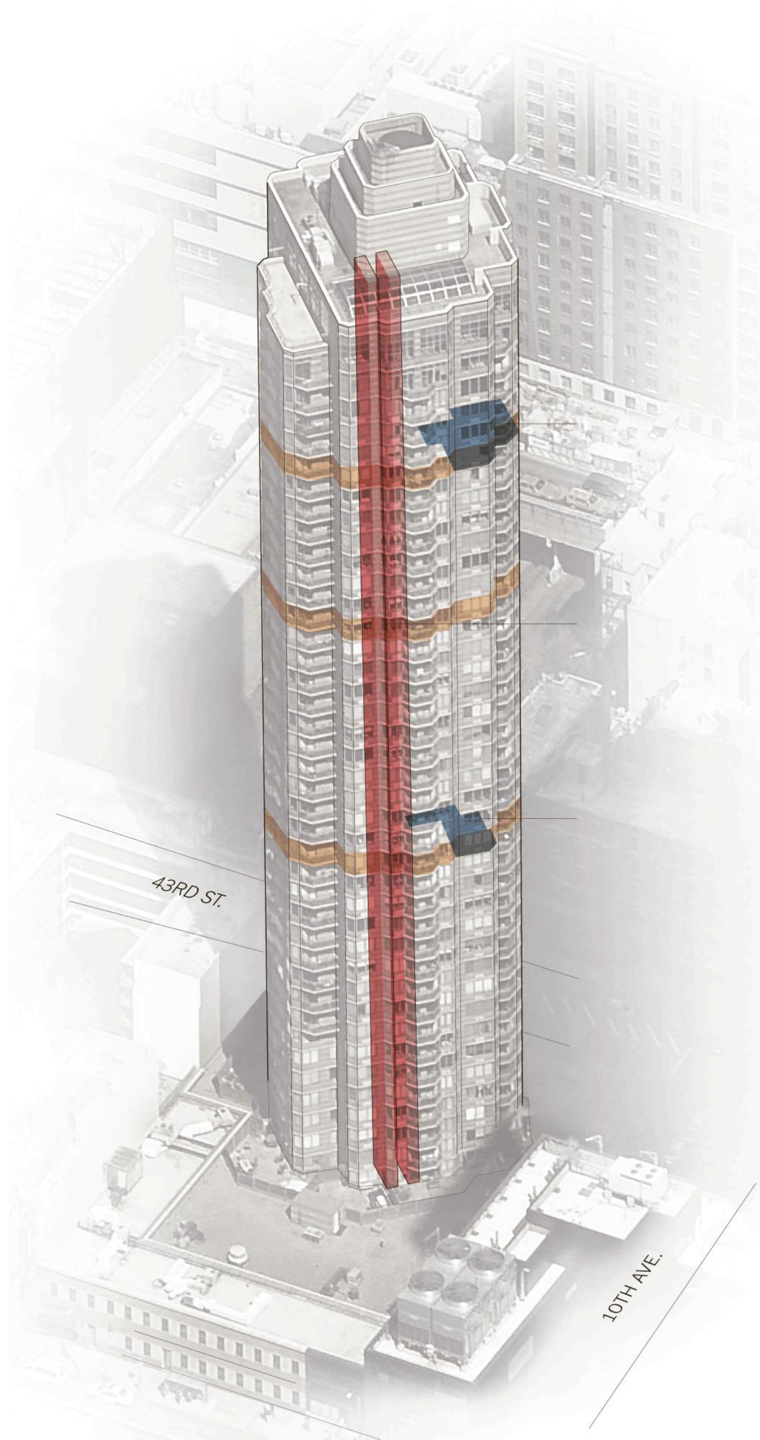
Fog Attack p276
1992

In 2005 New York City Deputy Fire Chief Vince Dunn made it very clear for us that we should protect the stairwells at building fires. Did we learn anything then? Is it relevant now?

“In 1995, six people died in the stairway of a burning high-rise apartment building in Ontario, Canada. In l998, New York City, four people were killed in a smoke-filled stairway on the 27th floor during a high-rise apartment fire. In Chicago, 2004, six office workers were killed in a smoke-filled stairwell attempting to escape fire in a high-rise building”.

Within nine years, 16 civilians had died in fires in Chicago, New York City and Toronto; the victims shared one common fate with three primary factors — **they were all found in the attack stair, they were well above the fire floor and all died of carbon monoxide (CO) poisoning.**

A new 2008 Law in NYC following the loss of lives in a stairway saw new residential buildings over 40m high to have fire service controlled voice alarms.

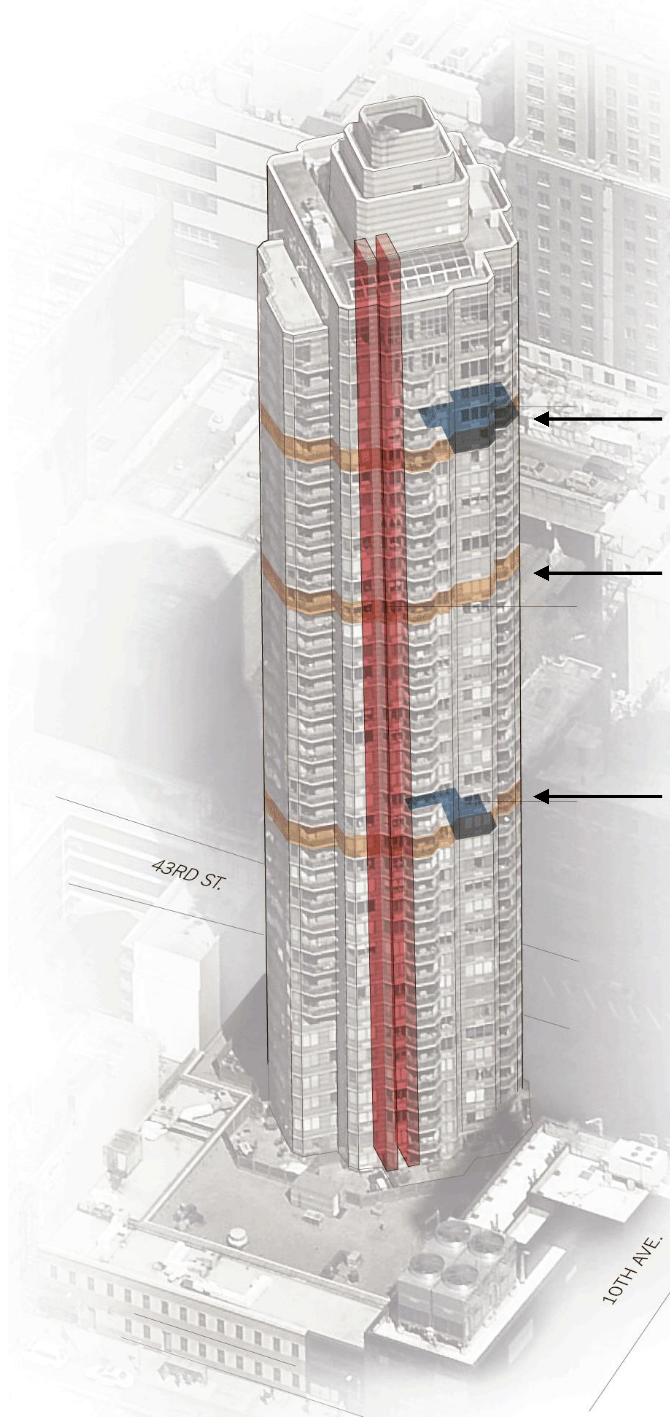


2014 DEATH IN A HIGH-RISE ATTACK STAIR

However, when people are entering the attack stair some eighteen storeys above the fire floor, it still presents a time-lag problem for firefighters. This conflict with rising main outlets in the stair and self-evacuating occupants entering the stair above becomes even more relevant at great height.

Sprinkler protected apartments, tactically deployed stair curtains by firefighters, stair search teams, fire service controlled voice alarms and smoke free alternative stairs specifically for evacuation may go some way in preventing this.

10^{th} Avenue Fire New York City 2014



The victims lived on the 38th floor, far above the fire. They decided to evacuate with their two dogs, and started down one of the two stairwells.

They made it as far as the 31st floor, where they were overcome by smoke.

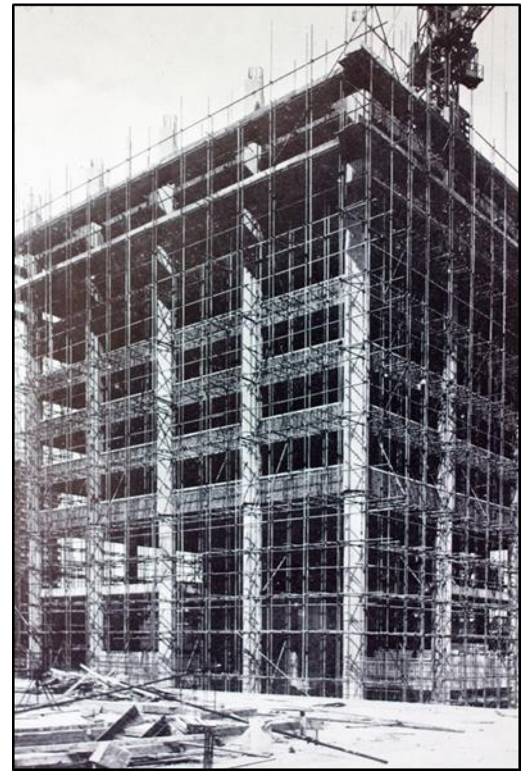
The fire was burning in a small apartment on the 20th floor, but had not spread.

Firefighters, coming up the same stairwell the victims were using, entered the fire floor, and opened the stair doors and the apartment door, sending the smoke up as if through a chimney. One of the men and both dogs died. The residents were evacuating in the firefighting stair whilst the evacuation stair remained relatively smoke free.

Six occupants die in a Chicago fire attack stair overcome by smoke as firefighters take hose-lines from the rising main through the stair door in 2003

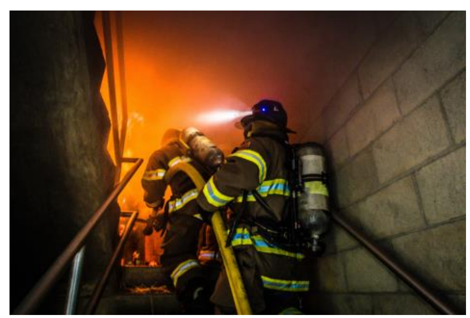
The design of CP3 (1960-70) high-rise buildings in the UK suggested that occupants may still evacuate at any stage should they wish to do so, despite the stay-put (defend in place) intentions. Since that design objective was established we now allow smoke into the stair due to building design and firefighting procedural conflicts, but still indicate that people can leave at any time whether affected by smoke or not. This is a clear disconnect in design and evacuation strategy.

The increasing popularity of taking the first hose-line from the fire floor is based on risk assessment. It isn't a major training burden and firefighters are actually just as safe when approaching from the access corridor/lobby **unless it has become the fire compartment.** Kent FRS firefighters have done this effectively and safely for the past 16 years.



As an example, current national high-rise procedure (GRA 3.2 2014) recommends '*Branches [nozzle and hose line] should be supplied from the closest rising main outlet to the fire which has not been affected by fire or smoke. This will normally be from the floor below the fire floor or, if unavailable, from the nearest available outlet below that*'.

Why do we deploy the first line from below the fire floor?



Prior to high-rise buildings becoming a major part of our risk profile, our firefighting procedures at upper levels in 6-7 storey buildings had evolved from escape ladders being pitched to the floor/s below the fire floor and hose-lines hauled aloft or taken up the 50 feet escape ladder.

This would place the primary attack hose-line in a safe location, from where an advance up to the fire floor could be made. It was often the case that the stair was not protected by fire resisting structure or doors and adequate ventilation did not exist in any design format. In short, we attacked the fire from the safest point, usually 1-2 floors below the fire.

This basic firefighting tactic has since found its way into many of our high-rise procedures based on GRA 3.2 and National Operational Guidance. But why?

'We were about to enter the apartment with a hose-line on the fourteenth floor when the windows failed and the wind blew in, forcing the fire directly at us and into the stair behind us. The BA Entry Control board a floor below us in the stair melted to a blob. There were injuries …. There were burns …. The stair door was still open on the hose and heavy smoke was heading upwards'.

Author's experience
London 1990

Firefighting Shaft and Firefighting Stairs

The protection of firefighting access stairs (60 minutes FR) and firefighting shafts (120 minutes FR) was a building design solution first seen in the 1990s and some older buildings may have since been upgraded to provide an increased level of access provisions. A *firefighting shaft* provides the fire and rescue service with a safe area from which to undertake *firefighting* operations from the fire floor itself. They link all necessary floors of a building, providing at least 2 hours of fire resistance to protect fire crews and are connected to fresh air. Usually there are vision panels in doors to enable firefighters to get a view of the accommodation from the stair.

From a tactical perspective and as a result of the Shirley Towers fire in 2010, firefighters in the SE UK region have adapted a collaborative approach since 2013 when using the protection of firefighting shafts or protected firefighting stairs, by taking the first two hose-lines from the fire floor using controlled dividing breechings. In effect, they are using the levels of fire resisting protection provided by the stairs that never existed in the 1970s. The advantages of this are clear –

- Hose-lays are reduced in length and are easier to manage.
- Firefighters are exposed to less stress and breathing apparatus will last longer.
- The stair door in residential buildings remains closed and smoke infiltration into the stair is dramatically reduced.
- Where occupants are self-evacuating, particularly but not solely in single stair buildings, the vertical escape routes are relatively clear of smoke and tenable throughout firefighting operations.

Two serious high-rise fires in Kent 2001

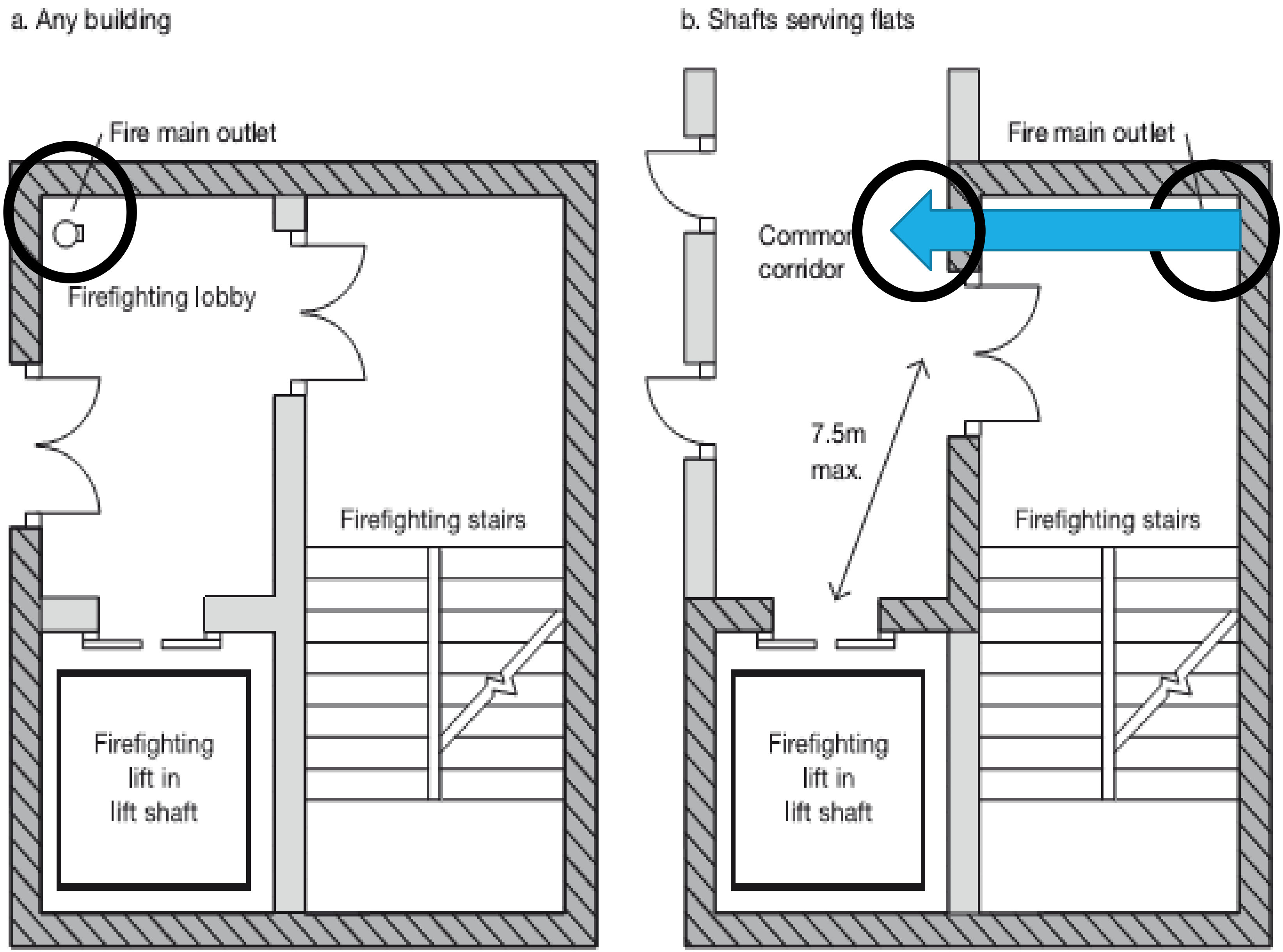
Kent FRS began their high-rise procedural development involving '**attack from the fire floor DRA**' strategies in 2003 following two serious fires in 2001, where escape stairs were compromised with smoke, trapping residents on upper levels. In 2010 following the Lakanal House fire in London, additional tactics were enshrined in the documented training involving the **RICE** (ICE) command decision tool and the introduction of **Stairwell Protection Teams.** In 2013 these strategies became part of the SE Regional research and training package involving nine FRSs.

In **2010** KFRS also began a programme aimed at building design changes to the rising fire main, taking the outlets off of the stair in order to protect stairs further from smoke infiltration.

In **2016** the introduction of 150mm rising mains with twin outlets at each floor was introduced, working with local architects and developers.

Diagram 52 A proposal to reposition rising main outlets by design to protect stairwells

See para 17.1



STAIRWAY PROTECTION TEAMS

Photograph © Trevor Hunt Dublin Fire Brigade 2019


A German fire chief once said that the most important room in a fire building is the stairwell! He is right. Stairwell protection is a critical strategy in a successful firefighting operation, in an occupied building involved in fire.

COMMUNICATION IS KEY –

During a recent training seminar series involving over sixty UK fire officers, a single key learning point was communicated and emphasised through a lone sentence, prior to a table-top exercise taking place. However, in effect, only five percent of students utilised that key piece of information and this negatively impacted on exercise outcomes.

Communication amongst professionals is as critical as human behaviour is at fires. Yet emergency workers under stress repeatedly experience failings in information transfer on the incident ground that may affect the outcome in some dramatic way. Add to this the time lag between message transfer and receipt so commonly experienced in high-rise firefighting and a sound tactical solution may be compromised by unwanted delays.

Furthermore, impacting positive and proactive amendments to established procedure can be time consuming and difficult to achieve. It has been suggested that "to make the most out of research evidence and to reach policy makers, you must give them something in a paragraph to get their attention; better still if you can give one sentence that can become a slogan" .... such as:

"Protect the stairs at all times"

National High-rise Firefighting Guidance GRA 3.2

In circumstances where teams need to work in an area above the bridgehead which is not affected by fire or smoke and the Incident Commander has confirmed that the building’s construction and any fire engineered solutions have not been compromised, **teams can be committed without respiratory protective equipment**.

These teams must **maintain communication** and a **Safety Officer** must be deployed in the stairwell and be **in contact** with other Safety Officers and the Incident Commander outside the building.

ROLES OF ‘STAIRWAY PROTECTION TEAMS’

- **Patrol** stairwells continuously from top-to-bottom to ensure that egress routes are safe and free of obstructions; monitor gas levels
- **Search** floors, stairwells, hallways, and lifts for building occupants who may be trapped or are entering an untenable environment
- **Report** information about conditions at each floor to the incident commander.
- Ensure the stairs are **clear of smoke**
- **Deploy to FSG calls** where required
- **Manage occupant evacuation** where required

When controlling stair evacuation, at what gas levels do you issue smoke hoods? Can you continue to support unaided self-evacuation both with or without smoke hoods? At what gas levels may this be safe to do whilst optimising the use of a limited amounts of available smoke hoods?

Acute exposure guideline levels (AEGLs)

	Concentration (ppm)				
	10 min	30 min	60 min	4 hours	8 hours
AEGL-1*	NR	NR	NR	NR	NR
AEGL-2†	420	150	83	33	27
AEGL-3‡	1,700	600	330	150	130

Carbon Monoxide

Acute exposure guideline levels (AEGLs)

	Concentration (ppm)				
	10 min	30 min	60 min	4 hours	8 hours
AEGL-1*	2.5	2.5	2.0	1.3	1.0
AEGL-2†	17	10	7.1	3.5	2.5
AEGL-3‡	27	21	15	8.6	6.6

Hydrogen Cyanide

Design tenability at 0.3 FED for exposure to concentrations of Carbon Monoxide		
Category	**Maximum asphyxiant concentration as CO 5 minute exposure**	**Maximum asphyxiant concentration as CO 30 minute exposure**
Fuel contains nitrogen (>2% by mass) such as fires in residences or retail premises	800 ppm	125 ppm
Fuel contains nitrogen (<2% by mass) such as office fires	1,200 ppm	275 ppm

Reference: BS 7974-6

The 2018 changes to Carbon Monoxide and Hydrogen Cyanide are as follows:

Carbon Monoxide

Current LTEL/TWA (8hrs) = 30 ppm **New LTEL/TWA (8hrs) = 20 ppm**

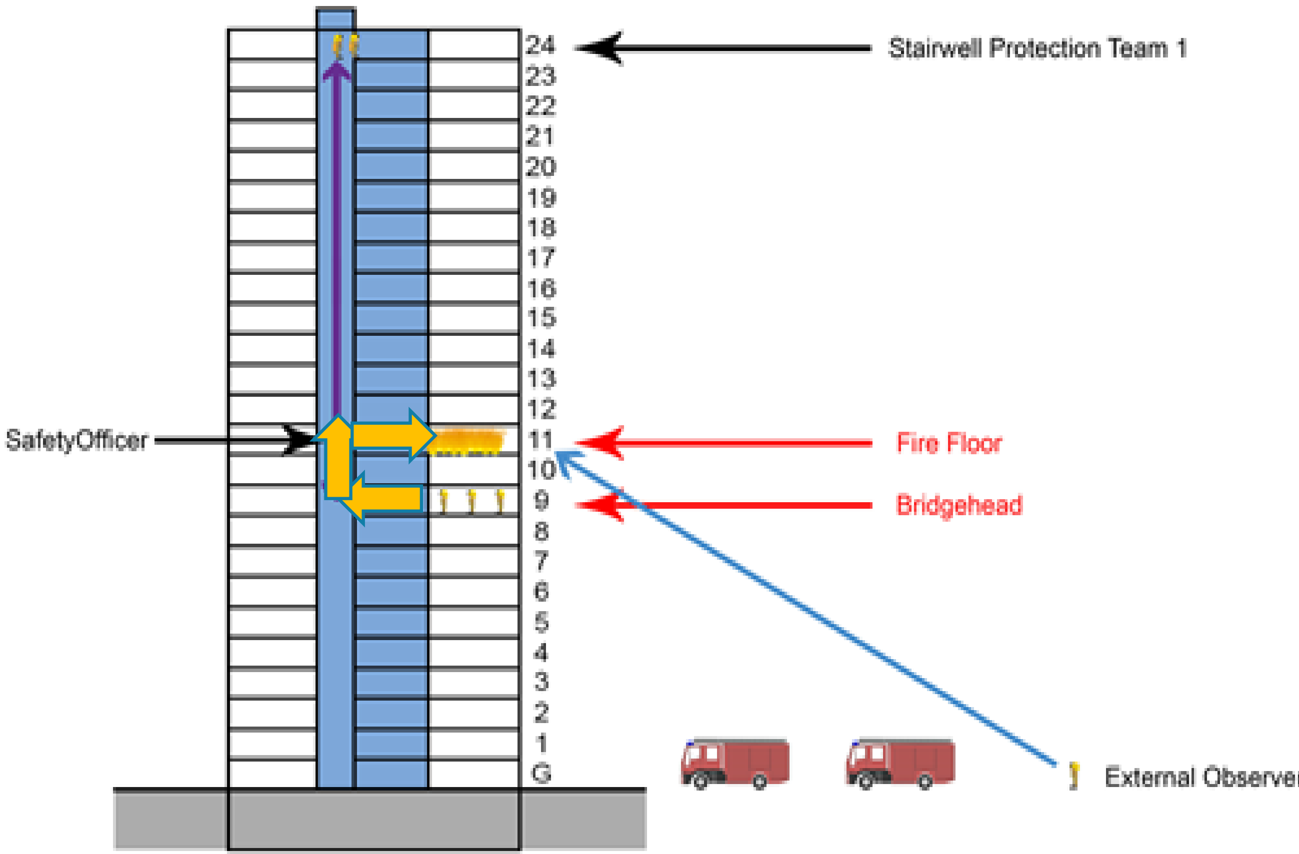
Current STEL (15mins) = 200 ppm **New STEL (15mins) = 100 ppm**

Hydrogen Cyanide

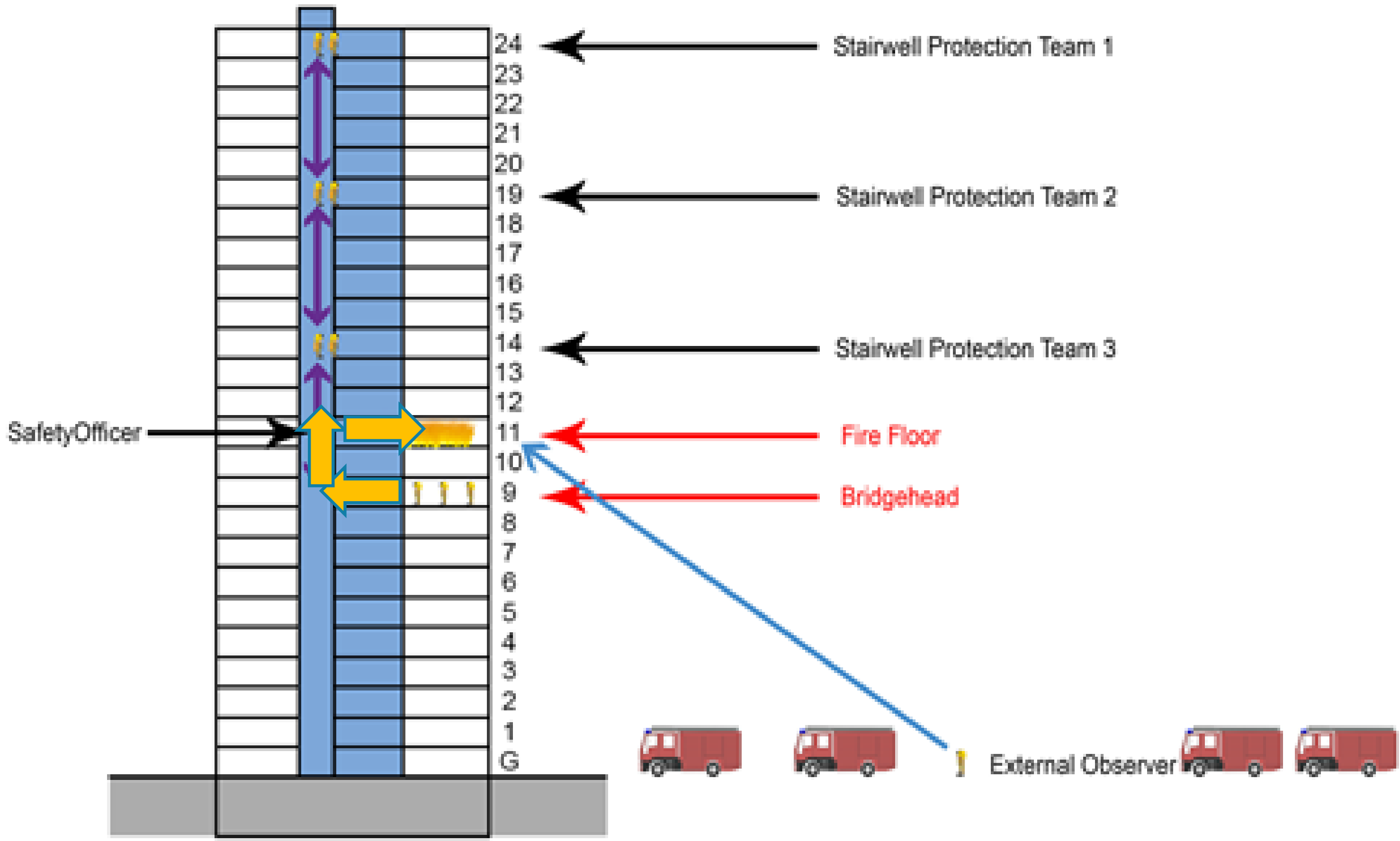
Current LTEL/TWA (8hrs) = N/A **New LTEL/TWA (8hrs) = 0.9 ppm**

Current STEL (15mins) = 10 ppm **New STEL (15mins) = 4.5 ppm**

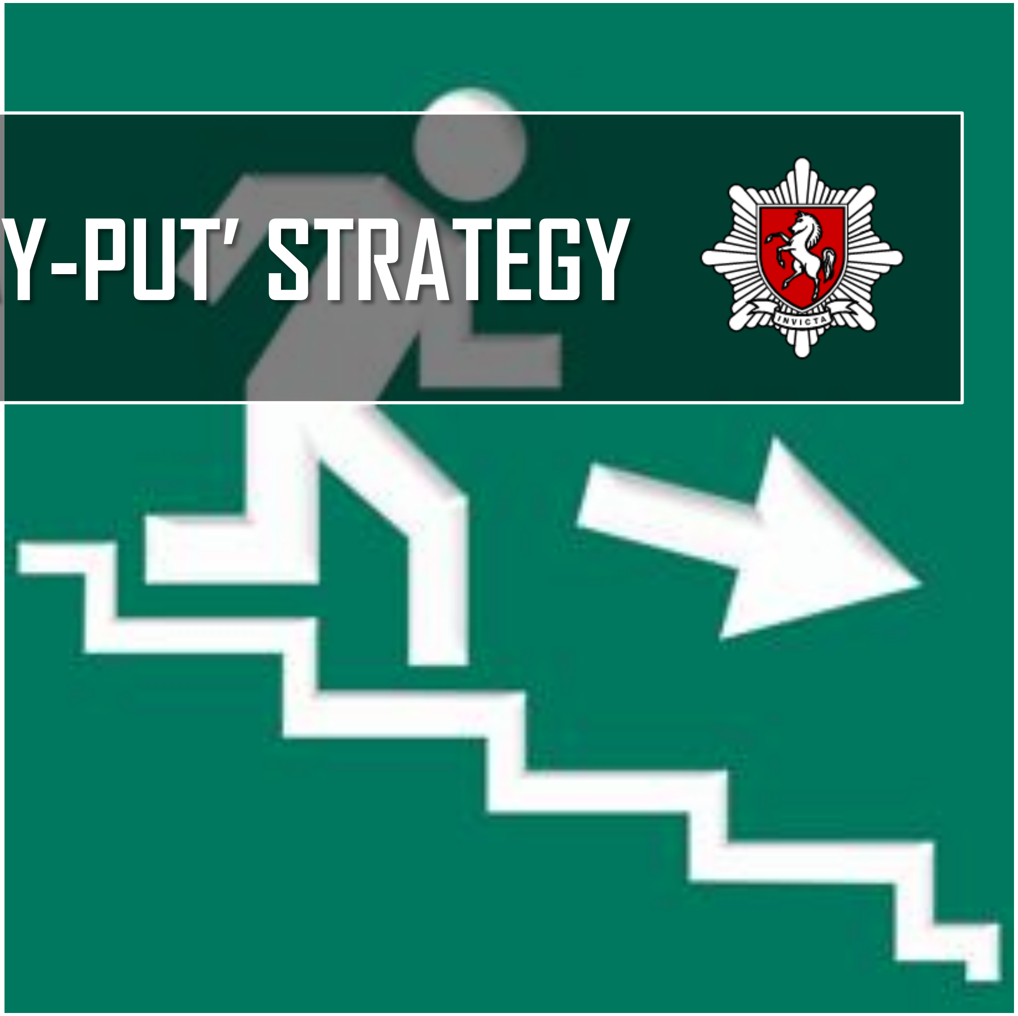
STAIRWELL PROTECTION TEAM DEPLOYMENTS - 1



STAIRWELL PROTECTION TEAM DEPLOYMENTS - 2



REVERSING A 'STAY-PUT' STRATEGY



Reversing a 'stay put' strategy?

It's true that National Operational Guidance and GRA 3.2 require all FRSs to formulate a plan to reverse a stay put strategy, where necessary. However, there are many factors that serve as a disconnect between building design and firefighting procedure, preventing any viable means of doing so.

One of the biggest is the building regulation requirement to re-locate the rising main in the stair (since CP3 design) and the operational guidance to take the first hose-line from below the fire floor.

You really need to think closely about this conflict between regulation and procedure. Where smoke is allowed to enter the stair in a single stair building and the need to reverse the stay put strategy occurs, we have missed that opportunity. We are now in the rescue phase and not an evacuation phase.

The likelihood of self-evacuating occupants and others finding refuge and comfort with neighbours, congregating in large groups, represent different behaviours to those seen in the past. The possibility of large numbers of assistance calls may further increase pressure on control staff and command systems.

Whilst the national GRA 3.2 guidance requires the FRS to establish an operational evacuation plan in the event a ‘stay put’ policy becomes untenable, it is unlikely that any FRS could effectively manage or reverse a stay put policy effectively without greater resources on-scene. However, by taking a different approach then the process itself may become a possibility.

‘An advantage in strategically and tactically supporting any ‘*self-evacuation*’ that may already be occurring, is to enhance any later decision to reverse a ‘stay-put strategy’, as the natural command and stair deployment structure will already be in place’.

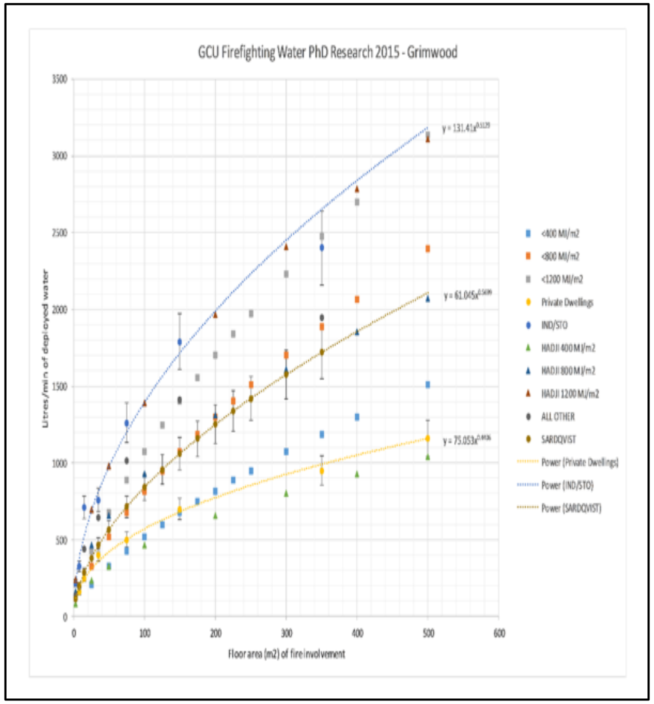
ADEQUATE FIREFIGHTING WATER

'ADEQUATE' FIREFIGHTING WATER

There is a legal requirement placed on the fire service to ensure that the water flow-rates used for fire suppression are of an 'adequate' amount. As there was no actual definition for what was meant by 'adequate', my 2012 PhD research (that actually began in 1989) endeavoured to demonstrate what were considered *critical*, *minimum and optimum* (adequate) amounts of firefighting water in a range of occupancies. An important factor in this was the increase or decreases seen in heat exposure and firefighter physiology as time on the hose-line was taken into account. As fire loads and compartment sizes increase, a greater quantity (L/min) should be deployed at the earliest opportunity and building designs should support this need. This work was also linked to the increasing amounts of building fire damage observed as a result of inadequate firefighting water deployment.

This research was to form the basis of firefighting water design codes (BS PD 7974-5-2015 [Rev.2019]) and National Operational Guidance (Optimum Firefighting Flow-rate)

The author's PhD research included analysis of the quantities of firefighting water used for suppression at 5,401 'working' building fires in the UK between 2009 and 2012. The lower line represents private dwellings and apartments with an upper line representing industrial units and warehouse fires. All other fires fall between these two lines, as represented by a median line of data provided by the Sardqvist research into non-residential premises. It should be noted that construction in the UK is widely solid masonry and structure fires are in general, only tactically ventilated at the point when fire is under control, or at least is 'surrounded'. However, lightweight building construction is now becoming more widely predominant in both the UK and Europe in general.



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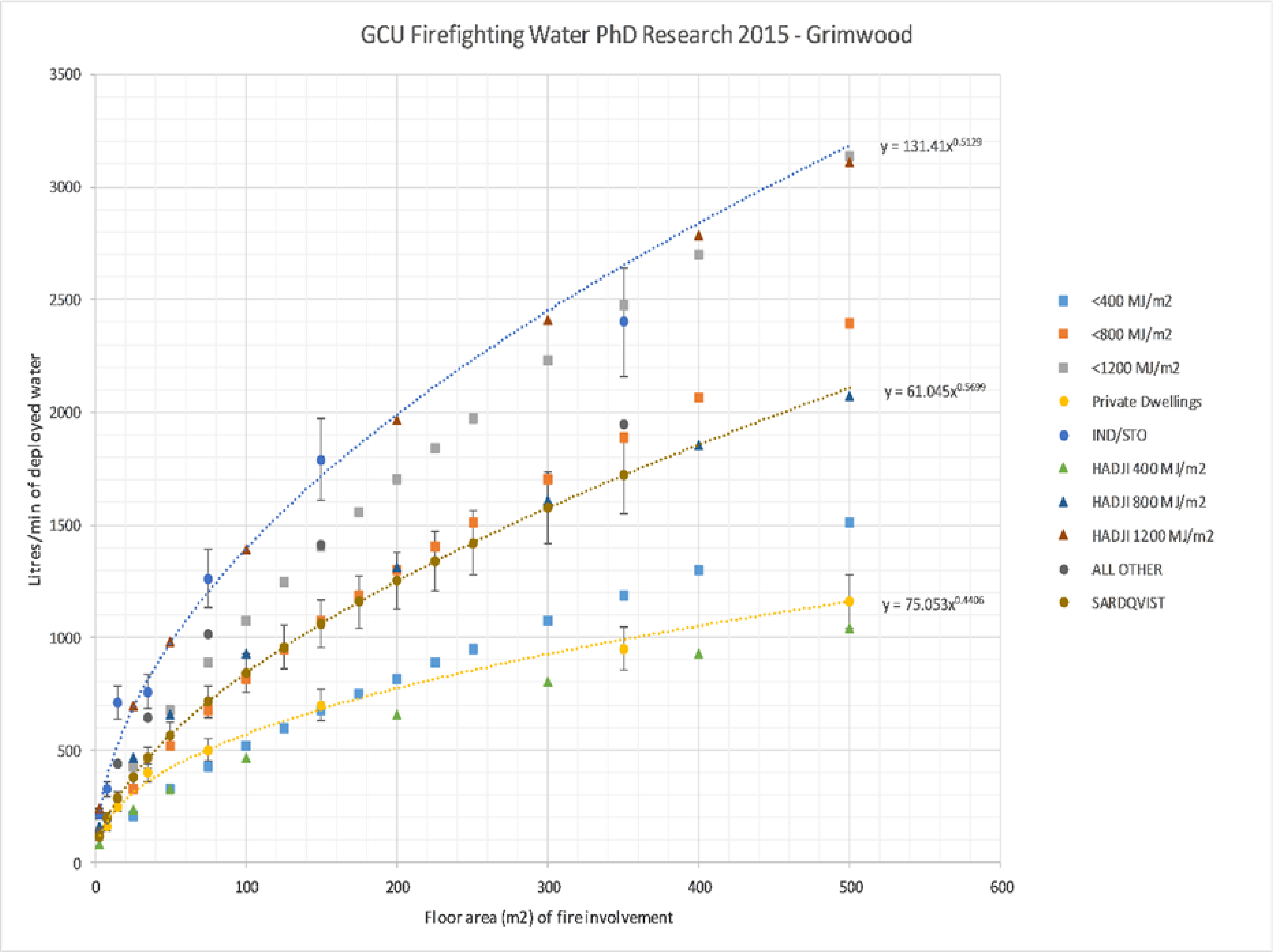
https://img1.wsimg.com/blobby/go/877d587b-6900-4f7f-b145-e75cc02aff97/downloads/1cvvee1c8_641325.PDF?ver=1555186108307

Deputy Chief Vince Dunn, a veteran of the New York City Fire Department once said that it would take close to 1,150 L/min using a 65mm hose-line to handle up to 230 square metres of office space fire. He went on to say that was the maximum amount of fire his firefighters could handle.

EuroFirefighter 2008 - p325

Take account of that and make a comparison on the central (offices) gradient line in the author's Glasgow Caledonian Research below. Where would a 750 L/min hose-line take you on the same line in a fast developing fire in an un-sprinklered open-plan office?


GCU Firefighting Water PhD Research 2015 - Grimwood
Litres/min of deployed water
Floor area (m2) of fire involvement
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
$y = 131.41x^{0.5129}$
$y = 61.045x^{0.5699}$
$y = 75.053x^{0.4406}$
<400 MJ/m2
<800 MJ/m2
<1200 MJ/m2
Private Dwellings
IND/STO
HADJI 400 MJ/m2
HADJI 800 MJ/m2
HADJI 1200 MJ/m2
ALL OTHER
SARDQVIST

National Operational Guidance Firefighting Flow-rate

At its simplest, the flow rate is the amount of extinguishing media being applied to a fire at any one time, referred to in litres per minute (L/min).

Required flow rate may be simply viewed as the amount of firefighting media required to control and ultimately extinguish a fire. This introduces many variables; more precisely two flow rates need to be considered:

Critical flow-rate (CFR): typically this would be the absolute minimum amount of firefighting media flow needed to fully suppress a fire at any given level of involvement

Tactical flow-rate (TFR): the target flow for a primary attack hose line or lines

The actual critical flow rate is dynamic; it is directly related to the phase of the fire and this may be unknown. It also has no built-in safety factor. More relevant is the tactical flow rate, which more accurately represents the flow rates required by firefighters to deal with a given fire in a known compartment.

The concept of firefighting flow rate requirements can be based theoretically in matching the flow of firefighting media against known rates of heat release in compartment fires (measured in megawatts or MW).

It can also be empirically based on fire loads, in established floor space, against the flow of firefighting media needed to suppress fires during their growth or decay stages. The latter is generally a defensive application.

It is recognised that flow rate i.e. the amount of firefighting media, extinguishes fire, not pressure.

Relying on pressure alone as the basis to deliver firefighting media does not provide information on the litres per minute being delivered and may be insufficient to prevent fire growth and spread.

The mathematical calculations for the amount of water required to extinguish a given fire are relatively complex. However, as a fire ground rule of thumb for fires from 50 to 600m2, the following calculation could be considered:

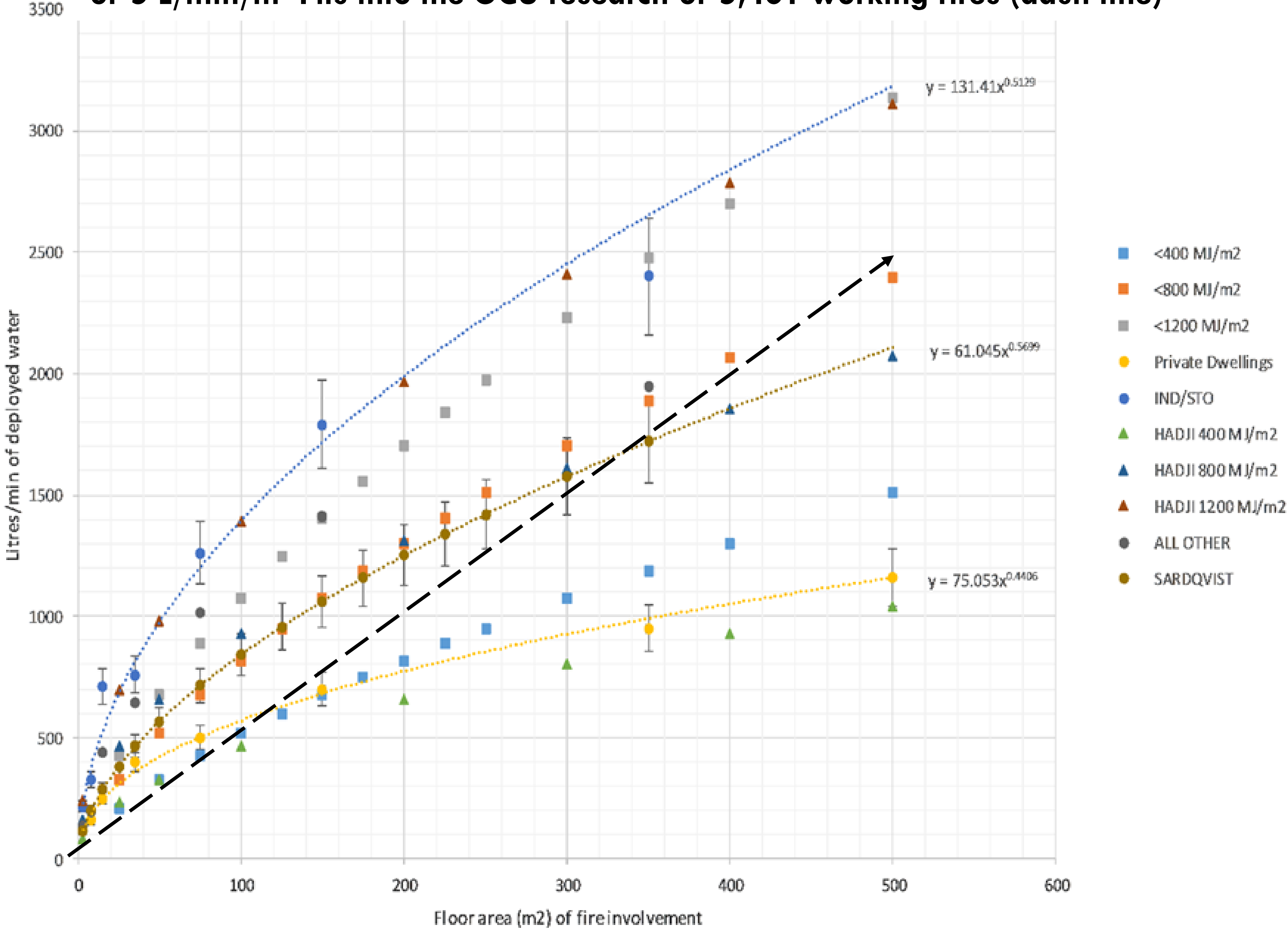
Optimum flow rate (L/min) = fire area (m2) x 5

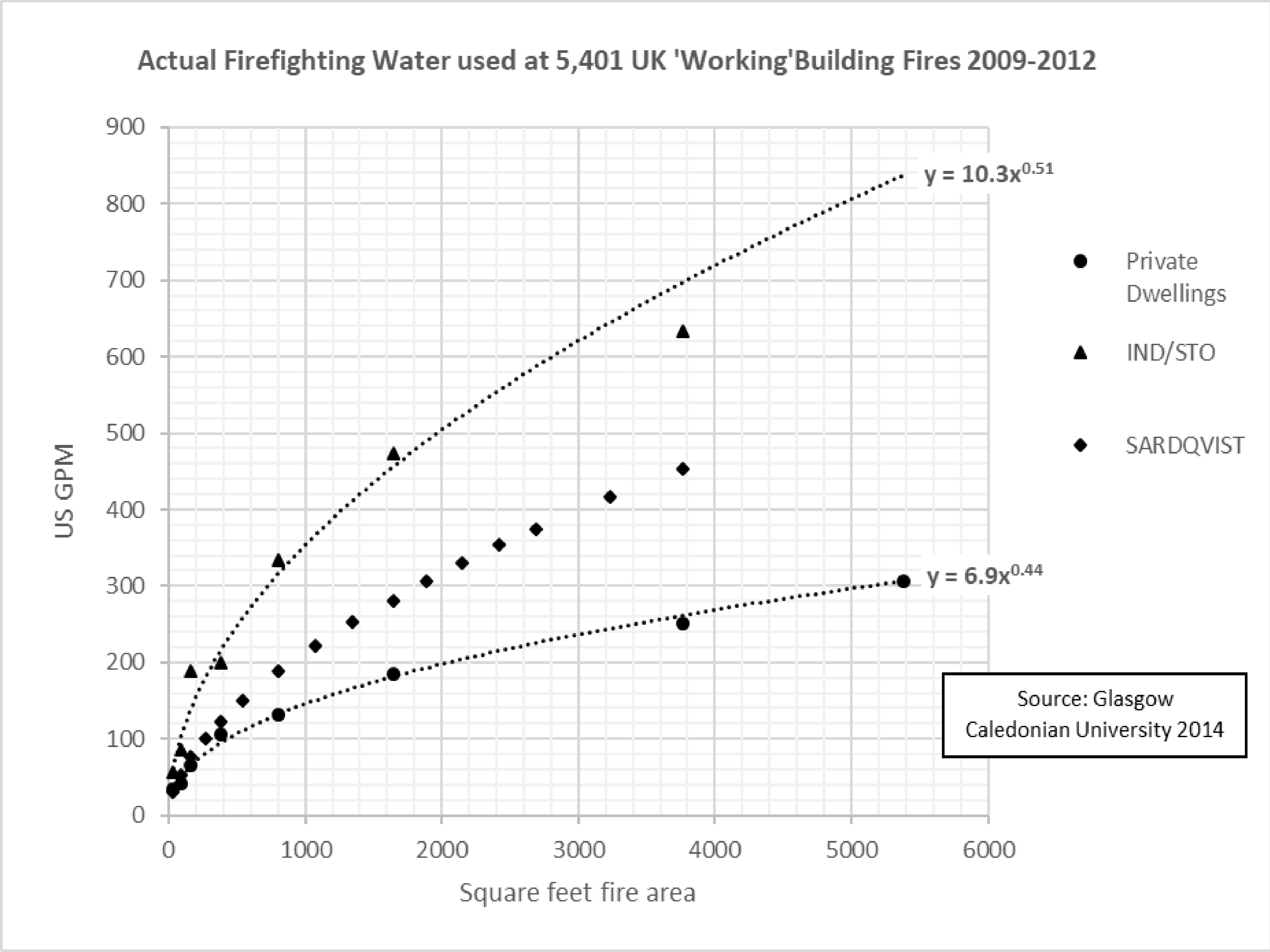
For example, in a situation with a fire in an open plan flat measuring 90 m2

Optimum flow = 90m2 x 5 = 450 L/min

This shows that an estimated flow rate of at least 450 L/min would be required as a minimum to extinguish the fire safely and effectively by lessening the amount of heat exposure firefighters may be subjected to, over time on the hose-line.

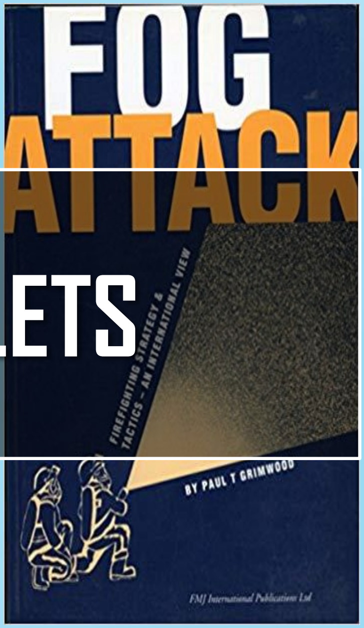
How the National Operational [Fireground] Guidance Optimum Flow-rate of 5 L/min/m² Fits into the GCU research of 5,401 working fires (dash line)



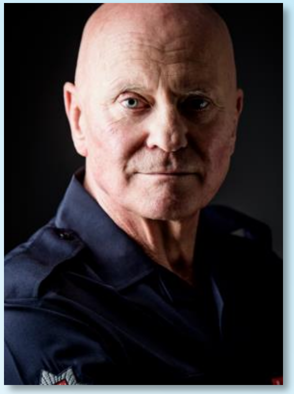


Actual Firefighting Water used at 5,401 UK 'Working'Building Fires 2009-2012
US GPM
900
800
700
600
500
400
300
200
100
0
0
1000
2000
3000
4000
5000
6000
Square feet fire area
y = 10.3x^0.51
y = 6.9x^0.44
Private Dwellings
IND/STO
SARDQVIST
Source: Glasgow Caledonian University 2014

150mm FIRE MAINS WITH TWIN OUTLETS



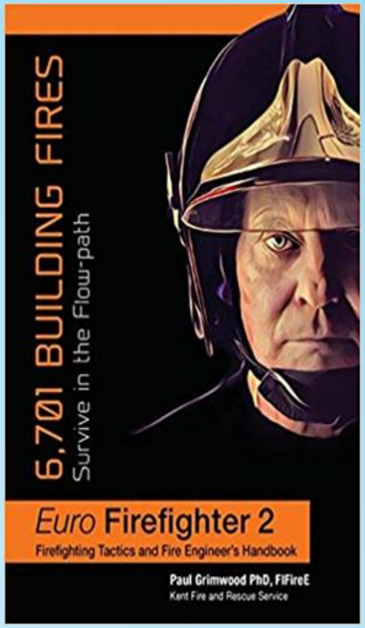
"The two 100mm rising mains were unable to provide adequate amounts of firefighting water to upper levels to deal with the amount of fire. Rising fire mains should be at least 150mm diameter with dividing connections to allow two hose-lines at each floor level"



Fog Attack p269 – Churchill Plaza Fire, UK 1992

"Two fire main outlets per level assists the laying of an attack hose-line additional to a safety hose-line in support, from the same floor (preferably the fire floor, to reduce hose-lay distances and also to protect the stairs from smoke infiltration)"

EuroFirefighter 2
P264 2017



In 1972 as a firefighter I attended one of the first commissioning tests of a wet rising main in the UK at the 91 metre Metropole Hotel in Paddington, London. High-rise buildings were now prominent on the capital's skyline and the growth of the vertical city phenomenon in the UK was becoming truly established.

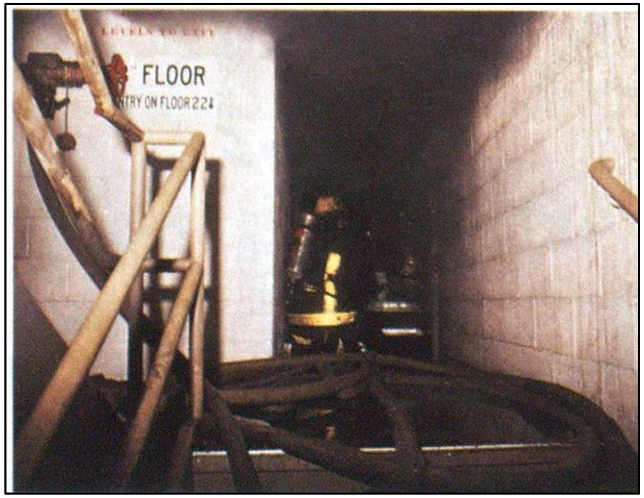
Over the following decades UK firefighters were to experience a range of challenging and sometimes terrible and tragic fires in high-rise buildings, both in residential and commercial settings. This led to a range of building design amendments and firefighting procedural updates. It is interesting to go back over some of these changes to consider why and where we are today.

100mm v 150mm Rising Fire Mains

The advantage of 150mm rising mains over 100mm mains are that they enable higher flows with less pressure losses. However, they also enhance the provision of twin floor outlets and four inlets at the base.

This enables an attack hose-line and a support safety hose-line to be laid from the same floor level. If the risers are located off the stair and into the lobby/corridor, the stair remains protected from any smoke infiltration.

The provision of four inlets at the base offers additional opportunity to augment the supply, especially if a low flowing hydrant was selected on first arrival.



BS 5588-5 : 1991 – ‘Landing valves ought to be sited where personnel can safely lay out and charge hose lines before entering the fire compartment, and ease of access; exposure to fire from the accommodation if a door is open; obstruction of fire doors by the hose line and the risk of unintentional discharge of water hitting the lift doors or controls; [all] need to be considered when siting landing valves’.

BS9990:2006 - Each landing valve should be sited:
a) Within a ventilated lobby of a lobby approach stairway, where this is provided; or
b) In a stairway enclosure; or
c) **In any other position as agreed with the appropriate authority.**

BS9990:2015 added - **NOTE 1**: For residential blocks of flats, where fire mains are proposed to be provided it is expected that the landing valves are located within the staircase enclosure on the full landings.

BS 5306-1 : 1976 Wet or Dry rising mains should have a nominal bore of 100mm where only one outlet is provided on each floor level on each riser. If two outlets are permitted on any level on any one riser the main should have a nominal bore of 150mm.

A 150mm main should be fitted with a four-way inlet breeching.

100mm v 150mm Rising Fire Mains

In practical terms, a 150mm rising main will take around 800 – 1000 litres to fill from an appliance tank and may take up to a minute to get water to the highest level. Rising mains should be laid dry on arrival and charged wet as soon as a fire is confirmed.

Pressure loss per unit length of 100mm rising main at 1500 L/min	9.3mbar/m	BS 5306 part 2 (1990) Table 64
Pressure loss per unit length of 150mm rising main at 1500 L/min	1.4mbar/m	BS 5306 part 2 (1990) Table 64
Velocity at 1500 L/min in 100mm pipe	2.98 m/s	CIBSE Pipe sizing tables V2.2
Velocity at 1500 L/min in 150mm pipe	1.34 m/s	CIBSE Pipe sizing tables V2.2
50m high 100mm riser with 6m horizontal run, allowing for 90^o bends	71m total length Pressure loss (71 x 9.3mbar) + 5000 m/bar static head loss = 5660 mbar (5.6 bar)	Estimated time to fill riser 56m at 2.98m/s = 19 seconds
50m high 150mm riser with 6m horizontal run, allowing for 90^o bends	71m total length Pressure loss (71 x 1.4mbar) + 5000 m/bar static head loss = 5099 mbar (5.0 bar)	Estimated time to fill riser 56m at 1.34m/s = 42 seconds

EXTERNAL WALL FIRES

SIX TYPES OF EXTERNAL WALL FIRE

There are typically six types of external wall fire that may spread rapidly and with great intensity up and across the face of the building, in some cases leading to re-entry into the accommodation.

In recent years there have been several fires in the UK of this nature, although none have come close to equalling the tragic scale of a fire such as Grenfell Tower in London (2017). However, it is clear to see that each fire type may present varying levels of risk and challenges, including external wall fire and multiple floor fires, but all will place demands on firefighters and incident commanders to utilise the most effective tactical options in achieving the best outcomes.

SIX TYPES OF EXTERNAL WALL FIRE

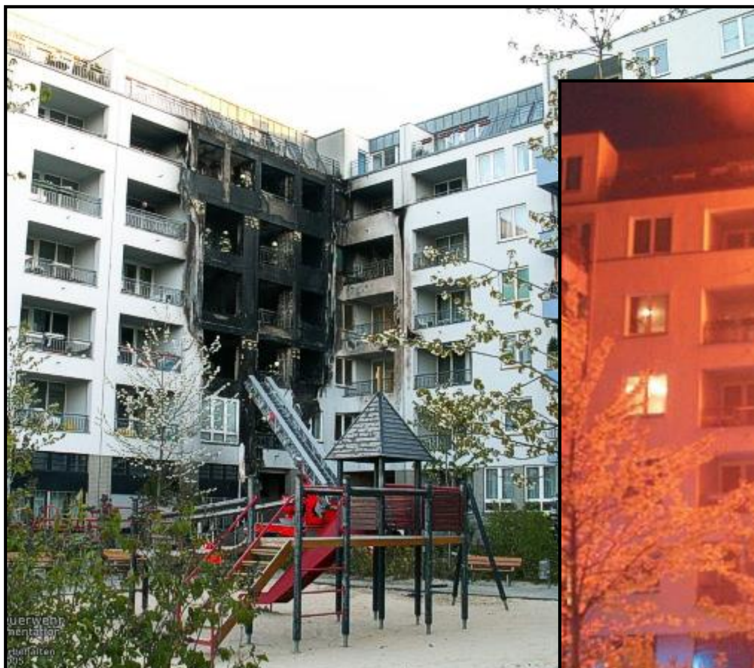
1) Typical window to window limited vertical fire spread
2) Combustible window sets ground to roof
3) External ACM or MCM wall cladding rainscreens over combustible insulation
4) External rendered wall systems or High Pressure Laminates (HPL) over combustible insulation
5) Glass curtain walls
6) Combustible Balconies with high hazard storage included in some cases

Potentially 6,000 existing UK buildings with combustible walls

- This includes buildings with rainscreen (or ventilated) façades clad with HPL etc., and External Thermal Insulation Composite Systems (ETICS) type façades, where a lightweight cement render covers the combustible insulation.
- Compared to the least flammable panels, **polyethylene-aluminium composites** showed 55 x greater peak heat release rates (pHRR) and 70 x greater total heat release (THR)
- widely-used **high-pressure laminate (HPL)** panels showed 25 x greater pHRR and 115 x greater THR.
- Compared to the least combustible **insulation products**, **polyisocyanurate foam** showed 16 x greater pHRR and 35 x greater THR
- **phenolic foam** showed 9 x greater pHRR and 48 x greater THR.
- A few burning drips of polyethylene from the panelling are enough to ignite the foam insulation
- **Smoke** from polyisocyanurates was 15 x, and phenolics 5 x more toxic than from mineral wool insulation.
- 1 kg of burning **polyisocyanurate** insulation is sufficient to fill a 50m3 room with an incapacitating and ultimately lethal effluent.

The Garnock Court fire occurred on 11 June 1999, involving a 14-storey block of flats in Scotland and resulting in one fatality. The fire had spread via the external window cladding, reaching the 12th floor within ten minutes of the start of the fire and destroying flats on nine floors.

Several other serious external wall fires have since occurred both in the UK and around the world and all have raised international concerns from a regulatory fire safety and tactical firefighting stance.



Far from being a new phenomenon. The hazards associated with this type of fire were brought home to us in 2009 when combustible cladding exacerbated the Lakanal House fire in London causing the deaths of six people.

In 2010 an external wall cladding fire in Dijon, France caused re-entry into multiples of apartments and led to the deaths of seven occupants and caused multiple injuries, including some firefighters.

GRENFELL 2017
1 FLOOR/MINUTE

SHANGHAI 2010
3 FLOORS/MINUTE

ADDRESS DUBAI 2015
5 FLOORS/MINUTE

SHANGHAI CHINA 2010

58 LIVES LOST

DUBLIN FIRE BRIGADE HIGH-RISE OPS


16


FIRE
DFB
SCOTT
300 BAR

Photograph © Trevor Hunt Dublin Fire Brigade 2019

‘Floor below Nozzle’ (Wind Driven Fires)

COMMERCIAL OFFICE HIGH-RISE FIRES

FIRE DEPARTMENT
CITY OF NEW YORK
RES 1 CUE
FR11001
F.D.
N.Y.
"OUTSTANDING"

Open floor space in office fires – Fire Spread Rates – Paul Grimwood IFP (IFE) Journal August 2018

Location	Spread rates
London 2004	• 24 m^2/min • 29 mm/second
Chicago 2004	• 15 m^2/min • 27 mm/second
Los Angeles 1988	• 25 m^2/min • 36 mm/second

https://img1.wsimg.com/blobby/go/877d587b-6900-4f7f-b145-e75cc02aff97/downloads/1cm2g3kb7_663897.pdf?ver=1555186108307

All technical perspectives articles and features are sense check reviewed before publication.
To submit your articles for IFP Journal publication please email Stephanie.morris@ife.org.uk

Structural fire engineering: realistic 'travelling fires' in large office compartments

Paul Grimwood PhD FIFireE Principal Fire Engineer, Kent Fire and Rescue Service, reports

The speed a fire develops in large open-plan office compartments >150m2 is reasonably well understood by experienced firefighters. Such fires will not conform to typical flashover fire spread rates commonly observed in smaller compartments, but will be seen to travel at a far slower pace across open-plan office floors. It has recently been suggested that this reduced rate of fire spread may have some alternative impacts on structural heat transfer to those provided in the Eurocode and as such, is now beginning to have greater influence on modern design parameters. We already have some very tall buildings on our skylines where fire resistance provisions have been analysed in a way to account for travelling fire methodology, but it is perhaps both prudent and relevant that previous real fire experience is also researched more closely by design engineers in order to establish some wider validation and provide more confidence in such an approach.

Under the expert guidance of Professor Guillermo Rein and Dr Adam Sadowski (Imperial College) and guest speaker Dr Panos Kotsovinos (Arup), I was fortunate enough to take part in the 2018 MSc Module on Structural Fire Engineering based at Imperial College London, where serving fire safety and senior operational officers are more than encouraged to gain some invaluable experience.

The nine-week module begins with an introduction to fire dynamics and fire spread followed by an investigation into the heat transfer mechanisms of conduction, convection and radiation. The mechanical and thermal properties of steel and concrete at elevated temperatures are described, as are the effect of thermal strains on simple structural systems. The MSc module introduces students to both prescriptive and performance-based design according to the Eurocode, concluding with an advanced computational design project using ABAQUS.

The relevance of this teaching is to develop a greater awareness and understanding amongst structural engineers in how fire may spread horizontally in various ways throughout enclosures and by vertical extension to involve multi-floor levels. Then, most importantly, detailing how heat transfer analyses into key structural elements are undertaken across the building frame so that buildings involved in fire can be most effectively protected from disproportionate collapse whilst under fire attack. That is protected for a reasonable period of time to enable occupants to escape and/or firefighters to undertake effective firefighting intervention and rescue. This creates a speciality role for the structural fire engineer, where prescriptive design codes might be considered inapplicable for the design of large, complex or tall structures.

As an introductory 'taster' session to the MSc module, Professor Rein introduced some of the most recent academic research undertaken by Rein and his students[1] (based on their earlier research published in 2011[2]) describing travelling fire spread in large open-plan office buildings. Other research into travelling fires undertaken by the University of Edinburgh has also been recently published[3]. It has long been known by the fire service, but more recently acknowledged by academics, that fires in large office compartments (>150 m^2) take a much longer period of time than an instantaneous fully developed flashover fire before flaming combustion reaches the furthest wall or area. In effect the fire 'travels' across the surfaces of the fuel load at a specific rate of spread, determined by various fuel configurations, compartment geometry/layout and ventilation factors. This specific form of fire development has been noted by Rein's students to form two distinct zones:

(a) the near field and, (b) the far field. The far field model represents smoke temperatures, which decrease with distance from the near field (steady-state fire zone) due to mixing with air. Most importantly from a structural engineer's viewpoint, this has quantitative impacts on the amount and

Estimated Building Fire Spread Rates (Grimwood)
According to on-scene command reports, videos, CCTV and fire timed messages

Interstate Bank fire Los Angeles 1988 12th floor 1,625 m^2 surrounding a 511 m^2 central core 100 per cent fire involvement Fire spread to involve four more upper floors	24.6 m^2/min	36 mm/s Fire took 66 minutes to travel 142.4 metres (average length of fire zone around a central core) Note: if using the external wall of the compartment the spread rate would be close to 48 mm/s, but the average (central line of measure) is taken as above	This rate of fire spread would reach the limits of suppressive capability of a 550 L/min hose-line within 4-5 minutes; or a 750 L/min hose-line within 7-8 minutes of beginning a fire growth-curve.
CCAB 67 West Washington fire Chicago 2004 12th floor – 264 m^2 (230 m^2 fire area) 24 x 11m 87 per cent fire involvement (two end rooms not damaged)	15.3 m^2/min Slower area-based fire spread in comparison, caused by a cellular non-FR office on one side of open-plan area	27 mm/s Fire took 15 minutes to travel 24 metres	This rate of fire spread would reach the limits of suppressive capability of a 550 L/min hose-line within 7-8 minutes; or a 750 L/min hose-line within 10-11 minutes of beginning a fire growth-curve.
Telstar House fire [illegible] [illegible] 1,120 m^2 100 per cent fire involvement Fire spread to involve four more upper floors	24.3 m2/min	29 mm/s Fire took 46 minutes to travel 80 metres	This rate of fire spread would reach the limits of suppressive capability of a 550 L/min hose-line within 4-5 minutes; or a 750 L/min hose-line within 7-8 minutes of beginning a fire growth-curve.
Churchill Plaza fire Basingstoke 1991 8th Floor 1,673 m^2 100 per cent fire involvement Fire spread to involve two more upper floors	Undetermined - Fire was under-ventilated for over an hour prior to self-venting and subsequently being heavily wind driven under a fuel controlled burning regime	Undetermined - Fire was under-ventilated for over an hour prior to self-venting and subsequently being heavily wind driven under a fuel controlled burning regime	N/A

The research demonstrated that commercial office fires and industrial storage fires are likely to spread beyond any practical firefighting capability within the 8-12 minutes, where a fire growth curve is established.

This means that firefighters must prepare, plan, train and equip to rapidly deploy higher flow-rates on the primary hose-lines – 500 L/min in residential buildings compared to 750 L/min in commercial and industrial premises.

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The provision of automatic fire suppression systems or effective compartment size reductions by design in such premises may be critical.

51mm HOSE FOR HIGH-RISE FIREFIGHTING

The use of 51mm (2") attack hose for high-rise firefighting was something I first learned in Los Angeles in 1990 whilst working with Task Force 3. This size hose optimises limited resources with rapid deployment of adequate flow-rates in high-rise buildings. It was something I first reported on in my book Fog Attack (1992) p239 and p285 and then went on to advise the BDAG researchers in 2003 of the benefits in using 51mm hose in high-rise situations. Less frictional loss per metre length, higher flow-rates and good lightweight manoeuvrability in comparison to 45 or 70mm hose-lines. Quite simply, more water onto the fire with less effort and staffing requirements.

Photograph © Trevor Hunt Dublin Fire Brigade 2019

Effect of reduced pressures on performance of firefighting branches in tall buildings – BDAG (Building Disaster Assessment Group) Research Report 2004 (ODPM) (Hunt & Roberts)

"Fire and rescue services should consider the adoption of 51mm hose instead of 45mm hose for high-rise fighting. This is due to its improved hydraulic characteristics and its ability to supply an adequate firefighting attack from fixed installations which may not be achievable with 45mm hose. These benefits would also apply to other firefighting applications currently undertaken with 45mm hose".

"When firefighting in tall buildings fitted with dry rising mains there will be an elevation beyond which there is inadequate pressure to undertake adequate compartment firefighting techniques with some firefighting branches. This elevation will depend upon the size and length of hose used for the attack line, the flow and the specific performance of the firefighting branch used.

For the same firefighting branch, where 45mm hose is used, this elevation will be significantly less than that where 70mm hose is used. If 51mm hose was used a firefighting attack could be mounted at higher elevations than could be achieved with 45mm hose currently used by most fire and rescue services".

BDAG Research 2004
Hunt & Roberts

Note: To be able to flow 750 L/min (BS9990 Wet Riser) through 60m of 65mm attack hose results in 1.4 bar pressure loss at the nozzle. Using 51mm hose results in a loss of 4 bars at the nozzle. However, the same flow using 45mm hose results in a loss of 8 bars at the nozzle. In other words, the BS9990 flow cannot be achieved at the nozzle using 45mm hose. If flowing 500 L/min (Residential) the 45mm hose is adequate at 2.5 bar loss.

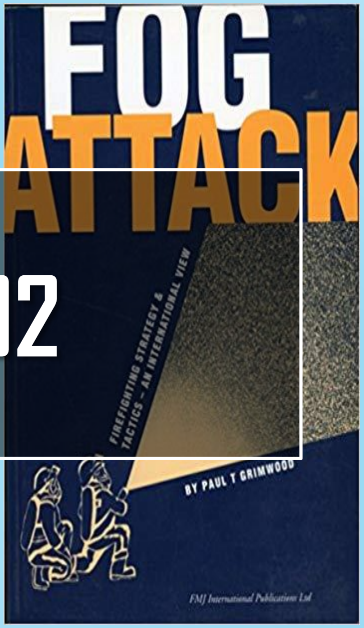
This is why 51mm hose or greater using low pressure or smooth bore nozzles should be deployed into commercial high-rise office fire buildings in order to meet the flow specifications for a rising fire main.

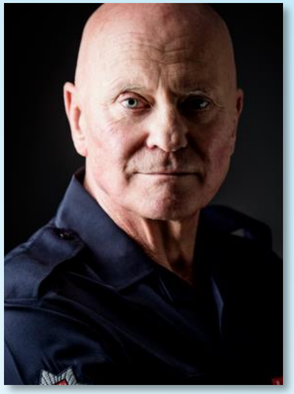
International Research – ‘Get more Proactive’

During my five decades of international fire research the greatest thing I learned was that we should all be more **‘proactive’.** It was clear to me that other fire authorities, services and departments had so much to teach us. At the same time we could offer them so much in return. However, it became disappointingly obvious that the knowledge sharing and changes were only genuinely taking place with hindsight, after an event or series of repeating incidents. Nobody seemed to be listening.

There was very little forward thinking, or no ‘horizon scanning’. The fire service is a very slow and reactive organisation in many aspects but to achieve optimisation, **our own strategic command policies, tactical approaches, preparation, equipment and training must be more widely based on a proactive view and with clear vision and foresight of what is happening elsewhere around the world.**

THE DANGERS OF SMOKE SHAFTS 1992





Inappropriate pressure differentials –

"In U.S. two-stair buildings, the evacuation stair (fire tower) is designed differently to the firefighting stair. The evacuation stair may be protected by a smoke shaft and if this stair is used as an attack stair, there is great danger in drawing, heat and smoke towards firefighters with the shaft now located behind them"

Fog Attack p265
1992

Advancing a hose-line along the corridor,

WHY does the fire turn towards you?

EMPIRE STATE BUILDING FIRE NYC 1990

A fire on the 51st floor in the 102 storey building led FDNY firefighters into an intense battle to save the building. Exterior winds, coupled with interior stack driven pressure differentials, had fully involved an 85 sq. Metre (916 sq. Feet) office suite and firefighters were forced to crawl as a 60 mph wind entered the floor as windows failed. Six firefighters were badly burned at this point. At this time there were also multiple calls from trapped occupants on the upper floors and firefighters immediately initiated their stair search and evacuation plan, deploying ten teams to upper levels.

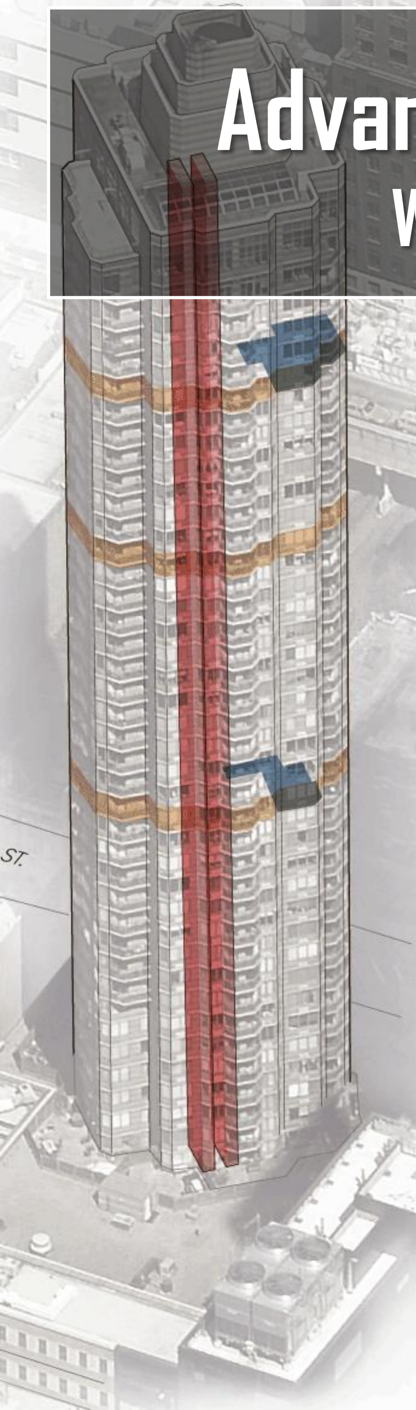
As there was a **smoke shaft located immediately behind** the advancing firefighters protecting an evacuation stairway, the flow path exacerbated the heat and smoke conditions being driven directly at the firefighters. Despite two 65mm hose-lines being advanced towards the fire the firefighters were unable to make little headway against the flames.

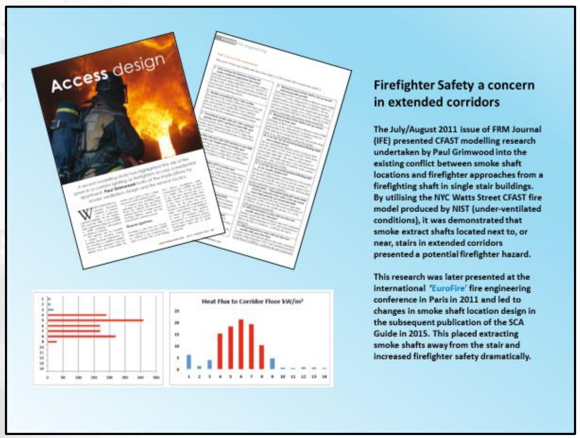
A change in strategy saw firefighters successfully redeploy using an alternative corridor, avoiding the negative flow-path created by a smoke shaft behind their advance.

Fog Attack p263-265
1992

Advancing a hose-line along the corridor,

WHY does the fire turn right towards you?





Firefighter Safety a concern in extended corridors

The July/August 2011 issue of FRM Journal (IFE) presented CFAST modelling research undertaken by Paul Grimwood into the existing conflict between smoke shaft locations and firefighter approaches from a firefighting shaft in single stair buildings. By utilising the NYC Watts Street CFAST fire model produced by NIST (under-ventilated conditions), it was demonstrated that smoke extract shafts located next to, or near, stairs in extended corridors presented a potential firefighter hazard.

This research was later presented at the international 'EuroFire' fire engineering conference in Paris in 2011 and led to changes in smoke shaft location design in the subsequent publication of the SCA Guide in 2015. This placed extracting smoke shafts away from the stair and increased firefighter safety dramatically.

'PRESSURE DIFFERENTIALS'

If the pressure differential is less behind the firefighters advance, either through the opening of a smoke shaft or a stair door, the fire will head towards the lowest pressure.

Firefighter Safety a major concern in extended corridors

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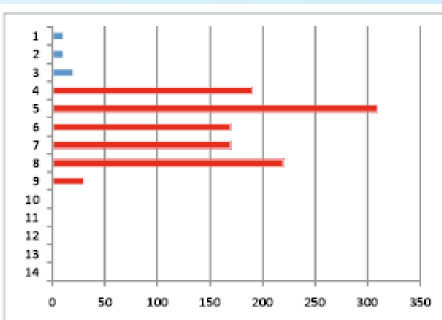
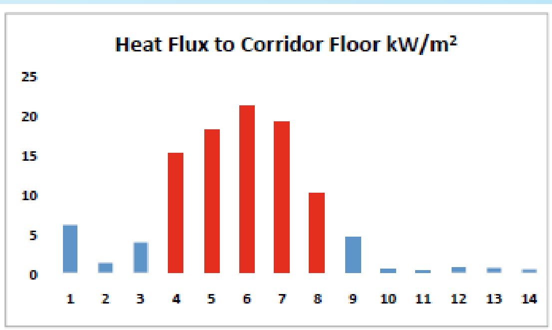
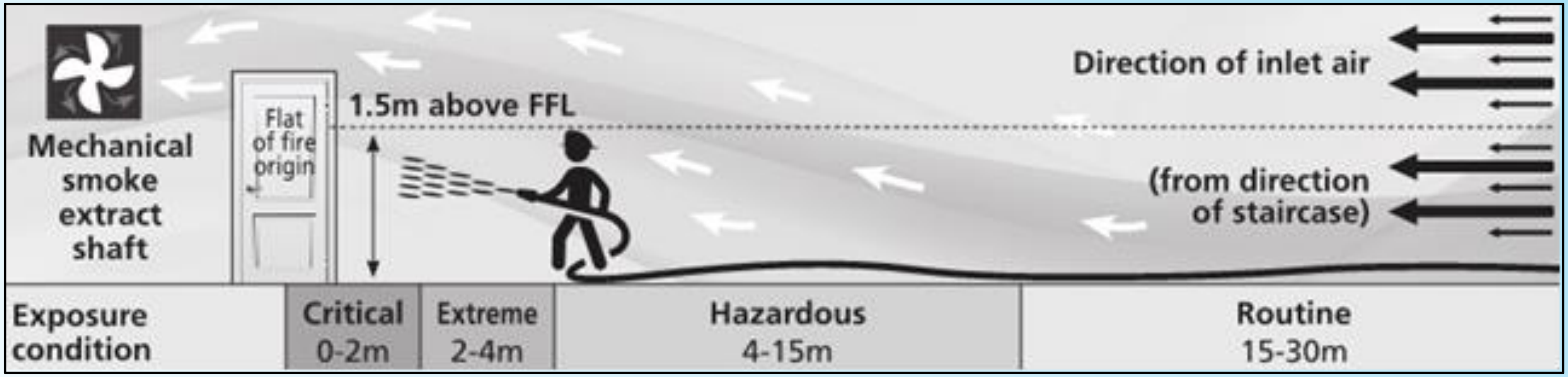




Mechanical Smoke Ventilation Systems (MSVS) (SCA Guidance 2015)

Exposure Condition	Maximum exposure time (minutes)	Maximum air temperature (^{0}C)**	Maximum radiated heat flux (kW/m^2)	Remarks	Recommended distance from apartment door*
Routine	25	100	1	General fire-fighting	15-30m
Hazardous	10	120	3	Short exposure with thermal radiation	4-15m
Extreme	1	160	4 – 4.5	For example, snatch rescue scenario	2-4m
Critical	<1	>235	>10	Considered life threatening	0-2m

The design guidance produced by the Smoke Control Association in 2015 for extended corridor MSVS took into account the 2011 research and demonstrated how placing the extracting shaft away from the stairs will improve firefighter safety and reduce exposure to unnecessary heat and smoke during firefighting.



“Experience is what you get five minutes after you needed it”

‘Don’t let us look back tomorrow and say what we did today, we could have done better’ . . . .

PLAN – PREPARE – EQUIP – TRAIN for it


FIRE DEPARTMENT
CITY OF
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