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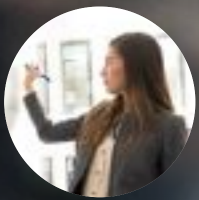
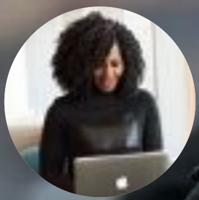
Lessons learnt to improve fire safety design





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Understanding pressure differentials in high-rise fires

Paul Grimwood PhD FIFireE takes a look at smoke control design from over the years and how their effects are present today.

In 1910 the New York City Fire Department Chief, Edward Croker, informed the New York State Assembly that the fire department could not successfully combat a fire in a building greater than 7 stories tall. Three months later a fire in the Triangle Shirtwaist Company, which occupied the top three floors of a ten story building in New York City, resulted in the deaths of 146 people. As a result of that fire, many improvements were made to the life safety of buildings. Many of these early developments in fire safety design are now commonly seen throughout our own UK building guidance. However it could be considered that some of our early smoke control objectives may have been misconstrued, resulting in inappropriate and potentially hazardous designs that remain with us today.

Why did the fire turn right instead of left? (pressure differentials)

It is now well understood by our firefighters that both naturally occurring or forced pressure differentials, particularly in a tall building fire, may impact greatly on their safety as well as their ability to function effectively during firefighting and search operations. Natural buoyancy, stack effects, external winds and the configuration of natural or mechanical smoke ventilation systems may all influence levels of fire intensity, firefighter's exposure to sudden temperature changes and smoke travel within common areas. Whilst smoke control systems are primarily intended to protect escaping occupants, it remains critical they are carefully configured and installed in order to also protect the lives of firefighters. Any potential for undesirable impacts on fire development will influence critical command decision making, particularly when prioritising the tactical protection of stairwells over an immediate firefighting intervention, or vice versa.

Using a graphic video of flames entering the corridor from a flat fire I posed the question in a series of command training seminars, *'why did the fire turn right into the corridor and not left'?* The fire officers instantly became aware of the likely pressure differentials existing in the corridor, created by a corridor smoke ventilation shaft located immediately adjacent to the firefighting stair from which they would be advancing. This demonstrated clearly how a negative pressure existing behind their advance could increase temperatures in their approach path to the fire as the fire turned right out of the flat doorway and headed towards the open smoke shaft. It is a known fact in the fire service that when implementing any tactical ventilation strategy, firefighters are generally safer whilst operating with a positive pressure differential (+) behind them and a negative pressure (-) ahead of their advance. Sometimes using portable pressure fans and by creating openings ahead of their approach, this strategy is intended to direct extreme temperatures and smoke away from their position. My computer modelling research[1] presented at the Eurofire international fire engineering conference in Paris (2011) explored and compared 14 different smoke ventilation design configurations, in both 15 and 30 metre extended corridors, for their impacts on firefighter safety. These system configurations included a range of natural and mechanical pressure differential systems (PDS) and the research outcomes were a catalyst to key amendments being made to BS 7346-8:2013; and the Smoke Control Association (SCA) residential guide of 2015, in terms of firefighter tenability and smoke shaft locations.

Regulatory smoke control design

In the 1940s, the UK regulatory guidance for fire safety designs in tall buildings was going through some detailed major post-war development. There was much collaboration at this time, between UK and US fire safety code development and the experience gained within the high-rise canyons of New York City seemed a logical route to follow. We can see in UK Post War Building Studies (PWBS) Parts 1-4 (1946-1952) several references to naturally ventilated 'Fire Towers'.

Fire (smoke-proof) Towers

In New York City (NYC) Fire Codes of the time, *'Fire Towers'* (also known as smoke-proof towers) protected an 'evacuation' stairwell, with two fire doors serving a ventilated lobby (vestibule). In Part 1 of PWBS we can see many references where a NYC *'Fire Tower'* was predominantly defined as a means to support firefighting access. However, the NYC Life Safety Code certainly didn't see it that way and defined a Fire Tower primarily as a means of protecting an egress stairwell, rather than as a means for getting firefighters up and into the building.

By the 1970s an alternative stairwell design, specifically configured with firefighting access in mind, presented a pressurised stair. These were now seen as the 'firefighting stairs' whilst *Fire Towers* were being provided for occupant or resident evacuation. In effect, although the stairs in *Fire Towers* had rising fire mains, these would only be used as a very last resort by firefighters. A serious fire on the 51st floor in the Empire State building in New York in 1990 served as an example. A fire that I had previously reported[2] on occurred whilst I was on detachment to the Fire Department of New York (FDNY) from London Fire Brigade for the purpose of studying high-rise firefighting and building design. This incident had clearly demonstrated the hazards of approaching an intense fire from a *fire tower*, with a negative pressure differential being created by the naturally vented smoke shaft positioned behind the firefighting advance. As it transitioned, firefighters were forced to relocate themselves into a pressurised firefighting stair to eventually mount a successful attack on the fire. This hazard created by negative pressure differentials existing in a naturally vented smoke shaft (Fire Tower) was made clear in subsequent revisions of the FDNY High-rise Firefighting procedures from 1997 onwards. [FDNY Procedures Vol.1 (Book 5) 1997 – *'CAUTION: When using a stairway for smoke removal, an adverse condition could occur on the fire floor, causing heat and flames to be drawn toward the stairway being used. The drawing of heat and smoke toward stairways is especially evident whenever fire towers have been utilized. Due to this experience, fire towers are not recommended for use as fire attack stairs'*.

Another life critical message of relevance was given as a directive in the same 1997 procedure - *A [hose] line is not to be operated from a stairwell until it has been cleared of building occupants*.

In 1968 the New York *'Fire Tower'* became a coded option rather than a regulatory requirement, as the provision of sprinklers became more widely regulated. During the 1965 design and construction phase of the World Trade Center twin towers in New York, although the 1938 NYC building code was still in force the forthcoming 1968 update (in draft) had less restrictive provisions and were adopted three years ahead of publication. This allowed the elimination of a fire tower as a required means of egress, reducing the fire rating of stair shaft walls from three to two hours and enabling a reduction in stairwells by doubling stair capacity in stairs. The more common approach now for both firefighting and evacuation stairs in NYC is to provide pressurization to all stairs, according to NFPA 92.

However, this all leads to a number of questions. Was there a misinterpretation by those involved in the PWBS in 1946 (and 1952) where firefighters are actually less safe when approaching the fire floor with a ventilated lobby behind their advance? Did the PWBS actually believe that the *Fire Towers* would assist firefighting access? Or was the combination of an *evacuation stair* design with a *firefighting access* design

1 Grimwood. P; Access Design; Fire and Risk Management (FPA-IFE); July/August 2011

2 Grimwood. P; Fog Attack; 1991 (p263-265); FMJ Publications UK (Fire Magazine).

considered adequate? By later combining the two designs of firefighting stair with an evacuation stair (single stair firefighting shaft), was the PWBS setting up a dangerous precedent where high-rise stairwell design would impede both firefighters and those building occupants who are evacuating into the same stair being used for firefighting?

"The design of both residential and commercial buildings should take into account the dedicated stairwell protection procedures that firefighters are now using to protect stairs from smoke infiltration and to search areas above the fire floor/s."

Current European and UK design standards

Smoke control designs in the USA and Europe now favour pressurisation in both evacuation and firefighting access stairs. However, the most common prescriptive approach in the UK for protecting evacuation and firefighting stairwells from smoke infiltration remains the *misapplied* 'smoke tower' designs from PWBS guidance, Automatic Opening Vents (AOVs) in external walls and natural or mechanical smoke ventilation systems (MSVS) that simply exhaust or flush smoke from extended corridors.

Of course, the most hazardous pressure differential that will create havoc at fires is created by the entry of an external wind. This may occur as windows fail in a fire compartment that is approaching or surpassing the flashover stage, sending intense heat and fire into common areas and immediately creating untenable conditions in unprotected stairwells. This is another reason why it is so life critical to evacuate primary risk zones (fire floor) early and ensure stair doors remain fully closed on the fire floor, as firefighters begin their firefighting intervention. Detailed research[3] undertaken by the FDNY in 2009, in association with the National Institute of Standards and Technology (NIST) and New York University, demonstrated that an imposed wind of 9 m/s to 11 m/s (20 mph to 25 mph) entering the window of a post flashover bedroom fire created devastating flow paths of intense fire, smoke and heat spreading into common areas. These flow paths would continue through the common area corridor and into the stairs, exiting out of the stairwell access door on the roof, with temperatures in excess of 400°C and velocities in the order of 10 m/s (22 mph) measured in the corridor and stairwell above the fire floor. Where stairwell doors remained closed on the fire floor, pressure differentials from corridor to stair were often in excess of 45 Pa. These experiments demonstrated the “extreme” thermal conditions that can be generated by a “simple room and contents” fire and how these conditions can be extended along a flow path within a real building, when wind and an open vent are present. This exemplifies the reasoning behind ensuring stair doors remain closed by design, providing adequately pressurised stairs, and ensuring that smoke shafts or other openings are located well away from stairwells.

The NIST research also supports the most detailed framework upon which FRN 958 (1972) and BS 5588-4:1978 introduced stairwell pressurisation in the UK, where 25Pa for standard fires and 50Pa (accounting for the possibility of wind driven fires and stack effect) were seen as the required pressure differentials to protect a stairwell from smoke infiltration, as stair doors were opened for firefighting access.

The recommendations given in FRN 958 and BS 5588-4:1978 were as follows: (Table 1)

Building Height (m)	Fire Pressure (Pa)	Wind and Stack Impact (Pa)	Recommended TOTAL Pressure (Pa) Differential (including a safety margin)
5	8.5	8	25
25	8.5	10.5	25
50	8.5	13	50
100	8.5	19.5	50
150	8.5	29.5	50

3 Daniel Madrzykowski; Stephen Kerber; Fire Fighting Tactics Under Wind Driven Fire Conditions: 7-Story Building Experiments; **NIST Technical Note 1629; 2009**.

In noting the tests reported in FRN 958[4] and referenced fire tests carried out during the 1960s, pressurisation must be sufficient to overcome pressures developed in the building by fire, wind and stack effects.

This compares with NFPA 92 (Pressurization) Requirements (Table 2)

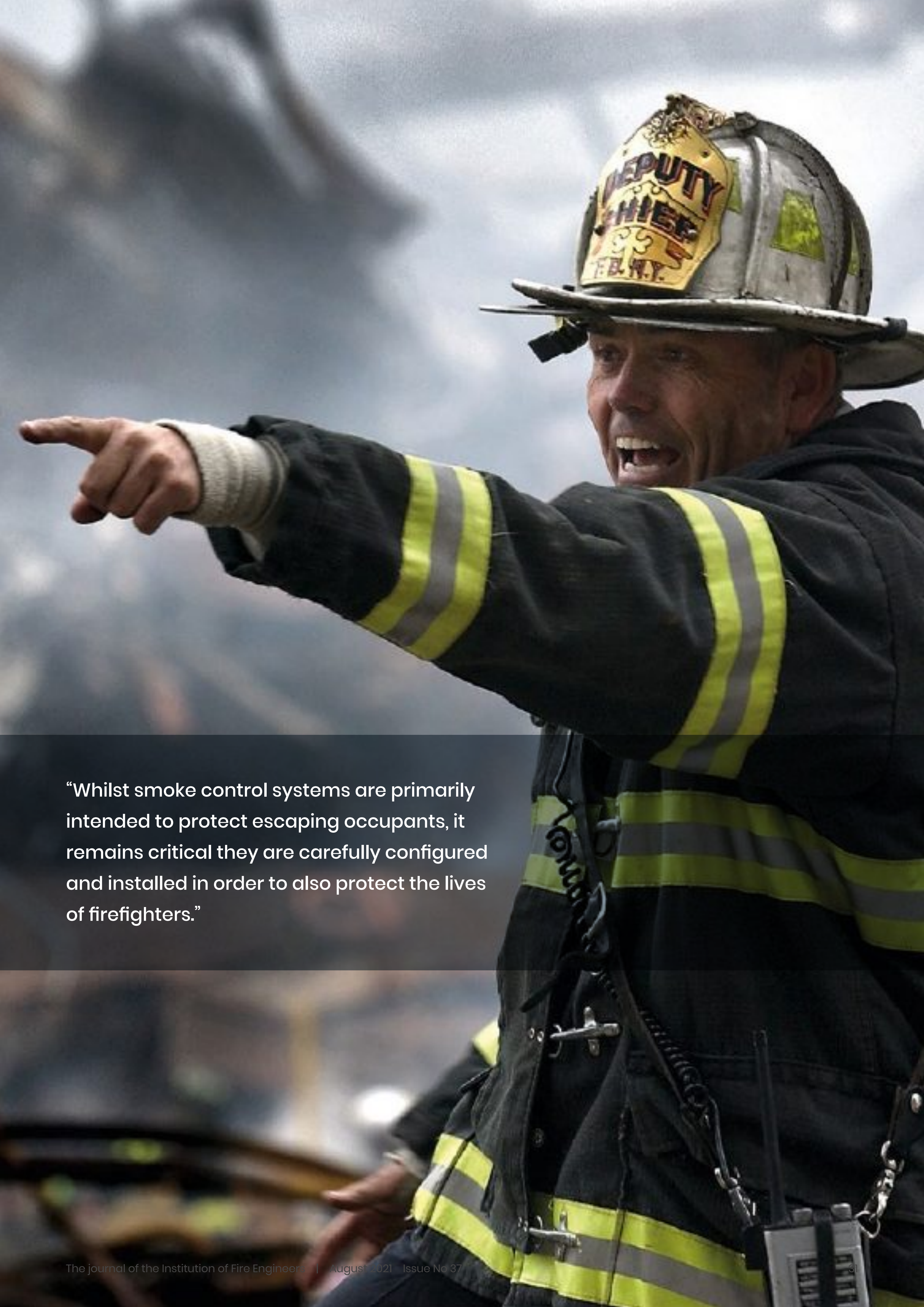
Sprinklers	Ceiling Height (m)	Recommended Pressure (Pa) Differential
Yes	Any	12.5
No	2.7	25
No	4.6	35
No	6.4	45

Safer buildings in future

If we are to make our buildings safer in future, it is important to consider the following design conflicts that impact both on occupant and firefighter safety:

1. ***In the UK – s3.3 ADB-1 2019**: (in part) ‘Sufficient protection to common means of escape is necessary to allow occupants to escape **should they choose to do so** or are instructed/aided to by the fire service. A higher standard of protection is therefore needed to ensure common escape routes remain available for a longer period than is provided in other buildings.’*
2. The conflicts between firefighting procedures and a higher standard of protection to escape routes in tall residential buildings urgently need addressing. Protection to firefighting shafts and egress stairs in residential buildings, but particularly in single stair buildings, must therefore be increased. Without dedicated firefighting lobbies, as are provided in commercial buildings, firefighters are forced to lay hose-lines through stair doors and break the seal of protection. Therefore, adequately sized firefighting lobbies are an essential enhancement.
3. For firefighters to be able to operate with relative safety in stairwells above the fire floor (stairwell protection teams), they should also be provided with enhanced protection beyond the current regulatory design requirement.
4. Rising fire mains in both residential and commercial buildings should be increased in size to 150mm diameter, allowing *two outlets at each floor* within a firefighting lobby, to accommodate both an attack and a safety hose-line (national procedure) to be deployed without taking hose through stair doors.

4 Hobson, P.J. and Stewart, L.J., 1972. PRESSURIZATION OF ESCAPE ROUTES IN BUILDINGS. Fire Research Notes 958 BRE



"Whilst smoke control systems are primarily intended to protect escaping occupants, it remains critical they are carefully configured and installed in order to also protect the lives of firefighters."

5. All doors leading onto a firefighting stair should *remain fully closed by design* and not form part of an air supply route for a smoke control system.
6. Any firefighting shaft should be pressurized to at least 30 Pa in sprinkler protected buildings, in accordance with BS EN 12101. Alternative egress or firefighting stairs (with lobby protection) may be protected by pressurisation or natural ventilation/shafts.
7. If extended dead-end corridors remain without alternate escape stairs, they should be limited in length to a maximum of 30 metres (two hose-lengths) and provided with corridor 'shaft to shaft' ventilation, directing airflow away from the stair.
8. The use of external wall AOVs should be avoided wherever possible.
9. If a single stair is centrally located, the wings should be separated by a firefighting lobby. Each wing should be provided with separate 'shaft to shaft' smoke systems if corridors are extended, as above.
10. A two stair building should be separated by central fire resisting doors in the corridor. Each separate corridor should have 'shaft to shaft' ventilation if extended beyond regulatory compliance.
11. Large or deep basement areas according to regulatory requirements, should be depressurised.

The design of both residential and commercial buildings should take into account the dedicated stairwell protection procedures that firefighters are now using to protect stairs from smoke infiltration and to search areas above the fire floor/s. In this respect, careful consideration should be given to retrofitting enhanced protection to existing buildings it the form of adequately sized firefighting lobbies, each provided with twin outlets at every level. In existing single stair buildings, stair pressurisation and/or sprinklers should also be considered. In all new buildings, alternative escape routes should be considered and stairwells should be protected by pressurisation (firefighting shafts) or by ventilated lobbies (egress stairs). Stair doors should remain closed and not be used to provide air supply for smoke control systems.

About the author:

Paul Grimwood PhD FIFireE is a Principal Fire Engineer with Kent Fire and Rescue Service. He is in his 50th year of service as a firefighter, fire investigator, fire behaviour instructor and fire engineer, serving mainly in London Fire Brigade and Kent Fire and Rescue Service. He has a series of books about firefighting tactics as well as the book '*EuroFirefighter 2*' which is now available as a free download at www.eurofirefighter.com