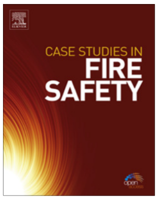
Case Studies in Fire Safety 1 (2014) 13–17

Contents lists available at ScienceDirect

Case Studies in Fire Safety

journal homepage: www.elsevier.com/locate/csfs



Pressurization systems do not work & present a risk to life safety

Simon Lay [*]

AECOM, 1 New York Street, Manchester, Greater Manchester M1 4HD, UK

ARTICLE INFO

Article history:
Received 24 October 2013
Received in revised form 2 December 2013
Accepted 3 December 2013
Available online 15 December 2013

Keywords:
Smoke control
Pressurization
Tall buildings
Fire safety
Performance based design

ABSTRACT

This paper considers why some fire safety professionals have become critical of a reliance on pressurization as the dominant form of smoke control in high rise buildings. Design, installation and operational challenges are discussed and alternative solutions presented alongside guidance to building designers and approval authorities.

The successful operation of pressurization systems is routinely called into doubt by fire fighters and numerous respected engineers have raised concerns about the practical use of pressurization systems. However, pressurization systems remain a standard feature of high rise building codes from the USA, UK, Australasia, China, India, the UAE and many other locations. In addition to stairs, some codes include the pressurization of elevator shafts and lobbies/vestibules.

There is considerable anecdotal evidence of problems with pressurization systems. The author has been called on a number of occasions to support Mechanical Engineers who are trying to commission a pressurization system which refuses to perform as intended. In conversations with fire fighters from the UK, the USA, India and across Europe, the author has repeatedly been told that they do not trust pressurization systems, having seen them underperform on many occasions. Discussions with fellow fire and life safety professionals have also suggested that many experts share the reservations of the author with regards to the application of pressurization systems.

In addition to anecdotal evidence, there have been studies by researchers such as those carried out by Tamura [2] which raised doubts about the performance of pressurization systems in simulated conditions, test facilities and field trials. Well respected experts in smoke control techniques and early proponents of pressurization, such as Budnick and Klote [3] have published papers reiterating important challenges and design considerations that need to be considered for pressurization systems.

Since the 1960s, pressurization has been a popular option for protecting stair enclosures in tall buildings, and the principle is relatively simple. A pressurization system is intended to prevent smoke leaking passed closed doors into stairs by injecting clean air into the stair enclosure such that the pressure in the stair is greater than the adjacent fire compartment.

---

[*] Corresponding author. Tel.: +44 (0) 161 601 1700.
E-mail address: simon.lay@aecom.com
URL: http://www.aecom.com

http://dx.doi.org/10.1016/j.csfs.2013.12.001

Then, if the stair door is opened, the system is intended to maintain a flow of air through the open doorway to oppose smoke flow and prevent contamination of the stair enclosure.

So if pressurization systems operate on logical principles and are based on simple physics, why are fire fighters and engineers concerned about their effectiveness, and if pressurization systems do not work, what are the consequences and alternatives?

Consequences of failure of pressurization systems

The intended function of pressurization systems is to provide protection to both building occupants and fire fighters.

In high rise buildings evacuation is normally phased such that occupants do not all move to the escape stairs at the same time. Instead, occupants who are most at risk (on the fire floor) evacuate first, followed by the rest of the occupants, phase by phase. The result of this is that evacuation routes need protection from smoke for an extended period of time, and pressurization aims to provide this protection.

Fire fighters may rely on pressurization to maintain a smoke free environment from which to commence fire fighting activities. Then, during fire fighting, pressurization should protect the escape route for fire fighters to use if required.

Lobbies and elevator cores may also be pressurized to limit smoke spread. In situations where elevators are used to support fire fighting activities or evacuation (something which is increasingly being considered in tall buildings), then pressurization of elevator cores may be proposed to ensure that the elevators are available and protected from contamination.

Under some building codes (for example NFPA Life Safety Code 101 and the International Building Code), pressurization can be proposed instead of providing a smoke proof vestibule. This makes the pressurization system the primary line of protection for building cores. Failure of the pressurization system could therefore place occupants and fire fighters at serious risk of incapacitation or death.

The challenges for pressurization

The principles of pressurization systems are simple, but the problems associated with them are many and complex. They can be broken down into problems associated with; design, commissioning, operation and legacy.

In the design process there are a number of key design parameters that have to be taken into account. The most fundamental parameter to have an impact on the design is estimation of leakage from the core.

Air leakage paths can include stairway doors, windows, gaps in walls, natural leakage through wall materials, elevator doors, service shafts, facades and raised floor systems. There are standard estimates which are recommended in pressurization design guides. However, if the calculations are to be correct, such that the system performs as intended, the engineer designing the system will be reliant on these variables being static from the point of design, through the rest of the design process, subcontractor design, construction, commissioning, fit-out, refurbishment and so on for the lifetime of the building.

Whilst it is common to include tolerances in the design process, these cannot guarantee sufficient design flex to accommodate significant changes in leakage paths. Also, the need for integrated building services design to be efficient means that it is very difficult to achieve changes to components such as ducts, fan sizes, power supplies and relief dampers after the initial design process.

The commissioning process cannot take place until the building is substantially complete. Any significant problems identified at commissioning that cannot be resolved by fine tuning the equipment already installed is likely to lead to substantial costs and delays to the building. It is common during commissioning for temporary doors to be in place or for construction openings to not be fully sealed. Also, many buildings are designed and handed over as "shell" only, with a final fit-out by a tenant. This final fit out by the tenant can have significant implications for the leakage paths and air supply paths.

Results from commissioning can also be highly sensitive to the wind and temperature conditions on the day of testing. This is well recognized within design codes for pressurization systems. For example, the BS EN 12101-6 [6] includes protocols to normalize the system test against the climate conditions on the day of the test. However, no account is taken of what might happen on a different day under different wind or temperature conditions. The impact of this will vary with the height and location of the building, but in cities which see large variations in temperature throughout the year, and in the case of very tall buildings where wind effects are a continuous feature, the significance of setting a system to work under a single climate condition is likely to result in system performance problems under other conditions.

To anyone not engaged in the building design and construction process, it may appear inappropriate that the effects of the weather on life safety systems are not fully accounted for. That may be the case, but ultimately it is a matter of practicality.

The number of doors open at any one time is critical to determining the peak flow rate of the fans serving the pressurization system. Normally in the design process, a door at the foot of the stair is assumed to be open during fire fighting (for fire fighters entering the building) and also a single door on the fire floor. However, this may not represent the practicalities of evacuation or fire fighting in a tall building. Any doors being opened beyond the small number assumed in the design case will cause a loss of air, preventing the pressurization system from performing as intended, potentially allowing smoke into the core.

One of the primary concerns for pressurization systems in operation is the effect that they may have on door opening forces. As doors typically open into stairways, the increased air pressure in the core arising from a pressurization system can prevent occupants from being able to open doors.

It can very difficult to balance the different air flow requirements for creating positive pressure in a core with closed doors and the large volume required when doors are open. This problem becomes exaggerated in very tall buildings.

There are design solutions intended to overcome the problems of balancing air flows and door opening forces. These range from simple weighted dampers to complex variable drive fans or damper arrangements linked to pressure sensors within the shaft. However, even with these arrangements there are still practical limits to the height of shaft that can be pressurized.

Some guidance documents for pressurization design recognize this practical height limit, such as the ASHRAE Design Manual for Smoke Control [10]. This leads to recommendations that in very tall buildings, the stair enclosure may need to be split into a series of stacked, but separated shafts. However such guidance is not recognized in all building codes, and the implications on stair enclosure size may be overlooked by designers. For example the BS EN 12101-6 includes none of the reservations on maximum height of any given section of core.

Pressurization systems emerged as a popular design solution initially in the US, a country where, there is a strong manufacturing and servicing base for mechanical systems coupled with legislation to ensure that building owners maintain life safety buildings. As a result of this, the reliability of pressurization systems should be highest in the US or similar territories. Despite this, a study by Lay [9] drawing on the experience across a range of fire safety professionals, product manufacturers, building occupiers and researchers, estimated that 35% of pressurization system might fail to function as intended. Tamura [1] found that none of the field tested systems that were studied actually performed as originally intended.

Data from the CTBUH [4] confirms that high rise development in emerging economies over the last decade has overtaken tall building projects in the established 'western' economies. However, some emerging economies have less robust inspection, maintenance and general building management regimes than those in established economies. Often fire safety enforcement in emerging regions is reactive, seeking prosecution after an event, rather than proactive or preventative. In some regions, these challenges are recognized such as the cautious acceptance of pressurization within the Indian NBC [7], but in the main, technologies have been transferred internationally without proper regards for the legacy resources that are required to ensure continued safe operation.

Recognizing the challenges for pressurization systems

It is fair to note that guidance documents such as NFPA 92 [5] and the BS EN 12101-6 include recommendations for many of the challenges encountered by pressurization systems to be taken into account by designers. These guides note that considerations should be given to additional smoke control elements such as floor plate extract in tandem with pressurization, or the use of vestibules as well as pressurized stairs. However, these additional considerations are not universally repeated in the guidance provided in all jurisdictions. It is also evident that even where such considerations are noted, they are sometimes ignored by building designers because they add complexity to the design or impact on building efficiency.

There is an inherent expectation by some designers that following the simple calculation processes in design standards will lead to an acceptable design, without tackling some of the trickier design challenges. There is also little value in statements in codes which require the designer to make the contractor or building owner aware of the restrictions arising from the design of the pressurization systems. This approach fundamentally fails to recognize the practicalities of the building design and construction process, and does little but attempt to indemnify designers against inevitable changes in buildings.

Alternative solutions

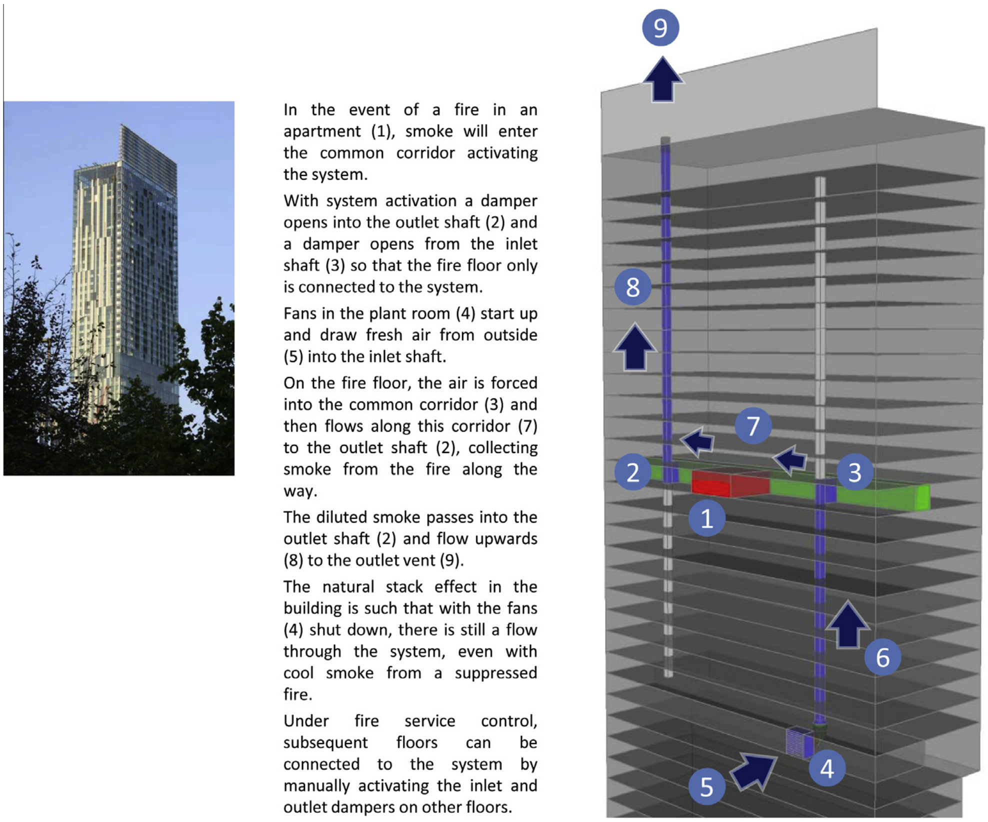
Designers can address the challenges for pressurization systems by reconsidering what the objectives of the systems are and considering bespoke smoke management solutions that match the needs and risks of individual projects.

Pressurization has a role in some schemes, but beyond application to relatively short (less than 30 m tall) schemes, its use needs to be very carefully considered. It is not a panacea to smoke protection of escape routes and was never conceived as such.

The challenge is to develop smoke protection solutions which can be specified in the early stages of building design, developed to a specification with confidence that they can be installed without compromise, perform as intended through the lifetime of a building, and achieve an adequate level of robustness for the jurisdiction where they are to operate. Appropriate solutions will not be developed by amending simple design calculations from pressurization codes. Instead a performance based design approach to meet the functional objectives of protecting occupants and fire fighters is required.

A solution adopted in recent years in the UK has been to move away from pressurization in many cases to a performance based solution based on air-exchange rates or "flushing" of smoke. The system installed at the CTBUH award winning, Beetham Tower in Manchester is one such system (Fig. 1).

The Beetham Tower system uses an air inlet shaft which can direct air into the common residential corridors on any chosen floor. A natural smoke relief shaft simultaneously opens. The system is configured to provide inlet from a plant floor below the floors served, with the vent to roof. In this way, the air flow route is upwards then, through the corridor being



In the event of a fire in an apartment (1), smoke will enter the common corridor activating the system.

With system activation a damper opens into the outlet shaft (2) and a damper opens from the inlet shaft (3) so that the fire floor only is connected to the system.

Fans in the plant room (4) start up and draw fresh air from outside (5) into the inlet shaft.

On the fire floor, the air is forced into the common corridor (3) and then flows along this corridor (7) to the outlet shaft (2), collecting smoke from the fire along the way.

The diluted smoke passes into the outlet shaft (2) and flow upwards (8) to the outlet vent (9).

The natural stack effect in the building is such that with the fans (4) shut down, there is still a flow through the system, even with cool smoke from a suppressed fire.

Under fire service control, subsequent floors can be connected to the system by manually activating the inlet and outlet dampers on other floors.

Fig. 1. Schematic of the smoke management system at the Beetham Tower (Lay).

protected and finally out the relief shaft, towards the roof. The natural stack in the building works with the system, wind effects enhance the system performance and the design does not have an adverse impact on door opening forces.

In tests, the system at the Beetham Tower was found to deliver approximately 70% of its performance without any mechanical fan assistance at all. This provides a very robust design as potential maintenance failures are mitigated by a reduced, but still adequate, performance. Similarly, the system was found to need approximately 1/3 of the air supply plant that a pressurization system would require. A key benefit of the system was that opening doors to the stair did not significantly impact on performance and the system could be applied on multiple floors simultaneously, giving fire fighters much greater flexibility of operations.

The concept applied at the Beetham Tower was previously applied on a project in London which had originally been constructed with a pressurization system that had subsequently been found to deliver less than 10% of the required performance. The same mechanical plant was adapted into a "flushing" based system to great success. Similar solutions have been adopted on a large number of high rise office, residential, hotel and mixed use schemes in recent years.

There are similarities in the approach used at the Beetham Tower to a smoke ventilation concept known as the "Fire Drainage System" proposed by Tibor Harmathy at the NRC Canada in 1987 [8]. The fundamental approach proposed by Harmathy was to harness the heat and induced convective flow from a fire through a series of shafts to reduce the spread of fire from the region of fire origin. There are some differences between the system employed at the Beetham Tower and the system proposed by Harmathy as the system of downstands proposed in the Fire Drainage System was not employed in the Beetham Tower and a mechanical input was used in the Beetham scheme to enhance performance, particularly for the cooler smoke that could occur from a suppressed fire or during the early stages of a fire when smoke is leaking into a corridor from the fire apartment. However, many of the analytical principles explored by Harmathy were validated in the Beetham Tower system.

A key driver in the system installed at the Beetham Tower (and other schemes) is that they are much less reliant on quantifying the air leakage paths. So even though construction materials changed and the building design underwent significant changes following the initial design stage, the smoke protection strategy remained unchanged, reducing design risk.

On a project in Mumbai, alternatives to pressurization of elevator shafts are being considered to improve long term robustness and address concerns that high pressures in a 200 m tall elevator shaft could impede the operation of elevator doors, preventing them from being available to support evacuation in a fire.

An advantage of a performance based system such as the cases described above is that the performance requirements can embody elements of system failure, future proofing and non-standard evacuation or fire fighting tactics. Many of the "what if this happened" type questions which remain unanswered by code based pressurization solutions can be addressed ensuring that the design solution *proves* that safety is achieved, rather than *assuming* that safety can be achieved.

As well as delivering a safer design, it is important to note that the above solutions deliver a more efficient building design which improves building value, reduces long term maintenance costs and reduces initial construction costs.

Guidance to designers and approvers

This paper has drawn together anecdotal and research data which raise concerns on the reliability and performance of pressurization systems used for smoke control in tall buildings. The primary concerns relating to such systems are:

- Inadequate appreciation by designers of the challenges associated with designing a pressure sensitive system in a high rise building.
- Limitations on system performance under typical operational circumstances.
- Life time maintenance and adaptability.

To architects, contractors and building developers, it is recommended that advice be sought from a fire and life safety professional with specific experience in the design and commissioning of core protection systems in high-rise buildings. Challenge your design team to set out very clearly what restrictions and assumptions are inherent in the design if pressurization is being recommended and insist that alternative, performance based options be considered as well. The goal should be to seek out solutions which are integrated into the building design and reflect the building function and risks.

To approval authorities, the advice would be to challenge from an early stage precisely how the building designers and construction teams intend to deliver a pressurization system that performs as intended. It should not be acceptable for a designer to pass the responsibility for material specifications and installation on to the contractor unless the contactor has made it absolutely clear that they understand the restrictions and challenges. By insisting on such evidence, designers will be forced to address some of the inherent challenges that pressurization systems face.

Ultimately, tall buildings require a bespoke fire and life safety solution which matches the needs and risks of each building. This performance based approach will deliver a safer, more efficient design and will address the specific challenges of each individual project creating more sustainable, lower cost, safer buildings.

References

[1] Tamura GT. Assessment of stair pressurization systems for smoke control. NRCC-35059; 1992.
[2] Tamura GT. Stair pressurization systems for smoke control: design considerations. NRCC-30896; 1989.
[3] Budnick EK, Klote JH. The capabilities of smoke control. Part II – system performance and stairwell pressurization. J Fire Protect Eng 1989;1(1):1–10.
[4] Wood A, editor. CTBUH tall buildings reference guide. CTBUH; 2010.
[5] NFPA. NFPA 92: standard for smoke control systems. NFPA; 2012.
[6] British Standards. BS EN 12101-6:2005 smoke and heat control systems. Specification for pressure differential systems. BSI; 2005.
[7] NBC, National Building Code of India. Bureau of Indian Standards; 2005.
[8] Harmathy TZ, Oleszkiewicz I. Fire drainage system. Fire Technol 1987;23(1 (February)):26–48.
[9] Lay SF. Data for the application of probabilistic risk assessment to the evaluation of building fire safety. WFRC/DoE; 1996.
[10] Klote J. The ASHRAE design manual for smoke control. National Bureau of Standards; 1984.