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Report on methods to improve smoke control in residential apartment buildings using pressurisation

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Foreword

Understandably, following the Grenfell Tower fire, smoke control in residential apartment buildings has come under the spotlight for review.

Considering the guidance that was available at the time of the construction of the original building, the question must be asked, "How did we arrive at the current catalogue of failings when the original construction was far safer?"

One of the consequences of the Grenfell Tower disaster is that, according to recent research, 72% of apartment building tenants would ignore advice to stay in place if fire broke out in their building; this could create serious concern over the building's fire-fighting strategy.

When considering the most appropriate method for keeping protected escape routes clear of smoke British Standard BS 5588: Part 4: 1978, *Smoke control in protected escape routes using pressurisation* was the document of choice, now depressurisation is the system of choice, but is this the best option?

It is not too difficult to explain how pressurisation fell from favour; more complex to design than depressurisation, more difficult to commission, additional work in construction, all aided and abetted by comments in a trade association's guidance document stating that pressurization systems were "expensive and difficult to commission".

CFD modelling brought a level of comfort to designers and regulators when they were able to see graphical validation of a depressurisation system's performance. BS9991 in Annex 2 Clause A3 refers to the potential for extending the permitted travel distances; we know from experience, for example, that the travel distance from an apartment to a place of safety, e.g. stairwell, may be increased from 7.5m to 30m if a mechanical ventilation system is installed with the system performance verified by CFD modelling. Also, if sprinklers are installed in the apartments and escape can be made in two directions, the travel distance can be increased to 60m (BS9991 clause 11.2 Permitted Variations). Can this really be right whatever type of system is installed?

There is still a lot more to come from the Grenfell Enquiry and these will, undoubtedly, be far reaching.

A small group of smoke control engineers were given the task of reviewing the current practices in smoke control system design, assessing what was done, what is now done, what lessons can be learnt and what is the best way forward.

The following pages are an outline of their report.

Introduction

Why is there so much resistance to smoke control companies, developers and consulting engineers to adopting pressurisation as the default type of system in residential or commercial buildings, particularly in high risk residential buildings?

To answer my own question, these are the most common reasons:

1. Smoke control specialists resist it because they believe a) it is more expensive and will make them less competitive, b) the system is more complex to design and c) because it will be more complex and difficult to commission
2. Consulting engineers resist it because it will be more complex to design and commission
3. Developers resist the system because they believe that it will cost them more in construction

All these assumptions may have had an element of truth in them 10-15 years ago due to the type of controls and equipment available to construct a pressurisation system and, for this reason, smoke control design engineers, consulting engineers and architects have clamoured for depressurisation systems because they thought that depressurisation systems were easier to understand when commissioned.

Comments by Others

In an article published in the July 2018 issue of the CIBSE Journal, Liza Young referred to comments made by Dr Barbara Lane of Arup Fire in her submission to the Grenfell Tower Inquiry. Dr Lane had commented that the smoke control system that was installed in the tower's 2012-2016 refurbishment was neither a smoke dispersal system nor pressurisation system, it did not follow the guidance in Approved Document B 2013 or BSEN12101-6 2005. Dr Lane's report added that even if the system had been compliant, it was designed to offer smoke control on one level only, not to clear smoke simultaneously on multiple floors.

In the same article, Martin Kealy, MD of MKA Fire and chair of the CIBSE Guide 'E' Fire Safety Engineering steering group commented that fire and life safety engineers should design robust and simple smoke management systems. He went on to say that the American NFPA guidance requires stairwells to be pressurised, however, where the NFPA guidance for a sprinklered building requires 12.5Pa pressure in the stairwell, the equivalent UK requirement is 50Pa. Mr Kealy added "it is almost impossible for a mechanical engineer to engineer this system and make it work and that is why, in the UK, pressurisation systems are avoided and alternative systems are used".

He went on to say that "these systems have multiple components, including motorised dampers, AOV's and controls, all of which have their own likelihood of failure. To minimise the risk of failure, engineers should design a system with the least amount of failure points, adding, "a pressurisation system is very simple - fans turn on when the signal calls - and protects the stair regardless of fire-floor location. The need for fire-fighter override controls is avoided, with fire-fighters given a simple start-stop switch".

In an article published in *Modern Building Services* Colt's technical director Conor Logan made some very valid observations in connection with evidence given to the Inquiry into the Grenfell Tower fire and the findings of the Hackitt report. He questioned why, according to the interim report submitted by Arup Fire Engineer Dr Barbara Lane, the smoke control system had not been properly commissioned and no service records kept, as required under the Regulatory Reform (Fire Safety) Order and why had the system was so difficult for the fire service to operate? Some of these comments closely echoed the comments by Martin Kealy that are mentioned above.

One point on which Conor Logan is at odds with Martin Kealy on is the smoke control system design criteria for pressurisation systems, stating that they should be “designed to the appropriate European standard and not the simplified National Fire Protection Association (NFPA) standards.”

This report will set out to demonstrate that, not only can a pressurisation system be basically very simple, reliable and will protect the escape stairs at all levels of the high rise building, but it can also be simple to design and commission with modern control systems.

The Designers Options

Three basic options are available to the engineer considering which smoke control system to adopt:

1. Natural ventilation employing a $1.5m^2$ natural smoke shaft for means of escape ($3m^2$ for a fire fighting shaft)
2. Depressurisation
3. Pressurisation

Natural Ventilation
Albeit the cheapest option in terms of installation costs, natural ventilation is rarely adopted nowadays due to the amount of space taken by the ventilation shaft and the limited benefits in terms of extended travel distances and the specific requirements to account for atmospheric and structural conditions.

Depressurisation
The current trend for mechanical smoke control systems is to adopt a depressurisation system. This involves extracting the hot smoky gases that may have entered the common areas on the fire floor by the use of extract fans and discharging these gases to atmosphere via a smoke extract shaft.

The objective of the depressurisation system, as with all the options, is to protect the common escape areas, especially the stairwell, from the effects of heat and smoke.

One problem associated with the depressurisation system occurs when the door to the apartment on fire is opened, by creating a negative pressure within the corridor, the smoke control system draws the hot smoky gases from the fire compartment into the common corridor that is used for both escape and for access by the fire service.

On some occasions a “push pull” form of depressurisation system is adopted. This version of the system is based on installing a supply shaft as well as an extract shaft, with the ability to reverse the operation so that the supply shaft becomes the extract shaft and the extract the supply. The downside of this arrangement is that the source of make-up air is drawn from the supply shaft rather than the stairwell, resulting in a much reduced velocity of air being drawn across the stairwell door when opened, with the result that smoke is more likely to migrate into the stairwell. In some cases, the rate of extract is increased to compensate for the reduced amount of air being drawn through the stairwell door, but this results in system balancing problems, larger fans being installed absorbing greater power and using more space.

The trend to make depressurisation systems “multi-functional”, such as assisting with common corridor or ceiling void cooling and incorporating multiple modes of operation to cater for comfort ventilation, escape phase ventilation rate in the event of fire and then a fire-fighting phase makes the systems extremely complex.

Perhaps designers of smoke control systems should now consider whether this practice has gone far enough and focus on making systems simpler. With complexity can come the potential for unreliability either in system function or system management.

Pressurisation

The third option is the pressurisation system. This system is based on forcing clean, cool air into the building creating a positive pressure difference between protected spaces such as the stairwell, lobbies, common corridors and the fire compartment. The objective is to prevent, or significantly reduce the risk of smoke migration from the fire compartment into the common escape and fire fighter access routes.

The key benefit is that, unlike a depressurisation system, the hot smoky gases are contained within the fire compartment, keeping the common escape routes clear of smoke.

Pressurisation systems have, for some time, carried the stigma of being notoriously difficult to balance and commission, but that is no longer the case with modern day controls. These historical problems relating to commissioning are nowadays overcome by modern control systems which keep balancing and commissioning extremely simple and the continuing operation of the system extremely reliable.

Additionally, whilst depressurisation systems will, by design, create a negative pressure within the common escape routes, including the stairwell, and protect only one level within the building, a pressurisation system will create a positive pressure within the stairwell protecting it at all levels. Within a multi-storey building, whilst it is possible that several stairwell doors may be open for a period at the same time, fresh air will continue to be provided to the stairwell during that period.

Pressurisation Control Systems

The old pressurisation design principles employed relatively low level technology, such as pressure relief dampers to maintain a constant pressure level within a stairwell for example. Such systems were relatively high maintenance as they need fairly frequent examination to ensure they maintained the required level of pressure and did not jam or create a higher than designed resistance to airflow.

Another commonly used device is the pressure sensor which is intended to measure the pressure difference between two areas and, if the level increased or decreased from design levels, would cause the pressurisation fan to decrease or increase speed to maintain the design pressure difference. The problem frequently experienced was that the fan speed would respond to “historical” data (the event had already happened) resulting in a significant fluctuation in pressure as the system attempted to reach a balanced state. Reference to historical data relates to an event recorded by a control device which then activates the pressurisation fan to adjust speed and return to the conditions identified to the design criteria. What invariably happens is that, before the control system identifies that the system has returned to design conditions, the design pressure has been exceeded, resulting peaks and troughs in the pressure conditions experienced.

This phenomena was the subject of research by Tamura and a report published by ASHREA. The research found that extremely high spikes in pressure were recorded in the stairwell, causing excessive forces on doors, even causing doors in escape routes to appear locked. This highlights the problems experienced when using dampers or variable speed fans controlled by pressure sensors responding to “historical” data.

A pressurisation system will vary the rate of airflow into a protected space, e.g. a stairwell, in response to recorded increase or decrease in pressure as doors open or close. Tamura conducted research into the variable air volume and damper bypass systems at the National Research Council of Canada. Time response curves for these systems are shown below in Figure 1. It can be seen from the graph how the recorded pressure spikes as the door closes.

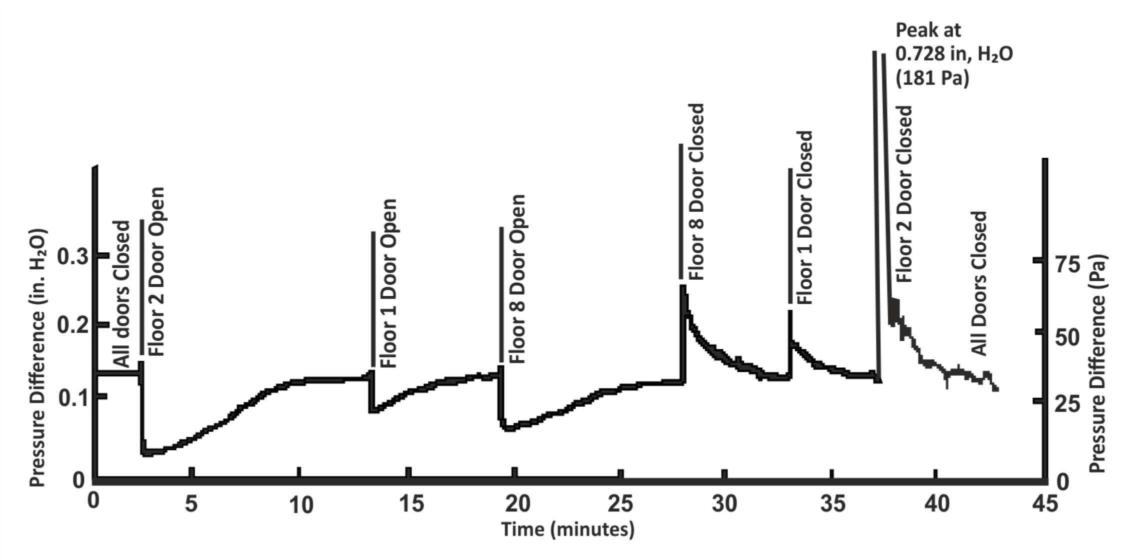

Figure 1 - Extract from the ASHREA report on research by Tamura

Where only one door is open and then closed, the resultant pressure spike can be very high. The research undertaken by Tamara ranged from 181Pa for a variable air volume fan system to 365Pa for a damper controlled system. Whilst the spikes in pressure only lasted 30-40 seconds, it was thought that anyone attempting to open a door under such conditions might have thought the door to be locked and may not have made a second attempt to exit via that door creating a dangerous situation.

There is a clear need for a solution to this operational problem associated with the use of pressure relief dampers and pressure sensors to control a pressurisation system. These performance problems associated with pressure fluctuation can be overcome by the use of electronic devices monitoring the condition of doors and which work in real time.

Siting the Pressurisation Fan

Traditionally pressurisation fans have been located at roof level, this practice overlooks the tendency of hot smoke to rise due to its buoyancy and thereby contaminate air the air being drawn into the pressurisation system, see figure 2. One way in which efforts have been made to minimise this problem is to incorporate a “T” junction and damper system controlled by smoke detection at the intake to the fan. If smoke is detected within the duct intake, the damper serving that leg of the intake duct will close and the damper to the opposing leg will open thereby attempting to draw clean air from the "clean" side of the building. This is obviously a bit hit and miss and, more often than not, it is unlikely that there will be a totally clean elevation of the building.

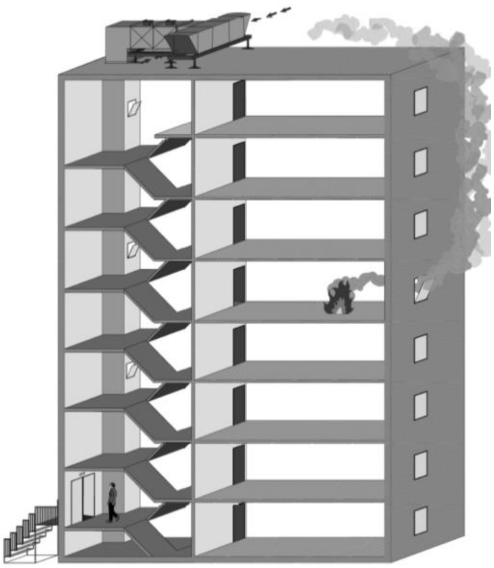

Figure 2 – Traditional pressurisation fan location with risk of inducing smoke back into the building

The more reliable way to overcome the problem of reintroducing smoke into the building and to avoid contaminated air being fed into protected spaces is to locate the fans at ground level, see figure 3. By locating the pressurisation fans at ground, or even basement level, the air is far more likely to be less contaminated by the smoke.

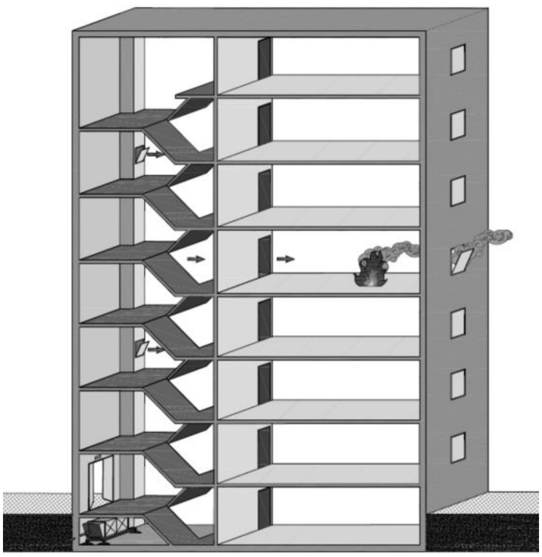

Figure 3 – Pressurisation fan located at ground or basement level

Current Control Technology

Control technology has moved on in leaps and bounds over recent years and become much more reliable and affective.

Fan Control
Inverters are now able to give extensive control over their full working range, giving extremely fast response time for acceleration and breaking operation. This fast response operation is critical in achieving the speed of reaction necessary to avoid excessive pressures on escape doors such as those to stairwells.

Modern inverters are also capable of providing detailed information on motor condition over the three phases and, with the correct programming, can carry out routine service interrogation from the commissioning data, to a monthly check on the systems current state, downloading the recorded information through a central data base, e.g., BMS.

Programmable Logic Control (PLC)
Not only has there been reduction in cost in PLC's over recent years, but there has also been a vast improvement in the programming power, bringing cost effective smart products to the area of life safety systems, including that of smoke ventilation. There should be no part of the smoke control installation that should fail without a clear indication given back to the building operator.

Nowadays, every moving part within the smoke control system can be remotely monitored by the smart control system to enable regular routine maintenance checks to be made automatically.

Evolving Buildings
Buildings do evolve during their lives as new owners move in. Resultant changes can be built into the PLC of building's smoke control system to reflect changes to the building and make any necessary changes to the system operational performance, enabling the smoke control system to recognize those changes and to continue to function appropriately.

During commissioning certain parameters are recorded on the controls, such as the static pressure that a fan develops at a specific operating condition and at a specific point in the system. This information can be recorded so that, if a building does change over time, any changes will be recognized by the PLC, which in turn will calculate and record any resultant changes in system performance and "report" these changes to the responsible person.

How Modern Day Pressurisation Systems Operate

The new form of controls for pressurisation systems are simple, reliable and effective, and remove virtually all the disadvantages and problems associated with the old style pressure sensors, dampers and pressure relief terminals.

The key is to determine what needs to be measured in order to achieve the desired conditions within the building in order to control the spread of smoke and heat in the event of fire.

The performance criteria for a pressurisation system remains unchanged, but the method of achieving these criteria has changed significantly.

The key performance criteria are:

- Pressure level within the protected space, e.g. stairwell 50Pa and lobby 45Pa
- Accommodation of leakage paths within the building
- Airflow velocity across a stairwell door, e.g. between 0.75 - 2m/s
- Maximum required airflow with required tolerance
- Maximum permissible door opening force 100N
- Maximum system response time to a changing condition, 3 seconds

Once this information is established, the system design can be developed and modern day system controls make design and commissioning of pressurization systems far simpler than in the past.

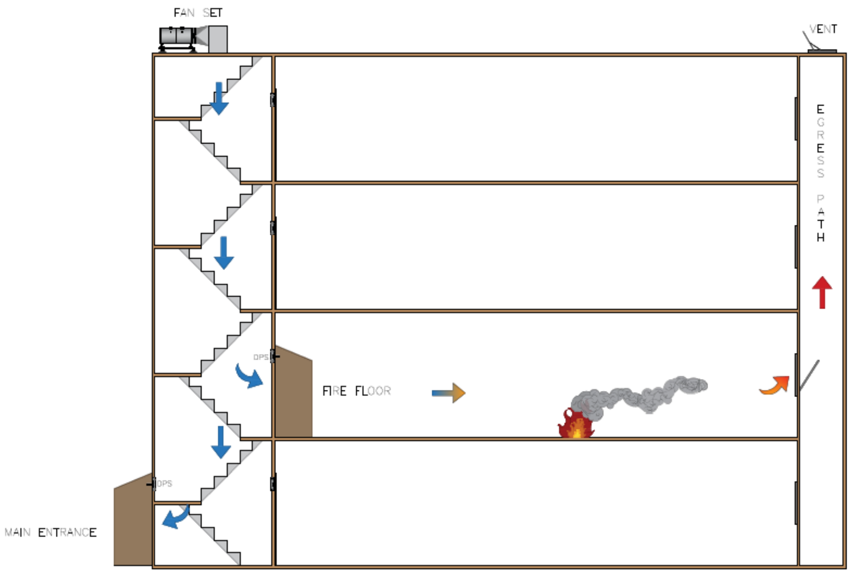

Figure 4 – Pressurisation system installation with door proximity sensor

Of course, the principle objective is to protect the common routes, keeping them clear of the hot smoky gases to enable the escape of the occupants. To achieve this we need to maintain or create a barrier to any potential migration of the smoke, from whatever source, into those common escape routes, whether doors are open or closed.

Fire doors, when closed, provide the barrier between the contaminated areas, which contain the hazardous life threatening hot smoky gases, and the places of safety. The objective of a pressurisation system is to provide a means of maintaining that protection when those doors are open.

To maintain a viable level of protection to the places of safety therefore, it is logical to be able to monitor whether a door is open or closed and, if open, know how far open the door is, in order to control the rate of airflow and/or pressure according to the prevailing conditions. This is done by the use of a door proximity sensor (DPS) mounted on each door which separates a protected space and an area from which smoke might pass.

The door proximity sensor is a device which is mounted on the door in the way illustrated in figure 5

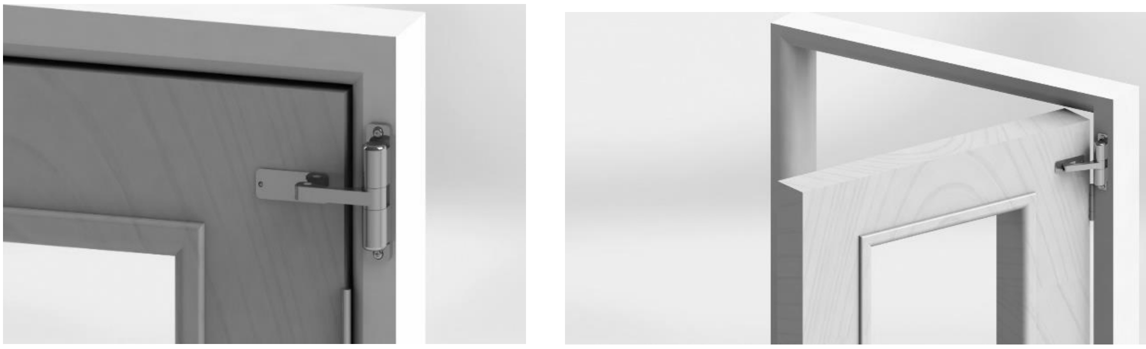

Figure 5 – The door proximity sensor action

The sensor is linked directly to the smoke control system panel via data cable. The DPS device incorporates a potentiometer and will send a signal to the PLC within the control panel to indicate the door’s actual position, see second image in figure 5. The control system will in turn adjust the speed of the pressurisation fan to meet the conditions required to maintain the integrity of the smoke control system.

The most important operational feature of this type of control is that it operates in “real time”, making it possible to respond to any change in condition very rapidly. Guidance in current standards is on the time taken to react to a door being fully open to fully closed and return the system to design conditions is 3 seconds, using the door proximity sensor design principle, the system reacts within 2 seconds. This rapid response time is made possible by the real time operation of the system and the use of a breaking system within the fan inverter control which enables the acceleration or decelerate the pressurisation fan very quickly.

This rapid response to changing conditions helps avoid the large spikes in overpressure caused by the slower response of the older style of pressure sensing control of pressurisation systems which created the problems discussed earlier in this article and which cause doors to be difficult to open or slam shut.

Each door proximity sensor in the system is given an address, so that the control system can, at any time, identify which door is in what position. This is also useful for fault management during the life cycle of the building; in the event a fault begins to develop in a sensor the control system can identify this and raise an alarm, identifying which sensor is at fault.

Where a pressurisation system is to be installed in a particularly tall building, the latest breed of controls is able to take account of the stack effect created within the building, automatically adjusting the airflow according to the level on which the fire occurs.

System Commissioning

The door monitoring system makes commissioning much easier than previously experienced using old technology and methods of control. Pressure levels are checked and set with fan speed at each level, and the “address” of each DPS device recorded on a laptop prior to these results being downloaded to the control system PLC.

System Maintenance

It is a requirement of the Regulatory Reform (Fire Safety) Order that all life safety systems are maintained in a fully functional and operating order. It is essential that any smoke control system is able to function in the manner for which it was designed and, in order to do this, it must be regularly tested and serviced.

The monitoring and servicing of the pressurisation system can be relatively simple. Modern electronic control systems can be programmed to incorporate a self-diagnostic program, enabling the system to automatically report an existent or developing fault. Full system checks can be programmed to be made automatically on a weekly or monthly cycle.

These self-diagnostic checks do not obviate the need for a regular full system examination on a planned maintenance program which will involve a more detailed visual and functional examination of components and of the full system operation. Information retrievable from the system PLC via a laptop computer.

Consideration at Building Design Stage

With the present day technology making the design, installation and commissioning of a pressurisation system so relatively simple, and the performance superior to the alternative depressurisation option, pressurisation should be the first option considered for smoke control in high rise buildings. It is true that a pressurisation system may not be suitable for all projects, but with current control technology available, it should be the first port of call.

Maybe at times, in the design of modern apartment buildings, with developer and architectural attention being focused on the comfort and aesthetics of the apartments for the benefit of future residents, the structural impact on the facilities essential to the optimum performance of life safety systems can be overlooked.

Whatever form of smoke control system selected, it is essential that it should form part of the architectural concept design at a very early stage in order that its performance can be optimised by the necessary allowance being made within the structure of the building.

Door Proximity Sensor Patents apply in the UK and other countries worldwide.

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