Activated sub-ducts – a potential solution for fire retrofit

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WARNING:
This paper discusses the design of a riser duct system for smoke exhaust or exit pressurisation relief that does not comply with the deemed-to-satisfy (DTS) requirements of the National Construction Code, Volume 1, Building Code of Australia (the BCA). It has been assessed under the provisions of the BCA for an alternative solution, and as such it is specific to a particular building and cannot be applied to any other building without an assessment under the requirements of Clause A0.9 of the BCA.

This paper addresses the mechanical engineering aspects of the alternative solution in reasonable detail but does not mention the parameters assessed by the fire engineer in the Fire Engineering Design Brief (FEDB).

If an HVAC designer adopts a solution such as this one, they should ensure a licensed fire engineer is engaged as a minimum to review – and provide guidance on – the departures from a DTS solution.

ABSTRACT
Retrofitting stair pressurisation into existing buildings is extremely difficult. The absence of plant space or riser locations, the presence of asbestos or the significant disruption placed on tenants are some barriers that in this current economic climate may discourage building owners from tackling problems with stair pressurisation or their associated relief systems.

One recent retrofit project posed this challenge. With its existing construction preventing more conventional solutions, the concept of “activated sub-ducts” was borne and delivered. While it was delivered successfully, there were lessons learnt that could make it easier for the next project. This paper sets out the “activated sub-duct” solution adopted to allow consideration by other designers who may face similar challenges.

BACKGROUND
Much of Australia’s existing building stock was constructed during a period prior to the launch of the Australian Code for Mechanical Ventilation AS1668.1-1991. Various editions of the code recognise the importance that relief systems play in obtaining compliant stair pressurisation results. Relief allows the stair-door airflow required without generation of excessive door-opening force. It means people can safely egress a fire once they reach the fire stair.

Two types of relief are possible. A natural or passive relief is advantageous, considering there is no relief riser required. However, for commissioning purposes, natural relief is either hindered or assisted by wind pressures, and for this reason it is rarely adopted. A fan-forced relief is more typical because it avoids the commissioning challenges with wind variety and can be upgraded to provide smoke exhaust duty.

With the advent of the Building Safety Act 2008, many building owners now face the potentially unsavoury prospect of annually reporting, to the Fire Brigade and tenants, the compliance status of their building’s stair pressurisation system. Compliance is reported for airflow and door-opening pressure, as well as acoustics.

In cases where door pressures are excessive, it could be argued the systems installed unfortunately defeat the purpose for which they were installed, i.e. to safely get people out of a high-rise fire.

STAIR PRESSURISATION SYSTEMS
Stair pressurisation systems aim to provide a positive airflow of outside air through the stairwell door. The purpose of the airflow is to minimise the ingress of smoke into the stairwell.

An average door velocity of 1m/s is sought. With work in existing building stock, alternative solutions occasionally permit some dispensations for velocities as low as 0.8m/s.

The fans that provide that airflow are at risk of simultaneously generating door pressures that are difficult for the general population to open. The maximum pressure permitted is 110N, which is judged the limit of a frail member of the public opening an exit door in a fire scenario.

In older buildings, this can be a particular challenge because often the doors will have a larger cross-sectional area than modern doors. Recognising the formula Force = Pressure x Area, a lower stair pressure is often necessary in older buildings.

To create the necessary airflow through the door, the fan needs to generate a pressure that will supply air down the stairwell, through the door and out to the affected floors. This includes the pressure necessary to relieve the air volume to outside. A typical pressure for a stairwell pressurisation system will be in the range of 30–50Pa.

It has often been considered that our buildings leak enough to allow relief at low pressures, but that assumption can be in error.
If the building were that leaky, there could be other problems such as accommodating the velocity pressure fluctuations from wind on a building façade. As such, reliance upon building leakage is likely to be problematic.

There are some common relief options available:

1) Relief through automated opening of windows, permanently opened windows or louvres with external dampers
2) Relief through sub-ducts into smoke exhaust systems or lobby-relief ventilation systems
3) Relief through combination dampers (actuated smoke and fire dampers) into the smoke exhaust or lobby-relief ventilation systems (as a fire-engineered solution).

When it comes to retrofitting relief systems into an existing building, it is apparent that these solutions may not be feasible.

**127 CREEK STREET**

127 Creek Street was one such building. It comprised two fire stairwells, each serving 24 levels of occupied space and two basement levels. The stair pressurisation system (dated 1975), comprised single-point injection through asbestos-insulated fans, situated at the top of the stairwells, with relief through building leakage only. To vary the air quantity, the stairwells had barometric dampers that, over time, had ceased to operate.

Circa 1985, additional fans had been installed to serve one stairwell, injecting at various levels. Unfortunately, these were undersized, and had also failed operationally.

In 2012, the system was forensically tested and demonstrated to have insufficient relief. Airflow on levels near the existing fans was overly generous, but door pressure was also excessive. Airflow in the middle and lower levels of the building was too low to prevent smoke ingress.

**SOLUTION ACCEPTED**

Options that were considered and could have been adopted included the fire-rated automation of façade glazing portions on each level, a new fire-rated exhaust riser outside of the building adjacent to the property boundary, or the de-commissioning of a lift to become a smoke exhaust riser.
These solutions were considered and rejected due to loss of NLA or expense. The solution that was ultimately accepted is what we term “activated sub-ducts.”

The solution was adopted because it could be retrofitted by converting the existing hydraulic riser into a lobby relief/smoke exhaust riser. It meant less tenant disruption, greater certainty of results and no loss of NLA.

Although the build-ability risk of the concept was evident, the stakeholders agreed it was the least costly of each option, and had the greatest confidence of success technically.

Almost all of the hydraulic services were removed from the cupboards. The walls were clad to achieve a FRL of -/120/120. The floors were carefully cut to form a riser.

The front elevation of the shaft was formed with fire-rated shaftwall to become a fire-rated shaft, with the sub-duct fitted at high level.

This strategy halved the riser size because half the relief air could exit at low level and half at high level. The “un-activated sub-ducts” provide a physical barrier and retain the shaft FRL, thus allowing a significant reduction in shaft cross-sectional area.

By combining sandwich pressurisation and activated sub-ducts, the required relief system could be installed as a smoke exhaust system and fit within a hydraulic riser 1.9m x 0.6m wide. This was a significant reduction from the original sizing of 3.5 sq m.

Main hydraulic and condenser water risers could remain within the riser. All other services portions requiring access were to be brought out of the riser.

**WHAT IS AN ACTIVATED SUB-DUCT?**

A sub-duct is described by AS 1668.1 (1998) as fire-rated projection into a fire-rated riser that forms a natural smoke barrier.

An activated sub-duct is a sub-duct that is only formed after activation. The obstruction to airflow formed by the horizontal panel, is only formed after the fire has been detected on that floor. In all other circumstances, the horizontal sub-duct panel is held out of the air path by a magnetic door holder such that the full airflow potential of the riser is achieved.

An activated sub-duct comprises fixed vertical panels (three sides of a sub-duct) and a hinged floor.

![Figure 4: Front elevation of the activated sub-duct.](image)

It had one advantage over an actuated combination damper, which could also provide most of the benefits of a smoke sub duct. In its released position (i.e. its “activated” position), the sub-duct provides a physical barrier to buoyant smoke. In the event of fan failure, it permitted potentially smoke-laden relief airflow to travel up the riser to exit through the fan exhaust louvre at high level. As only the fire floor is activated, the remaining shaft cross-section is free and available for smoke exhaust duty.

Another strategy adopted was the provision of both high and low-level smoke exhaust fans. Each fan was fitted with a non-return damper, thus minimising potential cold air ingress in the event of fan failure.
The vertical faces of the sub-duct are installed such that they present no real hindrance to vertical airflow. The floor of the sub-duct (the obstruction to vertical airflow) is hinged and held out of the riser airstream by a magnetic holder. Figure 6 demonstrates that any air passing past the upheld sub-duct will see little obstruction to airflow.

When the sub-duct is serving a floor that has become the fire floor, the magnetic holder lets go, allowing the sub-duct panel to fall and form a sub-duct, as in Figure 7 below.

**Figure 6:** The image portrays the operation of the sub-duct on the non-fire floor. With the sub-duct out of the way, the full riser cross-section becomes available for airflow.

**Figure 7:** The image portrays the operation of the activated sub-duct on the fire floor.

**Figure 8:** The intumescent strip will expand and seal when heated above 140°C (i.e., by hot smoke).
The edges of the falling panel mate with the angles built within the vertical face of the sub-ducts. The edges are fitted with intumescent strip such that they will seal with the temperatures experienced by transporting smoke-laden air. A hook in the panel allows the panel to be reset after maintenance testing.

Figure 9: This is the vertical face of the activated sub-duct, held in place by a magnetic door holder. The magnetic holder is powered by a small UPS.

Figure 10: This shows the released sub-duct resting on the vertical sides. The vertical panel extends more than 500mm above the soffit level, providing a buoyant smoke barrier.

2) Identification and activation of the sandwich pressurisation fans above and below the fire floor to provide sandwich pressurisation. The micro-switch provides identification of the status of the sub-duct. This is useful for re-setting the system after a test. This was added following peer review to provide assistance during testing. Its construction and wiring allows it to operate in a hot smoke environment for a minimum of two hours.

The FIP provides fireman’s control over each floor’s sub-duct. It also provides a status signal for the sub-duct.

Figure 11: The fire indication panel provides status of the sub-duct. It also has a simple control to allow the firemen to release a sub-duct if desired.

DESIGN COMMENTARY

The following may be of assistance to future designers:

1) The smoke exhaust air quantity per level should be set to suit the relevant version of the BCA. However, it must also accommodate the door airflows and leakage from the façade and lift doors. On this project, we determined site leakage could be as high as 4000L/s per floor.

2) We calculated the airflow per sub-duct panel based on the greater of either the two stair doors or a sprinkled zone’s smoke exhaust air quantity.

3) The sub-duct airflow velocity was set to 4m/s. It could probably rise to 6m/s without concern. Above that speed, the designer needs to consider the impact on smoke layers of such turbulence.

4) The smoke exhaust fans were selected such that one fan could do the whole duty. One was installed at the top of the riser and one was installed at the bottom so as to split the flows and halve the riser size.

5) Low-level smoke exhaust discharge and downward movement of smoke exhaust required the involvement of a fire engineering consultant.

6) Stair pressurisation fans were added to inject at low level in addition to high level injection.

CONTROLS FOR THE ACTIVATED SUB-DUCT

The sub-duct control system requires a zone fire alarm and a micro-switch.

The zone fire alarm provides the following:

1) Identification of the fire floor such that the fire-floor’s sub-duct is activated
7) Conceptually consider the building as two halves – control the top half smoke exhaust fan and stair pressurisation fans with its own sensors located in the top half of the building and likewise, treat the bottom half independently.

8) Get a fire engineer and certifier involved early so as to resolve the fire rating of construction elements as soon as possible in the design process. The 600mm wide shaft we started with was in danger at one point of shrinking by 150mm each side to accommodate FRL requirements.

9) Organise and witness factory testing of sub-ducts before site installation. This should include firing up intumescent strip. These are heavy panels, and the fabricator needs to be talented to demonstrate a neat fit when the panel has fallen.

10) Consider potential power failure. We had the sub-duct panels held in place by a small UPS and battery power allowing for a four-hour outage before the magnetic holders would let go of the sub-ducts.

11) Where demolition is concerned, consider whether neighbouring buildings may raise objections to after-hours core drilling.

12) Review carefully the AS1668.1, Section 3.6 on sub-duct construction. Consider particularly the issue of different rates of expansion for the different materials in the sub-duct construction.

13) Simon Hill, L.AIRAH, (Professional Engineering Solutions) pointed out to me that AS 1668.1-1998 suggests that control switches of zone smoke control dampers should be labeled FIRE/AUTO/NON-FIRE. This is done to assist the fire officer, who may not be familiar with the intricacies of the system design. We suggest this practice is adopted for future installations.

COMMISSIONING

The commissioning of the stair pressurisation systems demonstrated the system worked well. We achieved airflows in the range of 1.5m/s to 2m/s while maintaining door pressures at or below 90N. This was consistent throughout the 24 floors of the building.

Commissioning was a time-consuming process because each floor’s sub-duct had to be reset after each floor’s test. As a guide, the reader should note that it took three men seven hours to test 24 levels in two stairs. Every designer needs to make their own assessment of their required pressure differential.

The stair-to-lobby pressure differentials were set to 50Pa, while the exhaust riser-to-lobby pressure differentials were set to 90Pa. The exhaust fans were typically running at 20–30Hz.

When the panels let go, there is an almighty “bang”. This should be described to the fire safety adviser or whoever conducts egress training, as the uninitiated may consider something is awry.

LESSONS LEARNT

The following activities were difficult, and will require a dedicated focus for any future projects:

1) Concrete-cutting a riser in a space only 600mm wide and around existing wet services.

2) Achieving a two-hour fire rating for the existing riser walls in a pre-1975 building.

3) We over-sized the riser exhaust fans anticipating building leakage, which did not eventuate. We were fortunate to have good fan selections but a designer should consider the fan curve for both airflow and pressure development by the exhaust fan.

4) In all fan installations, consider carefully the required air-intake-clearance volume at the rear of the fan. In this instance we had to build a small fire-rated fan enclosure to ensure the fan’s curve was not impaired.

5) Achieving the tolerances necessary for the sub-duct panel to fall neatly onto the mating flanges. The building’s dimensions typically varied 20mm floor to floor.

6) Micro-switches can be finicky. When installing, consider a bracket to allow location adjustment.

7) Working with an older FIP. We eventually had to upgrade to incorporate addressable points.

8) Dealing with asbestos insulation wrapped around fan casings. Terminating variable-speed drive wiring required some consideration.

9) Organising handover to maintenance staff and the fire brigade. It is possible the brigade will need specific testing.

CONCLUSIONS

We consider the activated sub-duct concept to be a reliable solution, primarily for retrofit projects. It is particularly useful when available riser space is inadequate for typical solutions. It may not suit every project but it solves specific problems facing our older building stock.

The main advantage over static sub-ducts is the space saving. The main advantage over combination dampers is the security of the physical barrier (the 500mm overlap). The main disadvantage is that activated sub-ducts require specific installation and fabrication control over dimensions, which can be daunting in an older building.

ACKNOWLEDGEMENTS

Successful innovation in a project is usually the work of many partners. In this instance, we wish to acknowledge that specific contributions came from many directions, nominated as follows:

1) Peter Phelps – review engineer
2) Isothermal – mechanical contractors
3) Ikon Industrial – fabricators of the sub duct panels
4) Urban – builders and main contractors.
5) Ommni – fire engineers
6) McCarthy Group – certifiers
7) Johnson Controls – fire alarm contractors.
8) QFRS – Kerry Houlihan (fire brigade).

Without their assistance and diligence, this project may not have succeeded.

About the Author

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