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# THE UNINTENDED CONSEQUENCES OF IMPROVED AIRTIGHTNESS LEVELS ON THE OPERATION OF PRESSURIZATION SYSTEMS IN TALL BUILDINGS

## Introduction

This paper introduces the potential negative impact on fire safety levels within buildings caused by reducing air leakage rates. The paper discusses the use of pressure differential system (PDS) to protect means of escape and proposed research examining whether reducing air leakage rates within buildings, has a negative impact on PDS which rely on a specified air flow.

## Life safety and the reduction of carbon emissions from buildings

As part of the global drive to reduce carbon emissions from buildings in support of climate change targets, countries are reducing air leakage paths within buildings. Uncontrolled air leakage paths through the fabric of a building can have a significant adverse effect on the energy efficiency of a building.

UK guidance supporting the building regulations assume that infiltrating air rates of 5 to 10 $m^3/h/m^2$ @ 50 Pa will be achieved in newly constructed buildings. However many buildings are constructed with infiltration air rates of less than 5 $m^3/h/m^2$ @ 50 Pa.

This is of particular concern in tall buildings, where occupants rely on protected stairwells as a 'safe place' from which to make their escape from the building. To maintain a tenable escape route, such stairwells are constructed as fire tight compartments. To restrict the passage of smoke into the escape stairwell building codes throughout the world recommend that a form of smoke control known as a pressure differential system (PDS) is installed. PDS uses fans to keep the pressure in the stairwell higher than that in adjacent spaces thus restricting the passage of smoke into the stairwell.

In calculating the air supply needed for a PDS, assumptions are made about the air-tightness of the building. Estimating the air leakage rate can have a fundamental impact on the design. The design codes recognise that for PDS to perform as intended, the design assumptions for air leakage need to remain constant over the lifetime of the building. As PDS are based on a ‘typical’ air infiltration rate of ≥10 $m^3/h/m^2$ @ 50 Pa they may not function as intended in buildings with improved airtightness levels.

**Aim of Research**

The area of concern and the reason for undertaking this research project is to determine whether the desire for increasing airtightness within buildings to meet Government energy reduction targets is likely to have a negative impact on the ability of pressurization systems to adequately perform in the event of a fire. Current research [1] has already identified that some dwellings, tested for air-tightness, have been found to be tighter than the design value thus resulting in uncertainty about the adequacy of airflow rates. As a consequence, increasing levels of air-tightness may need to be considered as a part of the design of pressurization systems, to ensure that level of fire safety is not reduced otherwise the whole strategy of escape from tall buildings could be unsound.

This research project investigates current design guidance for pressurization systems used for the protection of stairs in airtight tall buildings through the review of the research literature, an examination of the factors involved in the design of PDS and of the changes taking place in the airtightness of buildings. To demonstrate the impact such changes are having on the effectiveness of PDS experimental research will be carried out using both a lab based test rig and computer simulations.

**Origins of the Design Codes**

In carrying out this research it is proposed to challenge the accepted view of current design methodologies for designing pressurization systems. The established guidance has been based on empirical experimentalism and using a qualitative approach, in that various data was gathered, collated and analysed to fit the desired outcome.

**Current Research Findings**

The basis of the calculations for designing smoke control pressurization systems are the Ideal Gas Laws and Bernoulli's principle. These mathematical principles have been used by researchers to explain the behaviour and movement of gases.

Since the 1950s, the use of pressurisation as an effective means to protect the means of escape particularly escape stair enclosures from smoke has been recognised. Australia in 1957 published the "Fire Protection Code for Buildings over 150 ft in Height" [2] which permitted the use of Pressurisation as a fire protection method. Throughout the 1960's various research using Bernoulli's theorem to develop formula for the mass rates of flow of hot gases was undertaken by Sims et al (1959/60) [3] [4] [5] Thomas et a l(1963) [6] "and Malhotra and Millbank [7]. During the research it was noted that the window provided at the top of the stair did not appear to have any significant effect on the clearance of the smoke. The tests showed that without a pressurization system sufficient quantities of smoke can penetrate through the gaps, to render the escape area untenable. With a pressurization system as used in these experiments the passage of smoke through the door gaps was prevented. The research carried out by Malhotra and Millbank [7] concluded that a pressure difference of 0.028 in.wg (6.97Pa) was adequate to prevent smoke entering through door gaps but to allow for door buckling a higher pressure of 0.05 in.wg (12.45 Pa) should be employed.

Such tests helped demonstrate that a properly designed system could overcome pressures from a fire, adverse weather and stack effect. It was also acknowledged that leakage paths would also need to be taken account of when working out the necessary total air input. This is the concept still used in the British Standard – BS EN 12101 PART 6 [8] and the ASHRAE smoke guide [9].

This qualitative research has identified that there are currently limited amounts of data collected on the impacts of increasing airtightness of buildings.

**Survey of Design Professionals**

To understand the awareness of design professionals of the impact of airtight buildings on PDS, a survey was carried out of companies that design, install and / or commission PDS.

There was a general belief from designers that increasing airtightness of buildings did not impact on the effectiveness of PDS in buildings as there is sufficient tolerance in the design that allows for adjustments to be made on site. The survey however identified:

- little awareness about the impact of air-tight buildings on their designs
- design data in the building codes are very old and not relevant to modern construction
- evidence that pressurization systems are not maintained.
- In particular, there was seen to be a need for guidance on re-commissioning of existing buildings when improvement works such as external cladding and window replacement have taken place.

**Next Steps**

To evaluate the impact of improving airtightness ratios of the external envelope and how this impacts on pressure within the building it is proposed to build a chambered test rig with three interconnecting spaces representing stair, lobby and circulation area. The primary objective of the experiments is to determine under test conditions the pressure difference from a pressurized stairwell to the lobby and to the accommodation space under varying levels of airtightness. Flow paths would be created to go from areas of high pressure (stairwell) to areas of low pressure (lobby – accommodation).

The experimental rig allows the investigation and identification of the consequences of varying the pressure and leakage paths by comparing the pressure difference across the different 'spaces' (stair to lobby to accommodation). This will then be used to determine how sensitive pressurization systems are to such changes.

**Testing Ratio**

The level of airtightness achieved in buildings in the UK is measured as air permeability, $m^3/h.m^2$ at 50 Pa. This is determined by measuring the amount of air that leaks out of a building in an hour ($M^3$) divided by the internal 'envelope' area measured at 50 Pa. A lower value indicates a building that is more airtight. To assess the impact of reduced airflows it is proposed to carry out a number of tests at airtightness ratios of 2 - 14 $m^3/h/m^2$@ 50 Pa, measuring the pressure differential in each of the three spaces .

This will allow the robustness of the various design guides to be interrogated with regards to airtight buildings or refurbished buildings which have improved levels of airtightness.

**Further Work**

Further international research of PDS as a discipline would be valuable to determine what impact the above outcomes will have on PDS. Initial research should focus on the following:

- The need for research into the leakage rates in the various design codes such as BS EN 12101 PART 6 [8] and NFPA 92 [10]. The current leakage rates are based on very old research and not relevant to modern construction standards
- The need for research into the difference between design and installation and how much they differ, and what can be done to reduce this.
- The need for research to identify areas of best practice as well as areas for improvement which could inform future legislative processes in the promotion of better regulation.

Consideration should also be given to further collaboration with Hampshire Fire & Rescue Service (HFRS) in England. The aim of the HFRS research is still being developed but will investigate the smoke movement in a number of buildings during a number of fire scenarios utilizing pressurization and other forms of smoke control.

## Appendix


[1] NHBC Publication - Phillips, T. Rogers, P. and Smith, N., “Ageing and airtightness - how dwelling air permeability changes over time,” NHBC Publication, 2011.

[2] FLÄKT WOODS LIMITED by JA Wild , “Fans in fire safety - Smoke control by pressurization,” Fläkt Woods Limted England., 1998.

[3] Fire Research Station, “Fire Research Note 390, Roof Venting of Burning Enclosures, Prelimary Experiments using Smoke Tracer.,” 1959.

[4] Fire Research Station, “Fire Research Note 391, Roof Venting of Burning Enclosures Part 11. The Construction of a Model and some Flow Patterns Obtained With It,” 1959.

[5] Fire Research Station, “ Fire research Note 419, Roof Venting of Burning Enclosures Part 111. Venting Fires Of Constant Heat Output”.

[6] Fire research Station, “ Fire Research Technical Paper No. 7, Investigation into the flow of hot gases in roof venting,” Joint Fire Research Organization publication, 1963.

[7] M. a. Milbank, “Movement of Smoke in Escape Routes and Effect of Pressurization. Results of Some Tests Performed in a New Departmental Store -Fire research note 566,” Fire Research Station, 1964.

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[9] ASHRAE Written By John H. Klote; James A. Milke; Paul G. Turnbull; Ahmed Kashef; Michael J. Ferreira, Handbook of Smoke Control Engineering, ASHRAE, 2012.

[10] National Fire Protection Association, “NFPA 92A: Standard for Smoke-Control Systems Utilizing Barriers and Pressure Differences,” National Fire Protection Association, Quincy, 1988.