EFFECTIVENESS OF SMOKE BARRIERS:

PRESSURISED STAIR ENCLOSURES

by

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ABSTRACT

Stair Pressurisation Systems (SPS) are a form of smoke control used in many high-rise buildings. They are designed to keep smoke out of the stairwell so that occupants have a safe evacuation route during an emergency. Throughout the years, however, many within the Fire Engineering industry have commented that SPS do not really perform as per their design intent. In order to assess this belief, an investigation was undertaken to assess the *effectiveness* of a SPS, whereby the effectiveness was assessed by considering the following: if the SPS operates, will the resulting performance be as required by the Australian Standards (i.e. AS1668.1 1998) and when required, will the SPS or components actually operate. To do this, two representative SPS within the Melbourne Central Business District were investigated; one with a Variable Speed Drive (VSD), System 1, typical of systems installed more recently and one without a VSD, System 2, typical of earlier types of SPS.

The effectiveness evaluation was divided into two parts. The first considered the influence of variations to wind speed, temperature and leakage (referred to as the E-factors), while the second considered the 'other factors' or F-factors, affecting the effectiveness of a SPS (i.e. those factors that can be influenced by commissioning, maintenance, operation of the system, etc.). For this study, these two parts were assessed in isolation to each other, such that when the E-factors were assessed, the other influences were considered not to exhibit any faults. Similarly, when considering the influence of the F-factors, the influence of the E-factors was ignored.

The influence of the E-factors was assessed in terms of achieving the door opening force and airflow performance conditions of AS1668.1. This was done using a computer network program known as CONTAM. Initially a base building model was developed, complying with the performance conditions of the Australian Standard and then variables such as external temperatures, wind and leakage associated with the building elements were varied as part of a sensitivity analysis. The results indicated that in most cases (unless extreme conditions were used), the effectiveness of the SPS was nearly equal to unity (i.e. '1'). The SPS with a VSD also had a slightly higher effectiveness than the system without, when 'Average' leakage conditions were modelled. However, if the stairwell leakage approached the building façade leakage, the effectiveness in relation to achieving the airflow velocity conditions of AS1668.1, for both Systems 1 and 2, significantly reduced.

The 'other factors' which may influence the effectiveness of a SPS were those that could be influenced by the design, installation, commissioning, maintenance and operation of the SPS and were assessed after interrelationship diagrams, in the form of fault trees were developed. These diagrams detailed the complex integration of the various components, which make up a SPS and assisted in identifying which components appear to be the most dominant in terms of reducing the reliability of the system. Probability of failure data was obtained through a survey completed by industry personnel intimately associated with SPS. The reliability assessment indicated that the two major dominant factors, in terms of not achieving the performance

conditions of AS1668.1, were high door opening forces, followed by low airflow velocities. The importance of high door opening forces is significant, as occupants who cannot enter the stairwell in an emergency, may not be able to evacuate safely.

The maintenance requirements associated with SPS as per AS1851.6, are illustrated in this thesis in relation to the fault tree diagrams. The results revealed that some of the dominant factors (such as the VSD, the pressure sensor, etc.), achieved low levels of effectiveness. These factors are only considered during the commissioning stage and there is no formal maintenance for these items. These findings help to reinforce the importance of commissioning as well as maintenance (especially for items currently not maintained) and the need for identified faults to be corrected as soon as they are found, or at least prior to the next maintenance inspection.

Assessing the effectiveness of a SPS, with respect to the performance conditions of AS1668.1, found that the factors referred to as 'other factors' have a greater influence on SPS effectiveness than variations due to wind, temperature and leakage changes. Having said this though, the results generated indicate that SPS are not very effective in terms of achieving the performance conditions of AS1668.1 for the whole system (i.e. every door). For example, there is a 1/10 chance that the door opening forces will comply and approximately a 1/2 chance that the airflow velocities will meet the required performance conditions. These low probabilities are for buildings that are being "commissioned" and "maintained", indicating that although factors appear to be identified, they are not being adequately corrected.

In summary, if commissioning is performed correctly, and so too the maintenance, the reliability associated with the components can be significantly improved and therefore, so can the overall effectiveness of the SPS.

DECLARATION

"I, Elissa Fazio, declare that the Master by Research thesis entitled "Effectiveness of Smoke Barriers: Pressurised Stair Enclosures" is no more than 60,000 words in length, exclusive of tables, figures, appendices, references and footnotes. This thesis contains no material that has been submitted previously, in whole or part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

Signature [redacted] Date 17/01/2007

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NOMENCLATURE and GLOSSARY

ACF .... Ancillary Control Facility (to control ancillary facilities eg. AHU, SPF - also has isolate and reset buttons)

AHU .... Air-Handling Unit(s)

AS .... Australian Standard(s)

ASE .... Alarm Signalling Equipment

AVF .... Alarm Verification Facility

Barometric/Weight Adjusted Damper .. A damper which is self-adjusting without the aid of electronic or pneumatic control devices, i.e. it is of mechanical operation without any power sources

BCA .... Building Code of Australia

BD .... Barometric Damper (see definition above)

BMS .... Building Management System

CBD .... Central Business District

CIE .... Control Indicating Equipment (eg. FIP, FFCP, ACF, ASE)

CONTAM .... The name of the software program used in this research

Damper .... Moveable plate(s) which regulate the flow of air eg. if the pressure in a space increases, the damper (plate[s]) open to relieve the excess pressure and vice-versa

dB(A) .... Decibel ('A' weighted overall sound pressure level), where 'A' refers to a frequency filter applied to measure noise levels representing how humans hear sound

DDC .... Direct Digital Control

DP .... Differential Pressure

Dump-Back/Bypass Damper .... A damper that is adjusted based on the pressure sensor reading, whereby electronic or pneumatic control devices cause the damper to either open/close

Effectiveness .... Measure of the reliability (i.e. whether or not the system/components operate) and whether the performance conditions of AS1668.1 are achieved, considered in terms of E- and F-factors

eg. .... For example

E-factors .... Considers the effect of changes to wind, temperature and leakage on SPS effectiveness

etc. .... Etcetera

F-factors .... see 'Other Factors'

Fault Tree .... A fault tree is a diagrammatic representation of logical relations to identify a hazard either qualitatively, or quantitatively. A fault tree starts with the top condition being an unfavourable condition or hazard of some kind. It is developed from the top-down to obtain the possible primary cause conditions. The fault tree helps to reveal the possible causes of a hazard, some of which may not have been previously envisaged (Lees 1980a).

FCP .... Fire Control Panel - now referred to as the FFCP

FFCP .... Fire Fan Control Panel - controls the automatic operation of the AHU, fans and (zone smoke) dampers

FIP .... Fire Indicator Panel

GFA .... General Fire Alarm(s)

GFAR .... General Fire Alarm Relay(s)

HLI .... High Level Interface - a programming interface which allows more functionality within one command statement

HVAC .... Heating, Ventilation and Air-Conditioning

id .... Identification box for the fault trees

i.e. .... That is

kg/s .... Kilograms/Second

Leakage .... Refers to air (flow) escaping from an enclosure either via the form of construction of the enclosure (eg. concrete walls/floors, etc.,) or gaps around barriers (eg. gaps around doors) or through openings such as windows, grilles, doors, etc.

L/s .... Litres/Second

L0 .... Refers to Level 0 within the CONTAM building simulations, which is equivalent to the Ground Floor (GF)

m .... Metres

m/s .... Metres/Second

MSSB .... Mechanical Services Switch Board(s)

N .... Newton

NA .... Not Applicable

NBFU .... National Board of Fire Underwriters

NFPA .... National Fire Protection Association

NRCC .... National Research Council of Canada

NS .... No simulation, i.e. a CONTAM simulation was not performed

OAF .... Outside Air Fan

Other Factors .... Considers the effect of design, installation, commissioning, maintenance and operation on SPS effectiveness

Pa .... Pascals

R .... Refers to the relief (exhaust) grille/vent on level L9 in the stairwell shaft

RAD .... Return Air Damper(s)

RAF .... Return Air Fan(s)

Reliability .... Whether or not the system/components operate, when required

s .... Seconds

SAF .... Supply Air Fan(s)

SCS .... Smoke Control System(s)

SET .... Standard external temperature conditions (i.e. wind conditions vary)

SETW .... Standard external temperature and wind conditions of 20°C and 5m/s, respectively

SEW .... Standard wind conditions (i.e. temperature conditions vary)

SPF .... Stair Pressurisation Fan(s)

SPS .... Stair Pressurisation System(s)

Stack Effect .... A condition resulting from the difference in air temperature between indoor and outdoor air

UPS .... Uninterruptible Power Supply

VAV .... Variable Air Volume

vs .... Versus

VSD .... Variable Speed Drive(s)

ZSCS .... Zone Smoke Control System(s)

.... Number, indicating CONTAM simulation

< .... Less than sign

> .... Greater than sign

1. INTRODUCTION

Stair Pressurisation Systems (SPS) are a form of smoke control used in buildings generally more than 25 m in effective height.[1] Their purpose is to keep the escape routes, such as stairwells, clear of smoke, thus allowing a safe egress path for occupants while evacuating the building. This is achieved by pressurising the stairwell (with a fan) to a higher pressure than the surrounding floors in the building, thereby, generating a pressure differential. As the stairwell is at a higher pressure than its surroundings, smoke flow into this escape route is restricted.

The basic concepts and issues associated with a SPS are illustrated in Figures 1a and 1b.

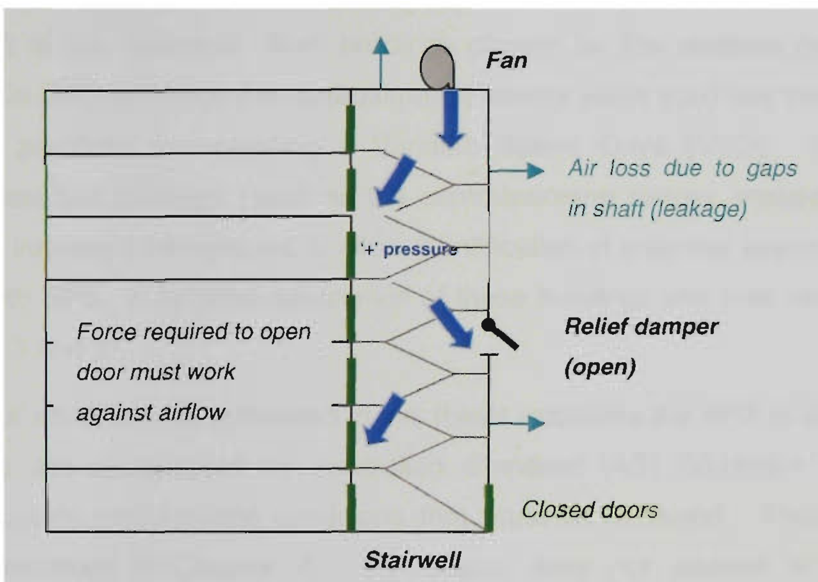

Figure 1a. No doors open inside stairwell, positive pressure from fan - not too high

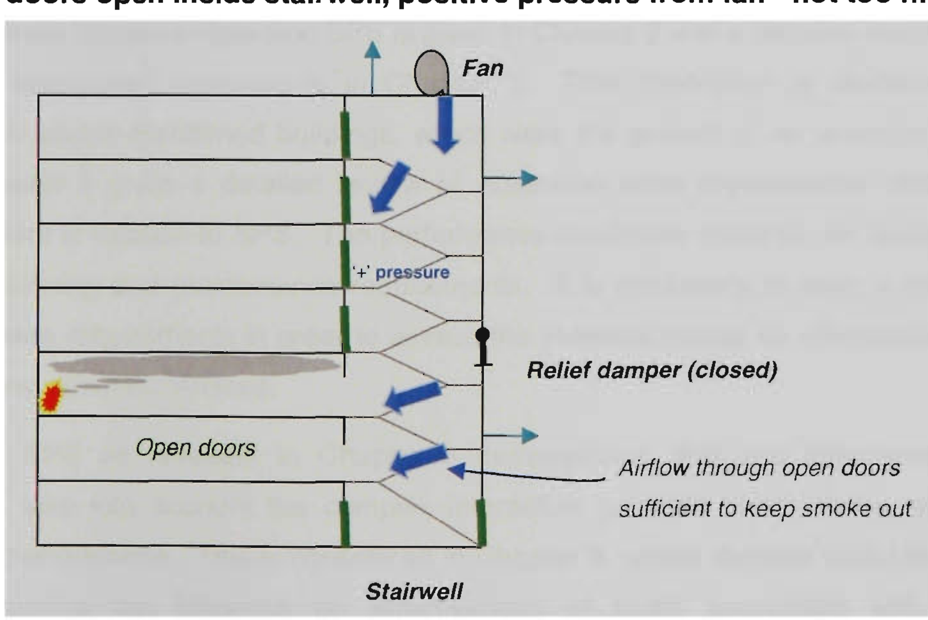

Figure 1b. Doors open with sufficient airflow to keep smoke out

[1] The term "effective height" is defined in the Building Code of Australia 2005 (BCA-2005) as "the height to the floor of the topmost storey (excluding the topmost storey if it contains only heating, ventilating, lift or other equipment, water tanks or similar service units) from the floor of the lowest storey providing direct egress to a road or open space."

Within the Heating, Ventilation and Air-Conditioning (HVAC) and Fire Engineering industries, it is sometimes stated that SPS rarely operate as designed. This view is expressed regardless of the age of the building i.e. recently built or older buildings; from when they are commissioned, to routine maintenance and actual performance of the SPS. This research project investigates the "*effectiveness*" of SPS. The effectiveness of SPS can be influenced by a great range of factors such as wind and temperature, the building leakage and changes thereof, and the SPS hardware components that are potentially influenced by design, commissioning and maintenance.

A detailed study of two buildings within the Melbourne Central Business District (CBD) has been conducted as part of this research. Both buildings chosen for this purpose have SPS – one which is common in older buildings (i.e. approximately twenty years ago) and the other is typical of recent design practices incorporating a Variable Speed Drive (VSD). The information obtained from these two buildings (such as the commissioning history, maintenance records, etc.), provided an important background to allow identification of potential issues and difficulties that may occur with SPS. A detailed description of these buildings and their relevant history is given in Chapters 3 and 5.

The assessment of effectiveness presented in this thesis evaluates the SPS in terms of whether the performances are as required by Australian Standard (AS) AS1668.1 (1998).[2] This standard gives specific performance conditions that must be achieved. These performance conditions are described in Chapter 4. This thesis does not attempt to evaluate SPS effectiveness in relation to the possible range of real fires.

A review of the relevant literature regarding SPS is given in Chapter 2 and a detailed description of SPS and their associated components in Chapter 3. This description is illustrated by reference to the two above-mentioned buildings, which were the subject of an in-depth study and auditing. Chapter 4 gives a detailed review of Australian code requirements and their historical *development* in relation to SPS. The performance conditions required are described, as are the commissioning and maintenance requirements. It is necessary to have a detailed understanding of these requirements in order to assess the potential impact on effectiveness of sound commissioning and maintenance.

The complexity of SPS as revealed in Chapter 3 demonstrates that any assessment of effectiveness must take into account the complex interaction between components and the uncertainty in their performance. This is considered in Chapter 8, where detailed fault trees are developed to determine the influence on effectiveness of faults associated with SPS components. The performance of these components can be influenced by design, commissioning and maintenance.

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[2] From hereon, when referring to AS1668.1, it is implied that the 1998 edition of this standard is being referred to, unless otherwise stated.

As noted previously, external environmental influences such as wind or temperature variations could have a potential influence on SPS effectiveness. Similarly, changes in leakages associated with the shaft and/or building over the life of the building, could have an influence. These potential influences are evaluated using a network analysis method in Chapter 7.

Chapter 6 presents a fuller discussion on the concept of system effectiveness and explains more fully the relationship between the effectiveness evaluations given in Chapters 7 and 8. The results from Chapters 7 and 8 are summarised in Chapter 9 in relation to overall SPS effectiveness.

2. REVIEW OF LITERATURE

The use of pressurisation to control the flow of airborne contaminants has been around for at least 50 years (Klote and Milke 1992) being provided initially to prevent the spread of poisonous gases in enclosures. While the use of airflow and pressurisation to control smoke (also a form of airborne contamination) flow within a building has only been formally recognised by codes and standards for the last three decades (i.e. in relation to when the first Australian Standard [AS] for pressurisation was released). It is believed that the technique of using pressurised spaces to control smoke flow was first suggested by a Fire Department officer known as Hall in 1961 (Butcher and Moss 1991).

This chapter details the history of Stair Pressurisation Systems (SPS) and makes reference to Smoke Control Systems (SCS) as applicable. It describes how these systems have been investigated, tested and assessed over the years.

In the late 1930s in the United States, the National Board of Fire Underwriters (NBFU) examined the National Fire Protection Association (NFPA) fire statistics from January 1936 to April 1938, in order to determine the extent of smoke hazards due to HVAC systems (NBFU 1939). Their studies recommended that the HVAC systems be shut down during fire incidents to *prevent* smoke spreading within a building. In the following years, HVAC shut down became the norm. This practice of air-handling/ventilation shutdown is still used today as a means of aiding fire and smoke control in multi-compartment buildings (AS1668.1 1998), thereby highlighting its continued relevance as a means of smoke hazard management today. The *use* of HVAC systems to *limit* smoke movement came at a much later stage.

Historically, systems defined as SCS use barriers such as walls, floors, doors, etc., and airflow (usually generated via mechanical fans) to generate pressure differences. More specifically, the use of pressure differences across a barrier to control smoke movement is referred to as 'pressurisation' (Klote 1995a). Today, these methods are collectively referred to as 'smoke hazard management systems'. For the purposes of this thesis, the term *pressurisation* refers to the use of barriers (i.e. stairwell doors, walls, etc.) and mechanical fan(s) to generate pressure differentials, to limit smoke flow into an egress/escape stairwell (i.e. fire-isolated stairwell, stair shaft).

One of the first countries to incorporate pressurisation of escape routes within the Building Regulations appears to have been Australia. This began in 1957 when a Code of Practice titled "Fire Protection Code for Buildings over 150 ft in Height" (Butcher and Moss 1991) was published in New South Wales (NSW), Australia by the Height of Buildings Act Committee. This Code permitted the use of pressurisation as a fire protection measure for buildings. In the early 1960s, a submission was made to this committee to install a pressurisation system within a Commonwealth Government office building (Lincolne Scott 1988), instead. According to Lincolne Scott (1988) a full-scale fire test at the Fire Research Station in England and experiments at the Experimental Building Station in NSW, Australia, had provided sufficient evidence to demonstrate that pressurisation of an enclosure, such as a stair shaft, could overcome the differential pressures developed by a fire and suppress the in-flow of smoke through gaps around the doors. This early evidence provided the impetus for conducting a pressurised stair shaft test. Following the successful completion of this test in early 1962, all Australian states required pressurisation systems, as per AS1668.1 (1974) "Fire Precautions in Buildings with Air-Handling Systems."

It is believed that the first building in the United States (Seattle) to be built with a SCS to limit smoke spread within the building was in 1971 (Klote 1994). The system in this Seattle building exhausted the fire zone and pressurised surrounding zones (i.e. the SCS operated similarly to the current zone smoke control system [ZSCS] detailed in AS1668.1 [1998]). At approximately the same time, the Heating Ventilation Research Association (HVRA) put a research proposal to the United Kingdom Department of Environment to establish the design requirements for SCS escape routes (Hobson and Stewart 1972). This study was undertaken in early 1970 and led initially to the requirement for natural vent shafts or mechanical extraction from staircases as a means of protecting the escape routes, i.e. stairwells. However, such measures were found to encourage smoke into the stair shaft and this concept was discarded with the requirement to pressurise stair shafts instead.

As early as 1967, Tamura and Wilson had already begun conducting field measurements to determine the overall air leakages and pressure differentials in several pre-constructed (i.e. already standing) high-rise buildings for the purpose of establishing meaningful design calculations. The data obtained was then characterised and used to assist in understanding the influence a building's ventilation system had in combination with the "chimney effect" (i.e. a phenomena resulting due to the change of internal and external temperatures of a building as the building increases in height, now commonly referred to as the 'stack effect'). Previously, the stack effect had only been analytically analysed.

Early research, such as that conducted in the 1960s and 1970s, focused on determining the likely efficacy of SCS in general. Examples of this approach included the full-scale fire tests in multi-storey buildings such as in a 14-storey hotel building in Atlanta (Koplon 1973), in a 22-storey office building, New York City (DeCicco 1973) – where a theoretical model of shaft airflows was also developed and tested. These buildings were tested using real fires (with materials appropriate to the use of occupancy eg. chairs, tables, etc.), since the buildings were to be demolished.

A 7-storey office building in Hamburg, Germany, was probably one of the first buildings to be tested in terms of an 'operational acceptance' test via a real (wood crib) fire, prior to occupancy (Butcher et al 1976), (i.e. as opposed to using real fires only when the building was to be demolished). This was done to identify where the smoke may travel and how effective the SCS was, as per the early 1960s and 1970s tests mentioned above. The aim of the Hamburg building test was to illustrate that both a pressurised stairwell with attached lobby/vestibule would be acceptable for the building in lieu of having two stairwells (this was successfully demonstrated to the authorities). Today, similar 'acceptance' tests are more commonly referred to as 'commissioning tests', which also must be performed prior to occupancy of a building in order to prove that the smoke hazard management features of a building operate and function as required. Real fires are not used as part of the commissioning process due to concern with damage to the building and its fabric. Other stairwell pressurisation tests are reported to have been conducted in the UK, Canada, United States, France, Germany and Japan (Klote 1995a). All of these full-scale tests showed that pressure differentials can prevent smoke migration from the low-pressure side of a barrier to the high-pressure side and could provide 'smoke-free' exits (Klote 1995b).

Note: The term 'smoke-free' refers to a space (for example, a stairwell) being essentially free of smoke. That is, there may be smoke within the stairwell space however, the amount of smoke is in such minor quantities that it still allows sufficiently tenable[3] conditions for occupants to be maintained. It is highly unlikely to economically design a SPS to provide a (100%) smoke-free environment all of the time for office type occupancies (eg. high-rise buildings).

Cresci (1973) also conducted a scale model test of DeCicco's (1973) 22-storey stairwell. This model test resulted in the observation of stationary airflow vortices in open doorways. Klote (1995b) states that these vortices are the reason why the airflow coefficient through open stairwell doorways is approximately half of what it would be otherwise. Such vortices are believed to have a significant effect on airflow in stairwells as they reduce the effective size of an open doorway. This concept has been incorporated into more advanced analysis procedures (Klote 1995b) such as those incorporated in the CONTAM software (see Chapter 7).

The level of pressurisation required to prevent the ingress of smoke was found from early testing to be dependent on whether or not the building was sprinklered, as this influenced the likely fire size. For example, DeCicco's (1973) full-scale 22-storey fire experiments showed that 'smoke-free' exits could be obtained for an unsprinklered large fire (Klote and Milke 2002) and that the minimum design pressure differentials required are more than two times those required for a sprinklered building. It was found that a 12 Pascal (Pa) differential pressure was required for a sprinklered building but 20 Pa was required for a non-sprinklered building (National Fire Protection Association 1998).

Tamura and Shaw (circa 1974) built on Cresci's (1973) work and performed field tests of pressure losses for eight external walls associated with multi-storey office buildings. They achieved this by pressurising all floor spaces of the buildings using 100% outside air for the central supply fan systems and shutting down the return and exhaust systems. The supply air rates were varied and the pressure differences across the pressurised enclosures were

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[3] The term 'tenable' refers to the smoke temperature not being too high, the smoke layer depth not being too low, the visibility being adequate and the concentration of toxic gases not being excessive as stated within the Fire Engineering Guidelines (FEG 1996) for life safety, so that occupant safety is not compromised due to the ingress of 'insignificant' amounts of smoke entering the escape route i.e. the stairwell.

recorded as well as flows across exterior walls. This enabled the leakage levels to be determined for various boundaries between pressurised spaces. Achakji and Tamura (1988) then went on to use this information and conducted tests in an experimental 10-storey tower (built by the National Research Council of Canade [NRCC] in the mid 1980s), whereby they developed a table of loss coefficients for various stair configurations i.e. open/closed tread stairs, with/without people in the stairwells. Their findings showed for example, that an increase in the number of occupants in the stairwell increased the airflow, resulting in a drop in pressure. This type of study and the influence of these factors had previously not been performed.

In the early 1980s, much of the above-mentioned experimental work was critically appraised and amalgamated into a publication concerned with the design of SCS based on the principles of engineering (Klote and Fothergill 1983). This (original) design book has since been revised and expanded, the most recent edition being "Principles of Smoke Management" (Klote and Milke 2002).

The studies listed in the above paragraphs presumed that the pressurisation systems would operate if required to do so. In practice, however, this may not be the case due to the uncertainties associated with the many parts of the system.

This latter aspect of system reliability can be studied using fault tree analysis (refer to Chapter 8 for more detail). Such an approach was used to study the reliability of SCS in shopping centres (Moore and Timms 1997) and Zhao (1998) used this technique when assessing the reliability of a simple SPS in an apartment building. The pressurisation system studied by Zhao was a single fan sub-assembly and the fault tree analysis was based on very limited published data that did not take into account the performance as observed by practioners responsible for the commissioning and maintenance of such systems. The fault tree adopted by Zhao considered only the power source, the alarm signal, the fan and damper(s), where the details associated with these components were greatly simplified compared with a real SPS. Due to this simplification, his reliability assessment gave a 90% reliability rate in terms of *no signal being received* by the damper or fan for a maintained SPS. No account was taken of whether the system components actually operate, whether the door opening forces are likely to be excessive or whether the other design conditions specified by AS1668.1 would be achieved.

Chapter 3 describes in more detail the complexities associated with these systems. This thesis extends Zhao's work to investigate SPS effectiveness in terms of variations to wind, temperature and building leakage and other factors (also related to reliability) influencing SPS as appropriate for multi-storey office buildings. To assist with the evaluation of reliability data on component uncertainties, data has been sourced from the literature, as well as from expert contracting companies who are experienced in the operation of SPS. Zhao did attempt to look at the effects of commissioning and maintenance, however more limited data was available at the time.

In relation to the uncertainties of a system and the component reliability issues, Klote and Milke (2002) comment that it is often assumed that all components in a complex system operate initially and that failures occur some time after system installation. However, this would only be true if the system was successfully commissioned at the time of occupancy. Moore and Timms (1997) found that the quality of commissioning has the greatest effect on the overall probability of failure of a SCS and is one of the most critical aspects in obtaining an effective system. This was also found to be the case in this research (refer to Chapter 8). Second to commissioning, Moore and Timms (1997) identified that the quality of maintenance and installation had similar effects to each other in terms of their effect on the probability of a SCS failing. Commissioning itself may take a long time (several or more years) before the SPS is made operational as per the design requirements. This fact suggests there is a significant level of complexity and uncertainty associated with these systems. Furthermore, during the possibly lengthy stage of commissioning the building may become occupied.

It is known that leakage within a stair shaft has a major influence on system performance (Klote and Milke 2002). What is not appreciated is that leakage is often a function of the standard of workmanship as opposed to the specific form of construction. Gaps to the outside and to other parts of the building do not have to be large to reduce the pressure able to be developed within a stair shaft. Sufficient pressure must be obtained to prevent the ingress of smoke. However, the pressure must also be low enough to enable the stair doors to be opened (doors open inwards, towards the stair shaft). In practice there is a narrow range of acceptable pressures. The implications are clear. A fan required to achieve adequate pressurisation in a "likely" stair shaft would prevent doors opening in a 'tight' shaft – however, until the building is constructed, the level of leakage associated with the shaft is not fully realised. Tamura and Shaw (circa 1974) recognised the importance of leakage and measured such for buildings after they had been constructed. Building leakages were found to vary considerably (for example, 0.61×10^{-3} $m^3/s/m^2$ to 0.24×10^{-2} $m^3/s/m^2$, measured at 74.7 Pa) and therefore, it is difficult to estimate the leakage values prior to construction.

The effect of leakage (as well as wind and temperature variations) on pressures within stair shafts can be modelled using the computer program CONTAM (National Institute of Standards and Technology 2003). This program is a multi-zone indoor air quality and ventilation analysis computer network program. It is designed to determine the airflows, contaminant concentrations and/or personal exposure limits within a building. It has the ability to calculate building airflows, the distribution of ventilation air within a building as well as to estimate the impact of envelope air tightening efforts on infiltration rates, i.e. building leakage. CONTAM can also be used to simulate several different building features - for example, pressurised stairwells, chimneys, etc., and to calculate room-to-room airflow pressure differentials induced by mechanical and natural forces. The CONTAM program is an extension of a similar, earlier network model program called ASCOS (Klote 1981). ASCOS was originally developed as a research tool for the analysis of SCS for 10 and 20-storey buildings. A number of studies have compared the predictions of ASCOS with actual measured flows and pressures within constructed buildings (Lincolne Scott 1991). These comparisons were sufficiently close to confirm that such a model could be used to simulate real behaviour. CONTAM has been used in this research as a tool to simulate the performance of SPS.

Today, and specifically here in Australia, designers of smoke management systems do not undertake detailed analysis in designing a SPS, nor are sophisticated tools such as CONTAM used. Rather, an estimate is made of leakage and this is combined with the required number of open doors in a stair shaft (see design criteria in Chapter 4) to obtain an estimate of the openings through which a minimum airflow must be achieved, thereby resulting in quite a subjective design (in terms of assumed leakage values). No account is taken of "stationary vortices" at doors (Cresci 1973) and the fan capacity is chosen in order to give the required airflow through the maximum openings (i.e. three doors open with 1 m/s through the stairwell door at the assumed "fire floor", as detailed in the design standard AS1668.1 [1998]). The 'fine' tuning of the system to ensure that the door opening forces are not exceeded is assumed to take place at the time of system commissioning.

Klote (1995b) predicted that research in the area of pressurisation would decrease and it has, especially in the case of physical building (fire) experiments and accurately determining the leakage values for buildings (either pre or post construction). Therefore, today, there is more emphasis on tapping into 'the experience' of designers, in terms of the operational success of SCS as well as the specific features required for the system.

This 'experience' of designers over the years (as indicated by the literature eg. Klote and Fothergill [1983]), suggests that the key factors influencing the effectiveness of pressurisation systems include:

- Stack effect (due to the height of the building and the temperature effects of inside to outside air);
- Wind effect;
- Building leakages (i.e. cracks, lift wells, buoyancy effects due to fire, etc.); and
- HVAC operation (eg. air discharges into egress routes).

The first three factors are considered in detail in this thesis; whilst for the purpose of simplification, the fourth factor has been ignored. That is, the interaction of zone pressurisation systems on the SPS has not been taken into account.

3. STAIR PRESSURISATION SYSTEMS (SPS)

3.1. Introduction

The components and features of practical stair pressurisation systems (SPS) are more fully described in this chapter. This is done by reference to two buildings, which incorporate different but typical systems as installed within many high-rise commercial buildings. The particular features of the SPS within these buildings are described and used as the basis for a broader understanding of SPS in buildings. These buildings are referred to as 'Buildings 1 and 2' and their corresponding systems as 'Systems 1 and 2'.

Only features associated with the SPS are considered and no account is taken of other smoke management systems such as zone pressurisation that would also, nowadays, be required in such buildings. Zone (pressurisation) Smoke Control Systems (ZSCS) were not officially introduced into an Australian Standard (AS) until the 1991 version of AS1668.1. It is likely that the building's Smoke Control System (SCS), i.e. a ZSCS, may actually effect the operation of the SPS. The ZSCS should result in a negative pressure on the fire floor and positive pressure on the adjacent floors, causing higher door opening forces on the fire floor and lower door opening forces on the adjacent floors. This would reduce the likelihood of smoke getting into the stair shaft at the fire floor. The interaction of these types of systems with a SPS is ignored for the purpose of simplification.

3.2. Buildings Considered

3.2.1. Introduction

In order to better understand SPS, two buildings were chosen within the Melbourne Central Business District (CBD), where Building 1 contains System 1 and Building 2 contains System 2. These buildings were chosen as access to most of their commissioning and/or maintenance/testing records were available and the pressurisation systems are representative of the newer (i.e. System 1) and older (i.e. System 2) systems installed in Australia in terms of fan speed control. Both buildings are of concrete or masonry wall construction with concrete floors. Details of these buildings and their components are given in Table 1.

Note: Both buildings had SPS installed at the time of construction, as opposed to being retrofitted at a later stage.

Table 1. Building/System Description

Description	Building 1 (System 1)	Building 2 (System 2)
Building Completion	~ 1985	~1990
Sprinklered	Yes	Yes
No. of floors	8 + plant/roof	54 + 3 plant/roof
Floors served by single SPF	8	11 (generally)
No. of stairwells	2	2
Design Standard	AS1668.1 (1979)[4]	AS1668.1 (1979)[4]
Maintenance Standard	AS1851.6 (1983)[5]	AS1851.6 (1983)[5]
No. of fans per stairwell	1	5 + OAF
No. of fans per block of floors	1	1
No. of injection points per block – located at floors	Single (1) Stair 1 – floor 7 Stair 2 – floor 7	Multiple (18) Stair 1 – floors P2/P1, LG/GF, 4/5, 7/8, 10/11, 13/14, 16/17, 18/19, 22/23, 24/25, 28/29, 32/33, 35/36, 38/39, 41/42, 44/45, 48, 52 Stair 2 – floors P2, LG/GF, 1, 5, 9, 12, 15, 19, 23, 25, 29, 33, 36, 39, 42, 45, 48, 52
Building Smoke Control Method / Building AC system	Air Purge (i.e. Smoke Spill) / VAV boxes	Sandwich (i.e. Zone) / VAV boxes
Plant Room - location	Central – on roof	Central – floors 22 and 47
Pressure Sensor type	Siemens QBM 61.202	Staefa FKE:P1
Variable Speed Drive	Toshiba	- NA -
Pressure Relief Dampers	- NA -	Celmec
Damper motors	- NA -	Belimo Motors
FIP	Ampac Fire Finder	FFE 9000
SPF	Axial, Woods fans 4.6 kW	Axial, Woods fans 38J (2.5 kW); fans #1, #2, #5-#10 48J (3.4kW / 4.6kW) fans #3 /#4

NA Not Applicable SPF Stair Pressurisation Fan OAF Outside Air Fan
VAV Variable Air Volume FIP Fire Indicator Panel

The stairwell systems are illustrated further in Figures 2 and 3.

[4] Commissioning requirements have been assessed against AS1668.1 (1998) (the most recent edition of this standard).
[5] Maintenance requirements have also been assessed against AS1851.6 (1997) (the most recent edition of this standard).
Note: At the time of writing this thesis, the new maintenance standard was released (September 2005 [AS1851 2005]) however, this latest edition of the standard has not been described in this research.

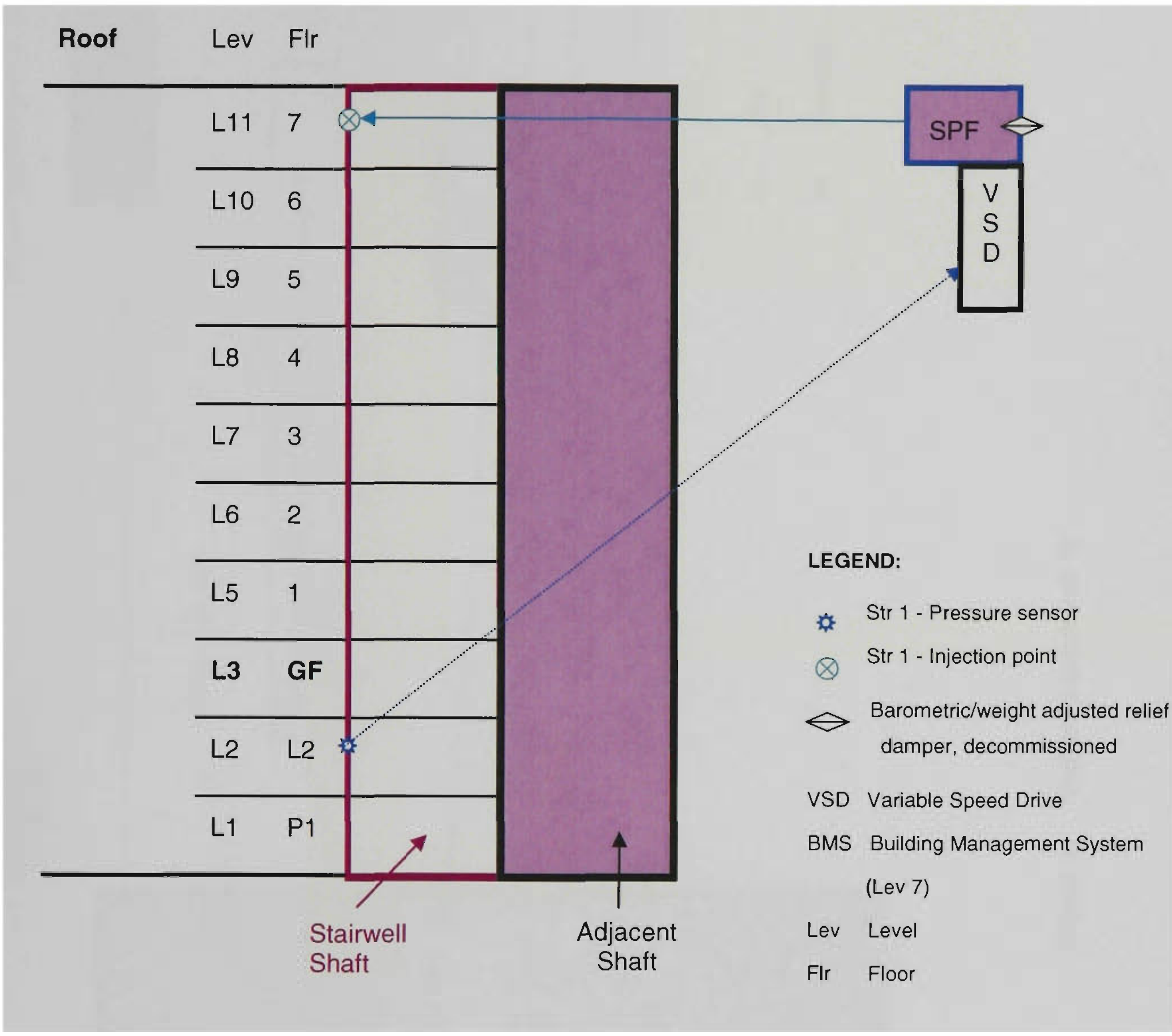


Figure 2. System 1 (stairwell 1)

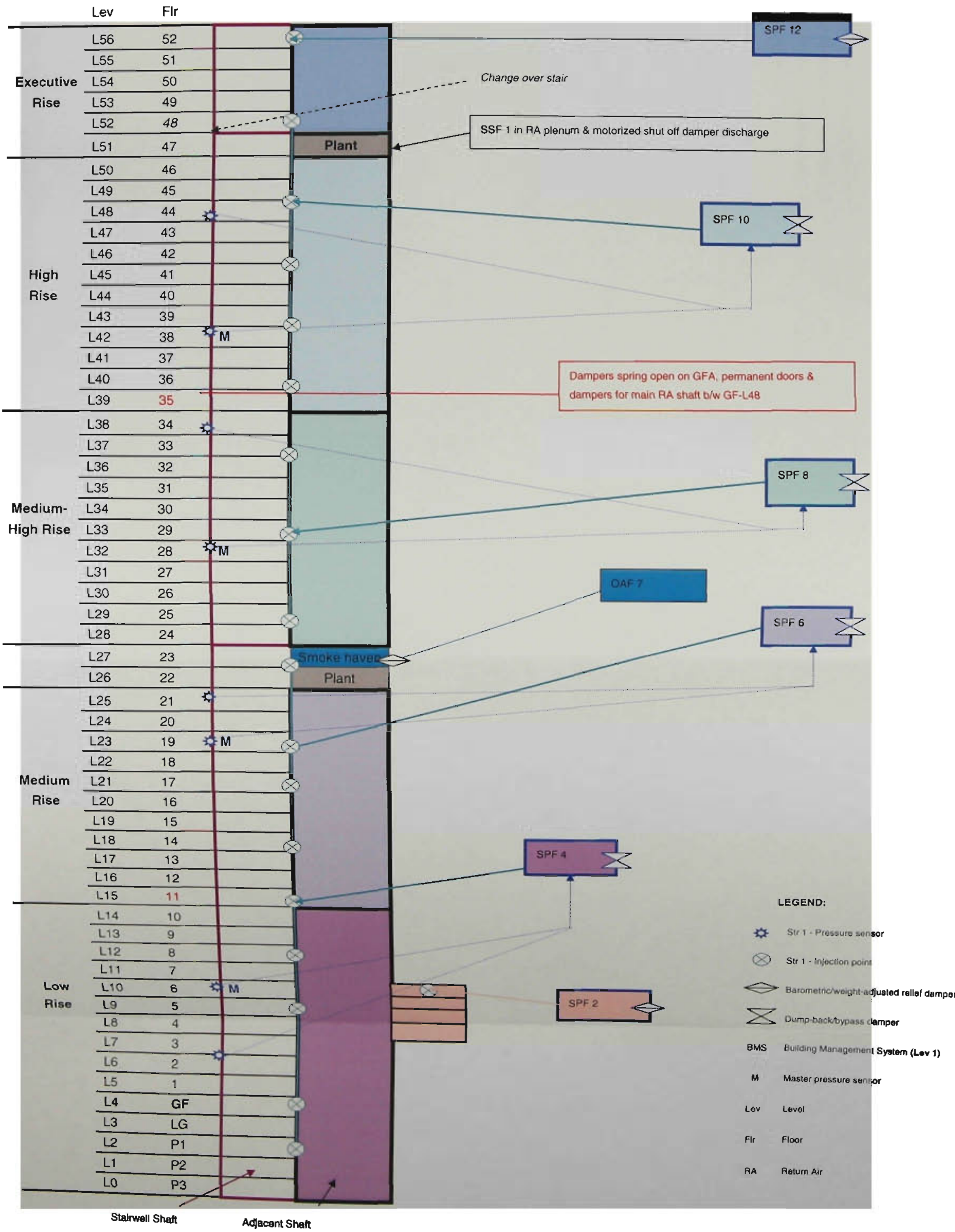


Figure 3: System 2 (stairwell 1)

3.2.1.1. Building 1 Description

3.2.1.1.1. General

Building 1 has one central plant room which houses the air-handling equipment serving the internal building zones (i.e. the Supply Air Fans [SAF], Return Air Fans [RAF], etc.). There are also two central Air-Handling Units (AHU) for the perimeter building zones on the east and west side of the building.

The specifications in the mechanical services documentation state that there are also door relief grilles (of the inverted chevron type) with a 60% minimum free area. The quantity of relief grilles, eg. one per stairwell door, was not specified. Upon physical inspection of the building, it was identified that these door relief grilles are not present within the building, except for air relief located within the tenancy lift lobby areas.

The original design drawings did not detail the location of the stair pressurisation fan (SPF) smoke detectors and evidence of the original commissioning data could not be sourced for this building.

3.2.1.2. Building 2 Description

3.2.1.2.1. General

Building 2 is separated into various stairwell compartments due to the size of the building as illustrated in Table 1. However, for modelling purposes, effectively only one block of the stair shaft will be investigated (i.e. approximately 10 levels).

Unique to System 2 are the unimod devices (i.e. a device similar to a High Level Interface [HLI], which forms part of the alarm communication system for the building). Originally, Sekita communication equipment was used however, in 1999 when the system was re-commissioned,[6] the Sekita device was replaced with the unimod system due to 'reliability issues associated with the Sekita communications' (as informed by the site contact for Building 2). The unimod operates by interpreting signals from activated detectors, sprinklers, etc., so that the Fire Indicator Panel (FIP) can 'see' the message and take action accordingly. It works in a similar manner to a 'translator' so that the FIP can understand incoming alarm messages from detectors. These devices can be located within the FIP or the mechanical services switchboard (MSSB) i.e. piggy-backed to this equipment. They are hard wired to energise/de-energise relays for pre-programmed fire mode operation. The override controls of the Fire Fan Control Panel (FFCP) also need to pass through the unimod device. The implications of failure of the

[6] It appears that when System 2 was re-commissioned, it was re-commissioned against the 1991 version of AS1668.1 "*The use of mechanical ventilation and air-conditioning in buildings - Fire and smoke control.*" The system was re-commissioned after the stair pressurisation shafts were re-sealed (as they were suffering from air loss through gaps in the shaft wall).

unimod device are significant as in that case, the FIP may not 'see' the alarm. The relationship of these various parts of the control system are considered later.

3.2.2. Key Hardware Components

There is a multitude of equipment used within a SPS. The following sections briefly describe the types of equipment and their uses with respect to the SPS analysed as part of this research.

3.2.2.1. Fans

Fans are the means by which stairwells are pressurised and they can either be of the centrifugal or axial type. Centrifugal fans generate airflow in a radial direction to the impellor. The impellor can either be designed with a forward curve, a backward curve or as an airfoil. Axial fans (see Figure 4) on the other hand, generate airflows parallel to the impellor. These fans can be further divided into either the propeller type, the tubeaxial or vaneaxial type of fan.

Figure 4: Axial Fan (example)

Both Systems 1 and 2 have axial SPF, which were sized to provide the minimum air velocity when the design number of doors (three, as per AS1668) are open. This is consistent with the design methodology noted in Chapter 2, in terms of sizing fans.

A fan's operating characteristics can be defined as a function of the pressure differential using the general flow equation (Klote and Milke 2002), as follows:

$$\dot{V} = C_e(\Delta p)^n \qquad \text{Equation 1}$$

where

$\dot{V}$ = volumetric flow (m^3/s)

C_e = flow coefficient for exponential flow ($m^3/s\ Pa^{-n}$)

Δp = pressure difference across a path (Pa)

n = flow exponent, dimensionless (where n varies from 0.5 to 1)

This equation shows that a small increase in the flow coefficient will cause a substantial decrease in the volumetric flow combined with a concurrent decrease in the differential pressure produced by the fan (Witt and Sohn). This relationship has been further illustrated in Figure 5 for a typical axial fan, where Equation 1 is represented by the 'saddle' shape of the curve.

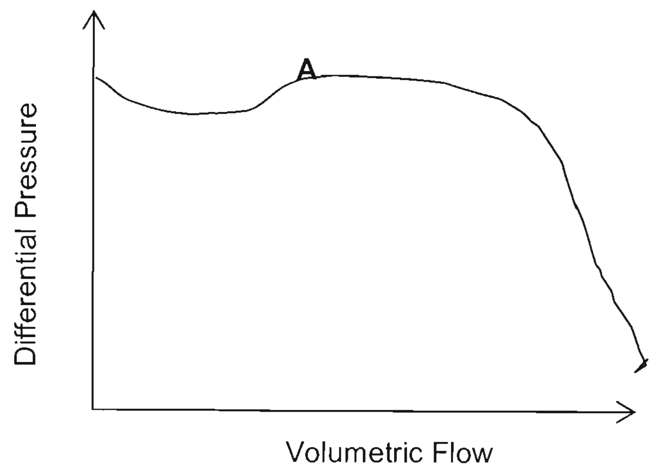


Figure 5: Pressure - flow relationship for an axial fan

The region to the left of the 'A' in Figure 5, is referred to as the 'unstable operational region' while the region to the right of 'A' is the 'stable operational region'.

The axial flow fans used for the SPS in System 1 have a total air quantity of 9,000 L/s, with a static pressure of 150 Pa and maximum Revolutions Per Minute (RPM) of 960. These SPF have a stable operation of 10% - 100% airflow by varying the fan motor via a Variable Speed Drive (VSD). The life cycle of these fans is rated at 40,000 hours.

The constant volume axial flow fans used for the SPS in System 2 range in air quantities from 4,500 L/s to 11,575 L/s[7], depending which SPF it is. Their static pressure is 120 Pa and their maximum RPM is 725.

The above details are presented in order to completely describe the two representative SPS.

3.2.2.2. Injection System

SPS can either be of the single injection type (Figure 6a) or the multiple injection type (Figure 6b). This refers to the quantity of inlet vents/grilles (Figure 6c) within the stairwell from either a SPF supply air duct or an adjacent shaft. Single injection systems, as the name implies, have one inlet vent/grille while multiple injection systems usually have inlet vents/grilles evenly distributed throughout the length of the stair shaft eg. every three floors or so.

[7] This values of 11,575 L/s was actually chosen for the SPF as part of the modelling analysis detailed further in Chapter 7.

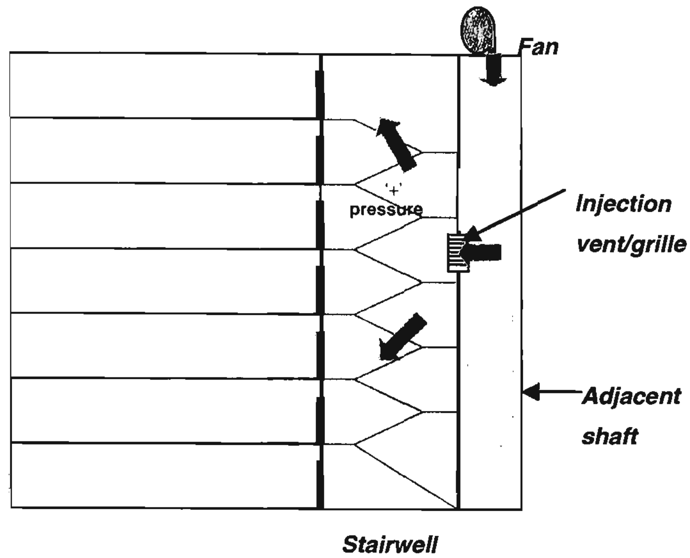


Figure 6a: Single injection system

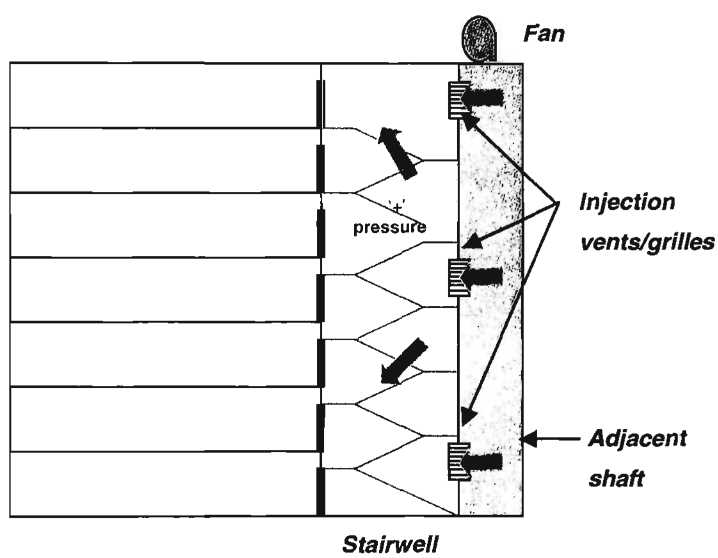


Figure 6b: Multiple injection system

Figure 6c: (extra large) Injection vent/grille

As indicated previously, injection can be either from a dedicated supply air ducting system within the stair shaft or an adjacent shaft (see Figure 7). Both Buildings 1 and 2 have a separate supply air shaft adjacent to the stairwell with vents/grilles joining the two shafts instead of a ducted supply air distribution system. That is, the air flows from the SPF supply air shaft through the vents/grilles into the stairwell in order to pressurise the stairwell.

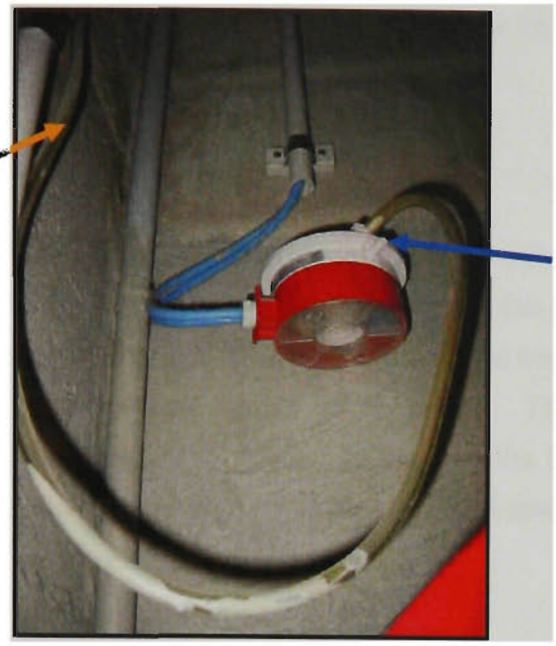
Figure 7: Separate supply air shaft

Single injection systems (as per System 1) most commonly inject air at the top of the stairwell (Klote and Milke 2002). System 2 is of the multiple injection type and has an inlet vent/grille at approximately every fourth floor (refer to Table 1).

3.2.2.3. Pressure Sensors

Pressure sensors (see Figure 8) are used to measure the differential pressures between the stairwell and another space. This 'other' space is usually the occupied floor space, as opposed to the ambient external conditions of a building.

Pressure sensor tubing protrudes into the stairwell shaft from this service cavity (which is at the same conditions as the occupied space)



Pressure sensor

Figure 8: Pressure sensor

In the case of System 1, a Siemens QBM 61.202 pressure sensor has been installed for each stairwell. It is located in the electrical riser adjacent to the fire-isolated stairwell on Level 2 (refer to Figure 2). It measures the pressure difference between the electrical riser (on the occupied floor) and the fire-isolated stairwell, as the 'ambient internal' conditions (i.e. pressures, temperatures, etc.), are assumed to be constant in this location independent of the floor of the building. This pressure sensor has a measuring range of between 0 Pa and 100 Pa and takes a measurement approximately every 12 seconds when the building is in fire mode operation (i.e. the SPS is operating). The pressure sensor for this system is connected to its associated VSD for the SPF in order to 'tell' the VSD to ramp up or down (corresponding to either an increase or decrease in fan speed), depending on the stairwell pressure differential.

System 2's pressure sensors are of the Staefa FKE:P1 type, also with a measuring range of between 0 Pa and 100 Pa, with a response time of 0.5 seconds. These sensors are located between the fire-isolated stairwell and the hose reel cabinet. They measure the pressure difference between the stairwell and the lobby on the occupied floor.

For System 2, the (motorised) dump-back/bypass dampers for SPF 3-10 are controlled by the pressure sensors inside the stairwell, which sense the differential pressure between the stairwell and the interior of the building (i.e. the hose reel cabinet). Originally, each of the above noted SPF had two pressure sensors (as illustrated in Figure 3). These pressure sensors had their readings averaged in order to initiate damper operation, however in 1999 this averaging operation was judged to be inadequate as it could result in inappropriate damper operation if the two pressure sensors were reading extreme pressure values (eg. 0 Pa and 100 Pa). As a result, the pressure sensor averaging operation was modified so that pressure readings were only taken from one pressure sensor, not two. The pressure sensors used to modify the damper operation were identified as the 'Master' pressure sensor and are located on floors 6, 19, 28 and 38 for each stairwell, resulting in one pressure sensor per block of stairs (refer to sensors marked with an "M" in Figure 3).

3.2.2.4. Variable Speed Drives

The VSD (see Figure 9) provides power and control to the SPF to either ramp up (increase the fan speed), ramp down (reduce the fan speed) or remain at the set fan speed, depending on the differential pressure as measured in the stairwell. The output signal from the pressure sensor is sent to the controller box/microprocessor 'brains' of the VSD. This 'brain' consists of a programmable algorithm which is set-up and modified at the time the SPS is commissioned so that the VSD output signal results in the necessary changes in SPF speed.

Figure 9: Internal of a VSD, with front cover removed

Anecdotal evidence suggested that when VSD were first introduced (Australian Institute of Refrigeration Air Conditioning and Heating 2002), their acceptance was limited due to reliability issues and difficulties in setting them up. However, today they are now recommended to be used as they make the commissioning process easier and their reliability is considered to have improved.

Each of the two stairwells for System 1 has a VSD connected to the respective SPF. System 2 does not have VSD control of the SPF.

3.2.2.5. Dampers/Actuators

Dampers are used to balance and/or control airflow. Specifically for SPS, dampers are used to relieve the air to limit the build-up of pressure inside the stairwell. Their opening/closing mechanism can either be of the barometric (i.e. weight-adjusted [mechanical] operation) type, pneumatic or the electric type. Dampers are either installed within the (stair) shaft or as part of the SPF assembly (in which case they are referred to as dump-back/bypass dampers). Again, these bypass dampers can have either one of the three mentioned damper actuating mechanisms described above. Barometric dampers have weights (Figure 10a) which are adjusted so that the damper opens when a particular (excessive) pressure is reached, while the other two damper opening mechanisms are activated/modulated depending on the pressure sensor reading (see Figures 10b and 10c).

Figure 10a: Barometric/weight adjusted damper

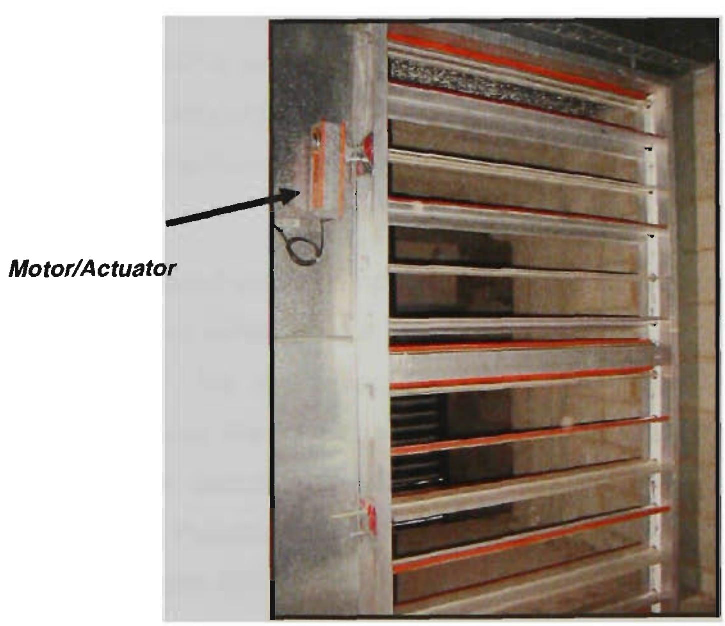


Figure 10b: Motorised (electric) damper

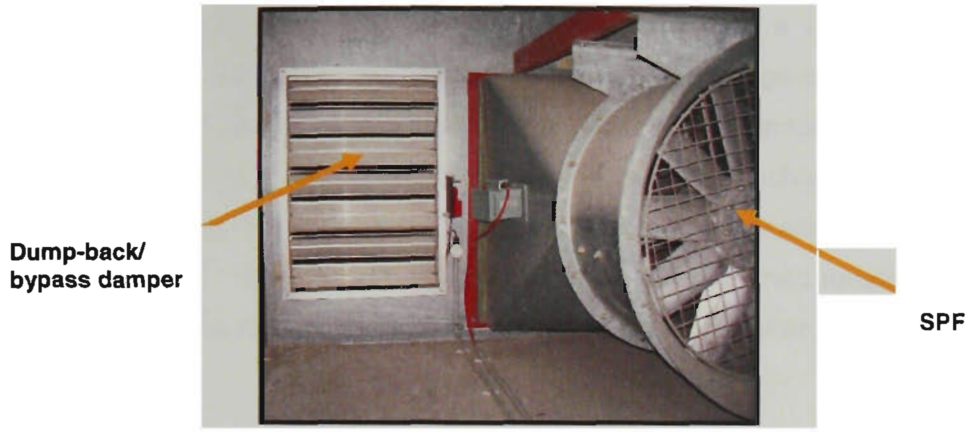


Figure 10c: Dump-back/bypass damper controls airflow from SPF (System 2)

Designs to-date typically have either a VSD attached to a fan for pressure variation in the stairwell, or a constant airflow supply fan with barometric damper (other variations are also possible). It is not usual to have both barometric damper pressure control as well as VSD controlled pressure (through the SPF) in the one SPS.

As part of the original construction for System 1, the stairwells had a barometric damper to prevent excessive pressure build up. However, in June 2001 these barometric dampers (located within the plant room) were sealed (and decommissioned), as their use was not warranted due to the VSD assisting in controlling the pressure within the stairwell.

The bypass arrangement in System 2 (refer to Figure 10c) is similar to those associated with the wind tunnels at the NASA Ames Research Centre (http://vonkarman.stanford.edu/tsd/pbstuff/tunnel/tdescript.html), although on a much smaller scale. The wind tunnels described in this reference have a filter/screen fitted to reduce the impact of turbulent airflow at the entrance to the tunnel.

System 2 has dump-back/bypass dampers for the SPF numbered 3-10. For example, when the pressure in the stairwell builds up (i.e. when all the doors are closed) due to activation of the constant volume SPF, the dump-back/bypass damper opens (depending on the pressure sensor signal) to increase the bypass air. This in turn reduces the available supply flow into the stairwell, resulting in a reduction of excessive pressure differentials between the stairwell and the building (ASHRAE Handbook 1987). As a result, the door opening forces are reduced. The dampers associated with SPF 1, 2, 11 and 12 are controlled via a barometric/weight-adjusted mechanism.

3.2.2.6. Fire Indicator Panel and Associated Equipment

The FIP are used to indicate a fire alarm. It does this by sending a signal to the fire alarm monitoring company via equipment referred to as Alarm Signal Equipment (ASE). The FIP also visually displays the alarm when activated in a building.

The detection system's language (or output signal) used within a building (eg. the smoke detection system), may not always be compatible with the language or signals recognised by the FIP and therefore, the detector's language may need to be 'translated' so that the FIP can 'read' the incoming (detector) alarm signal. This 'translating' mechanism can be performed through a unimod device (see Figure 11), which provides an interface between the incoming alarm signal and the FIP. The unimod can also have pre-programmed functions when used as an input/output device associated with MSSB in order to control auxiliary equipment.

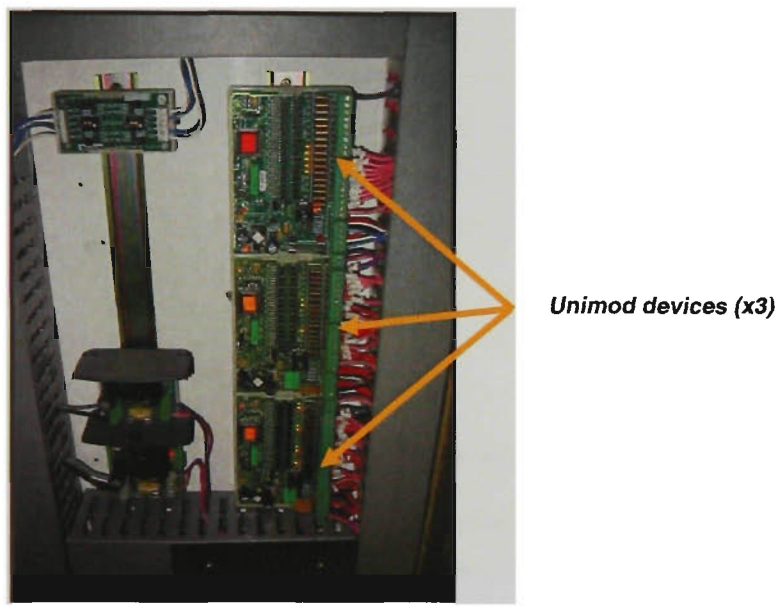


Figure 11: Unimod devices

3.2.2.7. Mechanical Services Switchboard

The MSSB house the relays, switches, controls, etc., for operation of the fans, indicators and other devices associated with the SPS. These relays are shown in Figure 12 below.

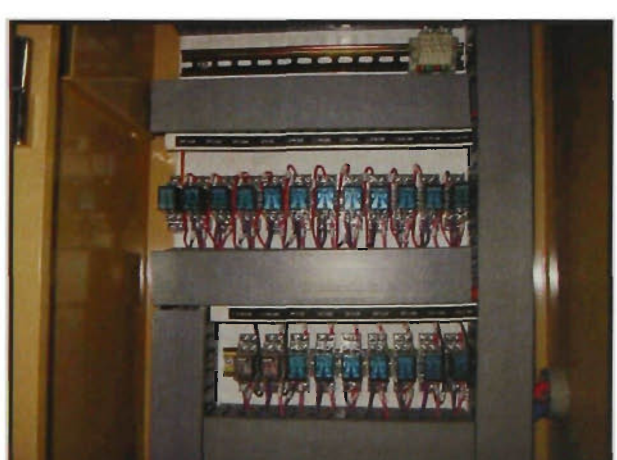


Figure 12: Relays (multiple)

3.2.3. *Hardware Interrelationship*

3.2.3.1. *Introduction*

The fire mode operation of a SCS installed in a building is specified by the performance conditions of the relevant Australian Standards i.e. AS1668.1. This standard details the design and operational requirements of the system whether it is an Air Purge (smoke spill) system (as per Building 1), a ZSCS (as per Building 2), a fire-isolated SPS (Systems 1 and 2), and so on.

Detailed below in the following two sections, are the specific fire mode sequences of operation for the two buildings' SCS. This information has been included in order to begin illustrating the complexities associated with SCS in terms of operation, and therefore, subsequent trouble-shooting identification and maintenance. It is important to establish these details in order to do future analysis and to evaluate system reliability.

3.2.3.2. *Fire Mode Operation – System 1*

In general, the following sequence of operations occur when the building is in fire mode:

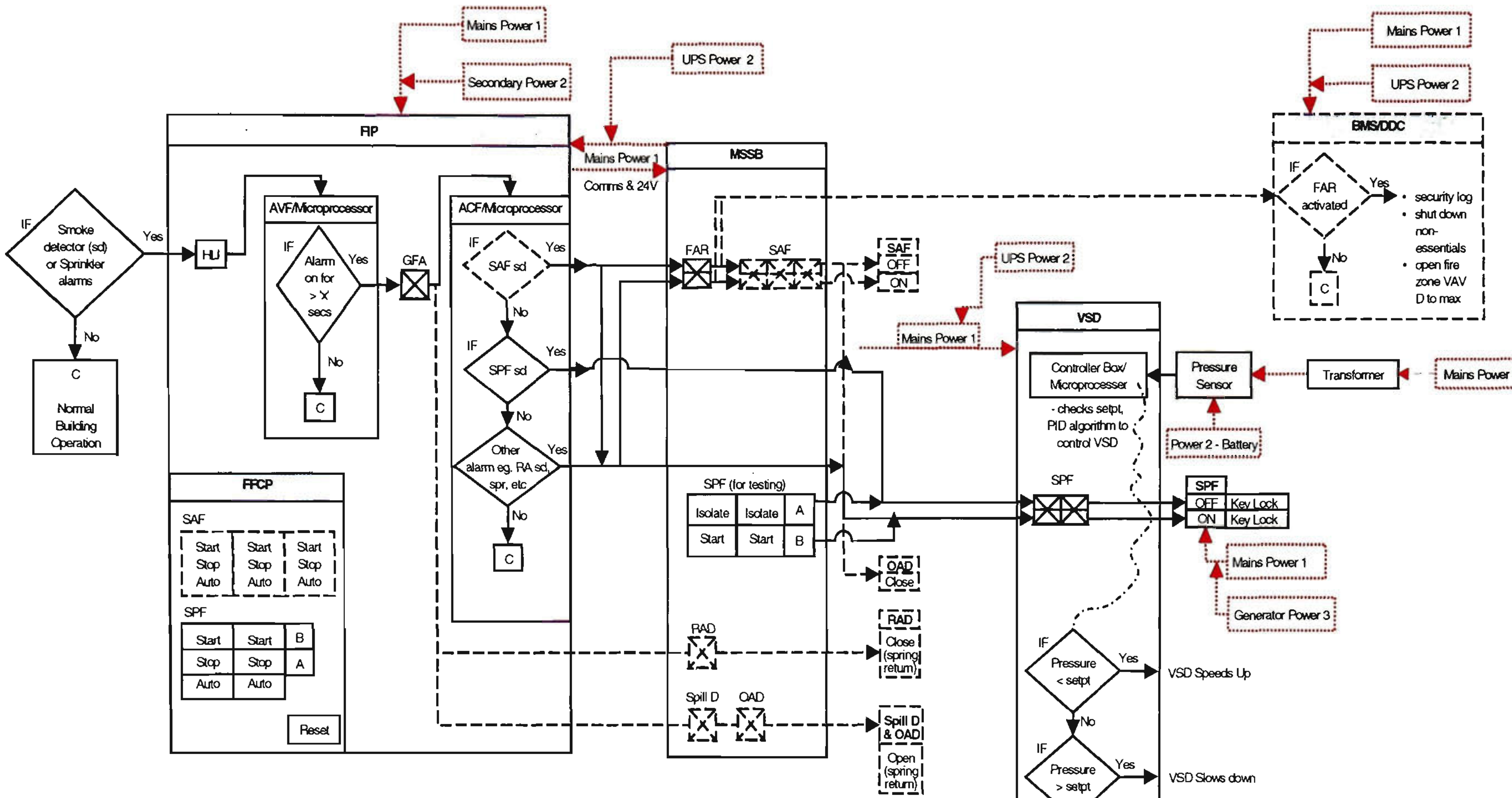
Upon initiation of a General Fire Alarm (GFA), i.e. an alarm initiated via the Return Air Fan (RAF) smoke detector or sprinkler alarm, the building's audible fire alarm system sounds, the RAF switch to smoke-spill mode, the Supply Air Fans (SAF) and SPF turn on, and the motorised outside air dampers open to full outside air. The toilet and carpark fans turn off and the full exhaust spill damper and Return Air Dampers (RAD) close. However, if a SAF smoke detector initiates an alarm instead, the above sequence of events occurs except that the associated SAF also shuts down, as do the motorised outside air dampers associated with the alarm, the full exhaust spill dampers and the RAD.

The above detail has been broken down further (see Figure 13) into the SCS components in order to appreciate the complexities of the system. This figure illustrates the sequence of events as well as the intelligence of various pieces of equipment (eg. the FIP, the VSD, etc.) from the time an alarm is initiated in Building 1 in terms of activating the SCS. For example, beginning from the left of Figure 13 and following the solid arrows, we see that:

- if an alarm is activated (eg. via either a smoke detector or the sprinkler system), this signal is sent to the FIP →
- upon initially reaching the FIP (for System 1) the High Level Interface (HLI) translates the incoming alarm signal so that the FIP components can 'read' the alarm

  [Note: This 'translating' function may not always be required and is dependent on the type of detectors and the FIP installed] →

- the FIP components (i.e. the Alarm Verification Facility [AVF] and the Ancillary Control Facility [ACF]) then decide what the next operational event will be (eg. once an alarm has been verified for a specified time period, the GFA relay is activated within the FIP and depending on which detector initiated the alarm, the next sequence is determined) →
  - if a non SAF detector is activated (eg. a sprinkler detector), the alarm signal sends a message to the SPF to start →
    - while System 1 is operating, the pressure sensor samples every 12 seconds and sends a signal to the VSD; depending on this pressure reading, the VSD will either send a signal to the SPF to speed up, slow down or remain constant, so that the maximum design limits (as per AS1668.1) are not exceeded
  - if a SPF smoke detector is activated while System 1 is in fire mode, the corresponding SPF will stop.



Note:
If pressure relief is required because the pressure is greater than the set point, and a motorised bypass/relief damper is used, there will be a power supply needed for this type of damper eg. refer to fault tree diagram i.e. Figure 47, id box 50.

Figure 13: System 1 interrelationship

3.2.3.3. Fire Mode Operation – System 2

In general, the following sequence of operations occur when the building is in fire mode:

Upon receipt of a fire alarm signal, the SPS starts and the VAV dampers close on the fire floor while the adjacent floors to the fire floor pressurise (as per a ZSCS). For example, the eight SAF will run/start (unless its SAF smoke detector has been activated, in which case the SAF will stop for a specified period), Smoke Spill Fans (SSF) 1 and 2 and RAF 3-6 will start, the return air shut off dampers open, the recycle air dampers close and all the outside air dampers and smoke-spill dampers open.

The build-up of pressure in the stairwell is then varied by the use of dump-back/bypass dampers associated with the SPF. These dump-back dampers modulate through a motorised actuator which is backed-up on the essential services power.

Again, the above detail has been broken down further for the SCS (refer to Figure 14). This figure also illustrates the sequence of events from when an alarm is initiated in Building 2 in terms of activating the SCS and how the system functions without a VSD. Beginning from the left of Figure 14, and following the solid arrows, we see that:

- if an alarm is activated (eg. via either a smoke detector or the sprinkler system), this signal is sent to the FIP →
- upon initially reaching the FIP the HLI translates the incoming alarm signal so that the FIP components can 'read' the alarm →
- the FIP components (i.e. the AVF and the ACF) then decide what the next operational event will be (eg. once an alarm has been verified for a specified time period, the GFA relay is activated within the FIP and depending on which detector initiated the alarm, the next sequence is determined) →
    - if a non SAF detector is activated (eg. a sprinkler detector), the alarm signal sends a message to the SPF to start →
        - while System 2 is operating, and stairwell relief (eg. the dump-back/bypass for the SPF) is via a motorised damper →
            - the pressure sensor samples every 0.5 seconds and sends a signal to the damper controller box; depending on this pressure reading, the damper will either open more, close more or remain unchanged, so that the maximum design limits (as per AS1668.1) are not exceeded
        - while System 2 is operating, and stairwell relief (eg. the dump-back/bypass for the SPF) is via a barometric damper →

- this damper will either open more, close more or remain constant, depending on the weight setting of the damper and the pressure inside the stairwell, so that the maximum design limits (as per AS1668.1) are not exceeded

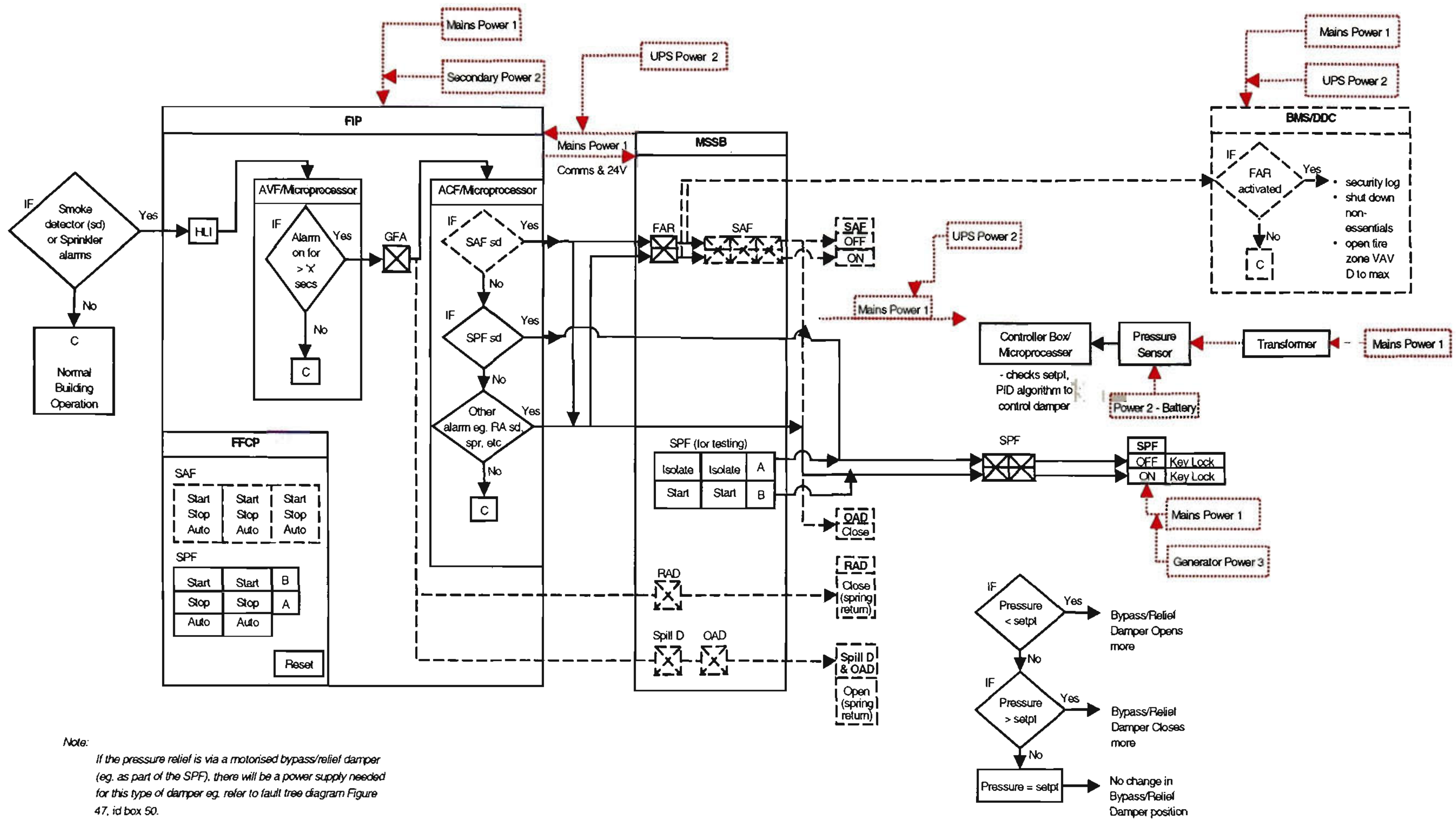
  [Note: The grey boxes in Figure 14 are not applicable];

- o if a SPF smoke detector is activated while System 2 is in fire mode, the corresponding SPF will stop.

Notes:

1. The dotted lines/boxes within Figures 13 and 14 are shown for illustrative purposes only to demonstrate the building's overall SCS operation, as opposed to only illustrating the operational features of the SPS.
2. The nomenclature associated with Figures 13 and 14 is detailed in Appendix A.
3. Other operations such as sending the alarm signal to the MSSB and the Building Management System (BMS) also occur simultaneously; however, as their operation is not required for the SPS, it has not been comprehensively detailed.
4. For the purposes of this research, it is assumed that the incoming alarm (detector) signal is correctly received, i.e. if a smoke detector is activated, it is assumed that this alarm signal reaches the FIP, activates the GFA and sends a signal to the ACF/Microprocessor. That is, potential faults are assumed only to begin from within the ACF/Microprocessor and beyond.

The power supplies associated with the various components are also illustrated in Figures 13 and 14 in terms of the primary power (identified with a '1') and secondary power supplies (identified with a '2' or '3'), in the event that the primary power supply fails.



Note:

If the pressure relief is via a motorised bypass/relief damper (eg. as part of the SPF), there will be a power supply needed for this type of damper eg. refer to fault tree diagram Figure 47, id box 50.

However, if the pressure relief is via a barometric damper, then the components in grey (in this diagram) will not be present in the system.

Figure 14: System 2 interrelationship

4. CODE CRITERIA FOR STAIR PRESSURISATION SYSTEMS

4.1. Introduction

Since the first Australian Standard (AS) was developed for the design and use of mechanical air-handling equipment as a means of smoke control in buildings, there have been moderate changes and additional methods of control introduced to the standard. This has resulted in revisions of the original standard (dated 1974) being published (the most recent of which is the 1998 edition). The following sections detail the design requirements, the commissioning and maintenance methodologies from the first Australian Standard up until the present day, in terms of their relevance to the two Stair Pressurisation Systems (SPS) being assessed. This information has been detailed so that the key performance criteria for this project can be established.

4.2. Australian Standard Requirements

Currently, within Australia, it is the Building Code of Australia (BCA) which ultimately decides whether or not stair pressurisation is warranted for a particular building. The requirement for stair pressurisation is largely based on whether the building in question is more than 25 m in effective height (i.e. a building more than 25 m in effective height requires stair pressurisation).

4.2.1. Design Requirements (General)

As stated in the above introduction, there are a few editions of the design standard AS1668.1. The version of the standard used when designing a SPS is dependent on when the building is constructed (i.e. the most recent edition of the standard prior to building construction is the applicable standard).

Many within the maintenance industry consider that AS1668.1 is the ultimate authority in terms of how to design, commission and *maintain* a SPS, while AS1851.6 is considered more as a *guide* to maintaining the SPS, even though the latter standard is actually the designated *maintenance* standard. This belief is predominantly due to the fact that there are discrepancies[8] between the design standard (AS1668.1) and the maintenance standard (AS1851.6).

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[8] Discrepancies identified as part of this project have been forwarded onto the Australian Standard committee for consideration when updating the latest edition of the design and maintenance standards. For an example, refer to Appendix B.

4.2.1.1. AS1668.1: 1974 Fire precautions in buildings with air-handling systems

The first Australian Standard for the design of smoke control systems (SCS) was AS1668.1:1974 *"Fire Precautions in Buildings with Air-Handling Systems".* This standard was prepared in response to a request by the Interstate Standing Committee on Uniform Building Regulations. The standard investigated the precautions, which needed to be taken when designing, installing and operating an air-handling system for the prevention of fire spread (including products of combustion) in the event of a fire. Up until this time, it was common to shut down the air-handling system in the event of a fire; however, with the introduction of this standard, it was required that each air-handling system had a smoke-spill fan which would start in fire mode in order to control the spread of fire and smoke within the building by exhausting it. The air-handling system was now only required to shut down if the supply air fan (SAF) detectors were activated. This standard did not include aspects such as testing and maintenance, which were to be developed at a later stage (Note: This 'later stage' did not occur until 1983, refer to section 4.2.3. of this thesis for more detail).

This standard also required the use of smoke detectors (i.e. which were not to aid in an early alarm but to initiate the smoke and fire controls for the building) and specified the optical settings for these detectors. Noise requirements were introduced in Section 3.2 of As1668 (1974), stating that in the event of a fire, the operation of the smoke control equipment (eg. the stair pressurisation fans [SPF]) was not to exceed a noise level of 80 dB(A) within both the occupied spaces and the stair shafts.

The power supply requirements for essential building services were nominated in this standard, in Section 5.10, stating that the electrical power supplies for air-handling plant and control equipment were to be in accordance with ASCC1 Part 1:1. *"Reference to the fire control panel"* (FCP[9]). The FCP contains the controls (eg. the stop/shut down and start/run switches) and indicators (eg. green and red lights, etc.) for manual control and operation of the air-handling plant equipment, as detailed in Section 6.4.2 of the standard.

Section 6.2 of AS1668.1 (1974) detailed the operational requirements when an (smoke) alarm detector was activated, while Section 6.5.1 required that a set of essential instructions for operating the air-handling system should be permanently displayed within the plant room. This requirement is not usually met, even today, despite its significant importance, the instructions detail the operational sequence of the SCS and associated equipment upon receipt of a fire alarm.

The design performance conditions were detailed in Section 7.4 of the standard and are summarised below:

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[9] FCP is now more commonly referred to as the Fire Fan Control Panel (FFCP). ASCC1 is the standard associated with the wiring rules.

A stair pressurisation system shall:

"a) maintain an airflow velocity from the stairshaft, ...outward through doors at not less than 1 m/s, average[d] over the full area of each door opening when two doors leading from any two successive storeys and the main discharge doors are fully open simultaneously;

"b) develop a pressure differential between stairshaft, ...[and the storeys] such that -

(i) when all doors are closed, the pressure differential across each door does not exceed 50 Pa; and

(ii) the force required to open any door against the combined resistance of the air pressure differential and any automatic door-closing mechanism shall not exceed 110 N at the door handle; and

"c) be automatically controlled such that when operation of doors or other factors cause significant variations in airflow and/or pressure difference [i.e. doors are opened within the stair shaft, etc.], the conditions in a) and b) above shall be restored in 15 s

Note: It may be necessary to provide specific air relief from the corridor or vestibule to enable air to flow from stairshaft, through the open doors."

Item a) above translates to mean that for the conditions detailed, the airflow through the open door in the stairwell is to be not less than 1 m/s. It is also important to note (again for item a) above) that the need to average the airflow measurements 'over the full area of each door opening' may in fact be a result of the influence of stationary vortices (Cresci 1973), on the airflow coefficient through open doors, resulting in the reduction of the effective size of an open doorway.

4.2.1.2. AS1668.1: 1979 Fire precautions in buildings with air-handling systems

A revision of the 1974 edition of the standard was undertaken as a direct result of the extensive use of this first standard and its implementation required by Building Regulatory Authorities. It was also revised as industry had requested further clarification of certain parts of the standard as well as additional information for some areas.

The importance of ductwork as a means of fire spread and its associated products of combustion was realised. With the exception of smoke detectors, there was, however, still no reference to the maintenance or commissioning requirements. In addition, it was also stated that as part of the design, "permanently open natural ventilation openings ..." were not to be installed at the top of the fire-isolated stair shaft. The design aspects detailed earlier in the 1974 edition of the standard, in terms of noise, indicators, etc., were identical, except that special mention was made regarding identifying the SPF specifically as part of the essential services (it had previously been only *implied*, that this was the case). The type of fans chosen to pressurise stairwells was also mentioned in terms of having a flat pressure-to-flow characteristic, as the fans are required to supply large flow on demand without building excessive static pressure in low demand. Referring again to Figure 5, if the pressure-to-flow characteristic had an exaggerated 'saddle' shape, then there would be a greater risk of generating high pressures at low demand (or flow) instead of only having high pressures at times of high demand (or flow). A flat pressure-to-flow characteristic results in large airflow changes for small changes in static pressure without the necessary need for a pressure control device.

The performance conditions detailed in Section 6.4 of AS1668.1 (1979) were the same as the previous edition's requirements, with the exception of the following:

> "c) [the] conditions in a) and b) .. shall be restored as soon as practicable' [as opposed to within 15 s]
>
> Note: An additional Note was also added, whereby 'the period of restoration detailed in c) [above] should preferably be 15 s, and should not exceed 60 s'".

4.2.1.2.1. (Commentary) SAA Miscellaneous Publication MP47, AS1668.1 - 1980

In 1980 a commentary on AS1668.1 (1979) was published in order to guide designers on the intended application and aim of this standard, specifically in relation to the areas, which were considered to be more open to interpretation. At this time, there was also a move towards utilising the air-handling equipment in the event of a fire emergency (as opposed to only shutting it down).[10] MP47 was intended for use where buildings had one or more fire-isolated stairwell.

Regarding the performance conditions of AS1668.1 (1979), MP47 comments that:

> "a) the reason for two successive doors and the main discharge doors being open (i.e. when measuring the 1 m/s design airflow velocity), was because the occupants would be evacuating via the ground floor door (hence it would be open most of the time) and the two successive doors were open, so that the firemen could run a hose from the storey below to the fire affected storey;
>
> "b) the 110 N force was stated so that a 'slight person' could push open the door; and

[10] The commentary in MP47 suggested that shutting down the air-handling equipment actually resulted in a build up of pressure between the fire compartments and non-fire compartments, thereby forcing the flow of heat and smoke through openings and shafts. This may result in the accumulation of smoke within the stair shaft, prior to the SPF starting, thereby making it difficult to purge existing smoke (refer to Section C2.1.2.7 of this commentary standard).

"c) 15 s was the preferred restoration time, as a short period of delay could evoke panic in a fire emergency situation."

4.2.1.3. AS1668.1: 1991 The use of mechanical ventilation and air-conditioning in buildings

This revision of the standard had been written in order to enable reference by the BCA. A commentary was also included as an appendix to this standard, as opposed to being a separate document as per the previous edition of this standard.

Testing in terms of commissioning was briefly introduced into this version of the standard under Section 4.19. Items to be tested included individual components as well as an operational test for the (whole) SCS. How these systems and components were to be measured (as part of the test) was also mentioned in Section 4.19.4 of the standard, specifically for fire doors, purging SCS and ZSCS. Only the ZSCS had a performance condition in terms of pressure differentials which needed to be maintained (eg. a positive pressure of at least 20 Pa was to be maintained above the fire-affected compartment in relation to the non fire-affected compartments, when all required exit doors were closed).

The performance criteria for a SPS was specifically detailed in Section 8.4.2 of this standard, in relation to whether it was in addition to a ZSCS or purging SCS. In brief the criteria specified for a purging and ZSCS was considered, for example:

The stair pressurisation system shall:

"a) with the main discharge door and door to the fire-affected floor fully open, sustain an airflow velocity of not less than 1 m/s into the fire-affected floor through the doorway opening from that floor, averaged over the full area of the door, whilst -
  - for a purging smoke control system, the door to the floor immediately above the fire-affected floor is fully open; and
  - for a zone smoke control system, all other doors are closed;

"b) comply with door opening force [maximum force of 110 N] and latching requirements, with
  - for a purging smoke control system, all doors to the fire stair closed; and
  - for a zone smoke control system, all doors to the fire stair closed except for the door above fire-affected floor;

"c) be automatically controlled so that operation of doors or other factors cause significant variation in airflow and pressure, Items a) and b) [i.e. as per previous editions of this standard] are restored with minimal delay and not exceeding 10 s [as opposed to between 15 s to 60 s];

"d) the required performance shall be achieved and sustained with all exits serving the fire-affected floor operating simultaneously in the manner described in Items a), b) and c) and with any other smoke control or air pressurisation systems operating concurrently in accordance with the relevant criteria for each system; and

"e) notwithstanding the requirements of Item a), the flow across the top two-thirds of the doorway to the fire-affected floor shall be in the direction from the stairway to the occupied space"

This standard also stated that pressure relief in the form of grilles was to be provided so that the conditions in b) and c) above could be attained. There was also provision in this standard for alternative designs, providing that they were not less effective than the 'deemed-to-comply' systems (i.e. the systems described within specified sections of this standard). Other provisions, as detailed in the earlier editions of this standard, were the same.

4.2.1.3.1. (Commentary) AS1668.1 - 1991

Appendix B of AS1668.1 (1991) details a commentary section to aid in interpretation of this standard. The relevant sections relating to SPS are described below:

Noise

The commentary acknowledges that the operation of the SPF (in terms of noise) should not deter occupants from entering the fire escape stairs in the event of an emergency. The noise level is to be measured in the doorway and the stair shaft landing, with the door open.

The mechanical equipment selected must be chosen so that its operation does not increase the noise to a level which could distress occupants.

Fire Doors/Pressure Differentials

It is noted that maximum forces required to open the doors (i.e. 110 N) is independent of whether or not a SCS is operating within the building (i.e. the occupied spaces), as well as whether or not the stair shaft is being pressurised.

That is, even buildings without SCS are not to have door opening forces exceeding 110 N.

Pressurised Stairwells

The commentary recommends air to be supplied to the stairwell through ductwork with outlets every three storeys to get an even distribution through the height of the stairwell shaft.

Relief air grilles were nominated for the 'deemed-to-comply' system in the standard, as they allow the simplest method of control and provide nearly instantaneous pressure control, resulting in minimising the excessive force which may be required to open stair doors. The use of variable speed fans (i.e. VSD), barometric dampers, etc., were considered alternative systems.

Alternative systems would need to be approved by the appropriate regulatory authority at the time of design.

4.2.1.4. AS1668.1: 1998 The use of ventilation and air-conditioning in buildings

The 1998 edition of AS1668.1 was developed in order to provide standardised minimum requirements for mechanical air-handling and mechanical SCS for designers, installers, inspectors and regulators. This standard includes five different methods of smoke control, more comprehensive testing clauses (for commissioning), requirements for non-electrical control systems and recommendations on reliability (due to concerns of long-term operational capabilities of highly complex systems). In this edition of the standard, commentary sections have been included, immediately preceding each of the requirements of the standard, as opposed to being a separate document or a separate appendix.

The noise requirements are more detailed in this edition; for example, it states in Section 4.6 of this standard that noise (during operation of the pressurisation system) is not to exceed 65 dB(A) or 5 dB(A) above ambient noise, to a maximum of 80 dB(A) in the occupied spaces. This measurement is taken in the paths of travel near the doorway in the occupied space, with the door closed. The noise levels in the fire-isolated exits are not to exceed 80 dB(A) when measured on the landing, with the door open.

Section 9.3 of this standard details the design performance conditions, which are identical to those listed in the previous edition of this standard (refer to section 4.2.1.3. of this thesis), except that when measuring the airflow velocities for a purge system, a shutdown system is now also included as part of this clause and either the door immediately above/adjacent to the fire compartment is open (i.e. as opposed to being only the door 'above' the fire compartment). The wind speed (positive) direction is also stated (i.e. as being out of the stairwell door onto the occupied floor). It is also important to note that the commentary section states that tests conducted by the Commonwealth Science and Industrial Research Organisation (CSIRO) indicated that airflows of greater than 0.8 m/s will keep smoke out. [11]

The commentary also states, that dedicated relief grilles/vents or ducts are to be located at the highest level within the fire stair shaft to assist in venting smoke (if it should inadvertently enter

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[11] In 1987 it was detailed within the Heating, Ventilating, and Air-Conditioning Systems and Applications book (ASHRAE 1987), that the design airflow velocity for sprinklered buildings could in fact be considered between 0.25-1.25 m/s. However, Klote and Fothergill (1983) suggested more specifically that 1.5 m/s could be used for a design fire size of 125 Kilo Watt (kW) for an unsprinklered building and 4 m/s for a 2.4 Mega Watt (MW) fire (as the theoretical fire size is used to determine the critical airflow velocity to prevent smoke movement [through a door]).

Note: These values are theoretical as they do not consider the door's transom design or the occurrence of doors opening during an evacuation.

the stairwell). However, if relief vents are not suitable for pressure relief, then either of the following could be installed; barometric dampers, motorised dampers in series with pressurisation fans, motorised relief dampers on the discharge of a pressurisation fan (as per System 2), VSD (as per System 1) or a combination of these.

In relation to the types of pressurisation fans used, the commentary (in Section C9.4.4 of the standard) notes that suitable pressure control devices should be incorporated so that small changes in pressure correspond to large changes in airflow. As mentioned previously, to obtain the required airflow on each storey, the air needs to be equally distributed throughout the height of the stairwell, especially if the building is greater than ten storeys; this is due to the stack effect and outdoor temperature changes. For this thesis though, the influence of the stack effect in combination with vertical temperature variations with (the total) building height have not been modelled, as each building is only 12 storeys (which is just above the ten storey limit guideline in the standard).[12] AS1668.1 also mentions that manual override control switches (which are contained within the Fire Fan Control Panel [FFCP]) are not operable at times of maintenance or repair.

Reference to current monitoring relays used for monitoring the airflow for a SPF, in terms of being able to discriminate between the current drawn from the fan motor when operating under design conditions, and the current drawn from the fan motor when the airflow has ceased, is also noted. Therefore, during commissioning these relays are to be tested to ensure that they repeatably indicate 'normal airflow' and 'failed airflow' on their respective pressure differential switches (at the FFCP). The commentary for Section C9.6.1 of the standard for shutdown SCS, states that having a fixed vent at the top of the stairwell to the outside, may assist in purging smoke out of the shaft and prevent over pressurisation of the stair shaft. However, this would appear to be in contradiction to the 1979 edition of the standard which stated that "permanently open natural ventilation openings ..." were not to be installed at the top of the fire-isolated stair shaft (due to the potential chimney effect within the stair shaft).

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[12] For the purpose of this thesis, a SPS 'block' is considered to be a selection of 12 consecutive storeys within a building, even though the building itself may be taller than 12 storeys. For example, if a building is 36 storeys in height, it may have three identical 'blocks' of 12 storeys and therefore, we consider only one such block (instead of the total building height), independent of where this block may be positioned within the height of the building. Therefore, the effects of the stack effect and outdoor temperature changes *across the building height*, have not been assessed.

4.2.2. Commissioning Requirements (General)

Despite the first Australian Standard for designing SCS was published in 1974, it took another 17 years before the first detailed procedures on how to commission these systems was made available. When commissioning SPS it is imperative that all the relevant contractors/parties associated with the various components which make up a SPS (the software programmers, the air-conditioning/fire panel/alarm detector contractors, electricians, etc.) are present, so that if there is a problem with a component, the relevant party is there to correct the issue. The following sections detail the references made to commissioning SPS.

4.2.2.1. Commissioning Requirements (1991)

The first detailed commissioning procedures were incorporated as part of the 1991 edition of AS1668.1. This standard was the first standard to detail the commissioning tests required for a SPS. The commissioning requirements were included as an 'informative'[13] appendix only and in brief detailed the following:

a) Within each stairwell, each stairwell door is to be opened and closed to check that it latches automatically

b) Testing must include initiating the pressurisation system by introducing smoke into a detector (adjacent to a doorway on any floor of the building)

c) All doors are closed when testing occurs, and at this time
   - check the noise level in each stair shaft at each door entry (i.e. open the stair door and note the meter reading when the meter is pointing into the stair shaft, then traverse the stair shaft landing; the maximum noise reading is to be no more than 80 dB(A)); record the results
   - check the force required to open each stair door against the maximum pressure generated within the stair shaft by the pressurisation system (i.e. take a reading slowly and steadily pulling the spring balance across the door handle and read the scale as the door just starts to open; the maximum door opening force is to be 110 N or 11.2 kg); record the results

[13] The term 'informative' in this context implies that the information contained within that section/appendix is for 'information and guidance' only as opposed to being a *mandatory* requirement. Therefore, it could be argued that commissioning the SPS was not mandatory.

Note: A 'Purge' and 'Zone' system are described (as per the installations within Buildings 1 and 2, respectively) for completeness, even though the operation of these SCS has not been analysed as part of this thesis.

d) Whilst the pressurisation system is running, in each required stairwell, chock open the main discharge doors[14] (i.e. the one which opens onto the street) so that all required stairs may be tested simultaneously

e) Conduct air velocity and door opening force tests at each door location as follows:

Purge System

Air Velocity

In turn, select each occupied floor to be the fire-affected floor; chock open the fire-affected floor's door and an adjacent floor's door and measure the air velocity through each required exit door on the fire floor only (i.e. 3 doors open - the fire floor door, an adjacent door and the main discharge door).

Door opening forces

It is not necessary to re-check the door opening forces again.

Zone System

Air Velocity

In turn, select each occupied floor to be the fire-affected floor, chock open the fire-affected floor's door and measure the air velocity through each required exit door on the fire floor only (i.e. 2 doors open - the fire floor door and the main discharge door).

Door opening forces

In turn, select each occupied floor to be the fire-affected floor, check the door opening force for each fire-affected floor while the air-conditioning system is operating for the building in fire mode and the exit door on the adjacent floor is chocked open (i.e. 2 doors open - the fire floor door and an adjacent door). However, as the differential pressure across the doors serving the non-fire floors may be very low and the door opening forces can be lower than in fire mode, it may not be necessary to concurrently check adjacent floors.

f) The restoration performance conditions may need to be tested in more than one location in each fire-isolated exit (eg. one location near the fan and another at a point farthest from the fan).

[14] Points d) and e) of this testing procedure state that the main discharge door is to be opened for the airflow velocity and door opening force measurements. However, the intention of the standard was that the main discharge door is open for the airflow velocity tests only, not the door force tests. Therefore, when referring to these test procedures, the number of doors to be open will be based on the *intention* of the standard rather than the possible (literal) interpretation of the standard.

<u>*4.2.2.2. Commissioning Requirements (1998)*</u>

AS1668.1 was the second (and most current) standard to detail the commissioning tests required for SCS, and more specifically, fire-isolated SPS. The requirements are detailed in Appendix F of this standard, as an 'informative'[15] reference. In brief, the appendix describes the following requirements prior to beginning the commissioning tests:

- "where emergency power supply has been provided for the smoke control systems, additional commissioning tests should only be carried out to demonstrate that the system operates and the provided capacity is adequate. Load tests[16] should be carried out for a minimum of 30 minutes.
- "all building ventilation and air-conditioning systems should be fully commissioned in the normal operation mode. The total maximum return airflow rate should be recorded for each *purge system.*
- "each component of the smoke control system as well as all sub systems should be tested to verify their correct function and to ensure that they meet the performance criteria.
- "Fire Mode Tests are conducted to prove that other building systems will operate in the correct mode. Tests are to be conducted with all building systems initially operating in the normal mode. Other building systems should have moved into their respective fire modes after initiation of the test. Results are also to be recorded."[17]

The commissioning test procedures in this edition of the standard are the same as those listed in the 1991 edition of the standard, except for the modifications listed (the numbering used below is taken from the 1998 edition of the standard):

"F8 As well as checking the noise measurements inside the stairwell (maximum reading is to be 80 dB(A)), the noise level within the occupied space is to be measured when the fire-isolated stairwell doors are closed, readings are to be between 65 dB(A) and 80 dB(A).

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[15] In AS1668.1, if the appendix had been described as a 'normative' appendix instead, it would then be considered an integral part of the standard and the information contained within, would need to be followed i.e. it would be *mandatory*.

[16] 'Load tests' refer to testing the essential services (i.e. in this case, the SPS), using the essential electrical power supply (the emergency power/secondary power) instead of the primary power supply.

[17] Test Documentation – prior to any testing, a SCS diagram should be drawn up, which includes all zone boundaries, doors (in the boundaries) and all SCS detectors within the zones. A test schedule and report should also be prepared. For example, test reports are to include the door locations/floors, velocities, door closure devices, door opening forces, noise levels for stairs and floors, pressure restoration times, fan numbers (and operation during fire mode i.e. on/off), stopping of fans if smoke in air stream, auto reset of fans, FIP overrides, cabling/fire rating correct, air-handling unit (AHU) numbers and zone numbers, design requirements and test requirements for: airflow rates, operation with fire in zone, operation during general fire alarm (i.e. outside zone), manual control from FFCP, indication at the FIP, fittings of supply air detectors/return air detectors, etc.

"F14 All elements of the smoke control system that are required to be provided with manual override through the FFCP should have the manual override provision manually operated, in accordance with the requirements of the standard."

4.2.3. *Maintenance Requirements (General)*

The maintenance requirements were not officially recognised until 1983 when the first maintenance Australian Standard was introduced for maintaining the mechanical air-handling equipment used during fire mode operation. This means that mechanical air-handling equipment, which was to operate or function in some manner during a fire emergency, may in fact have been installed for up to nine years without being maintained or tested (even at commissioning). Although the previous design standards stated that the systems needed to be tested, there was not yet a standard or protocol developed to perform such a task (until 1983).[18]

4.2.3.1. *AS1851:6 - 1983 Maintenance of fire protection equipment – Management procedures for maintaining the fire-precaution features of air-handling systems*

This was the first maintenance standard for the mechanical air-handling equipment required to function (in a particular manner) during a fire emergency. This standard was developed by a sub-committee of the Association's Committee on Mechanical Ventilation and Air-conditioning, as there was concern regarding the lack of guidance available to building owners in relation to maintenance of the fire precaution features of air-handling systems, which had been specifically designed, installed and operated as per the 1974 or 1979 edition of AS1668.1.

At this time, the importance of testing the mechanical air-handling equipment required to operate in fire mode was again realised as it had been by Hobson and Stewart (1972). Maintaining this equipment would improve the probability that an adequate level of performance was available in an emergency, thereby assisting with the safety of occupants and minimising property damage.

Industry had begun to recognise that poor management was one of the key sources of failure for a large number of maintenance programs associated with building services and so this standard was aimed at the *management* aspect of maintenance programs. Mandatory requirements as well as informative (i.e. for information and guidance only) corrective actions were also detailed. The mandatory aspects were required as part of scheduled periodic maintenance following satisfactory completion of commissioning, or re-commissioning, of the mechanical air-handling equipment.

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[18] Hobson and Stewart (1972) had however, recommended that pressurisation systems including their starting controls should be tested, in conjunction with fire alarm tests, at regular intervals not exceeding 12 weeks, to ensure that the systems are 'maintained' in working order. This was recommended back in 1972! However, specific details of how to actually 'maintain' the systems was not provided.

Note: This standard was not intended to be applied to commissioning or recommissioning tests, however it could be used as a basis for such testing where appropriate. Also, at the time this standard was released there were no guidelines/test procedures on how to commission such a system in any case!

Following on from the 1974 edition of AS1668.1, where operational instructions were required for the SCS, the need for up-to-date 'as installed' drawings was also reiterated. This continues to be one of the downfalls associated with maintaining these systems. For example, if assessing the design aspects or operational requirements of a mechanical ventilation system during fire mode operation, and the operational requirements and drawings are not available, this review analysis process can be extremely difficult.

This standard set out the *mandatory* maintenance requirements in Section 3.3. The maintenance routines were then further divided into four 'levels' of maintenance as follows:

Level 1 Diagnostic inspections in terms of sensory assessments such as sight, touch, hearing or smell

Level 2 Includes a Level 1 routine as well as cleaning, lubricating, simple routine maintenance and adjustments (usually without taking the equipment out of service)

Level 3 Includes a Level 2 routine as well as testing and measuring procedures resulting in adjustments, as necessary, to ensure optimal performance (equipment may need to be taken out of service however, rapid reinstatement is possible if required)

Level 4 Performed as part of defects identified in a Level 3 inspection and consists of an overhaul and test procedures resulting in the piece(s) of equipment being off-line, possibly for prolonged periods

Table 2 lists the specific components to be maintained as well as their frequency intervals for the level of inspection associated with SPS, as detailed within the standard.

Table 2. Maintenance Frequencies (1983)

Item	Description	Routine	Frequency			
			Level 1☙	Level 2	Level 3	Level 4
Fans	Air pressurisation	B2	Quarterly	Half-yearly	Two-yearly	Only if necessary
Motors, induction	Fan drives, test and emergency use only	B3	Quarterly	Half-yearly	Two-yearly	Only if necessary
Batteries for fire/smoke control services	Lead-acid or Alkaline	♣	Refer to Australian Standard ASXXXX			
Fire mode air dampers for smoke-spill, fresh air and recycle air, complete with their automatic gear		B5	Half-yearly	Yearly	NA	Only if necessary
Air-handling changeover under fire/smoke conditions		B12	Monthly	Yearly	NA	Only if necessary
Fire-isolated escape routes protected by air-pressurisation systems		B13	Monthly	Yearly	Two-yearly	Only if necessary

☙ Level 1 routines are *mandatory* inspections ♣ refers to Australian Standard ASXXXX

NA denotes Not Applicable

More specifically, the Level 1 *mandatory* monthly routines for “fire-isolated escape routes protected by air-pressurisation systems” are detailed below:

“a) Simulate[19] initiation of operation of all systems

“b) While all air-pressurisation systems are operating, check the following:

i) excessive noise

ii) ease of opening doors
(it is recommended that the same door be used every time)

iii) movement of air from each pressurised area through a selected open door *(the use of a sensing device eg. ribbon is sufficient)*

“c) Switch all systems back to normal.”

The other (higher level), i.e. ‘informative’ routines, are described further in Appendix C.

[19] ‘Simulate’ refers to replicating an alarm (eg. smoke detector activation), without physically triggering the alarm (i.e. do not use smoke to trigger the alarm). This simulated alarm could be performed at the FIP in order to check the functionality of the air-handling equipment and associated dedicated smoke detector circuits, as opposed to the smoke detector itself.

4.2.3.2. AS1851:6 - 1997 Maintenance of fire protection equipment – Management procedures for maintaining the fire and smoke control features of air-handling systems

This revised standard was developed as the maintenance standard for air-handling systems was well overdue for revision (the Australian Standards committee endeavours to revise standards every five years). Another reason for its revision was that a standardised maintenance program was to be developed for smoke control features of air-handling systems designed, installed and operated in accordance with the more recent edition (1991) of AS1668.1, as this newer 1991 edition of the standard had been expanded in terms of types of SCS. System integrity testing requirements were also a new addition to this standard.

Table 3 lists the differences in the maintenance frequencies, from that detailed in the 1983 maintenance standard (refer to Table 2). For example, even though the Level 1 *mandatory* inspection frequency has changed for "fire-isolated escape routes ..." from a monthly inspection to a quarterly inspection, the inspection routine itself is identical to the 1983 maintenance standard.

Table 3. Maintenance Frequencies (1997)

Item	Description	Routine	Frequency			
			Level 1☙	**Level 2**	**Level 3**	**Level 4**
Fans	Air pressurisation			Yearly	Yearly	
Motors, induction	Fan drives, test and emergency use only					
Batteries for fire/smoke control services	Vented cells Sealed cells	Refer to Australian Standard AS2676.1 Refer to Australian Standard AS2676.2				
Fire mode air dampers for smoke-spill, fresh air and recycle air, complete with their automatic gear						
Air-handling changeover under fire/smoke conditions		B9	Quarterly			
Fire-isolated escape routes protected by air-pressurisation systems		B10	Quarterly			

☙ Level 1 routines are *mandatory* inspections

The other (higher level) informative routines are described further in Appendix D for information.

4.2.4. *Maintenance of associated components of a SPS*

The maintenance standard AS1851.6 details the maintenance for associated components of a SPS such as the detectors; the 1983 edition of this standard stated that 'automatic smoke detectors for fire/smoke control services' are to be maintained with reference to AS1670 (1997) "*SAA Code for automatic fire alarm installations*", while the 1997 edition of AS1851.6 states that this item is to be maintained in accordance with AS1851.8 "*Maintenance of fire protection equipment - Automatic fire detection and alarm systems.*" Based on the assumption noted earlier in this thesis (section 3.2.3.3. Note 4), that the smoke detectors operate correctly and are not faulty, the maintenance associated with this component has been ignored in the work described in this research.

Maintenance associated with the FIP, which is also an integral component of a SPS, is to be performed in accordance with AS1851.8 (1987) "*Maintenance of fire protection equipment – Automatic fire detection and alarm systems,*" whereby weekly, monthly and annual inspections are performed.

In contrast, the 1997 maintenance standard does not detail maintenance routines or reference a standard for fire doors associated with the SPS, nor does it make specific reference to relief dampers despite these items being important in terms of achieving the performance conditions of AS1668.1. For eg. if doors or relief dampers are faulty, the door opening forces could be excessive inside the stairwell. As it happens, fire door maintenance is covered under another standard, AS1851.7 (1984) "*Maintenance of fire protection equipment – Fire-resistant doorsets,*" whereby they are visually inspected every month and once a year the door opening forces are measured to ensure they do not exceed the performance conditions. However relief dampers, which are not specifically identified in the AS1851.6 standard (or any other standard), might be grouped under the maintenance B5 routine for 'fire mode air dampers ...' by a "reasonable engineer" whereby they are inspected every six-months, or it could also be argued that these dampers are never really maintained as there is no explicit mention of them in these standards.

This helps to highlight that in terms of identifying the maintenance practices associated with a SPS, multiple standards may need to be referenced, and multiple contractors may in fact be involved in maintaining the overall SPS, thereby adding to its complexity.

4.3. Summary of Australian Standard Requirements

Table 4 provides a summary of the design, commissioning and maintenance requirements for a Level 1 *mandatory* maintenance routine, for fire-isolated escape routes protected by air-pressurisation systems as detailed within the AS1668.1 since 1974.

Table 4. Design, Commissioning and Maintenance Summary

Aspect	Standard	Limits for Items Assessed						
		Airflow Velocity	Door Opening Forces	Noise	Pressure Differential	Restoration Times	Override Controls	Emergency power
Design	AS1668.1 (1974) (shut down)	1 m/s[20] (3 doors open)	110 N (or 11.2 kg) (all doors closed)	80 dB(A) (in stair shaft & occupied space)	50 Pa (all doors closed)	15 s	Details stated	Standard referenced
	AS1668.1 (1979) (shut down, purge)	"	"	"	"	between 15 s to 60 s	"	
	AS1668.1 (1991) (shut down, purge, ZSCS)	" (3 doors open – purging) (2 doors open – ZSCS[21])	" (all doors closed - purging) (2 doors open - ZSCS[22])	80 dB(A) (in stair)	20 Pa (all doors closed for ZSCS)	10 s		
	AS1668.1 (1998) (shut down, purge, ZSCS)	" (3 doors open – purging) (2 doors open – ZSCS[21])	" (all doors closed - purging) (2 doors open – ZSCS[22])	80 dB(A) (in stair shaft, door open) 65 dB(A), or 5 dB(A) above ambient to 80 dB(A) (closed door occupied space)	"	"		

[20] The airflow velocity measurement of 1 m/s is measured averaged over the door. Refer to Appendix E for an example.
[21] The two doors open for a airflow velocity test for a ZSCS are the main door and the nominated fire floor door.
[22] The two doors open for a door force test for a ZSCS are the nominated fire floor door and the door above the fire floor.

Table 4. Design, Commissioning and Maintenance Summary (continued)

Aspect	Standard	Limits for Items Assessed						
		Airflow Velocity	Door Opening Forces	Noise	Pressure Differential	Restoration Times	Override Controls	Emergency power
Commission-ing	AS1668.1 (1991) (shutdown, purge, ZSCS)	1 m/s (3 doors open – purging) (2 doors open – ZSCS[21])	110 N (or 11.2 kg) (all doors closed - purging) (2 doors open – ZSCS[22] or all doors closed)	80 dB(A) (in the stair)		10 s		
	AS1668.1 (1998) (shutdown, purge, ZSCS)	1 m/s (3 doors open – purging) (2 doors open – ZSCS[21])	110 N or 11.2 kg (all doors closed - purging) (2 doors open – ZSCS[22] or all doors closed)	80 dB(A) (in stair, door open) 65 dB(A) or 5 dB(A) above ambient to 80 dB(A) (closed door occupied space)		To be tested	To be tested	Load test for 30 mins
Maintenance	AS1851.6 (1983) (monthly)	Check the movement of air (out of stairwell)	Check for ease of opening the door	Check for excessive noise (as per AS1668.1)				
	AS1851.6 (1997) (quarterly)	"	"	"				

Note: ☐ refers to standards which would have been relevant at the time the two case study buildings (i.e. Building 1 and 2) were constructed

☐ refers to the most recent standards and the standards utilised for this project

" refers to 'as above'

4.4. Key Performance Criteria Adopted

Based on the information presented in section 4.3. of this thesis, the following key performance criteria have been adopted. That is, the information presented in Table 5 are the criteria used for the purpose of assessing whether or not the performance conditions of AS1668.1 have been met. The 1998 edition of AS1668.1 has been referenced as predominantly, within the Heating, Ventilation and Air-conditioning (HVAC) industry, the most recent standard is used when assessing a building's SCS, especially if the original information or date of construction/installation cannot be determined. Within the industry, it is also implied that if a SCS complies with the most recent standard (which is generally more onerous), then it is assumed that it would also comply with the standard at the time of construction.

Table 5. Key Performance Criteria for Research

Aspect	**Standard**	**Performance Limits**			
		Airflow Velocity	**Door Opening Forces**	**Noise**	**Restoration Times**
Design	AS1668.1: 1998 (shut down SCS as building's SCS is assumed not operational)	1 m/s (3 doors open)	110 N (or 11.2 kg) (all doors closed)	- in stair shaft, door open, 80 dB(A) - closed door occupied space; 65 dB(A), or 5 dB(A) above ambient to 80 dB(A)	10 s

Note: refers to the performance criteria which could not be assessed via the computer modelling package CONTAM, due to its limitations (refer to Chapter 7 for more detail)

Providing that the above performance criteria, eg. the airflow velocity and door opening force conditions are achieved, the modelled SPS assessed as part of this research will be effective (in terms of achieving the performance conditions of AS1668.1).

5. FIELD PERFORMANCE OF STUDIED BUILDINGS

5.1. Introduction

The field performance data associated with the two studied buildings (Buildings 1 and 2), such as the commissioning and maintenance information, have been collated and are detailed in the following sections. It is important to study the history associated with these two buildings and their associated stair pressurisation systems (SPS) (i.e. Systems 1 and 2) in order to identify and highlight potential problems and issues with these forms of smoke control. The assessed systems are considered representative of many of the smoke control systems (SCS) within the Melbourne central business district (CBD). Once the potential issues have been identified, by reviewing the history profiles for the systems, this information then sets the scene for development of the survey, as detailed later in Chapter 8.

The comments and observations listed below (prefixed with a 'C' or 'O'), refer to correspondence and notes obtained, respectively, during and subsequent to, stair pressurisation testing performed by the maintenance contractors and consultants for the two building systems assessed. The items in *italics* refer to discrepancies identified during the testing/maintenance routines.

5.2. General Background

During the early stages of this research project, when investigating the commissioning requirements and conditions, it was identified that commissioning tests are not performed on 'windy' days. That is, industry personnel have accepted that commissioning is to be performed on still, calm (i.e. in terms of weather) days. Discussions with industry maintenance personnel as to why calm days are chosen revealed that windy days result in difficulty in measuring the door opening forces and velocities within the stairwell due to constant pressure variations and instability in measuring these variables. Because of this difficulty, maintenance (in terms of measuring the door opening forces and velocities) is also avoided on such windy days.

An explanation or definition of what actually constitutes a 'windy' day, in terms of wind speed for example, cannot be provided however, the general consensus within the industry (based on anecdotal evidence) suggests that if commissioning and/or maintenance is required on a system, the (maintenance) personnel involved "try and pick a 'still day'" for testing. That is, if the wind is noticeably strong and/or gusty, the work to be performed on the building is postponed until the wind effects are less significant. Hobson and Stewart (1972) suggested that "tests should not be carried out in winds greater than 5 m/s, since it would be difficult to allow for the adverse effects of wind on pressurisation."

Even though, for this project, the building's SPS were designed as per the 1979 edition of AS1668.1[23] and their maintenance standard was the 1983 edition of AS1851.6, both buildings have been compared with the requirements of the 1998 edition of AS1668.1 (in terms of design and commissioning) and the 1997 edition of AS1851.6 (in terms of maintenance). This is because, it has been agreed (again within the industry) that providing compliance with the latest edition of the standard, which at times can in fact be more onerous than earlier revisions of the standard, will provide the safest SCS in terms of operational conformity.

When maintaining the SPS, AS1851.6 (1983, 1987) requires that the building be put into fire mode so that equipment required to operate (or not) during fire mode, is in the state it needs to be in for stair pressurisation maintenance. Therefore, if the building's SCS incorporates a purging or zone smoke control system (ZSCS), etc., then these forms of smoke control should be running at the time of the SPS maintenance test as their functionality may influence (usually advantage) the operation of the SPS. For the analysis performed for this thesis (more specifically in relation to the modelling [CONTAM] analysis), the influence of the building's SCS (as suggested above) was not assessed.

5.3. Historical Review of Stair Pressurisation System 1

System 1, as illustrated in Table 1, was installed (circa) 1985 and consists of a single top injection SPS where the stair pressurisation fan (SPF) speed is controlled via a variable speed drive (VSD). Prior to 2000, there had only been intermittent maintenance/testing performed on System 1 and unfortunately the original commissioning data could not be sourced for this research thesis.

The [available] testing and maintenance records for System 1, are described below in chronological order. The recorded descriptions only detail the items relevant to the SPS as opposed to the building's overall SCS (i.e. air purge system, etc.).

Late July 2000 <u>A test was conducted, whereby the building was put into fire mode, i.e. a general fire alarm (GFA) was raised.</u>

O *There was excessive pressure in both stairwells, i.e. greater than 50 Pa* (AS1668.1 1979a), *i.e. the west and east stairwells had a pressure of 145 Pa and 100 Pa, respectively.*

C This excessive pressure was attributed to the SPF VSD operating at full speed (i.e. 50.2 Hz and 50.6 Hz for the east and west stairwells, respectively, with all doors shut) and the static pressure sensor controls were not operating correctly. The pressure sensors were therefore, identified as requiring replacement.

[23] Note: System 2 was assessed against the requirements of the 1991 edition of AS1668.1 and it is believed to have been re-commissioned against this standard in 1999, refer to Table 4.

O *The door opening forces were excessive.*

C The doorway airflow velocities were mostly fine (as verbally reported on the day), however, the measurements were not sighted by the supervising consultant at the time. *Measurements near the lift lobbies were not acceptable as the lift lobby areas were sealed and the stairwell air could not escape onto the occupied floor spaces.*

O *The sequence of testing (i.e. which doors were opened/closed, etc.), was not recorded. Also, the recovery time and noise levels were not recorded.*

May 2001 Fire mode tests were conducted to test the pressurised stair shaft enclosures.

O The SPF VSD ran at full speed.

C *The replacement pressure sensors had a pressure range of 0-1250 Pa,* however, the stairwell's maximum pressure was rated at 50 Pa therefore, the new pressure sensors were thought to be inappropriate for the pressure measurements required within the stairwells, as their sensitivity vastly exceeded the pressure requirements within the stairwell.

O *The noise measurements were not recorded.*

O The stairwell door pressures and stairwell pressures generally complied.

O *The airflow velocities were well below the performance conditions* (AS1668.1 1979) *for the two high rise systems* (however, the carpark airflow velocity measurements were compliant).

June 2001 Comments made based on the fire mode tests preformed in May 2001.

C *The SPF which were previously controlled via the direct digital control (DDC)* are now to be controlled through the FIP, independent to the DDC.[24]

C The *barometric plant room dampers, are to be sealed as they are no longer used* (or were never really used) due to the installation of the VSD which was installed to assist in control of pressures within the stairwells (relief is available through the occupied spaces).

C *Isolation switches and labels are to be fitted to the SPF so that they may be locked in the 'On' position, to ensure that they are not 'accidentally' turned off and/or left off.*

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[24] The design specification manual for the building stated that the SPF are to be operated by the DDC, which was to control the fan speeds in order to maintain a positive pressure of not greater than 50 Pa differential pressure within the stairwell and office space. The drop in pressure (due to stairwell doors opening) would result in the DDC modulating the fan speed to compensate for the pressure loss. However, control via the DDC did not take into account risks associated with the DDC becoming inoperable, resulting in incorrect control for the fan speeds for the SPS. The DDC was also not part of the essential services, whereas the FIP was. Therefore, the control system was modified so that the SPF would be controlled via signals directly from the FIP as opposed to the DDC.

June 2002 A GFA was activated to test the SCS.

O *Stair pressurisation results were limited due to problems with control and varying pressures within the stairwell; i.e. ramping up/down and stabilisation of the SPF (following the opening of a door). This will need to be improved in order to comply with the standards, as currently the control system is slow in responding.*

O *Initially, velocities were poor (eg. on the lower levels they were only 0.5 m/s),* however, when the test was reset and the three SAF VSD were reduced to 30 Hz, velocities improved.

O *Lobby reception areas may be sealed, resulting in no relief paths.*

O *There was a loose pressure sensor in the east stairwell.*

O *The VSD cabling was not fire rated and will need to be replaced.*

July 2002 A GFA was activated in order to assess the SCS.

O The pressures measured in the west and east stairwells were 145 Pa and 100 Pa, respectively (*which were both anticipated to exceed the maximum door opening forces (i.e. maximum door pressure difference is to be 50 Pa* [AS1668.1 1979]).

August 2002

C It was identified that occupied *space relief vents/grilles (of size 1200 mm x 600 mm each) were required* on the Ground to 4th floors and floor 7.

O Correct wiring was installed back to the MSSB and then the FIP.

May 2003 A GFA was initiated to test the SCS as per AS1668.1 (Commissioning Tests).

C The ramp up/down controls for the SPF had been repaired and the fan speeds were now stabilised.

C The airflow velocities on the lower floor doors were reassessed.

C The pressure sensor in the east stairwell was securely fastened.

C New relief vents/grilles have been fitted.

O Door opening forces, noise levels and airflow velocities were measured for the stairwells.

O *The east and west stairwell smoke detectors were configured incorrectly, in that when the east stairwell smoke detector was activated, the west SPF stopped and vice-versa. This was corrected on the day of the test.*

O *The noise levels on one floor (i.e. Level 7, near the plant room), was in excess of the 80 dB(A) limits* (AS1668.1 1979).

O The *airflow velocity measurements for some of the doors were below the limits of 1 m/s* (AS1668.1 1979). This was corrected on the test day by adjusting the VSD setting for the SAF from 25 Hz to 15 Hz. *However, this then resulted in one of the door opening forces being excessive. Therefore, an optimum VSD setting will still need to be identified.*

February 2004 GFA was activated to test the SPS.

O The manual controls were tested on the FIP and the SPF stopped and started as required.

O The SPF stopped (for approximately 60 seconds) when the respective smoke detectors were tested and when the smoke had cleared from the detector, the detector re-set itself and the SPF started up again, as required.

C Representative floors were tested to compare the results with previous tests.

O Floors were tested for both the east and west stairwells referencing which doors were opened, the fire floor, average velocities, door opening forces, stairwell and occupancy noise levels, as well as the restoration times.

5.4. Historical Review of Stair Pressurisation System 2

Building 2 was constructed (circa) 1990. System 2 is tested annually as per a Level 2 routine (AS1851.6 1983). Prior to an organised test day, the door closers, pressure sensors and SPF dump-back dampers are inspected and their functionality is tested.

The tests described below were performed with the building's SCS in fire mode. Generally, the same floors are tested every year.

The airflow velocity testing is performed such that the fire floor door, an adjacent door and the main discharge doors are opened (as required). The building's SPS is tested in this manner, despite the building having a ZSCS, as this test sequence is a site specific requirement. Due to this requirement, it also enables direct comparison with System 1 and therefore, the modelling approach adopted (refer to Chapter 7 of this thesis for more detail). Within System 2's testing procedures, there is provision to open the tenancy doors in the lobby if the airflow velocities are not achieved, due to restricted airflow relief paths.

The door opening force testing is performed with the stairwell doors closed, once the airflow velocity tests have been completed. In addition, for this building the door opening forces are measured at the same time as the airflow velocity testing, again due to a site specific requirement. The procedures also note that high winds have been known to effect the stairwell pressures for this building (therefore, testing is not to be performed on a 'windy' day) and prior to testing, the pressures within the stairwell should be settled at approximately 50 Pa.

Noise level tests are also performed, as per the later version of AS1851.6 (1997) inside the stairwell (with the door open) and in the occupant space, adjacent to the stairwell (with the stairwell door closed).

The restoration time is detailed as the time it takes to restore the stairwell pressure to 50 Pa on the fire floor. The time-frame to be used is 10 seconds, which was first detailed within the 1991 edition of the design standard AS1668.1. The 1979 version of this standard referenced a restoration time of between 15 seconds up to 60 seconds. However, for System 2, the more stringent time period of 10 seconds has been chosen by the building management team. Currently, this restoration time test is not performed for System 2.

October 1990 <u>Tests performed for both stairwells as part of Commissioning.</u>

- SPF (i.e. SPF 2, 3, 4, 5 and 6) were tested.
- Door opening forces were measured for stair shafts 1 and 2 (floors - below lower ground, lower ground, 2, 9, 14, 18 and 22) and stair shaft 2 (floors - below lower ground, lower ground, 5, 7, 11, 15 and 19) and were less than 110 N.
- Airflow velocities measured for stair shaft 1 (floors - Ground Floor, 12 and 13) and stair shaft 2 (floors - ground, 10 and 11) were greater than 1 m/s.
- Pressure results were obtained from the DDC and compared with a manometer for the following floors - lower ground, 6, 15 and 19 (i.e. for both stair shafts 1 and 2).

March 1991 <u>Tests performed as part of Commissioning.</u>

- SPF (i.e. SPF 7, 8, 9 and 10) were tested.
- Door opening forces measured for stair shafts 1 and 2 (floors 26, 32, 36 and 42) were less than 110 N.
- Airflow velocities measured for stair shafts 1 and 2 (floors 41, 42 and 31, 32) were greater than 1 m/s.
- Pressure results were obtained from the DDC and compared with a manometer for the following floors, 26, 32, 42 and 47 (stair shafts 1 and 2), *however, floors 42 and 47 had pressures greater than 50 Pa for stair shaft 1.*

June 1996 <u>Fire mode tests.</u>

- *SPF 2 (in the low rise) and SPF 6 (in the medium rise) did not start upon receipt of a GFA* however, their override operations did work.
- *SPF 1-4 (on the low rise) were only working intermittently when a GFA was activated; this was attributed to a software problem in the FIP.*
- SPF 3-5 and SPF 7-10 operated correctly upon receipt of a GFA and when their respective smoke detectors were activated with smoke.

O *One SPF, i.e. SPF 6 (in the medium rise), was only working intermittently when a GFA was activated, this was attributed to a software problem in the FIP.*

O *The Sekita board in the fire control room (for the low rise) was only communicating on one channel.*

July 1997 Fire mode tests with a GFA.

O *When a GFA was activated in the low rise, the SPF 1-3 did not operate however, SPF 3-10 override controls did operate as required and SPF 4-10 did operate upon receipt of a GFA.*

O *The Sekita board in the fire control room (for the low rise) was only communicating on one channel.*

February 1998 Some minor tests performed.

C SPF appear to be working satisfactorily.

O All twelve SPF were tested to ensure that they turned on upon receipt of a GFA signal, which they did.

April 1998 Pressurisation test was carried out (this was a repeat of tests performed in October 1990 and March 1991).

O The following SPF (SPF 2, 3, 4, 5, 6, 7, 8, 9 and 10) were tested and a range of floors were measured for various components, including:

- Pressure measurements; stair shafts 1 and 2 floors - lower ground, 6, 15, 19, 26, 32, 42 and 47.
- Door opening forces, stair shaft 1 floors - below lower ground, lower ground, 2, 9, 14, 18, 22, 26, 32, 36 and 42
  stair shaft 2 floors - below lower ground, lower ground, 3, 7, 11, 15, 19, 26, 32, 36 and 42.
- Airflow measurements; stair shaft 1 floors - ground, 12, 13, 23, 31, 32, 41 and 42
  stair shaft 2 floors - ground, 10, 11, 23, 31, 32, 41 and 42.

C Overall results were unsatisfactory, because:

- *Pressures were exceeding 50 Pa for stair shaft 1 on the following floors - lower ground, 19 and 47, while all floor pressures measured in stair shaft 2 were excessive (i.e. floors - lower ground, 6, 15, 19 and 47).*
- *Door opening forces measured on the following floors – below lower ground, lower ground, 2, 9, 14, 18 and 22 were greater than 11.2 kg (i.e. equivalent to 110 N force) for stair shaft 1 and floors below lower ground, lower ground, 3, 15, 19 , 26, 32 and 36 had excessive door opening forces in stair shaft 2.*

- Airflow velocities were less than 1 m/s when the two consecutive floor doors were open (i.e. floors 12 and 13, 10 and 11, 31 and 32 and 41 and 42) for stair shaft 1, and the main discharge door was open on the Ground Floor (and floor 23); while for stair shaft 2 floors 10, 11, 31, 32 and 42 had airflow velocities of less than 1 m/s.

O *A dump-back damper (controlled by a pressure sensor) had problems.*

C *Pressure sensors were relocated for two SPF as an additional barometric damper was to be installed due to the occurrence of the stack effect (and too much pressure entering the stairwell for just one damper). The existing damper position was also changed to 25% open.*

August 1998 The second pressurisation test was carried out (this was a repeat of tests performed in October 1990 and March 1991).

C *Test results were unsatisfactory and it was suspected that air was leaking into the stairwell shaft (i.e. there were penetrations from the main air duct to the stairwell duct, resulting in high pressures) - this was confirmed later in the same month.*

O SPF 2-10 were tested and a range of floors were measured for various components, for example:

- Pressure measurements; stair shafts 1 and 2 floors - lower ground, 6, 15, 19, 26, 32, 42 and 47.
- Door opening forces; stair shaft 1 floors - below lower ground, lower ground, 2, 9, 14, 18, 22, 26, 32, 36 and 42
  stair shaft 2 floors - below lower ground, lower ground, 3, 7, 11, 15, 19, 26, 32, 36 and 42.
- Airflow measurements; stair shaft 1 floors - ground, 12, 13, 23, 31, 32, 41 and 42
  stair shaft 2 floors - ground, 10, 11, 23, 31, 32, 41 and 42.

C Overall results were unsatisfactory, because:

- Pressures were exceeding 50 Pa for stair shaft 1 on the following floors - lower ground, 6 and 15 and in stair shaft 2 for floors - 6 and 19, while there were no pressure readings recorded for floors 26-47 for stair shafts 1 and 2.

- Door opening forces measured on floors 9 were greater than 11.2 kg for stair shaft 1 (however, floors lower than lower ground level, ground and floor 2, were not measured) and for stair shaft 2, floor 15 was excessive, while there were no stair door opening forces measured for floors 26–42 for stairs 1 and 2.

- Airflow velocities were only measured for stair shaft 1 floors - ground, floors 12 and 13, which were greater than 1 m/s, however for stair shafts 1 and 2, floors - 10, 11, 31, 32 and 42 did not have measurements taken.

September 1998 Structural engineers informed of requirement to design an access shaft system so that the shaft penetrations can be safely sealed.

July 1999 A fire mode test was performed for the mechanical services and the stairwell where significant repairs had been completed (i.e. further sealing of the stairwell shafts) system also re-commissioned.

C The test running sheets have tick boxes to identify what has been tested.

O All twelve SPF were tested to ensure that they turned on upon receipt of a GFA signal (which they did).

O Airflow velocities were measured on five floors (floors - ground, 3, 14, 30 and 40) and were greater than 1 m/s, as required, for both stairwells.

O Some pressures were measured (ranging from 13 Pa – 65 Pa) on floors - lower ground, 6, 65, 45, 32, 38 and 43.

O Door opening forces were also measured for floors up to and inclusive of floor 46 *however, some of the basement level forces were excessive of 11.2 kg for both stairwells (eight floors in one stairwell and five floors in the other).*

Early 2000 Report findings.

C *A report dated early 2000, stated that there were a number of construction related problems (eg. 'incomplete shaft walls'), preventing the satisfactory operation of some of the SCS installed. However, rectification works (such as further sealing the stairwell shafts) conducted in 1999 appeared to have been successful and improved the effectiveness of the SPS. This report also stated that this SCS was a complex system.*

August 2000 An annual fire test was performed using a smoke machine.

O All twelve SPF were tested to ensure that they turned on upon receipt of a GFA signal (which they did).

O The shut down mechanism for SPF 2 was tested (in fire mode operation) and the fan shut down as required. The override function was also tested successfully. *However, when the smoke had cleared the SPF did not restart.*

O Airflow velocity readings were taken on eight floors (floors 6, 11, 15, 19, 32, 35, 38 and 43). *One of the airflow velocity readings for both stairwells was below 1 m/s (floor 32 and 6).*

O Pressures were recorded for a selection of floors (the same floors as where the airflow velocities readings were taken).

O Door opening forces for each door were measured *and the same two floor stair doors had marginally greater door opening forces than the 11.2 kg limit for the two stairwells (i.e. in the high rise levels, floors 43 and 46).*

August 2001 Tests were performed to prove the building's capability with the design requirements.

O The building's building management system (BMS) was tested for calibration in relation to the pressure sensor readings.

O SPF 1-6 were tested in terms of turning on upon receipt of a GFA signal, while SPF 7-10 were tested to ensure that when their respective smoke detectors were activated with canned smoke, they shut down and then re-started when the smoke had cleared from the detector.

O *Noise measurements were not taken.*

C Pressures were measured on the nominated fire floors (i.e. the same floors as where the airflow velocities were measured). *The stairwell pressures were low on some floors, while high on others*, this was investigated and it was found that if a Return Air Fan (RAF) was off, the pressures improved. Therefore, this modification was considered for future testing.

O *The stairwell pressure sensors were found to be faulty and therefore, were repaired on the test day.*

O Airflow velocities were measured for six fire floors (floor - ground, 4, 14, 27, 42 and 49) in both stairwells with the main discharge doors open and were greater than 1 m/s on the fire floor, however, *successive fire floor doors were not open.*

C Door opening forces were measured for all floors *and many were excessive, especially near the plant rooms.* It was thought that this may be because the plant rooms were vented to the outside.

O *Previously, SPF 9 did not operate in AUTO mode;* this was corrected on the day of the test.

C The test sheets were approved by the building surveyor for previous tests performed.

August 2002 An annual SCS test was performed.

O Noise measurements were taken at approximately every 4^{th} floor (starting from the Ground Floor). Measurements complied with maximum limits of 80 dB(A) with the doors open.

O Door opening forces were measured for every floor *however, some forces were excessive, i.e. between 12 kg – 17 kg for approximately 18 floors (stair shaft 1) and 5 floors (stair shaft 2).*

O Airflow velocity measurements were taken on floors - ground, 14, 27, 42 and 49 *however, the successive doors were not opened, even though they were required to as part of the test.*

O Pressure measurements were taken at the same floors as airflow velocity measurements were taken as well as floors - lower ground, 6, 15, 19, 28, 32, 38 and 43.

August 2003 A GFA was activated to test the building's SCS, as part of the annual testing.

O Noise level testing was performed for each floor. *However, the doors were closed when they should have been open.*

O Door opening force testing was performed with all doors closed, as well as with the test fire floor door and adjacent door open (i.e. three doors). *Some of the door opening forces measured were excessive (i.e. 21 kg where the maximum allowed is 11.2 kg). When tested on a subsequent day (November 2003) with the doors closed, only five door opening forces were marginally greater than the 11.2 kg limit (i.e. stair shaft 1 – floors 15 and 34 and stair shaft 2 – floors 20, 21 and 52).*

O Airflow velocity testing was performed (i.e. with the appropriate three doors open) on the following floors: stair shaft1 floors - Ground Floor, 4, 14, 27, 42 and 49;

stair shaft 2 floors - Ground Floor, 4, 14, 27 and 42).

All velocities were greater than 1 m/s.

C *The stairwells could not relieve the pressure and maintain 50 Pa (i.e. the pressure was 'hunting' between 60 Pa – 100 Pa) due to the location of the SPF's outside air intake position (i.e. on the building's perimeter). The high winds adversely effected the pressurised space in one of the stairwells and therefore, the noise and door opening force measurements could not be completed (they were re-tested in November 2003). It was considered that a baffle arrangement may need to be developed to reduce the possibility of air rushing back up through the dump-back damper.*[25] Pressures were measured on the same floors as the airflow velocity measurements.

C A subsequent test was performed a month later,[26] where a fault was identified with one of the low level SPF controls. *There was a fault input on the controller which was repaired on the day.*

O *The SPF failed to stop and start when their respective smoke detectors were activated for stair shaft 1 (high rise floor 52) and stair shaft 2 (high rise floor 51).*

C Ambient conditions on the final test day (November 2003) were relatively calm (still).

---

[25] It is believed that as the stairwell already had excessive pressure; the dump-back damper was open to relieve this pressure however, concurrently the turbulent wind entering the SPF/bypass enclosure (see Figure 10c), entered the open bypass damper, resulting in additional pressure increases (followed by sudden reductions) within the stairwell due to the turbulent nature of the wind.

[26] As annual testing of the SPS has since been conducted on (relatively) calm days, the proposed baffle/filter arrangement has yet to be installed for this system. It is however, suggested that this baffle/filter arrangement follow the same principles as the screens used in wind tunnels (refer to section 3.2.2.5. of this thesis), in order to reduce the turbulent effect of the wind entering this space.

The anecdotal building history files state that:

- it took the initial 3-4 years of building occupation to identify what was wrong with System 2's SPS;
- for the last eight years, the SPS has been operating quite well in accordance with the Australian Standard requirements.

5.5. Summary History Profiles for Systems 1 and 2

While reviewing the maintenance history data for the two systems, it was observed that although restoration times are detailed within the design standard (AS1668.1), the Level 1 *mandatory* maintenance routines do not require either restoration or override controls to be tested at this service level. Maintenance tests for these items are only performed at the higher levels of maintenance i.e. Levels 2 and 3 (refer to Appendix D). These higher levels of maintenance are not *mandatory* and therefore, the occasion could arise whereby the performance of these items is never inspected or tested. This issue as well as others will be discussed further in Chapter 8.

Table 6 details the faults/issues identified in both of the SPS over the years, in order of frequency (where the items listed in the first few rows of the table occurred more often than the subsequent items listed). The faults listed include both hardware faults associated with the physical elements as well as maintenance testing faults. On the basis of the review of these SPS, it was possible to formulate a meaningful survey for identification of the frequency of faults with various parts of the SPS considered. This survey and its findings are presented in Chapter 8.

Table 6. Building System Fault Summary

Fault Items	
System 1 (circa 1985)	**System 2 (circa 1990)**
Low airflow velocity readings	High door opening forces
High stairwell pressures	High stairwell pressures
Sealed relief paths	Low airflow velocity readings
High door opening forces	SPF do not start/restart i.e. software problems
Pressure sensor not operating correctly, i.e. incorrect sensor range	Damper problems
VSD not operating at correct frequency	Successive doors not opened for airflow velocity tests[27]
DDC controlled the SPF (not the FIP)	Pressure sensor not operating correctly, i.e. incorrect sensor range
Slow response of equipment, i.e. pressure sensors, communications	Pressure sensors relocated
Loose pressure sensor	Excessive shaft penetrations/leakage
Incorrect cabling for the VSD	Incorrect noise measurement setup i.e. door closed
Incorrect smoke detector configurations for the SPF	Environmental conditions i.e. extreme wind affecting SPS performance
No noise measurements (until 2003) at which time there was a high reading	No noise measurements (until 2002)

The faults listed in Table 6 indicate that for both Systems 1 and 2, low airflow velocity readings, high stairwell pressures and high door opening forces are the three most frequent fault occurrences. It needs to be understood that the *mandatory* level of maintenance (Level 1) specified in AS1851.6 does not require the measurement of airflow velocity or door opening forces (see section 4.2.3.1. of this thesis). These are only measured during voluntary higher level maintenance.

[27] System 2 has been given approval to measure the airflow velocities without a successive door being open, although typically this is not allowed for stair pressurisation testing required in association with the SCS installed for this type of building.

Table 7 summarises the maintenance performed on the two systems, in terms of the maintenance standard, as well as the design and commissioning requirements at the time of construction, compared with today's requirements.

Table 7. Building History Summary in terms of Australian Standards

Aspect	**System 1**	**Comments**	**System 2**	**Comments**
Design (AS1668.1) 1979	✓		✓	
1998	✓		✓	
Commissioning (AS1668.1)	NA	No commissioning standard available at time of construction, no commissioning data for system.	✓	In 1990 - commissioned, even though no commissioning standard available at time of construction. In 1999, re-commissioned against 1991 standard.
1998	✓	System has subsequently been assessed this standard.	✓	System has subsequently been assessed this standard.
Maintenance (AS1851.6) (*mandatory* for SPS) 1983 Monthly	-	-	✓	-
Annual	-	-	✓	-
2-Yearly	-	-	✓	-
1997 Quarterly	✓	Maintained against this standard and frequency, since 2000.	✓	-
Annual	✓	-	✓	Including noise testing.
2-Yearly	✓	-	✓	However, modified as restoration times not tested.

6. EFFECTIVENESS – CONCEPT AND APPROACH

6.1. Definitions of Effectiveness

The effectiveness of a fire-safety system has been previously defined as a combination of the *efficacy* and *reliability* of the system. In this case, the efficacy is a measure of how well the system achieves its design objectives in terms of the range of potential fire scenarios, assuming that the system operates. The reliability of the system reflects the likelihood that the system will operate (Thomas 2002). The measure of efficacy is given by a number between 0 and 1 with zero representing a system that never achieves the design objectives and '1' representing a system that will always achieve the design objectives for the full range of fire scenarios. Similarly, the reliability is represented by a number between 0 and 1 with the latter number representing a system that will always operate.

Such a definition of effectiveness has been used to characterize sprinkler systems where the efficacy relates to the probability that the sprinkler system in a particular environment will extinguish/control the fire. If the efficacy is 0.80, it means that for the particular environment being considered, the sprinkler system will adequately deal with the fire in 80% of situations, assuming that the sprinklers activate. If it is known that the sprinklers activate 98% of the time, then the reliability is 0.98. The overall effectiveness in this case can be taken as the simple product of the two numbers, giving an effectiveness of 0.8 x 0.98.

In the context of this thesis, a SPS having an effectiveness of '1' is one which will always achieve the performance conditions specified in AS1668.1 for the whole system; i.e. every stairwell door (see Table 5). It is not considered necessary to separately consider the efficacy and reliability as for the above sprinkler example, but to determine the effectiveness directly using fault or failure tree analysis. The key pass/failure criteria are the performance conditions specified by AS1668.1.

Factors that influence whether a SPS will achieve the AS1668.1 performance conditions are shown in Figure 15, as id boxes 1.-7. Appendix F describes these id boxes. This figure is essentially a truncated fault tree, which identifies the key factors that may prevent achievement of the required levels of performance. This fault tree is expanded in Chapter 8 where the lower parts of the tree are added. It will be noted from Figure 15 that some of the boxes are coloured grey. These boxes represent the effects of variations in external wind speed and external temperature and the possible effect of changes over time to the building leakage on failure of a SPS to achieve the respective AS1668.1 performance conditions. These factors are denoted as E-factors and their influence on effectiveness is considered in detail in Chapter 7. Extensive analysis using the program CONTAM is undertaken so as to evaluate the influence of variations in external wind speed and temperature, and changes in building leakage. There is assumed to be no influence from the 'other factors' (i.e. those not in grey boxes). The probabilities of various wind speeds and temperatures are also taken into account.

The 'other factors' (i.e. those not in the grey boxes) are termed F-factors and represent those associated with the SPS equipment, including those arising from:

- Poor design - inadequate for the task (would be addressed by commissioning)
- Inadequate installation (would be addressed by commissioning)
- Faults that develop over time with the equipment (influenced by maintenance)

The effects of these F-factors on effectiveness are considered in Chapter 8 using the extended fault trees. In that chapter, it is assumed that there is no influence from the E-factors.

The overall effectiveness is a function of both E- and F- factors and is considered in Chapter 9.

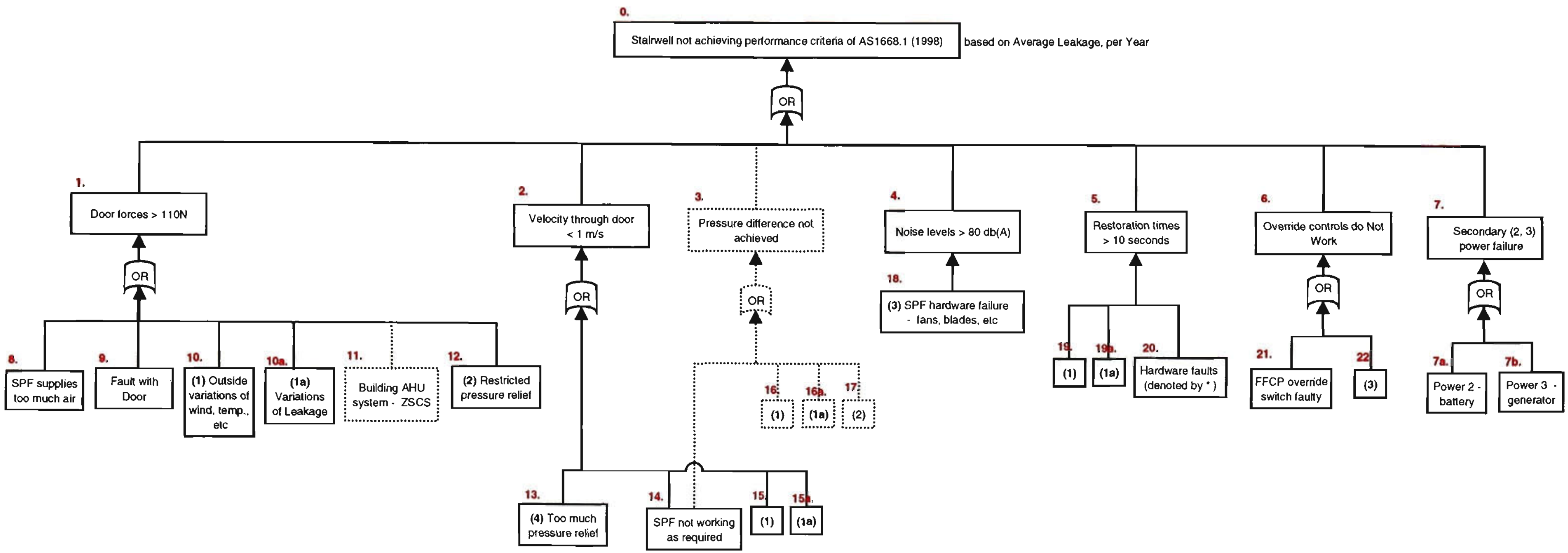

Figure 15. Factors Influencing Effectiveness of SPS in terms of AS1668.1

7. THE INFLUENCE OF WIND, TEMPERATURE AND LEAKAGE CHANGES ON EFFECTIVENESS (E-factors)

7.1. Introduction

This chapter looks at the probability of exceeding the permissible door opening force (110 N) and not achieving the air velocity conditions (minimum 1 m/s) at the nominated fire floor door, due to *variations in temperature, external wind speed* and *possible changes in leakage* due to structural changes. In the case of the effects of temperature and wind, the probabilities of various values of these variables are also taken into account.

Before undertaking the above analysis, it is important to:

- Explain the basis of the modelling theory;
- Describe the software and data input; and
- Design the representative Stair Pressurisation System (SPS) for both Systems 1 and 2 (i.e. design the 'base' building situations).

The 'base' building designs for Systems 1 and 2 are then analysed looking at the effect of variations in wind speed, temperature and leakage.

7.2. Modelling Theory

7.2.1. Approach and Key Equations

The analysis of SPS is mostly performed on a very basic level relying on later commissioning to (hopefully) 'fine-tune' the system. The stair shaft is seen as a box with a total opening size (equal to a number of open doors plus leakage) and the fan used as the stair pressurisation fan (SPF) is chosen so that it supplies sufficient air to achieve the airflow velocity condition of the Australian Standards (AS), AS1668.1, at a nominated (i.e. the fire floor) door, when this door is open. In effect;

$$Velocity_{req} = \frac{\theta_f}{A_T} \qquad \text{Equation 2}$$

where

$Velocity_{req}$ = the velocity required at the (fire floor) door, m/s (as per AS1668.1)

θ_f = the SPF flow rate, m^3/s

A_T = the total area of openings including leakage, m^2

Reducing the stairwell pressures so that door opening forces are not exceeded (as detailed within AS1668.1), is handled on site by either adjusting the damper controls (i.e. either the damper weights or the pressure sensor settings, depending on whether a barometric or motorised damper is installed, respectively); or alternatively, a variable speed drive (VSD) can be programmed so that the SPF slows down and does not generate excessive pressures in the stair shaft. If dampers are installed in order to provide stairwell relief, the actual damper size (i.e. the effective opening area) is chosen on the basis of experience for relieving airflow pressures, such that the airflow velocity conditions will still be achieved.

Despite this simple analysis approach, more sophisticated approaches can be used to model smoke control systems (SCS). This is done by using flow equations in the form of the orifice equation, where the total flow from a space (eg. a stairwell shaft) is the sum of the flows through various leakage paths (eg. doors, walls, etc.), as illustrated below (Klote and Milke 2002):

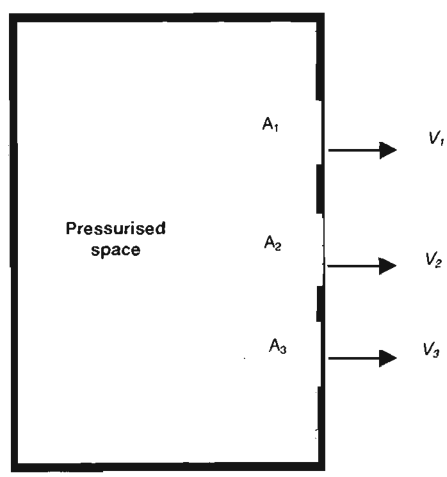

Figure 16. Flow paths in Parallel

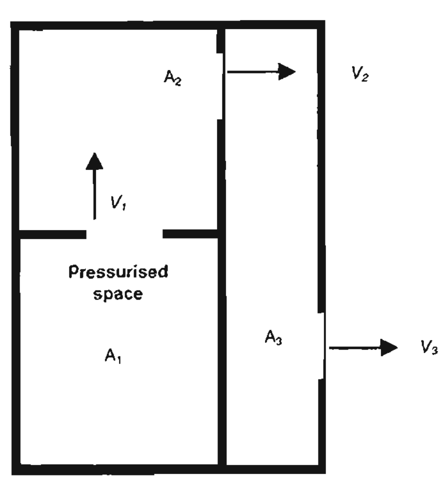

Figure 17. Flow paths in Series

The total parallel and series flows can be expressed as per Equations 3 and 4, respectively:

Parallel Flow and equal pressures: $$\dot{V}_T = K_o C A_e \sqrt{\frac{2\Delta p}{\rho}}$$ Equation 3

Series Flow and equal flow rates: $$\dot{V} = K_o C A_e \sqrt{\frac{2\Delta p_T}{\rho}}$$ Equation 4

where

$\dot{V}_T$ = the (total) volumetric (parallel) flow rate through all of the leakage paths, m^3/s; i.e. $\dot{V}_1 + \dot{V}_2 + \dot{V}_3$

$\dot{V}$ = the volumetric (series) flow rate which is equal through all of the leakage paths, m^3/s

K_o = 1

C = dimensionless flow coefficient

A_e = the (total) effective (parallel) flow area or leakage area, m^2; i.e. $A_1 + A_2 + A_3$

A_e = the (total) effective (series) flow area or leakage area, m^2; i.e. $\left(\frac{1}{A_1^2} + \frac{1}{A_2^2} + \frac{1}{A_3^2} \right)^{-1/2}$

Δp = (parallel) pressure difference across the path, Pa

Δp_T = (series) pressure difference from the space to the outside, Pa; i.e. $\Delta p_1 + \Delta p_2 + \Delta p_3$

ρ = density of gas in path, kg/m^3

Equations 3 and 4 are based on the Bernoulli equation and therefore, apply to steady, frictionless and incompressible flows. The flow coefficient (which depends on the Reynolds number and the geometry of the flow path) is introduced to account for friction losses due to viscosity and for dynamic effects.

These equations can be used in order to identify the capacity of the SPF needed to maintain the required stairwell airflows to keep smoke out of the escape routes. These simplified flow relationships are useful if the building does not have external openings, however they are of limited accuracy for conditions where external wind effects are present, or variations in internal and external building/outside temperatures, etc., occur. Considering a building's SPS and the complexities of identifying all of the possible leakage paths, whether they are in parallel, series or a combination of both, the result is a very large set of simultaneous equations. The best way to solve complex sets of simultaneous equations is via a network model, eg. CONTAM. The following section details the history associated with the development of this network model, in order to solve these simultaneous equations.

7.3. Software

7.3.1. ASCOS

Analysis of Smoke Control Systems (ASCOS) was specifically developed for the analysis of SCS and is actually an extension of a program written and developed for the analysis of pressurised stairwells and elevators (lifts) (Klote 1981).

ASCOS was originally intended as a research tool and was extended to incorporate the analysis of stairwells with vestibules, lifts with lobbies, Zone Smoke Control Systems (ZSCS) and pressurised spaces in general. The program calculates the airflows and differential pressures throughout a building. The building itself is represented by a network of spaces (or nodes) each of which has a specific temperature and pressure. Stairwells and other shafts are represented by a series of connected vertical spaces.

Within a building, air flows from regions of high pressure to low pressure via leakage paths (eg. doors, windows, floors, walls, etc.). The airflow through these leakage paths are a function of differential pressures across the actual leakage path. SPS are modelled by introducing air from the outside of the building via a pressurisation system into any level or building space. Air can also be exhausted from a space.

The pressures and flow rates through the building flow paths are solved using the airflow network system, as well as the driving forces such as wind, the pressurisation system and the temperature differences between the inside and outside of the building.

This program is based on the following assumptions:

- each space is considered to have one specific pressure and temperature (perfectly mixed);
- the flow and leakage paths are located at the mid height of a level;
- the total air supplied by the air-handling unit (AHU) or pressurisation system is constant (i.e. independent of the building pressure);
- the outside air temperature is constant;
- the barometer pressure at ground level is constant at 101,325 Pa (however, this can be changed if required).

The network airflow equations used in this program were based on Equation 1 and the program itself was originally written in ANSI-1977 FORTRAN language.

7.3.2. CONTAM

In the mid-to-late 1980s, the first CONTAM computer modelling program was based on the original ASCOS program. This early CONTAM program was originally developed to enable the dispersal of building contaminants to be analysed, via use of the building's airflow system and consideration of flow elements connected to defined system nodes (Axley 1987). The airflow equations used in the early versions of CONTAM (i.e. ASCOS) as well as the equations governing contaminant dispersal due to these flows, were formulated by generating elemental equations (i.e. sets of simultaneous equations), so that the fundamental conservation of mass criteria was satisfied in each zone. In 1989 Walton described the improvements in the above program-specific algorithms for computing the airflows and this was done through the AIRNET modelling program. AIRNET provided a faster and more robust algorithm for calculating the contaminant variables. The approach used for these programs was a compromise between the single-zone building models (only useful for simple buildings) and the computational fluid dynamic models (which were very time consuming for use on a regular basis, especially for large buildings).

In the early 1990s, it was decided that a graphic interface should be developed for use on small computers, by using the best available algorithms. This program was referred to as CONTAM93. Later in 2000, the first CONTAM**W** program was developed (also by the National Institute of Standards and Technology [NIST] as per the earlier programs), which enhanced the previous programs in that it enabled the determination of room-to-room airflows, contaminant concentrations and personal exposures to be calculated. This program now used a Windows based computer operating system (hence the '**W**'). It enabled the distribution of ventilation air within a building to be calculated as well as estimation of the impact of envelope air tightening efforts on infiltration rates (i.e. building leakage), and investigation of the impact of various designs related to ventilation systems and building material selection, etc.

Both the ASCOS and various CONTAM programs take the multi-zone network approach to airflow analysis, where the building is divided into a collection of zones connected by airflow paths. The more recent versions of CONTAM are still based on the equations and assumptions identified earlier and represent a sophisticated approach to analysing SCS. Key assumptions and features of CONTAM include:

- the pressure variation with height follows hydrostatic principles;
- air and contaminants flow through the leakage paths between spaces;
- air and contaminants flow through the leakage paths between spaces and the outside;
- the flows can be represented by a number of algebraic equations (selected by the user);

- conservation of mass is applied to each space (i.e. the air entering a space equals the air leaving a space).

CONTAM has been chosen for this project to determine the key flows and pressures with the presumption that the answers are correct. Comparisons of the predictions of ASCOS with measured differential pressures have been found to give acceptably close results (Milke and Mowrer 1994). It is on this basis that it is assumed that CONTAM can adequately predict flows and pressures.

For this project, version 2.1 of COMTAM[28] has been used which has more user-friendly features as well as sophisticated means of representing the data and results, such as schematic building layout diagrams and graphs, respectively. Pressures and flows are also determined. The program has been used to study the influence of temperature, wind and building leakage. By varying these factors a sensitivity study is performed to determine their impact on the operation of a SPS.

7.3.2.1. CONTAM Results - Modification

CONTAM provides the results of a simulation in the form of pressures and mass flow rates. Mass flow rates are presented in terms of kilograms/second (kg/s),[29] while pressures are recorded in Pascals (Pa, or Nm^2). However, in order to assess whether or not the door opening forces would be excessive during the simulations, the CONTAM pressure results (in Pa) were converted to Newtons (N) using Klote and Milke's (2002) equations, as illustrated below. These equations enabled the maximum stairwell pressure to be calculated, such that the maximum door opening force requirement of 110 N (AS1668.1), when all stairwell doors were closed, was satisfied.

$$M_r + K_d\, A\, \Delta p \left(\frac{W}{2} \right) F(W - d) = 0 \qquad \text{Equation 5}$$

where

M_r = moment of the door closer and other friction, Nm

K_d = 1

A = door area, m^2

Δp = pressure differential across the door, Pa

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[28] At the time of writing this thesis, version 2.4 of CONTAM was released (late 2005). From hereon, CONTAM refers to the 2.1 version used in this thesis, unless otherwise stated.

[29] CONTAM provides mass flow rate results in terms of kg/s, however in order to compare the simulation results with the requirements of AS1668.1, these results are converted to airflow velocities in metres/second (m/s). Refer to Appendix G for computation example.

F = total door opening force, N

W = door width, m

d = distance from the doorknob to the knob side of the door, m

The door closure force equation is:

$$F_r = \frac{M_r}{(W - d)} \qquad \text{Equation 6}$$

where

F_r = force to overcome the door closer and other friction, N

By rearranging Equations 5 and 6, it can be shown that the maximum allowable pressure within the shaft is 103.82 Pa, when the maximum door opening force permitted by AS1668.1 is 110 N (see Appendix H for computations). In other words, provided that the pressure within the stairwell shaft does not exceed 103.82 Pa (when all the stairwell doors are closed), the door opening force will not surpass 110 N and this performance condition of AS1668.1 is achieved.

7.3.2.2. Calculated Results - Mathematical Assessment

In order to assess whether or not the calculated results (absolutely) passed the performance conditions, it was necessary to agree on the number of decimal places to adopt.

Throughout this research, information related to wind and temperature has been presented to one decimal place. Therefore, for the results obtained for this study (i.e. from CONTAM), the values have also been presented to one decimal place. For example, if the CONTAM door opening force obtained was 110.08 N, then when rounded up to one decimal place,[30] the resultant door opening force would be 110.1 N (which exceeds the maximum door opening force condition of 110 N). Therefore, the SPS would not pass in terms of this performance condition, even though it only *just* did not pass.

[30] Rounding up the values in the results is based on the following: if the second value after the decimal point is equal to or greater than 5, it will be rounded up to one decimal place, however, if the second value after the decimal point is less than 5, the first value after the decimal point will not change. For example, if the CONTAM airflow velocity was 0.94 m/s, this would become 0.9 m/s.

7.4. Design of Systems 1 and 2

7.4.1. *Introduction*

In order to assess the effectiveness of a SPS, in terms of achieving the performance conditions detailed in AS1668.1, it was first necessary to develop a compliant 'base' building model. The building model was based on both Buildings 1 and 2 in terms of the building geometry and SPS design eg. the fan location, relief location, etc. (as detailed earlier in section 3.2. of this thesis). The aim was to design a building model with a compliant SPS in terms of the Australian Standard performance conditions. This would then allow variations to be simulated (eg. temperature changes, etc.), in order to assess the influence these factors have on the effectiveness of the SPS against a 'base' building incorporating either System 1 or 2.

7.4.2. *Set-up of 'Base' Building Case*

The 'base' building model designed for System 1 and 2 is identical in terms of the building and stairwell geometry, the (maximum) fan speed and the number of injection vents/grilles (including their size). The only difference between Systems 1 and 2 is the type of (relief) venting and the SPF operation. Therefore, to model System 1, a fixed relief opening was incorporated into the 'base' building model and the fan speed was varied; while to model System 2 the relief opening size (in the stairwell) was varied and the fan speed remained constant.

By incorporating the modifications noted above, the 'base' building model could be adapted to easily simulate either SPS during the sensitivity study of this research.

With reference to Figures 18-21d, the 'base' building to be modelled is 11 storeys including the Ground Floor (i.e. L0) and the roof level. The overall dimensions are 70 m (wide) by 20 m (deep) by 34.2 m (height). The floor to floor height is 3.8 m. There are two stairwell shafts with dimensions of 4 m (deep) by 3 m (wide) and a volume of 45.6 m^3. Each stair door is 0.91 m in width and 2.13 m in height. The vertical and horizontal gaps around the closed doors are taken as 0.00305 m and 0.00636 m respectively.[31] The distance from the doorknob to the side of the door is 0.0762 m (see Figure 19). Adjacent to the two stair shafts are two supply air shafts (i.e. for the pressurised air from the stair shaft fan). This adjacent shaft is a quarter the size of the stair shaft i.e. 1.5 m (wide) by 2 m (deep) and runs from Level 1 to the roof level. There is also a central lift shaft in the building with dimensions of 3 m (deep) by 3 m (wide) by 3.8 m (height).[32] Each stairwell is pressurised by a separate fan on the roof (capacity per SPF is 11.575 kg/s [equivalent to 11,575 L/s][33]). For modelling purposes, the 'constant mass flow' fan

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[31] Stairwell door dimensions including door gaps obtained from Klote and Milke (2002).
[32] Lift shaft dimensions are taken from Klote and Milke (2002).
[33] The SPF capacity of 11,575 L/s was chosen for this thesis based on the fan capacities for System 2 and the preliminary CONTAM simulations in order to design an operational and compliant SPS as per AS1668.1's performance conditions. Refer to Appendix I for the simulation Run # details.

option has been used when defining the fan equation in CONTAM (as opposed to the 'constant volume flow' fan equation). The pressurisation system is a multiple injection system, with injection vents/grilles located at Levels 1, 5 and 9.[34] These inlet grilles/vents have the following dimensions 0.6 m by 0.91 m divided by 2.[35] A relief vent/damper is also located on Level 9 in the stair shaft for both buildings, and is (typically) 1 m by 1 m in size, in terms of the relative opening area.

Note: The reason for the nominally sized relief grille of 1 m^2 is that as part of the preliminary CONTAM simulations (i.e. Run #56, Appendix I) for System 2, it was identified that this size opening allowed the door opening force conditions to be achieved as per AS1668.1, for the chosen fan speed.

At first, an attempt was made to model the performance of the barometric (weight-adjusted) damper in CONTAM, for Building System 2. However, this proved too difficult to model (due to the complexities of the barometric damper's operation) and therefore, it was assumed that the damper will have been correctly set-up to open adequately (i.e. to achieve the nominated effective opening) when all the doors are closed. The complex operation of a barometric damper is as follows: as the pressure in the stairwell increases, the damper opens (once the weight-setting is reached on the damper), refer to Figure 10a. However, as soon as this damper opens, the pressure in the stairwell decreases and so the damper will try and close again (or close more); as soon as the damper begins to close more, the pressure in the stairwell builds up again and the damper will open; this cycle is then repeated.

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[34] The injection grille/vent locations were chosen so that they were equi-spaced along the length of the stairwell, in order to provide uniform injection along the height of the stairwell shaft.

[35] The injection grille/vent area is calculated as 50% of the grille's free area (i.e. 0.6 m x 0.9 m x 0.5 = 0.27 m^2), where the term "50% of the grille's free area" was obtained from the DUCTELTO.LB4 library (Walton et al 2000). Therefore, the grille area used for the computer analysis refers to the 'effective' opening of the vent as opposed to the total physical dimensions of the grille/vent. Klote and Milke (2002) also note that determining a grille's flow area is complicated as the grille's surface is usually covered with louvres or a screen (refer to Figure 6c) and so the flow area is less than the actual grille area. A value of '50%' of the grille's area is therefore, considered to be a conservative estimate for the grille's flow area.

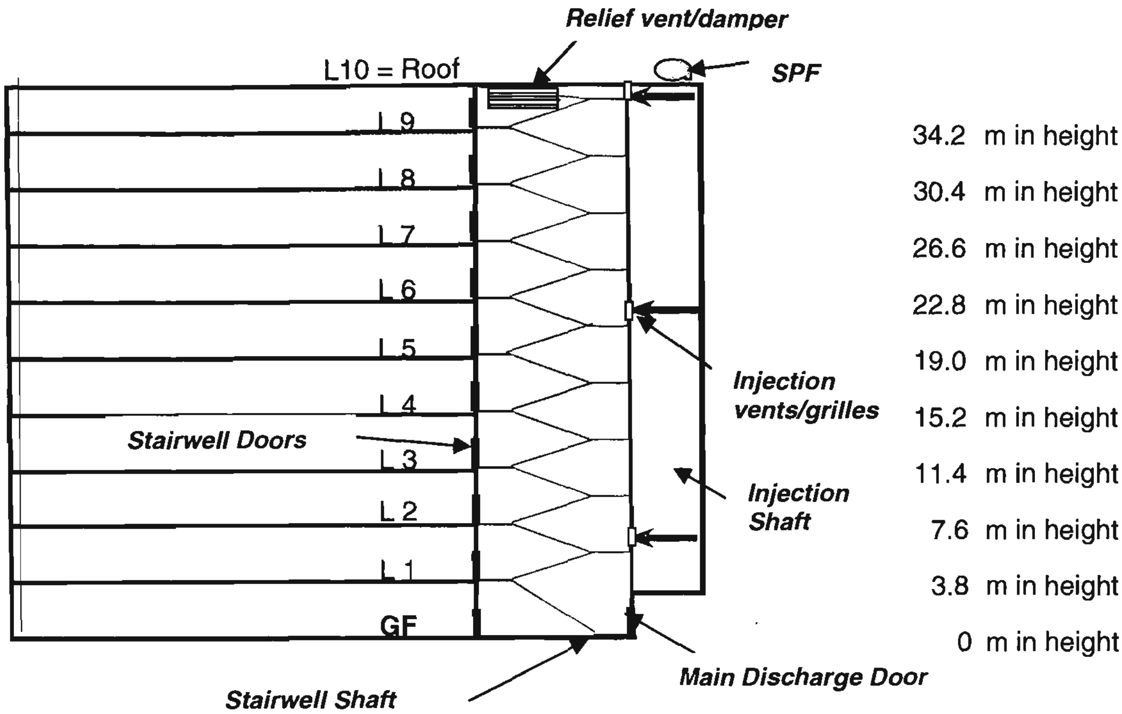

Figure 18. 'Base' building schematic, for one stairwell

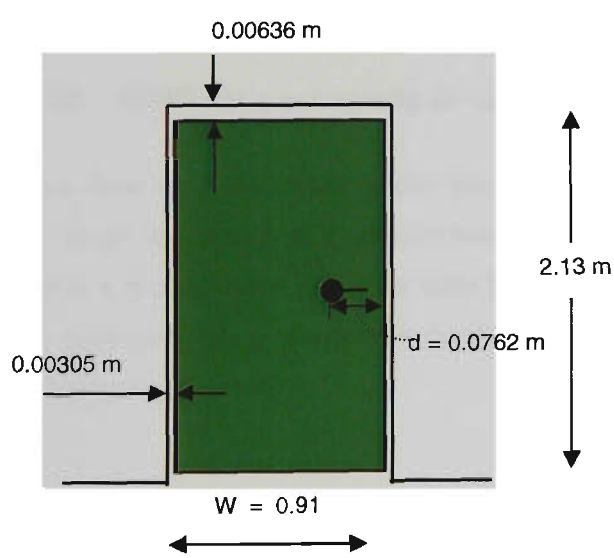

Figure 19. 'Base' Building Stairwell Door Dimensions

This 'base' building does not have openable windows and the stair shafts are modelled assuming that the stairs are a series of vertical zones connected by low-resistance openings. Also, each floor is considered as a separate zone and the building layout is symmetrical (for each stairwell), therefore, the results for one stairwell are assumed identical to the second stairwell in the building.

CONTAM's sketchpad was used to create a schematic representation of the 'base' building to be modelled. This schematic is not a scaled drawing however; the flow paths, inlet and outlet vents/dampers, etc., can be added onto the sketch. Refer to Figure 20.

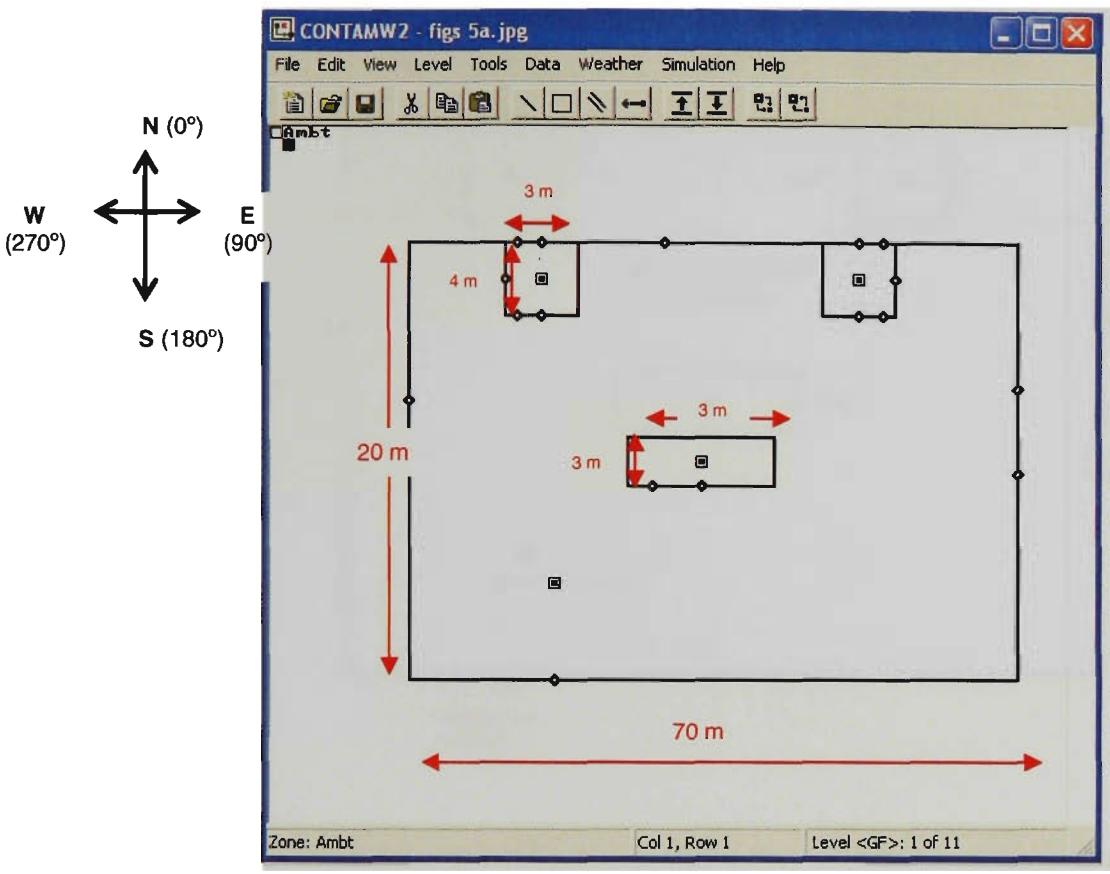

Figure 20. CONTAM's schematic of 'base' building

There is one foyer entrance door on the Ground Floor (i.e. L0) leading into and out of the building, on the East side. Each stairwell has a ground level exit door to the outside on the North side of the building, and a ground level entrance door (from the foyer) on the South side of the stairwell. Each level above L0 has one stairwell door (per stairwell) providing access to the occupied space (refer to Figures 21a-21d).

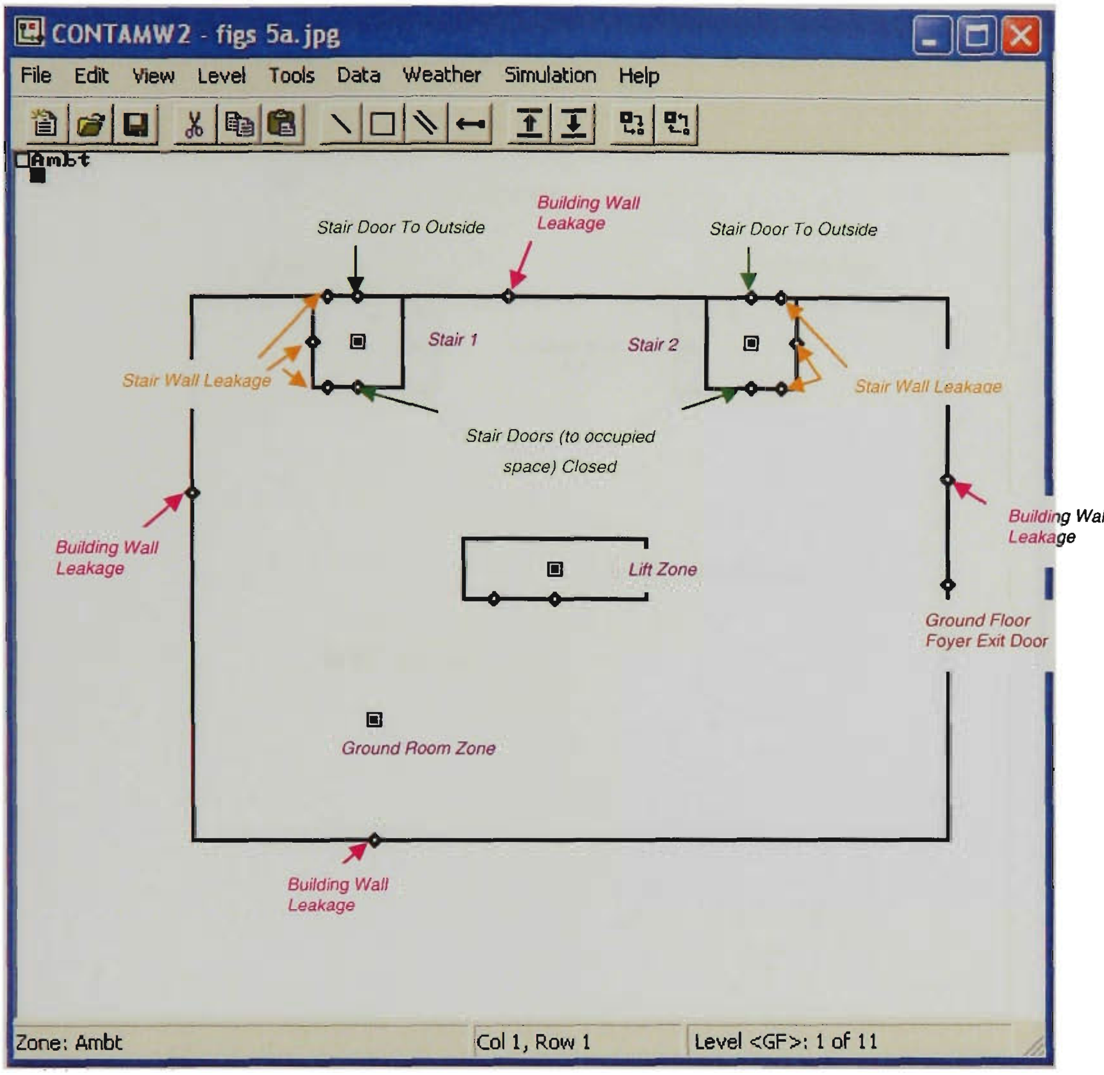

Figure 21a. Sketchpad illustration of 'base" building - Ground Floor (L0)

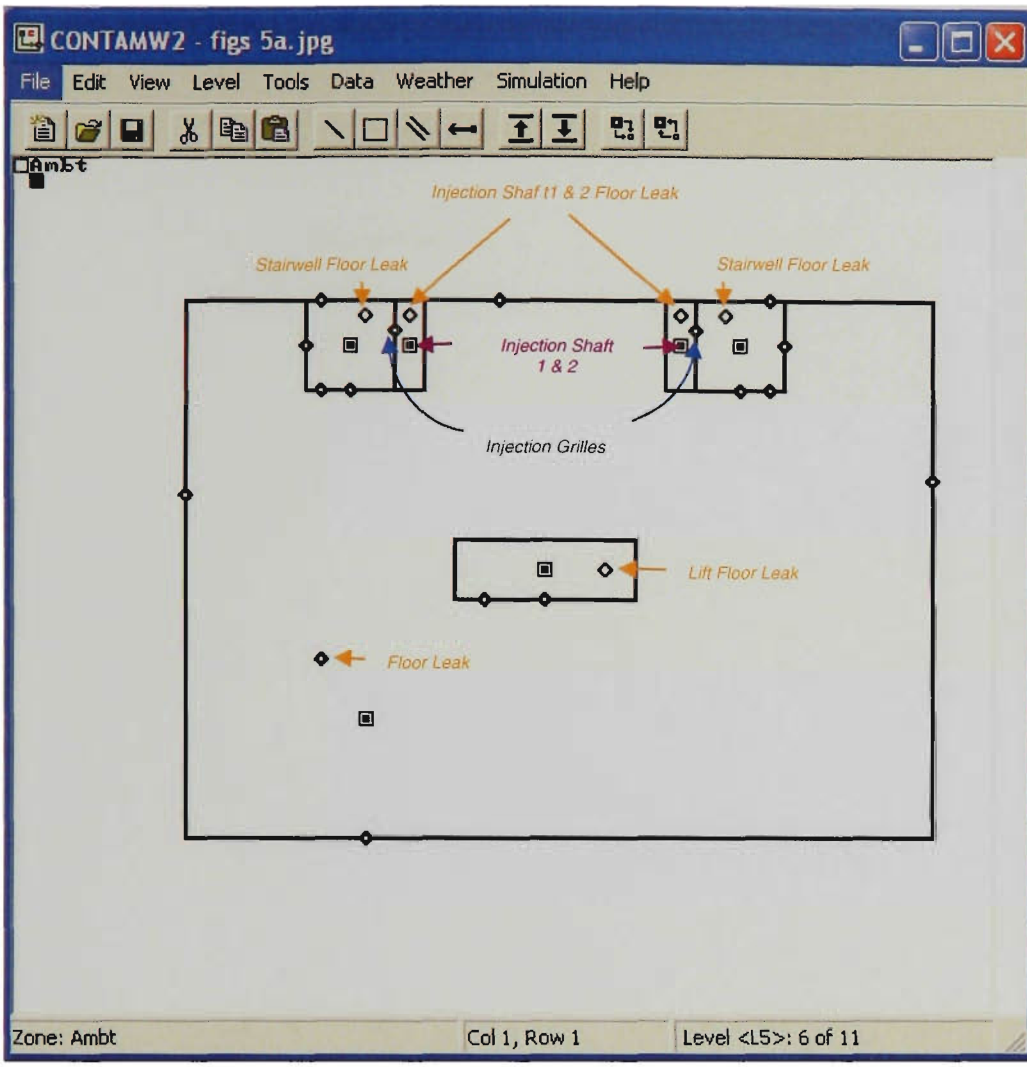

Figure 21b. Sketchpad illustration of 'base" building - Level 5

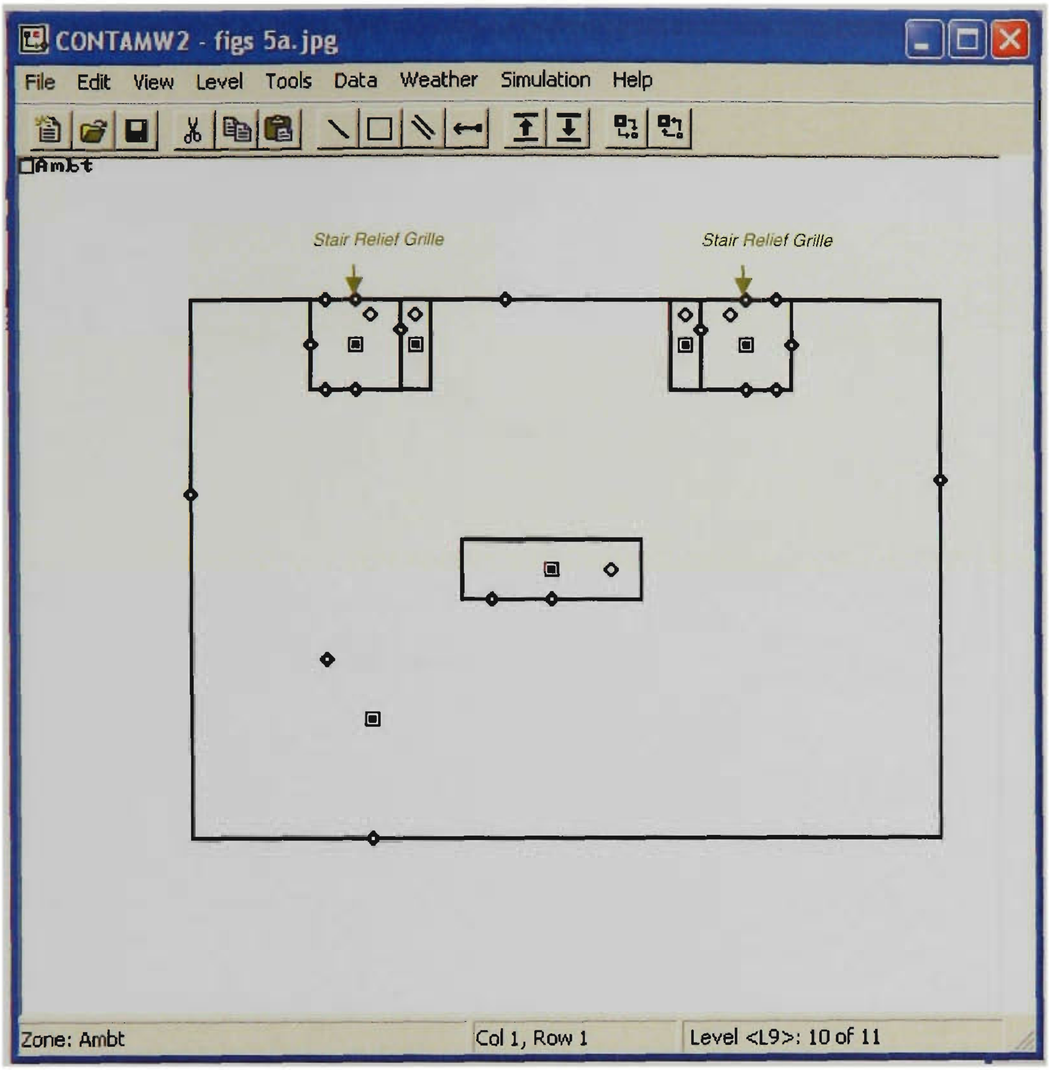

Figure 21c. Sketchpad illustration of 'base" building - Level 9

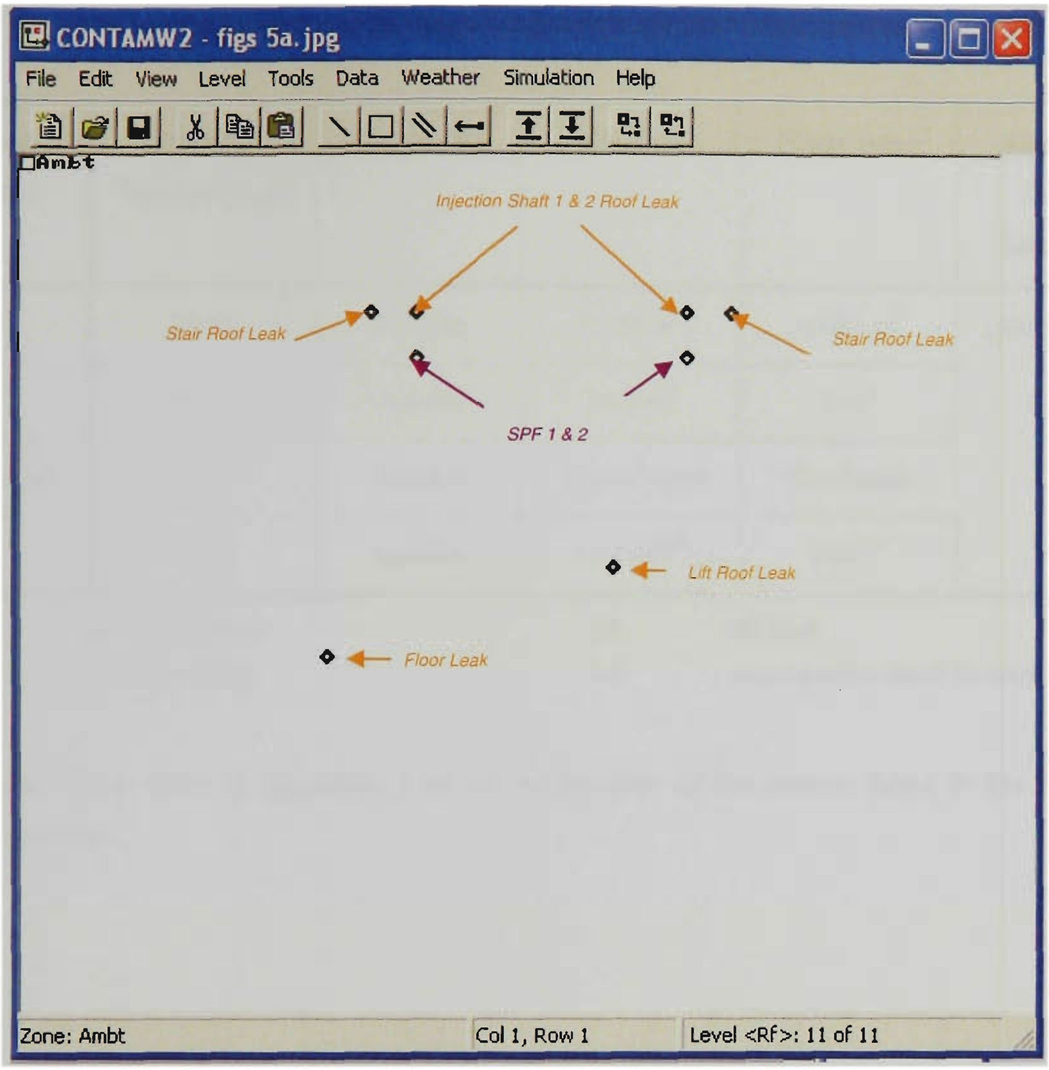

Figure 21d. Sketchpad illustration of 'base' building - Roof Level (i.e. Level 10)

The floor plan on the occupied levels (i.e. Levels 1-9) is of open plan arrangement. This means that there is limited obstruction to the natural airflow paths within the occupied spaces of the building, as opposed to a floor space with high partitions and numerous internal offices, whereby the airflow may be restricted because of the office barriers. For simplicity, the building has been modelled excluding a mechanical ventilation system. This idea of not considering an operational mechanical ventilation system is also consistent with Tamura's (1990) field tests on a SPS with over pressure relief, where the building's AHU was shut down during fire mode, as the AHU's influence was not being assessed.

In developing the 'base' building model described in this thesis, fixed values of leakage, wind speed, temperature (internal and external) and SPF speeds were adopted and are considered as the 'standard' conditions for the 'base' building model. The following sections further describe these 'standard' conditions in more detail. Variations to the 'standard' conditions for the purpose of determining sensitivity are discussed later in section 7.5. of this thesis.

The input data for the 'base' building model is given in Tables 8 and 9, in terms of the internal design conditions.

Table 8. (Internal) Zone Properties

Zone Name	Internal Temperature	Pressure	Volume	Floor Area	Injection Grille Location
Rm	20 °C	Variable	5,320 m^3	1,400 m^2	Levels 1, 5, 9
Lft	20 °C	Variable	34.2 m^3	9 m^2	
St1 and St2	20 °C	Variable	45.6 m^3 each	12 m^2 each	
Inj	20 °C	Variable	11.4 m^3 [36]	3 m^2 [36]	

Rm	occupancy area	Lft	lift shaft
St1, St2	stairwell shafts	Inj	(air) injection shaft for each stairwell

For Tables 9-14, refer to Appendix J for an explanation of the names listed in the 'Element Name' column.

[36] It was assumed that the inlet air shaft (injection shaft) for the SPS was one quarter of the stair shaft's dimensions.

Table 9. Airflow Properties - Powerlaw Model: Orifice Area

Element Name	Airflow Properties					Flow Path				Wind Pressure			Opening
	Cross-sectional Area[37]	Flow Exponent	Discharge Coefficient	Hydraulic Diameter	Reynolds Number	Relative Elevation	Multiplier	Positive Flow Direction	Limits	Wind Pressure Option	Wind Pressure Modifier	Wall Azimuth Angle	
MBldgexitdrc	0.058 m^2 [38]	Default (0.5)[39]	Default (0.6)	Calculated by program (0.27175)	Default (30)	1.07 m	1	Bldg to ambient	None	Variable	0.275799	90	Small (closed)
Stdropin	0.96915 m^2 [40]	Default (0.5)	Default (0.6)	Calculated by program (1.11084)	Default (30)	1.07 m	1	Stair to room	None	NA	NA	NA	Large (open)
Stdrclin	0.023 m^2 [41]	Default (0.5)	Default (0.6)	Calculated by program (0.171127)	Default (30)	1.07 m	1	Stair to room	None	NA	NA	NA	Small (closed)
Stdropext	0.96915 m^2 [40]	Default (0.5)	Default (0.6)	Calculated by program (1.11084)	Default (30)	1.07 m	1	Stair to ambient	None	Variable	0.275799	0	Large (open)
Stdrclext	0.023 m^2 [41]	Default (0.5)	Default (0.6)	Calculated by program (0.171127)	Default (30)	1.07 m	1	Stair to ambient	None	Variable	0.275799	0	Small (closed)
Lftdrcl	0.058 m^2 [42]	Default (0.5)	Default (0.6)	Calculated by program (0.27175)	Default (30)	1.07 m	1	Grd/Room to lift	None	NA	NA	NA	Small (closed)
StReliefGr1	Varies[43]	Default (0.5)	Default (0.6)	Calculated by program	Default (30)	1.9 m	1	Stair to ambient	None	Variable	0.275799	0	Small
InjGrille_H[44]	0.27 m^2	Default (0.5)	Default (0.6)	NA	NA	1.9 m	1	Injection to stairwell	None	NA	NA	NA	Small

NA refers to Not Applicable Bldg refers to Building Grd refers to Ground

[37] Refer to Appendix K for calculations of the leakage areas and cross-sectional areas.
[38] Size of the *Main building (foyer) exit door* obtained from lift door data as the main foyer doors are greater in size than the stair doors and are more comparable to the size of the lift doors.
[39] Flow exponent of 0.5 is for large openings (whereas 1 is for narrow openings).
[40] The design flow cross-sectional area of an *open stair door* is half the geometric area (i.e. width by height) of the stair door, as per Cresci's (1973) research which identified complex flow patterns (eg. such as stationary vortices) near the open doorways, resulting in lower flow rates through open doors.
[41] *Closed stair door* cross-sectional area measurements from Tamura and Klote (1990).
[42] *Lift door* dimensions are stated as being between 0.051 m^2 and 0.065 m^2 (ASHRAE 2003). The median value of 0.058 m^2 was chosen as per the methodology adopted by Fang and Persily (1995).
[43] The *stair relief grille* varies in flow area size from 0.01 m^2 up to 1 m^2 depending on the System modelled. For eg. for System 2 with all doors closed, the effective relief grille opening size is 1 m^2 and when three stairwell doors are open, the effective relief grille opening size is 0.01 m^2.
[44] The *injection grille* is modelled using the Connection ASCOS file (Walton et al 2000).

7.4.2.1. 'Base' Building (standard) Leakage

Leakage values were assigned to the floors within the occupied spaces, the lift floors and roof, the inlet air (injection) shaft floors and roof (for the SPS), as well as the stairwell shaft floors and roof. The wall and floor construction for the 'base' building model was (initially) considered to have 'Average' leakage which could correspond to a construction material consisting of a combination of both concrete and masonry (Tamura 1994),[45] (as opposed to 'Loose' [constructed totally of masonry], 'Tight', etc.). It was considered that 'Average' leakage would be representative of the type of construction present within Buildings 1 and 2 for the 'base' model, due the age of these buildings and the on-site observations (Fazio 2001).

When assigning floor leakage values for the floors (L1 and above) and the roof of the plant room, the same leakage values were used for both as a 'simplification'. This simplification is based on Tamura's comments (circa 1969), where "the leakage areas of first floor and mechanical equipment floors usually differ ... but for ... simplification, all are assumed to be the same." It was also considered that the leakage areas are uniformly distributed around the perimeter of the building.

Tables 10 and 11 specify the leakage values used.

Table 10. Input for Calculating Leakages

Element Name	(Average) Leakage Coefficient[46]	Length (m)	Width (m)
Wallext1	0.17×10^{-3}	20	3.8
Wallext2	0.17×10^{-3}	70	3.8
Stwallext	0.11×10^{-3}	3	3.8
Stwallin1	0.11×10^{-3}	3	3.8
Stwallin2	0.11×10^{-3}	4	3.8
Lftwallint	0.84×10^{-3}	3	3.8
Floorleak	0.52×10^{-4}	70	20
StrRooflek	0.11×10^{-3} [47]	3	4
InjSRflek	0.17×10^{-3} [47]	1.5	2
LftRflek	0.84×10^{-3} [47]	3	3

[45] The leakage values are based on eight building tests conducted in the United States.

[46] 'Average' leakage values for *building walls, internal stair walls, external stair walls, internal lift walls* and *floor leaks* obtained from Klote and Milke (2002).

[47] 'Average' leakage values for *stair roof leak* and *injection shaft roof leak* obtained from ASHRAE (2003), as Klote and Milke (2002) stated that roof leaks can be considered the same as wall leaks for shafts and the ASHRAE (2003) publication considers shafts as part of the external building in terms of construction, respectively. Therefore, lift wall leakage is considered equivalent to *lift roof leakage*.

Table 11. Airflow Properties - Powerlaw Model: Leakage Area

Element Name	Airflow Properties				Flow Path				Wind Pressure			Opening
	Leakage Area[48]	Flow Exponent	Discharge Coefficient	Pressure Drop (Pa)	Relative Elevation	Multiplier	Positive Flow Direction	Limits	Wind Pressure Option	Wind Pressure Modifier	Wall Azimuth Angle	
Wallext1	0.01292 m^2	Default (0.65)	Default (0.6)	Default (10)	1.9 m	1	Ambient to Grd/Room	None	Variable	0.2758	270	Small
Wallext2	0.04522 m^2	Default (0.65)	Default (0.6)	Default (10)	1.9 m	1	Ambient to Grd/Room	None	Variable	0.2758	0	Small
Stwallext	0.001254 m^2	Default (0.65)	Default (0.6)	Default (10)	1.9 m	1	Str to ambient	None	Variable	0.2758	0	Small
Stwallin1	0.001254 m^2	Default (0.65)	Default (0.6)	Default (10)	1.9 m	1	Str to Grd/Room	None	NA	NA	NA	Small
Stwallin2	0.001672 m^2	Default (0.65)	Default (0.6)	Default (10)	1.9 m	1	Str to Grd/Room	None	NA	NA	NA	Small
Lftwallint	0.009576 m^2	Default (0.65)	Default (0.6)	Default (10)	1.1 m	1	Grd/Room to lift	None	NA	NA	NA	Small
Floorleak	0.0728 m^2	Default (0.65)	Default (0.6)	Default (10)	0 m	1	Grd/Room to Room	None	NA	NA	NA	Small
StrRooflek	0.00132 m^2	Default (0.65)	Default (0.6)	Default (10)	0 m	1	Str to ambient	None	None	None	None	Small
InjSRflek	0.00051 m^2	Default (0.65)	Default (0.6)	Default (10)	0 m	1	Injection Shaft to ambient	None	None	None	None	Small
LftRflek	0.00756 m^2	Default (0.65)	Default (0.6)	Default (10)	0 m	1	Lift to ambient	None	None	None	None	Small

Str refers to stairwell shaft

[48] 'Average' leakage values were (i.e. for the formula of length x width x leakage value) based on information obtained by Klote and Milke (2002).

7.4.2.2. 'Base' Building (standard) Airflow Paths

An airflow path is a building component through which air can move between two adjacent zones. For this 'base' building, the following airflow paths were identified; exterior walls, interior walls, doors, floors, fans and shafts. Each airflow path is described in terms of its flow characteristics. For example, horizontal and vertical airflow paths are specified where horizontal paths include 'large' and 'small' openings such as doors and leaks in walls or closed doors, respectively. Vertical paths also include 'large' and 'small' openings. Large openings are considered as stair and lift shafts and small openings are considered as leaks between levels. The CONTAM model was solved using one-way flow equations eg. as per Equation 1, as opposed to the two-way flow equation option (i.e. where two-way airflow might occur through open windows).

Note: In considering the flow paths it was assumed that there was no leakage between the walls and floors, the walls and roof/ceilings or the walls and foundations.

The previous Tables 9 and 11 as well as the following Tables 12-14 further detail the airflow properties assigned for the 'base' building.

Table 12. Airflow Properties - Powerlaw Model: Shaft

Element Name	Airflow Properties					Flow Path				Wind Pressure			Opening
	Distance between Levels	Cross-sectional Area	Flow Exponent	Perimeter	Roughness	Relative Elevation	Multiplier	Positive Flow Direction	Limits	Wind Pressure Option	Wind Pressure Modifier	Wall Azimuth Angle	
Lftfloorlek	3.8 m	9 m^2	0.510241	12 m	Default (0.1)	0 m	1	Lift to lift	None	NA	NA	NA	Large
InjSflrlk	3.8 m	3 m^2	0.506927	6.25 m	Default (0.1)	0 m	1	Injection to injection shaft	None	NA	NA	NA	Large

Table 13. Airflow Properties - Powerlaw Model: Stairwell

Element Name	Airflow Properties					Flow Path				Wind Pressure		
	Distance between Levels	Cross-sectional Area	Flow Exponent	Density of People	Stair Treads	Relative Elevation	Multiplier	Positive Flow Direction	Limits	Wind Pressure Option	Wind Pressure Modifier	Wall Azimuth Angle
Stfloorlek	3.8 m	12 m^2	0.5	0 pers/m^2	Closed	0 m	1	Str to str	None	NA	NA	NA

Table 14. Airflow Properties - Constant Volume Fan Model

Element Name	Airflow Properties	Flow Path				Wind Pressure		
	Design (Max) Flow Rate	Relative Elevation	Multiplier	Positive Flow Direction	Limits	Wind Pressure Option	Wind Pressure Modifier	Wall Azimuth Angle
SPF_x	11,575 L/s	0 m	1	Ambient to injection	None	None	None	None

7.4.2.3. 'Base' Building (standard) Environmental Conditions

The ambient environmental data used in CONTAM was determined from the Bureau of Meteorology website in Melbourne.[49] Appendix L describes in detail the values chosen for the wind data. The terrain chosen was Category 1 (as suggested by Klote and Milke [2002]), whereby 50% of the buildings are taller than 21 m – i.e. a large city centre. A local terrain constant denoted as 'urban' with an 'a' value of 0.35, a wind speed profile exponent also of A_0 0.35 (ASHRAE I-P 1989) was also chosen.

Wind pressure characteristics were chosen for elements for which a flow existed between 'normal' (i.e. occupied spaces) and 'ambient' zones, such as the outside of the building. A wind pressure profile was also developed for the CONTAM model based on the wind pressure data from AS1170.2 (2002) and was identified as 'variable'. The corresponding wind profile coefficients are in brackets, where relative North was chosen as 0° (0.8), East as 90° (-0.65), South as 180° (-0.225) and West as 270° (0.65) [360° had a coefficient of 0.8). The 'standard' wind speed chosen over the height of the building was constant at 5 m/s (as discussed in section 5.2. of this thesis). In Australia, and more specifically within the Melbourne central business district (CBD), wind is not directly considered as part of the SPS design, unless the building is extremely tall or is located in an unusual position.

Table 15 summarises the 'base' building environmental 'standard' conditions, eg. the standard external temperatures and wind speed (SETW).

Table 15. 'Base' Building Environmental Conditions

	Wind (m/s)	External Temperature (°C)	Fan Location
'Base' Building (System 1 and 2)	5	20	Roof (Level 10)

7.4.3. Development of 'Base' Building for Systems 1 and 2

To some extent, the 'base' building design was developed via trial and error, in that one item (variant; temperature, wind speed, etc.) at a time was modified to identify the effect the variant had on pressures and airflows within the stairwell and the building. As an example, the following items were initially modified in order to determine the 'base' building characteristics noted in the previous sections. For example, Runs #1-57 in Appendix I show the differences between multiple injection (on L1, L5 and L9) versus single injection (on L9), SPF speed variations, modifications to the number of open doors in the stairwell (including which door is the

[49] The Bureau of Meteorology website address is http://www.bom.gov.au/climate.

adjacent[50] door to the fire floor when assessing the airflow velocity conditions detailed within AS1668.1), changes to the injection grille/vent size (between the supply air shaft and the stairwell) and changes to the (exhaust) relief grille/vent (on L9), etc.

This analysis was aimed at covering sufficient cases such that the 'base' building designs for both System 1 (VSD and fixed relief) and System 2 could be specified to allow the SPS to comply with the door opening force and airflow velocity conditions of AS1668.1. That is, with these specific conditions, the designed systems have an effectiveness of '1' (in the context of this chapter).

The Heating, Ventilating, and Air-Conditioning Systems and Applications book (1987) states that the buildings without a VSD to control the SPF speed (eg. System 2), the size of the constant speed SPF should be chosen so that the fan provides at least the minimum air velocity when the design number of doors[51] are open. However, if all of the doors in the stairwell are closed, the pressure differential between the stairwell and the occupied space will increase and a relief path will need to be opened, albeit a bypass damper or relief barometric damper, resulting in the bypass/relief air increasing, and so reducing the potential supply airflow into the stairwell. The end result is that any excessive stairwell pressure differentials (due to the closed doors) are reduced.

Using the above design principle, System 2 was initially modelled with a constant speed SPF and a barometric relief damper. The fan speed (of 11,575 L/s) was eventually chosen (refer to Appendix I for the computer simulations) so that the airflow velocity (i.e. with three doors open) and the door opening force requirements (i.e. with no open stairwell doors), were separately satisfied. When deciding on the SPF speed, the damper relief size was also varied in order to find the effective area required (for the fixed SPF speed), depending on whether or not the (required number of) stairwell doors were open or closed. For example, when (three) stairwell doors were open, the effective size of the relief damper was at its minimum (i.e. 0.01 m^2), however when all of the doors were closed, the effective size of the damper was set to its maximum opening size (i.e. 1 m^2) for a constant speed SPF of 11,575 L/s.

The presence of a VSD within a SPS (as per System 1) can limit the fan speed during maximum stairwell pressure conditions (i.e. when all of the stairwell doors are closed). As the doors are opened, in order to maintain the required airflow velocities, the SPF speed is then increased but not so much that the remaining door opening forces are exceeded. In the 'real' environment, the VSD speed is modified based on the average pressure readings within the stairwell, over a specified time period. However, as CONTAM uses steady state conditions, the 'real' averaging measurements could not be modelled. To simulate modifying the SPF speed with a VSD, the

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[50] Note: The term 'adjacent' in this context, refers to the door immediately above or below the nominated fire floor. Once the 'base' building model was obtained, the 'adjacent' door referred to the door above the nominated fire floor.

[51] 'Design number of doors' refers to the number of doors opened/closed as detailed within AS1668.1. For example, for the airflow velocity assessment, there would be three open doors. See Table 5.

SPF speed was initially varied between 10-50% of its maximum speed of 11,575 L/s. The range of fan speeds chosen, therefore simulated the ramping up/down of a VSD to adjust the SPF speed. These values are detailed in Table 16.

Table 16. System 1 SPF Speed Options

VSD setting	SPF Flow rate (L/s)
10%	1,157
20%	2,315
30%	3,472
40%	4,630
50%	5,787
100%	11,575

For consistency, it was decided that the same fan speed would be used for System 1 as that adopted for System 2. This corresponded to a fan speed of 11,575 L/s; which was chosen as the upper fan speed limit when assessing the airflow velocity condition. It is important to realise that SPS incorporating a VSD may or may not have a fixed relief opening. However, if a fixed relief opening is used, it allows more flexibility with the VSD should the stairwell or building conditions change. Therefore, for this assessment a fixed relief was used in the design. Having said this, the design conditions obtained for System 2's airflow velocity assessment (in terms of the relief opening [0.01 m^2] and the fan speed [11,575 L/s]) could have been used for System 1 also. However, if this relief opening was used, the CONTAM simulations showed that when the door opening forces were assessed (all doors closed), the reduced SPF speed would need to be approximately 2,000 L/s or less (i.e. less than 20% of the upper fan limit of 11,575 L/s), in order to comply with the performance condition of 110 N in AS1668.1.

It is not common practice to have the SPF speed at or so close to the minimum VSD setting, therefore this fixed relief opening size was not adopted. If the VSD was set to its minimum setting of 10%-20%, it would not be possible to reduce the fan speed further should the need arise where the stairwell/building conditions have changed. Numerous simulations were performed to assess the door opening force conditions at a low fan speed with and without a fixed relief opening. It was found that at low fan speeds with no relief the door opening forces were less than 70 N. Although this achieves the performance condition in AS1668.1, it was more realistic to find a result closer to the performance condition of 110 N, as is typically the case for 'real' systems.

In order to provide the flexibility needed (as stated above), a realistic fixed vent opening was chosen at 0.06 m^2. Simulations were then performed where the fan speeds were varied to identify if the fixed relief would achieve the door opening force condition and the airflow velocity conditions at an upper fan speed of 11,575 L/s. It was found that the lower fan speed was to be 3,473 L/s when all the doors were closed. It is important to note that if System 1's fan and fixed relief conditions had been analysed first, instead of System 2, the results presented in this thesis (in terms of the fan speeds and relief sizes) would have been different.

7.4.3.1. Details of the Development of Solutions for Systems 1 and 2

This section gives the specific details regarding how the 'base' building solutions were obtained for both Systems 1 and 2, including the results.

7.4.3.1.1. Door Opening Forces

Using the 'standard' conditions (see Tables 8 and 15), the door opening force pressures were modelled, with all the stairwell doors closed. The resulting stairwell pressure calculated using CONTAM was then the pressure required to be overcome, in order to open one of the stairwell doors. That is, if the maximum pressure in the stairwell was less than the 110 N force requirement in the Australian Standards, then it was taken that one door could be successfully opened. Additional doors could also be opened, since opened doors provide additional relief within the stairwell, resulting in a reduction in stairwell pressure. The building leakage values were considered to be 'Average'.

For System 2, it was found that the (exhaust) relief effective opening area necessary to open a stairwell door while complying with the maximum 110 N force detailed within AS1668.1 and AS1851.6, was 1 m^2.[52] The simulation results are presented in Figures 22a and 22b. For this particular simulation case, the resultant maximum door opening force calculated was 97.1 N on L0. Refer to Run #56 in the following graph legend.

[52] Note: A relief size of 1.1 m^2 (Run #54) also does not exceed the maximum door force of 110 N, however, to err on the conservative side, a relief of 1 m^2 was chosen, as it resulted in a door opening force, being closer to the maximum limit of 110 N.

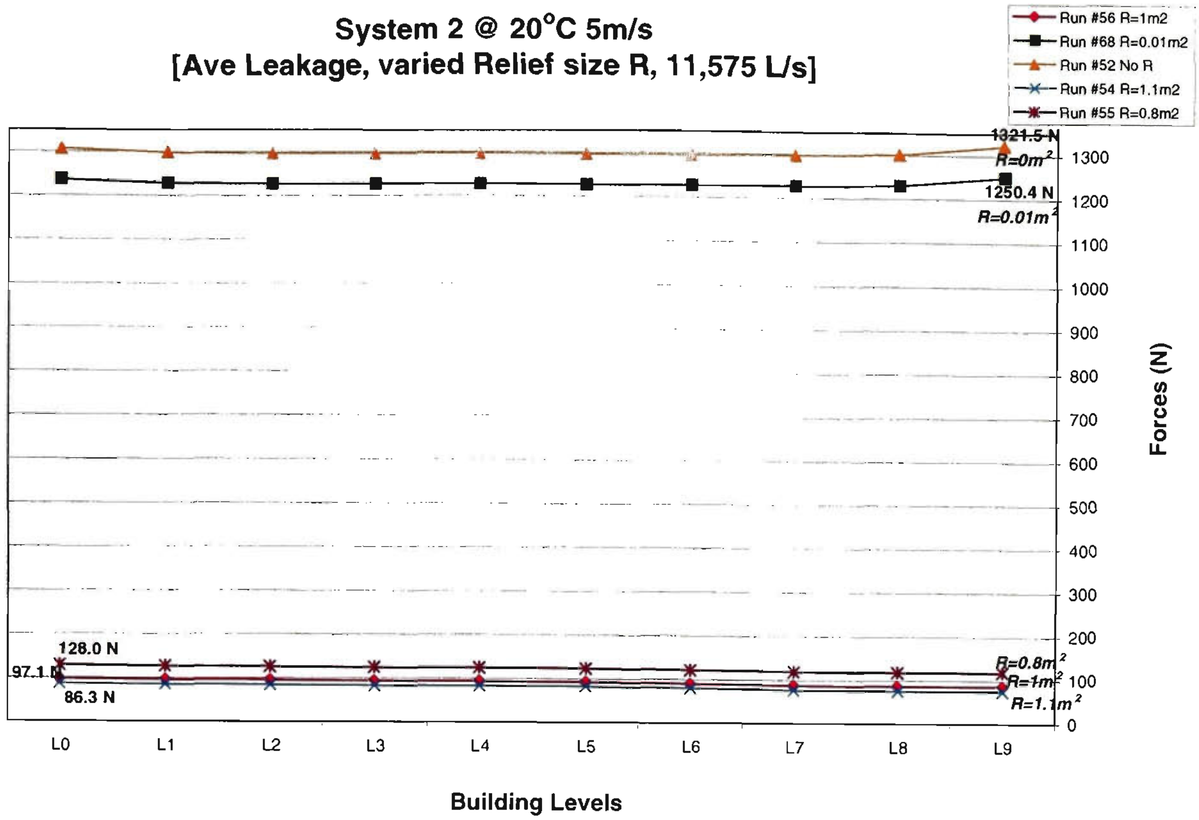

Figure 22a. System 2 - Door Opening Forces for building levels using SETW and varied Relief (R)

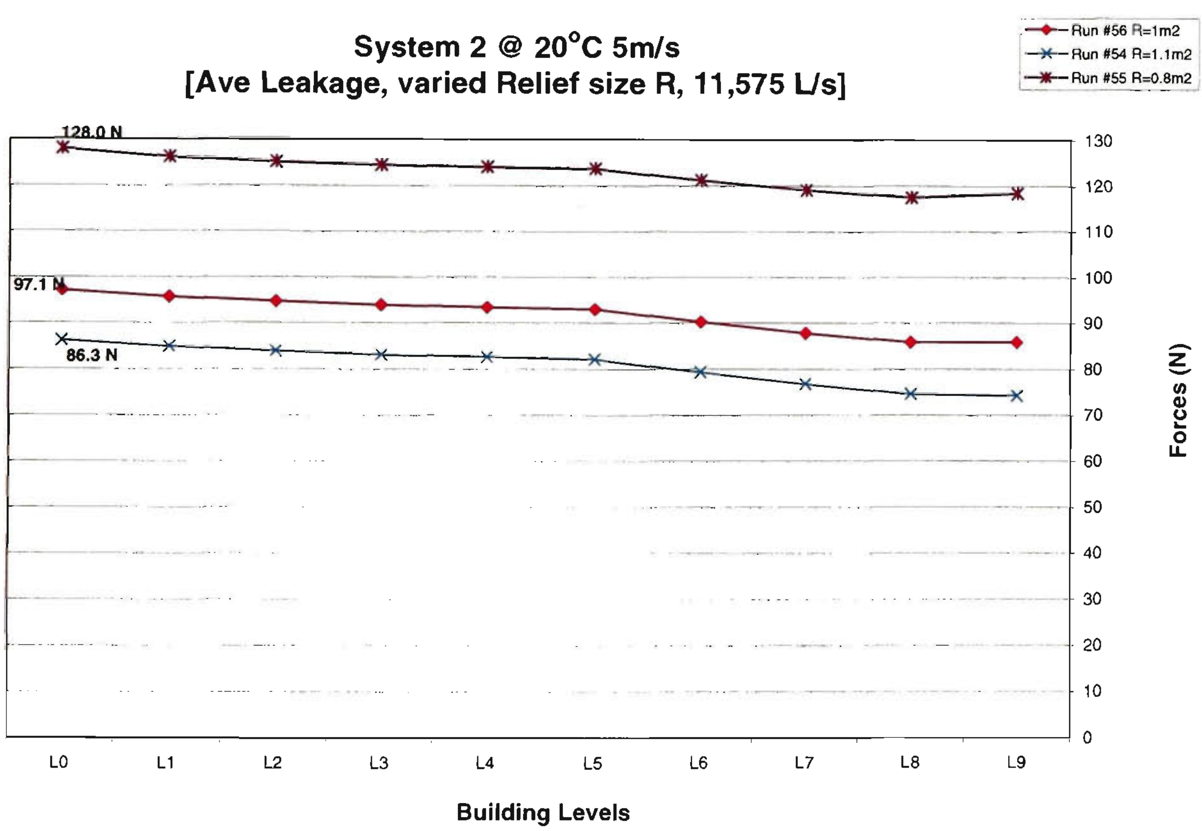

Figure 22b. System 2 - Enlargement (Figure 22a) Door Opening Forces for building levels using SETW and varied Relief (R)

In order for System 1 to pass the performance conditions when using a VSD, the VSD setting had to be lower when assessing the door opening force conditions (i.e. with all doors closed) than when assessing the airflow velocity conditions (i.e. with three doors open). This is so that the required airflows at the doors and the pressures in the stairwell were maintained when additional doors were opened. As stated previously, the upper fan speed of 11,575 L/s was chosen. Therefore, for the door opening force assessment (with all doors closed) the fan speed would need to be reduced due to the build up of pressure. Figure 23 shows the results from this simulation when the fan speed setting (as a percentage) and the effective relief (area) opening size were considered. When the SPF speed was 10-20% of the maximum fan speed, no relief was required[53] in the stairwell shaft, resulting in very low door opening forces. However, when the VSD setting was increased to 30% of the maximum fan speed (i.e. 3,472 L/s), the optimum effective (exhaust) relief opening needed was 0.06 m^2 (Runs #190, #281) in order to obtain a door opening force reading, which was close to the maximum Australian Standard limit (i.e. 110 N). In this case, a maximum door opening force of 103.6 N was achieved for L9. The 10-20% VSD settings (i.e. with no relief opening) were not used in this analysis (even though the performance conditions were satisfied) because they would not allow the flexibility suggested previously, should the stairwell/building conditions change.

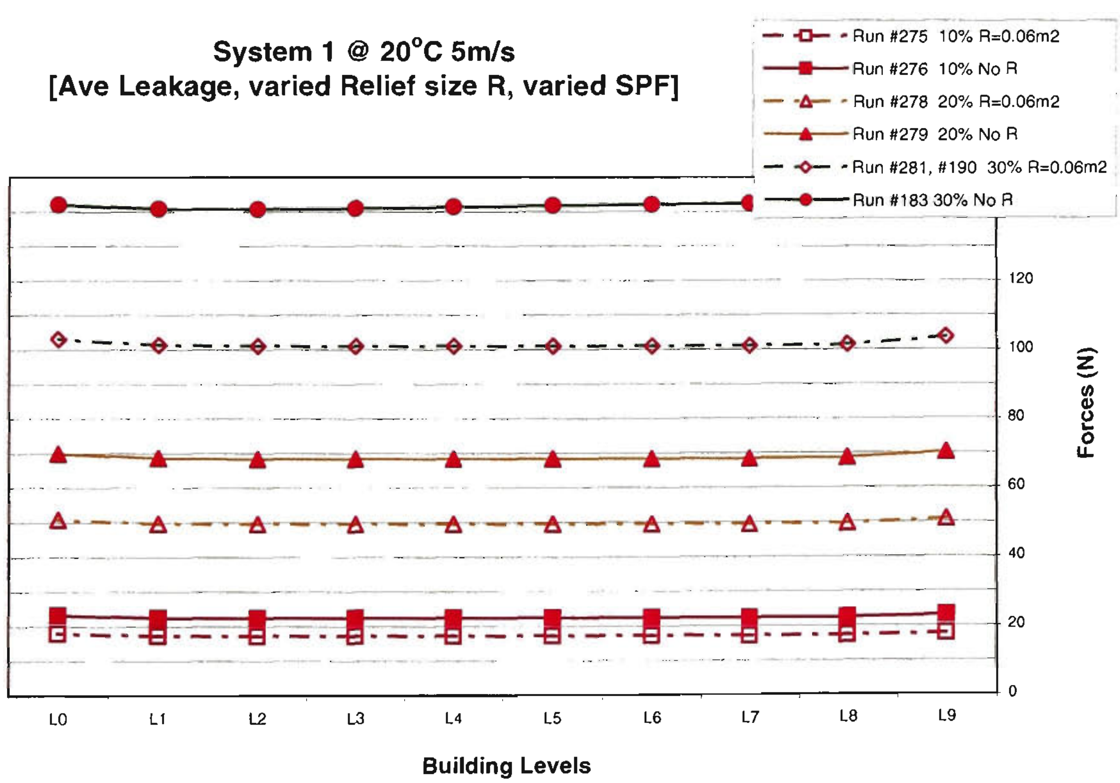

Figure 23. System 1 - Door Opening Forces for building levels using SETW with varied Relief (R) and VSD speed

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[53] No relief was required, as the leakage within the building and stairwell shafts provided sufficient airflow to enable the SPF to operate (as some form of relief is required for these systems [eg. building/stair wall leakage] when an area is being pressurised).

7.4.3.1.2. Airflow Velocities

Once the compliant door opening force scenarios were obtained for both systems, the airflow assessment was modelled in order to comply with the 1 m/s airflow velocity measurement through the nominated fire floor door with three open doors (refer to Table 5). Compared to System 1, a smaller relief (exhaust) is required when the airflow measurements are modelled for System 2 as the pressure in the stairwell shaft reduces with the opening of additional doors.

In order to find the required relief (exhaust) for System 2, an evaluation was performed whereby the number of doors open in the stairwell was varied. Initially one door was opened, then two and then three doors (where three are required to be open by the Australian Standard). This sequence of opening doors is also representative of what may occur in a genuine building evacuation where, one door and then multiple doors are opened. The results in Figures 24a and 24b show that when the SPF supplies 11,575 L/s, as the number of open doors increase, for the same effective relief opening size, the airflow velocity at the fire floor door reduces; resulting in the relief vent needing to be reduced (in order to try and maintain the pressure and the required airflow within the stairwell shaft). These results are also summarised in Table 17.

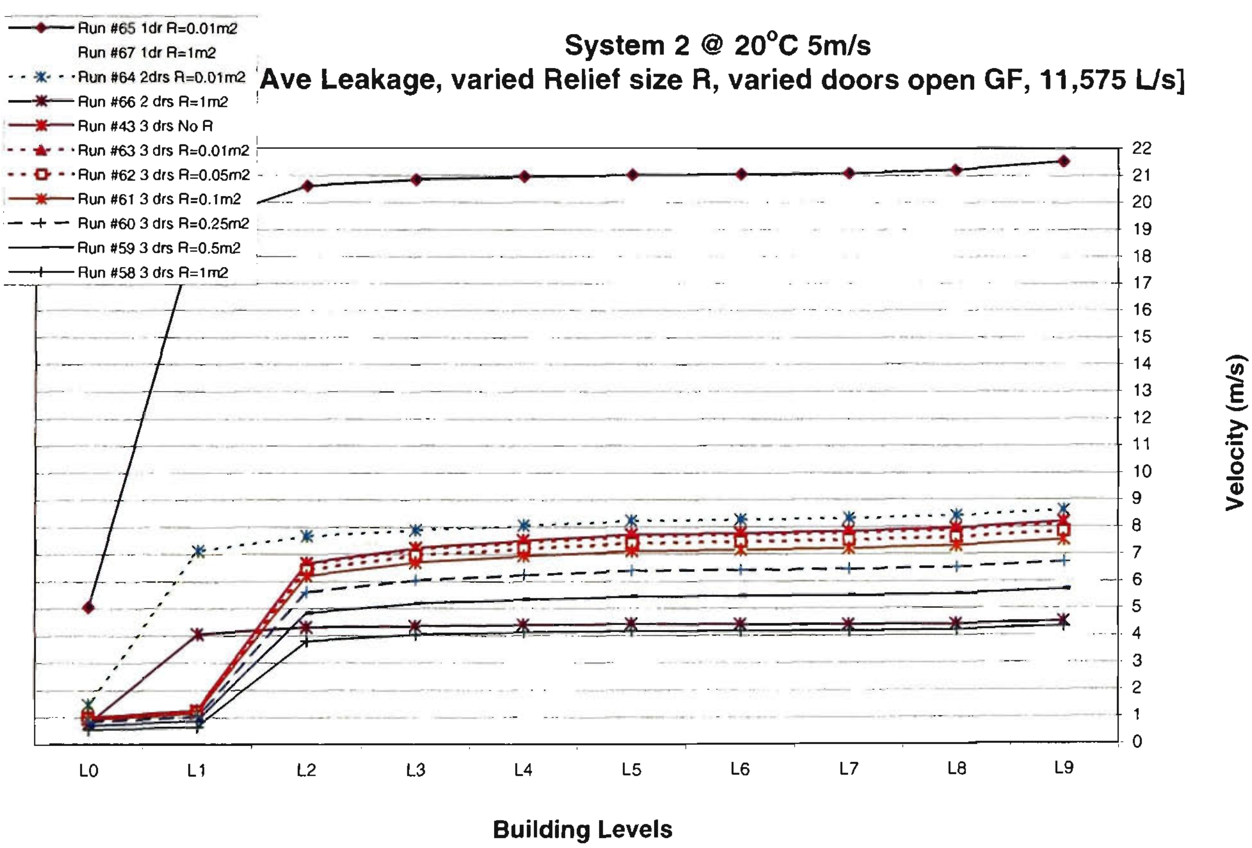


Figure 24a. System 2 - Airflow Velocities for Fire Floor building levels using SETW with varied Doors Open and Relief (R)

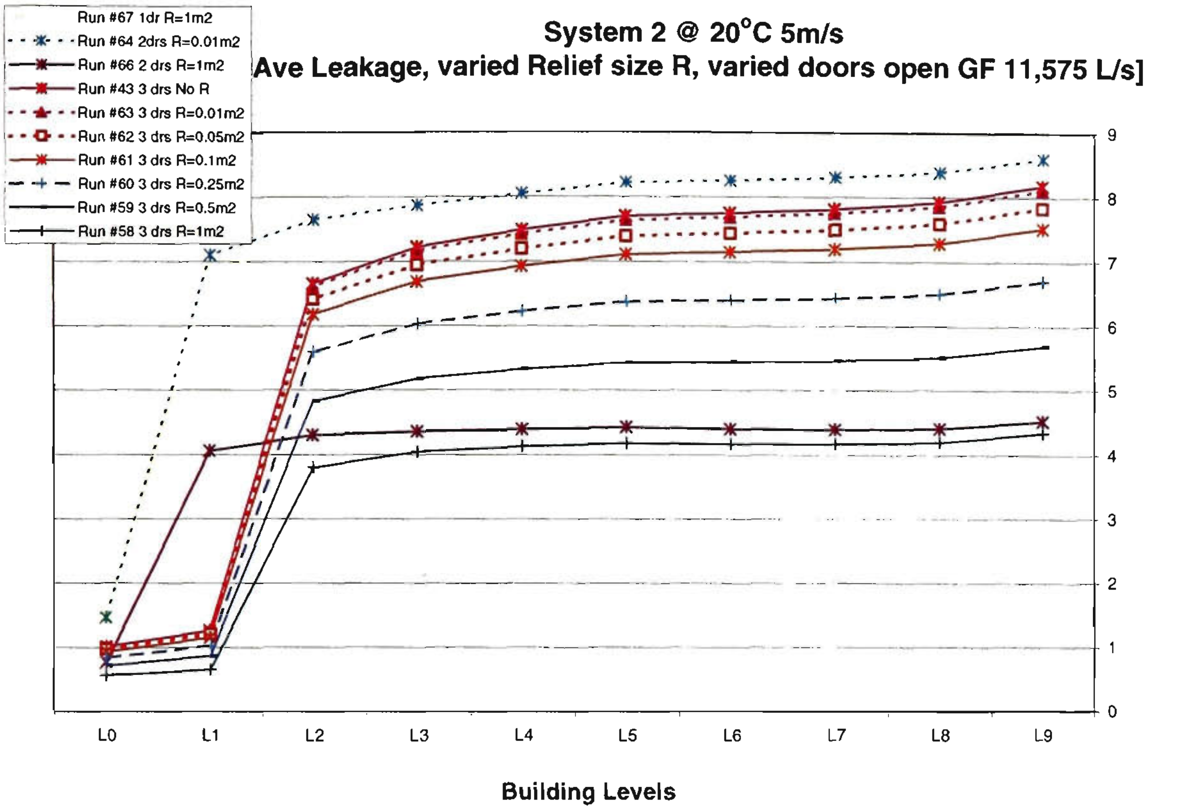


Figure 24b. System 2 - Enlargement (Figure 24a) Airflow Velocities for Fire Floor building levels using SETW with varied Doors Open and Relief (R)

Note: For Figures 24a and 24b (and subsequent airflow velocity figures), R refers to relief size and '1 dr, 2 drs and 3 drs' in the graph legend refers to:

- '1 dr' means that the stairwell door on L0 from the occupied space into the stairwell is open, when the nominated fire floor is L0;
- '2 drs' mean that the main discharge stairwell door out of the building and the stairwell door on L0 from the occupied space into the stairwell are open, when the nominated fire floor is L0; and
- '3 drs' mean that the main discharge stairwell door out of the building, the stairwell door on L0 and the stairwell door on L1 from the occupied space into the stairwell are open, when the nominated fire floor is L0.

The airflow velocity measurements on the remaining floors are when these stairwell doors are closed (being non-fire floors) and therefore, the higher airflow velocity measurements shown (i.e. greater than 4 m/s) are for the door gaps due to closed doors.

Table 17. System 2 - Airflow Velocities for Varied Fire Floor Doors Open using SETW and chosen Relief (R)

No. of Doors Open	Effective Opening Relief size (m^2)	Run No.	Airflow Velocity (m/s)	Airflow Velocity rounded values (m/s)	Remaining Door Opening Forces (N)
1	0.01	#65	5.05	5.1	433.7 - 543.9
	1	**#67**	**1.5**	1.5	**60.2 – 66.5**
2	0.01	#64	1.46	1.5	64.1 – 91.6
3	**0.01**	**#63**	**1.01**	1.0	**56.4 – 81.9**
	0	#43	1.02	1.0	57.11 – 83.3

Notes:
1. Where two results have been provided in the table above, the more onerous solution was chosen, in **bold**.
2. For the three doors open scenario, the average difference in airflow results between an effective relief opening area of 0.01 m^2 and 0 m^2, is 0.005.
3. For System 2, in order to achieve the door opening force requirements with no doors open, an effective relief opening area of 1 m^2 is required (refer to Figures 22a and 22b). It is not possible for a damper to completely close if air is supplied into the stair shaft therefore, a minimum opening of 0.01 m^2 has been adopted (for assessing the airflow requirements).
4. The door opening forces coloured in red in Table 17, illustrate how excessively high the remaining door opening forces are initially, with only one stairwell door open, that is until the damper opens to it's maximum setting of 1 m^2. Of course, the door opening forces required if no doors were open would be even higher. This illustrates how important it is that the barometric damper operates correctly and rapidly when trying to open one or two doors.

For System 1, when the VSD setting was 30% of the maximum SPF speed (maximum speed is 11,575 L/s) an effective fixed relief opening area of 0.06 m^2 was used for the door opening force assessment. A simulation was conducted with both the maximum fan speed and the chosen effective fixed relief opening area, to assess whether the airflow velocity conditions were achieved. Figure 25 shows that the airflow velocity conditions pass when each floor, in turn, is nominated as the fire floor, for three open stairwell doors. Level L0 *just* passes, when the second decimal point value is rounded up (as described in section 7.3.2.2.), i.e. 0.97 m/s rounded up to 1.0 m/s.

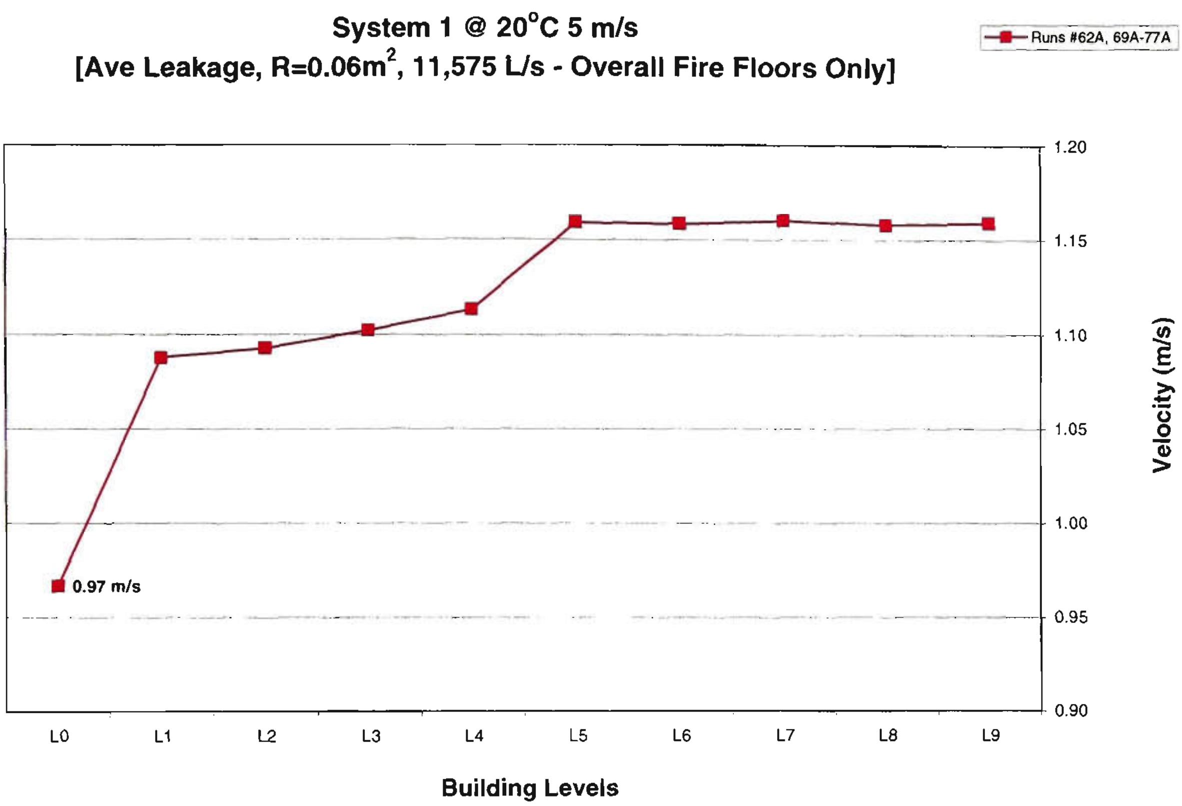


Figure 25. System 1 - Airflow Velocities for Fire Floor building levels using SETW

As with System 2 (Table 17), the remaining door opening forces for System 1 may initially be high (when trying to open one or two doors) if the VSD setting and corresponding SPF have not responded in sufficient time.

7.4.4. Summary of 'Base' Building Solutions for Systems 1 and 2

Based on the information obtained using CONTAM and the 'real-life' scenario sequence of events (i.e. opening one door, then two doors, etc., in the stairwell), the following summary table was developed to show what will occur for the simulations performed.

Table 18. Summary of Sequence of Events for Systems 1 and 2 - 'standard' Conditions

Sequence of Events	System 1 Run No.	System 2 Run No.
a. Initially all stairwell doors are closed, building operating in 'normal'/non-fire mode, (exhaust) relief or dump-back damper closed for System 2 (i.e. at minimum 0.01 m^2) or fixed at 0.06 m^2 for System 1.		
b. The FIP receives a fire alarm signal and the building goes into fire-mode operation.		
c. The SPS for System 2 turns on to max (11,575 L/s), all stairwell doors are still closed, as is the effective relief opening (i.e. open area 0.01 m^2) resulting in excessive pressure within the stairwell and preventing doors from openings. In System 1 (relief area 0.06 m^2), the fan speed begins to increase.	Not modelled	#68
d. A (very) short time later, the (exhaust) relief damper/ dump-back/bypass damper for System 2 opens to 1 m^2. In System 1 (relief area 0.06 m^2) the SPF further increases so that the design pressure limit does not exceed the door opening forces.	#281	#56
e. An occupant then tries to enter the stairwell by opening one door.	Not modelled	#67
f. In order to maintain the airflow velocity and door opening forces for the remaining closed doors, when another door is opened (i.e. two doors open), the relief opening is reduced to 0.01 m^2 (System 2). For System 1 (0.06 m^2) as more doors are opened, the SPF speed increases.	Not modelled	#64
g. To maintain the airflow velocity conditions (when three doors are opened as per the Australian Standards) and door opening forces, the relief opening remains at 0.01 m^2 (System 2) and 0.06 m^2 (for System 1). The fan speed reaches its maximum setting for System 1.	#62A	#63

For the 'base' building conditions modelled, buildings with System 1 or System 2 have an overall effectiveness of '1' and the performance conditions of AS1668.1 are satisfied, when:

- System 1: Door Opening Forces (no doors open), Fan speed 3,472 L/s, Relief 0.06 m^2

  Airflow Velocity (three doors open), Fan speed 11,575 L/s, Relief 0.06 m^2
- System 2: Door Opening Forces (no doors open), Fan speed 11,575 L/s, Relief 1 m^2

  Airflow Velocity (three doors open), Fan speed 11,575 L/s, Relief 0.01 m^2

Note: Within the industry, it is also assumed that the above noted design specifications in terms of fan limits and effective damper relief opening areas can be achieved.

Failure of the SPS is therefore, considered to occur if the design specifications listed above for Systems 1 and 2, or the performance conditions of AS1668.1 are exceeded (i.e. door opening force exceeds 110 N, airflow velocity less than 1 m/s). Below are two examples of SPS failure:

> System 2: if the door opening forces exceed the performance condition of 110 N, then this would be considered as a failure of the system, since the relief damper could not open further.
>
> System 1: if the pressure in the stair shaft (and therefore, the associated door opening forces) decreases, the fan speed will continue to increase until the maximum allowable pressure within the stair shaft reaches the set limit (to avoid excessive door opening forces) or the maximum fan speed is achieved. It is considered that the fan speed cannot be reduced below a VSD setting of 30% (i.e. 3,472 L/s) due to the programming of the VSD. Thus an increase in door opening force (i.e. pressure in the stairwell) at the lowest fan speed will be considered a failure of the system.

The effects of varying temperature, wind and leakage parameters are now considered in this thesis, noting that from hereon, the design specifications (bulleted on the previous page) for both Systems 1 and 2, will be repeated in *italicised brackets* to remind the reader.

7.5. Sensitivity Study

An extensive sensitivity analysis was conducted (using CONTAM) in relation to 'base' Building System 1 and 'base' Building System 2 where the following was considered:

- Variations in wind speed and direction;
- External temperature changes such as temperature increases [summer] and decreases [winter]; and
- Potential leakage changes (i.e. increases in building leakage for walls, etc.).

This study was undertaken to consider the impact of such variations on the performance of the SPS in terms of the conditions specified in AS1668.1 (in particular the door opening forces and airflow velocities).[54]

The actual CONTAM analysis has been divided into various groups, which are referred to as 'Study Groups'. The Study Groups are listed below:

[54] Note: The noise and restoration time performance conditions (as shown in Table 5) were not modelled using CONTAM, however, they were assessed as part of the effectiveness model where 'other factors' influencing the effectiveness were studied (refer to Chapter 8).

Study Group 1	'Base' Building System 2 set-up at SETW *
Study Group 2	'Base' Building System 1 set-up at SETW *
Study Group 3	Increased Wind Speed above 5 m/s
Study Group 4	External Temperature Increase and Reduction
Study Group 5	Combination Condition (Hot and Windy)
Study Group 6	Wind Direction Assessment
Study Group 7	Increased Leakage

Note: * SETW refers to standard external temperature (20°C) and wind (5 m/s)

Study Groups 3-7 refer specifically to the sensitivity analysis performed as part of this research.

7.5.1. Sensitivity to Wind

CONTAM was used to assess the influence of wind speed and wind direction on the effectiveness of a SPS. These variables were chosen based on observations recorded by Fazio (2001) for System 2 (also refer to section 5.4. of this thesis) and Hobson and Stewart's (1972) suggestion that winds greater than 5 m/s could affect the pressurisation system. Despite these observations, British Standard (BS) BS5588.4 (1998) and NFPA 92A are the only standards, which currently references that 'adverse weather conditions' should be 'considered as part of the design'. The following sections detail the CONTAM analysis findings.

7.5.1.1. Wind Speed

The first sensitivity study performed in this thesis was related to changing the external wind conditions for both buildings.

The external wind speed conditions were varied from the 'standard' conditions of 5 m/s, to 15 m/s in increments of 2.5 m/s. This range of wind speeds was chosen based on the data from the Bureau of Meteorology (http://www.bom.gov.au/climate) where the average wind speed is measured over a period of 10 minutes. This range of wind speeds also aligns with Klote and Milke's (2002) suggestion of using the 'mean average wind speed.' Appendix L explains how these values were obtained in more detail.

The Bureau of Meteorology also measures wind speed in terms of "gusts" where the maximum value obtained over a 3 second period is recorded. Bearing this in mind, a maximum wind speed of 30 m/s was adopted for this thesis, with the aim of investigating the effects of short (gust) or long-term high wind speeds. A secondary reason for incorporating high wind speeds was that within the industry high wind speeds (or gusts) are considered to affect the performance of SPS.

7.5.1.2. Effect of Wind Speed

Using the 'base' building condition of standard external temperature (SET) at 20°C, the wind speeds were varied and CONTAM analyses of door opening forces and airflow velocities were performed as shown below.

7.5.1.2.1. Door Opening Forces

System 1's *[fan speed 3,472 L/s, fixed relief 0.06 m^2]* door opening forces were assessed using the CONTAM 'base' building model. The results of the analysis are presented in Figure 26 and show that the door opening forces increase for each level when the external wind speed is increased. The maximum door opening forces are also shown to occur on L0 and L9. In all cases, except for a maximum wind speed of 30 m/s, the door opening force limit of 110 N was not exceeded. In the case of 30 m/s (Run #320A) a maximum door opening force of 114.7 N was generated.

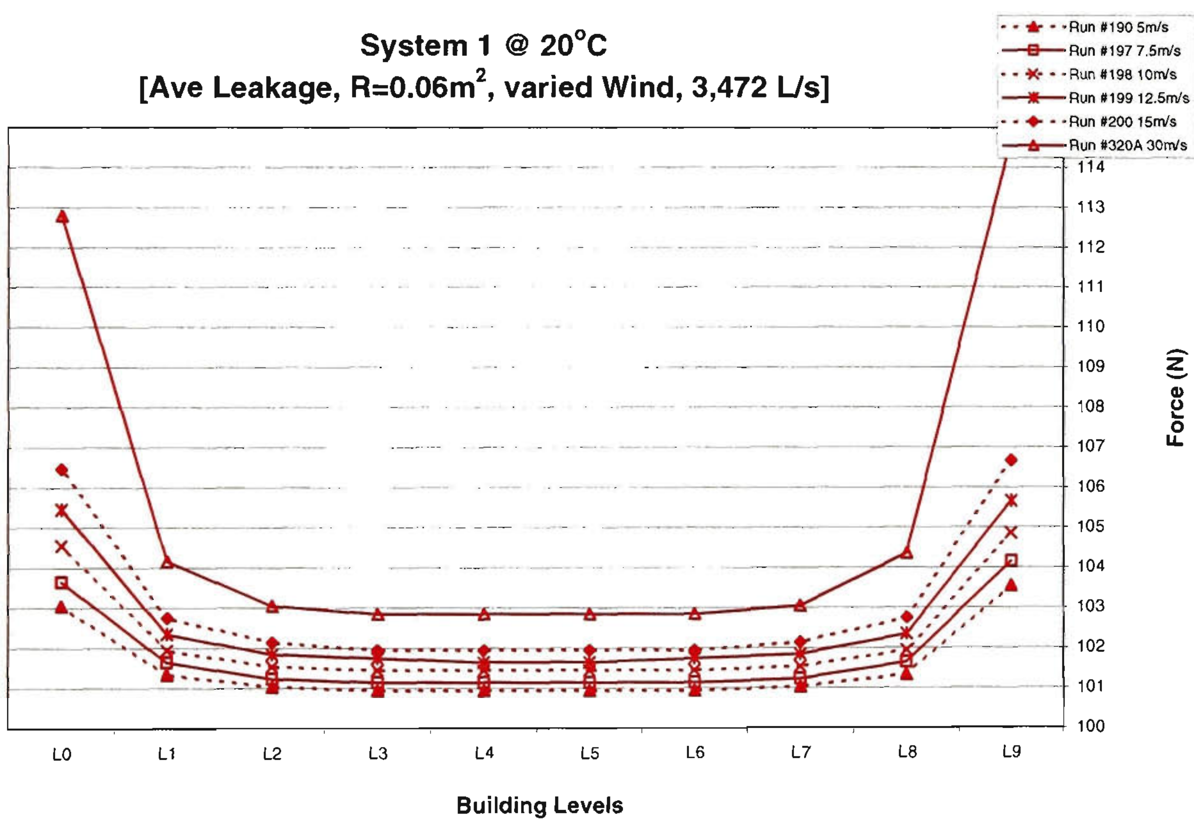


Figure 26. System 1 - Door Opening Forces for building levels using SET and varied Wind

The results for System 2 *[fan speed 11,575 L/s, relief 1 m^2]* as presented in Figure 27, were similar to System 1, in that as the external wind speed increased, so did the door opening forces for each level. The maximum door opening forces were on the lower levels (i.e. L0) and overall reduced as the building height increased. System 2 did not pass the door opening force requirement on L0 when the maximum wind speed was 30 m/s (i.e. Run #122, L0 door opening force 114.7 N), however, all other wind speeds modelled complied with the performance condition of 110 N. If the relief could have been increased to 1.1 m^2 (see Run #123 in the graph legend), the door opening forces would have passed for the maximum wind speed.

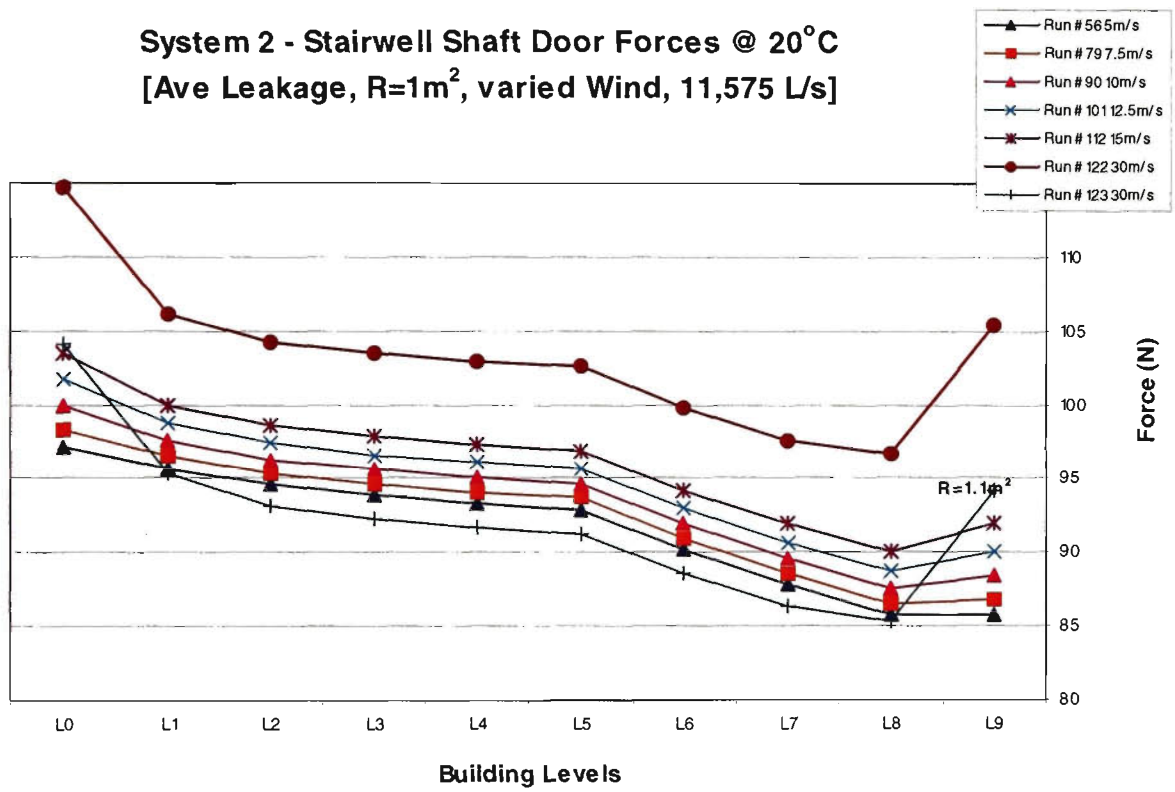


Figure 27. System 2 - Door Opening Forces for building levels using SET and varied Wind

7.5.1.2.2. Airflow Velocities

The results for the airflow velocity analysis for System 2 *[fan speed 11,575 L/s, relief 1 m^2]*, show that as the external wind speed increases, the overall airflow velocities on the nominated fire floors also increase for each floor (i.e. from L0 to L9). These results are presented in Figures 28a and 28b.

For the 'base' building case of wind speed 5 m/s, the airflow velocity was 1.0 m/s on L0, while for a wind speed of 30 m/s (Run #124) the airflow velocity was 1.3 m/s for the same nominated fire floor. Higher airflow velocities were obtained when the nominated fire floor was other than L0. On this basis, for a wind speed of 30 m/s, the nominated fire floor was considered for L0 only as it was recognised that this floor would have a lower airflow velocity than if the nominated fire floor was at other (higher) levels. The high wind speed simulation result (when only one floor is nominated the fire floor), is also shown in Figures 28a and 28b. During the CONTAM analysis for a high wind speed of 30 m/s, it was identified that although the airflow velocities complied for three open doors; the Ground Floor foyer discharge door (on the East side, see Figure 21a), had excessive door opening forces of more than 280 N. This was due to the direction and velocity of the external wind. However, occupants could still enter the stairwell doors when the fire floor was L0, despite not being able to use the Ground Floor foyer discharge (Easterly) door.

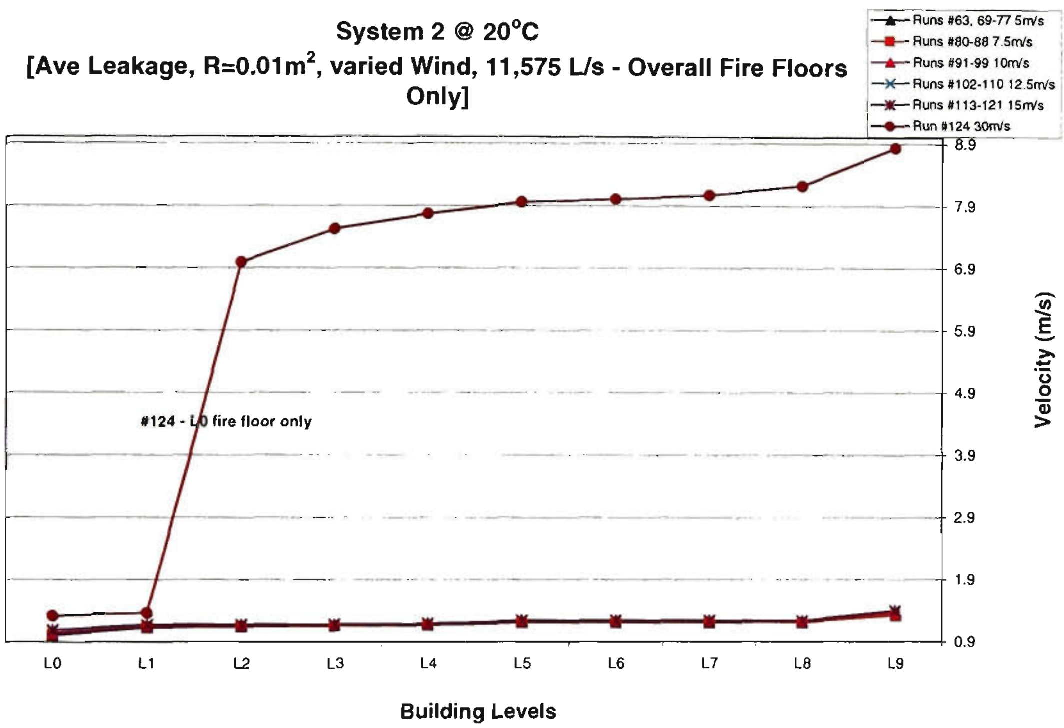


Figure 28a. System 2 - Airflow Velocities for Fire Floor building levels using SET and varied Wind

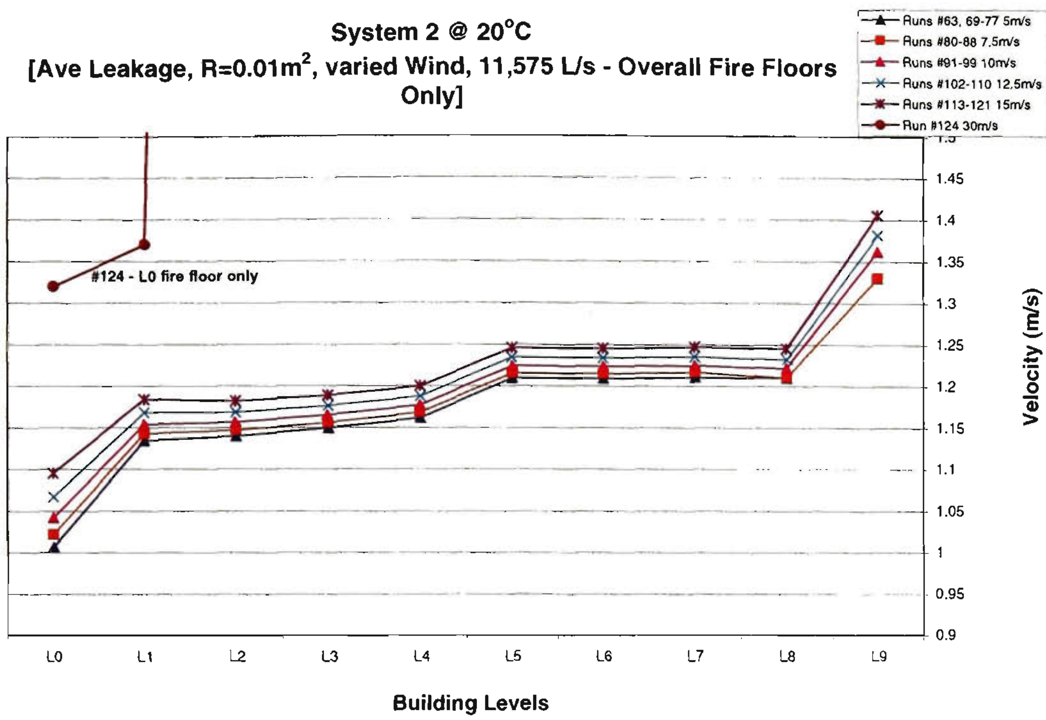


Figure 28b. System 2 - Enlargement (Figure 28a) Airflow Velocities for Fire Floor building levels using SET and varied Wind

In System 1 *[fan speed 11,575 L/s, fixed relief 0.06 m^2]*, the results for the varied wind speed analysis show that the airflow velocity *just* passed on L0 (i.e. Run #62A). The airflow velocity through the fire floor door was 0.97 m/s (rounded up to 1.0 m/s). In contrast, when modelling a maximum wind speed of 30 m/s, the airflow velocity safely passed on L0. This outcome was not analysed directly but interpolated from other analysis results (see Appendix M, Table M2).

7.5.1.3. Wind Direction

Using the 'standard' wind speed condition of 5 m/s, the wind direction was varied from an Easterly direction to a Northerly, Southerly and then Westerly direction. This was done in order to assess whether or not the wind direction affected the operation of the SPS during 'standard' conditions (i.e. SETW). Appendix L details the background behind the wind directions chosen.

7.5.1.4. Effect of Wind Direction

The influence that wind direction has on the effectiveness of the SPS was only modelled in terms of the door opening force performance conditions (i.e. when all doors are closed).

7.5.1.4.1. Door Opening Forces

Figures 29a and 29b illustrate the influence wind direction has on the performance of the SPS. The results indicate that the East and West wind directions appear to have the greatest influence on the door opening results, followed by the South and North directions. Therefore, additional wind direction simulations did not need to be generated, as the Easterly wind direction was originally chosen for the CONTAM scenarios. The Bureau of Meteorology data (presented in Appendix L) however, shows that the North, South, West, and then finally the East wind directions are the order of frequency. However, for this project the East wind direction was maintained for the CONTAM simulations, as it displayed the highest door opening forces (although marginally so).

Systems 1's *[fan speed 3,472 L/s, fixed relief 0.06 m²]* East (Run #190) and West (Run #220) simulations indicate that L1-L8 have practically identical door opening forces, while L0 and L9 have the highest door opening forces. This is illustrated in Figure 29a. For System 2 *[fan speed 11,575 L/s, relief 1 m²]*, the East (Run #56) and West (Run #221) results are also extremely similar (refer to Figure 29b). The maximum door opening forces are on L0 in this case. The graphs displayed for both SPS are consistent with the door opening force graphs presented earlier, in terms of the patterns produced.

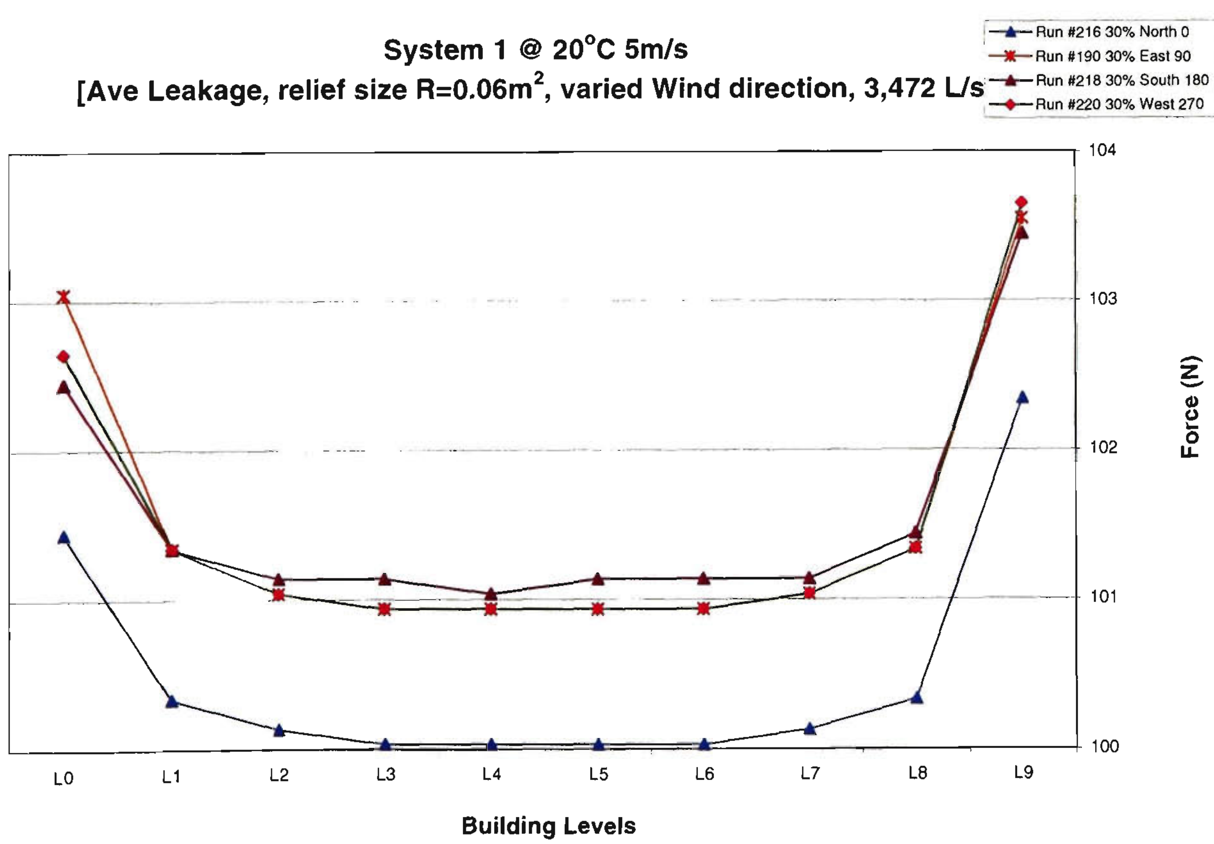


Figure 29a. System 1 - Door Opening Forces using SETW and varied Wind Direction

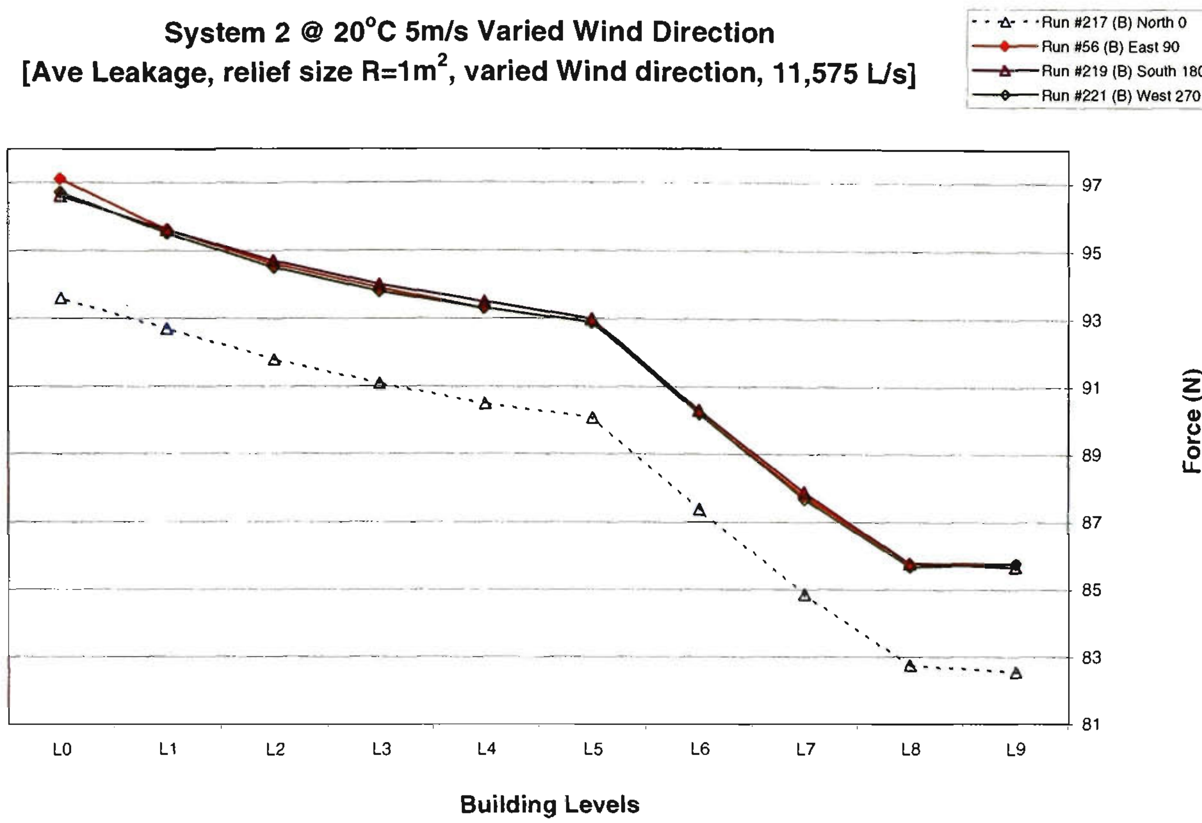


Figure 29b. System 2 - Door Opening Forces using SETW and varied Wind Direction

7.5.2. Sensitivity to Temperature

A sensitivity study was performed where the external temperatures were varied consistently over the height of the building. These variations (generally) included external temperature increases and reductions, while the remaining external environmental variables did not change. That is, the standard external wind [SEW] speed of 5 m/s was used.

7.5.2.1. Temperature Increases

To assess external temperature variations on the performance of a SPS, the internal temperature of the building was set to 20°C, while the external temperatures were increased from 5°C to 30°C, in 5°C increments. Summer and winter conditions were replicated with external temperatures of 25°C and 15°C, respectively. These temperatures were chosen with use of data obtained from the Bureau of Meteorology (http://www.bom.gov.au/climate; see Appendix L).

When external temperatures were greater than the internal temperature, the reverse stack effect occurs and was modelled (refer to Figure 30).[55]

[55] Note: The 'Neutral Plane' referred to in Figure 30, is where the inside pressure equals the outside pressure.

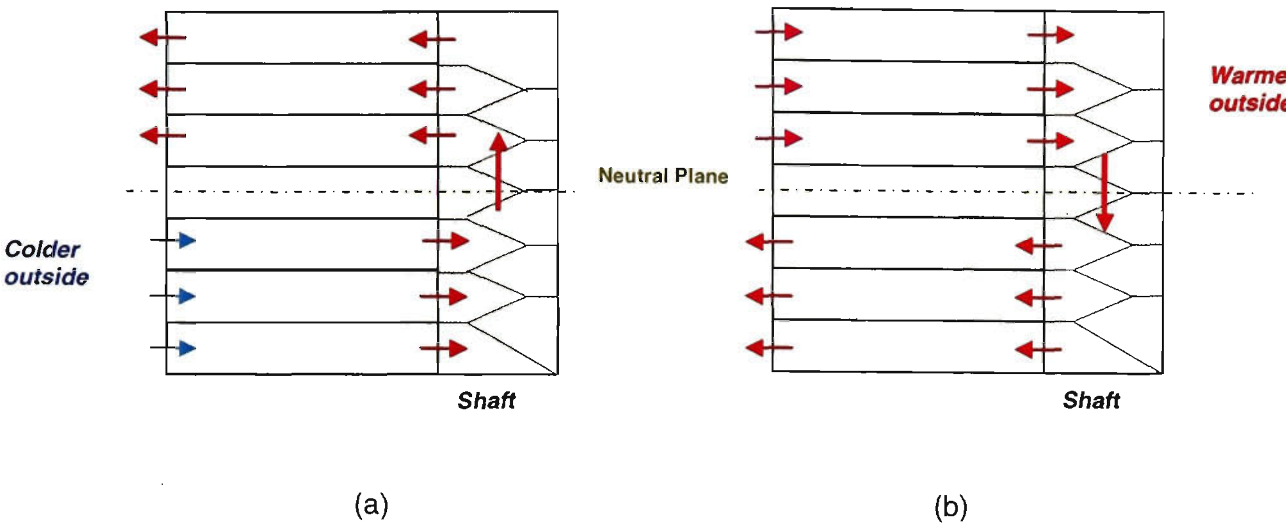
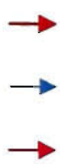


Figure 30. Stack Effect - (a) Normal and (b) Reverse



Note: refers to building airflow direction

refers to cool air flow direction

refers to hot air flow direction

7.5.2.2. Effect of Temperature Increases

7.5.2.2.1. Door Opening Forces

Figure 31 presents the results for the door opening force analysis for System 1 *[fan speed 3,472 L/s, fixed relief 0.06 m^2]*. The results show that in all instances, the maximum door opening force of 110 N is not exceeded for System 1, independent of the external temperature. Figure 31 also shows that when the temperature increases from 5°C to 15°C, the door opening forces reduce up until L4, at which time the door opening forces then begin to increase over the height of the building as the temperature increases further. The SETW conditions (i.e. 20°C and 5 m/s), result in reasonably symmetrical door opening forces on either side of L4 (the middle zone of the building). Further increases in temperature (i.e. 25°C to 30°C) result in an increase in door opening forces from L4, as the building height increases. The door opening forces vary in total by approximately 8 N.

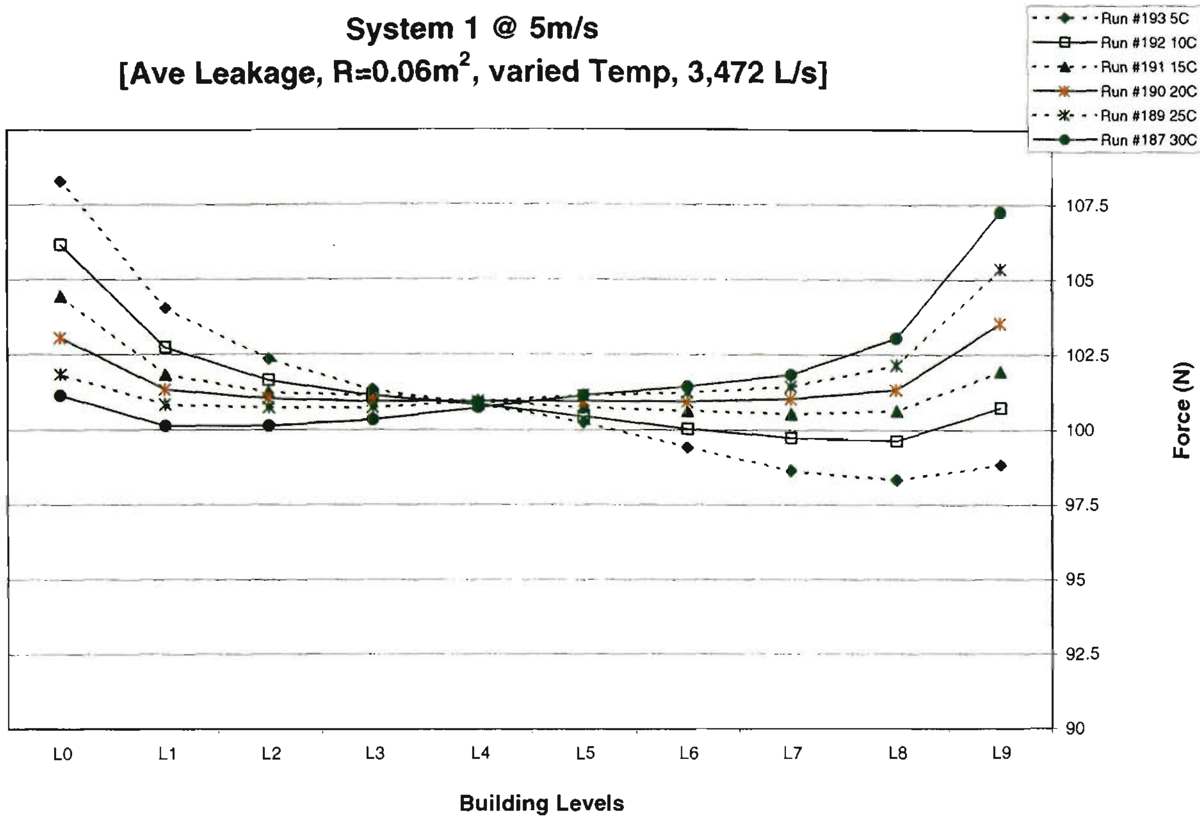


Figure 31. System 1 - Door Opening Forces using SEW and Increased Temperatures

The results for System 2 *[fan speed 11,575 L/s, fixed relief 1 m^2]* presented in Figure 32, show that the maximum door opening force of 110 N is not exceeded. This figure also shows that as the external temperature increases the door opening forces reduce as the building height increases, up to L9. That is, the lowest door opening force for each temperature scenario is generally on L8. However, between L8 and L9, as the temperature increases from 25°C to 30°C, the door opening force on L9 is greater than on L8. For System 2, the door opening forces vary in total by approximately 20 N.

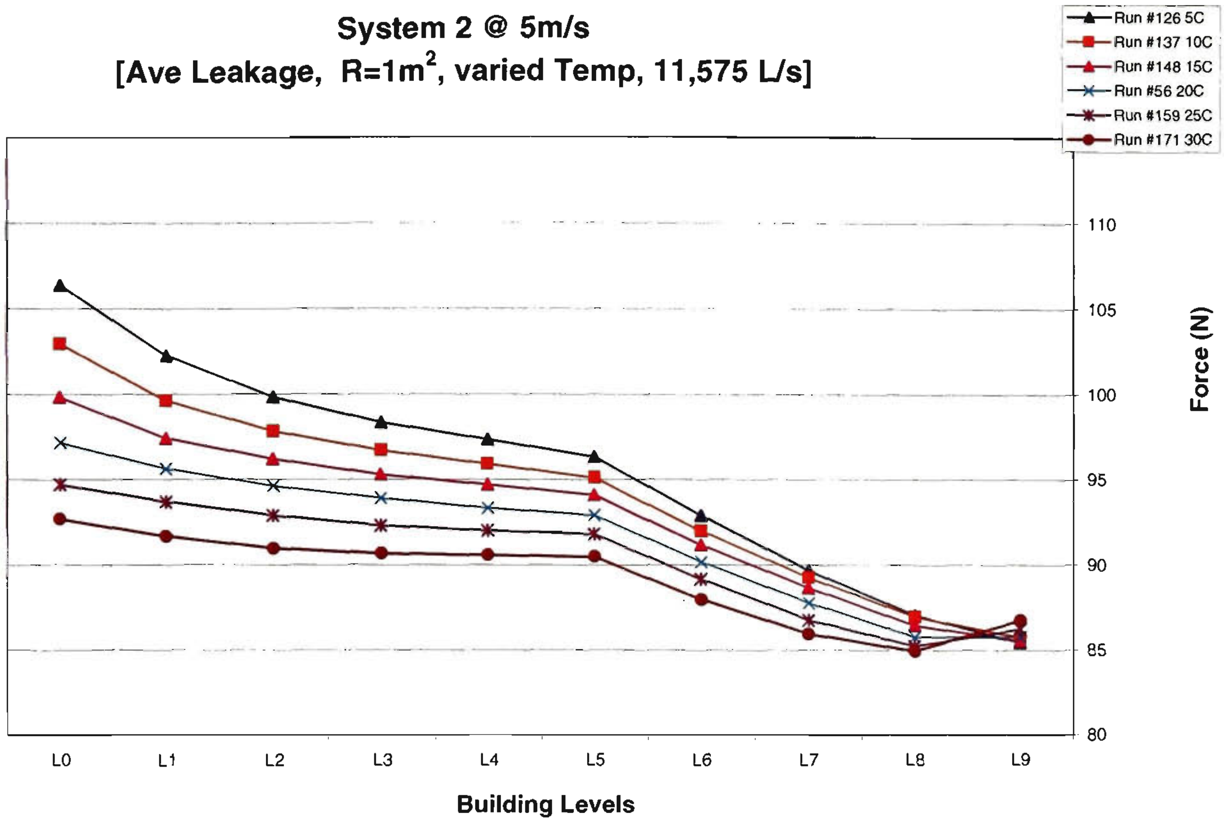


Figure 32. System 2 - Door Opening Forces using SEW and Increased Temperatures

Note: In Figures 31 and 32 where external temperatures exceed the internal temperature (i.e. of 20°C), the reverse stack effect phenomenon is displayed.

7.5.2.2.2. Airflow Velocities

The results for the airflow velocity analysis for System 2 *[fan speed 11,575 L/s, relief 0.01 m²]* are presented in Figure 33 and Table 19. The results presented in this figure show each floor in turn, nominated as the fire floor. In all instances, the minimum airflow velocity of 1 m/s on the fire floor was achieved, independent of the external temperatures assessed. As the external temperatures increase, the airflow velocities on the nominated fire floors were shown to also increase for each floor.

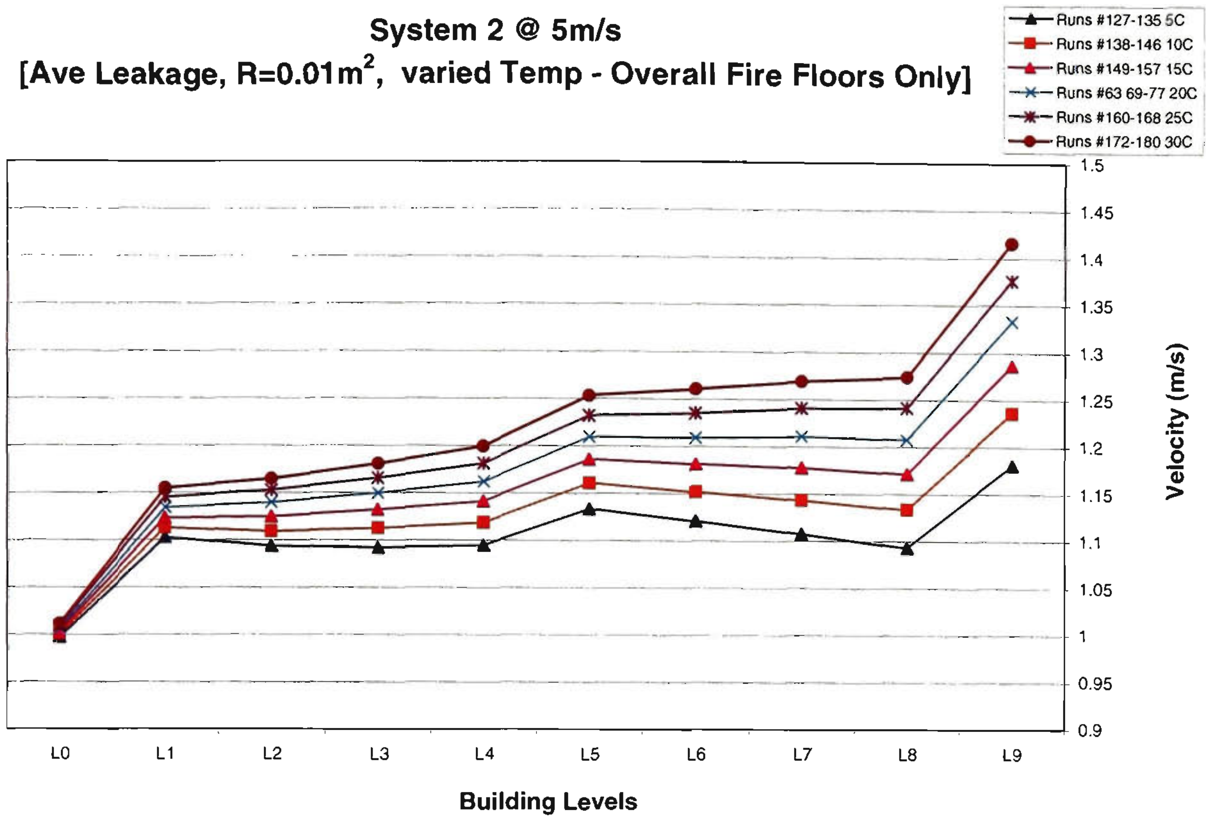


Figure 33. System 2 - Airflow Velocities for Fire Floor building levels using SEW and Increased Temperatures

Note: In Figure 33 where external temperatures exceed the internal temperature (i.e. of 20°C), the reverse stack effect phenomenon is displayed.

Table 19. System 2 - Airflow Velocities through Fire Floor (L0) using SEW and Increased Temperatures

External Temperature (°C)	Airflow Velocity (m/s)	Airflow Velocity rounded values (m/s)	Run No.
5	0.9974	1.0	#127
10	1.0007	1.0	#138
15	1.0038	1.0	#149
20	1.0066	1.0	#63
25	1.0092	1.0	#160
30	1.0117	1.0	#172

When System 1 *[fan speed 11,575 L/s, fixed relief 0.06 m^2]* was assessed with increasing external temperatures, the airflow velocity *just* passed on L0 with 0.96 m/s rounded to 1.0 m/s at 5°C and 5 m/s (refer to Run #422 in Appendix I).

7.5.2.3. Negative Temperature Variations

The external temperature was reduced from 1°C to -15°C while the internal temperature remained at 20°C. This analysis was simulated in order to assess the SPS during extreme wintry conditions. The temperatures used were also assumed to be constant with time over the height of the building.

When external temperatures were less than the internal temperature, the normal stack effect occurs and was modelled (refer to Figure 30).

7.5.2.4. Effect of Negative Temperature Variations

Extreme wintry conditions were modelled starting with an external temperature initially of 1°C. The normal stack effect was modelled when the external temperature was less than the building's internal temperature (i.e. of 20°C). The external wind remained at 5 m/s.

7.5.2.4.1. Door Opening Forces

System 2 *[fan speed 11,575 L/s, relief 1 m^2]* was assessed with reduced external temperatures. The results are shown in Figures 34a and 34b and illustrate that as the external temperature reduces from 1°C to -10°C, the door opening forces increase per level until L7-L8 is reached, at which time the door opening force reduces as the external temperature increases. The maximum allowable door opening force of 110 N was not exceeded when the outside temperature was 1°C and the internal temperature was 20°C (i.e. a temperature change of 19°C), refer to Run #303 in the graph legend. An assessment was then conducted to see whether the results were dependent on the temperature difference as opposed to specific internal and external temperatures. An external temperature of -15°C and an internal temperature of 4°C was modelled (Run #304), resulting in non-compliant door opening forces for L0-L2 inclusive, as illustrated in Figures 34a and 34b. These results demonstrated that it is not simply the difference between internal and external temperatures that effects the internal pressure state within the stair shaft, but the specific values of temperature.

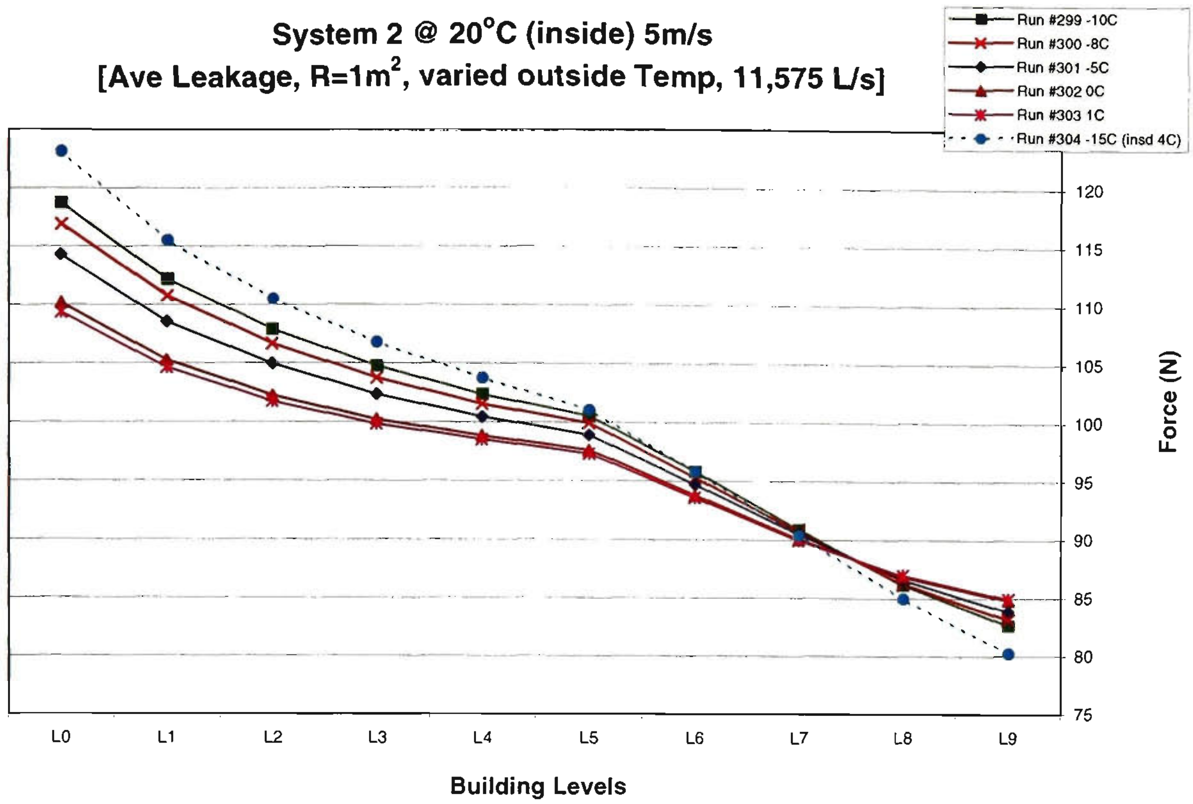


Figure 34a. System 2 - Door Opening Forces using Reduced External Temperatures

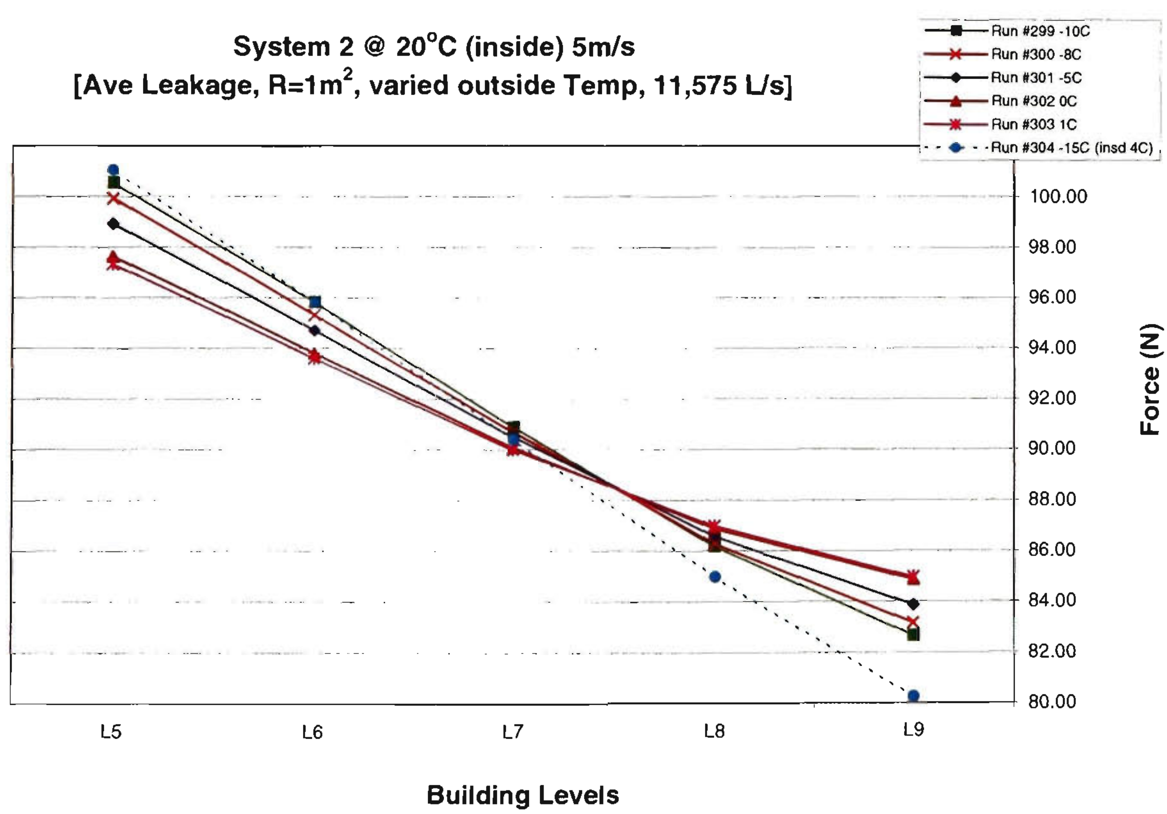


Figure 34b. System 2 - Enlargement (Figure 34a) Door Opening Forces using Reduced External Temperatures

System 1 *[fan speed 3,472 L/s, fixed relief 0.06 m²]* was also modelled with a selection of (extreme wintry) external temperatures (Figure 35). The pattern of results obtained when modelling System 1 were the same as those obtained for System 2, whereby the door opening forces increase per level as the external temperatures reduce. The maximum door opening force obtained was when the external temperature was 1°C. This occurred on L0, with a value of 110.1 N. This *just* exceeds the maximum limit when the second value after the decimal point is used, as per this study. Therefore, another simulation was performed with an external temperature of 2°C and the door opening forces *just* complied (refer to Run #307A, door opening force of 109.6 N on L0).

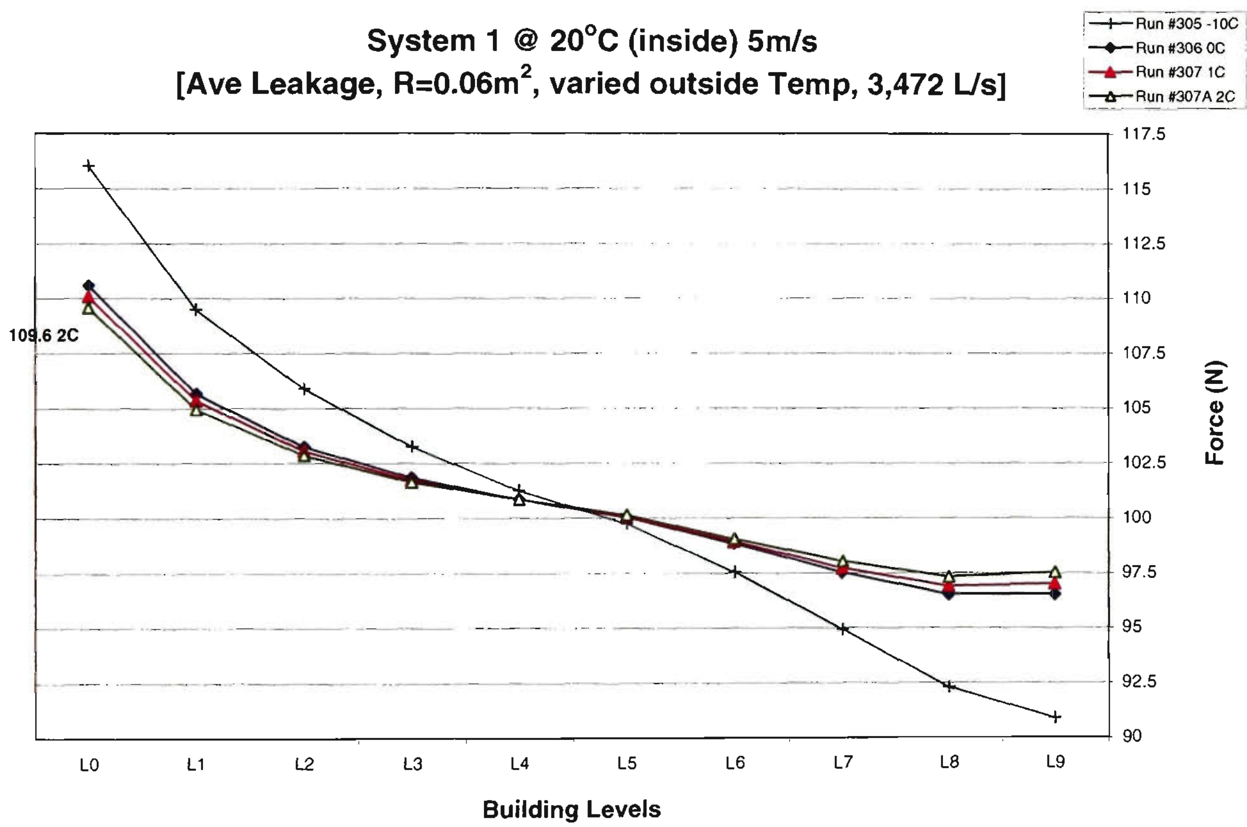


Figure 35. System 1 - Door Opening Forces using Reduced External Temperatures

For the normal stack effect (i.e. when the external temperature is less than the internal temperature, 20°C), Figures 36 and 37 illustrate that in order for *every* floor to pass the door opening force performance condition (110 N), the external temperature needs to be greater than 2°C for System 1 with a VSD however, for System 2, the external temperature can be 1°C.

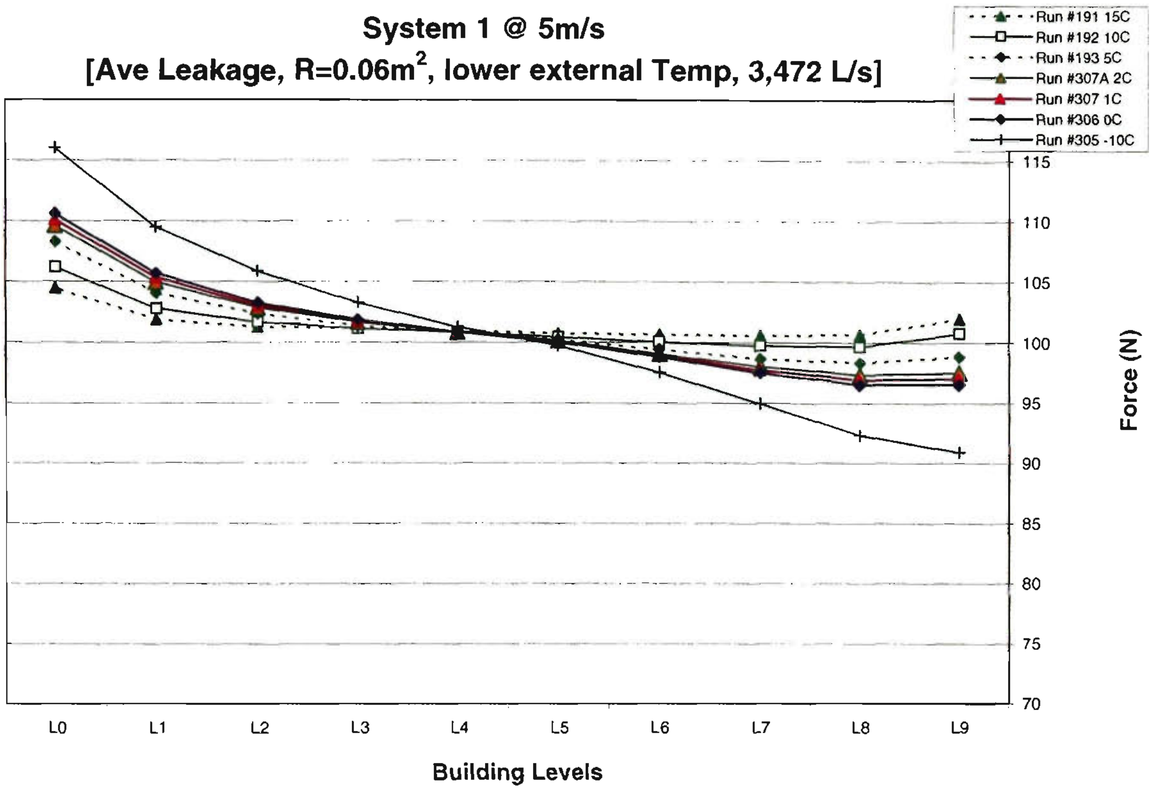


Figure 36. System 1 - Door Opening Forces when the Normal Stack Effect Condition Occurs

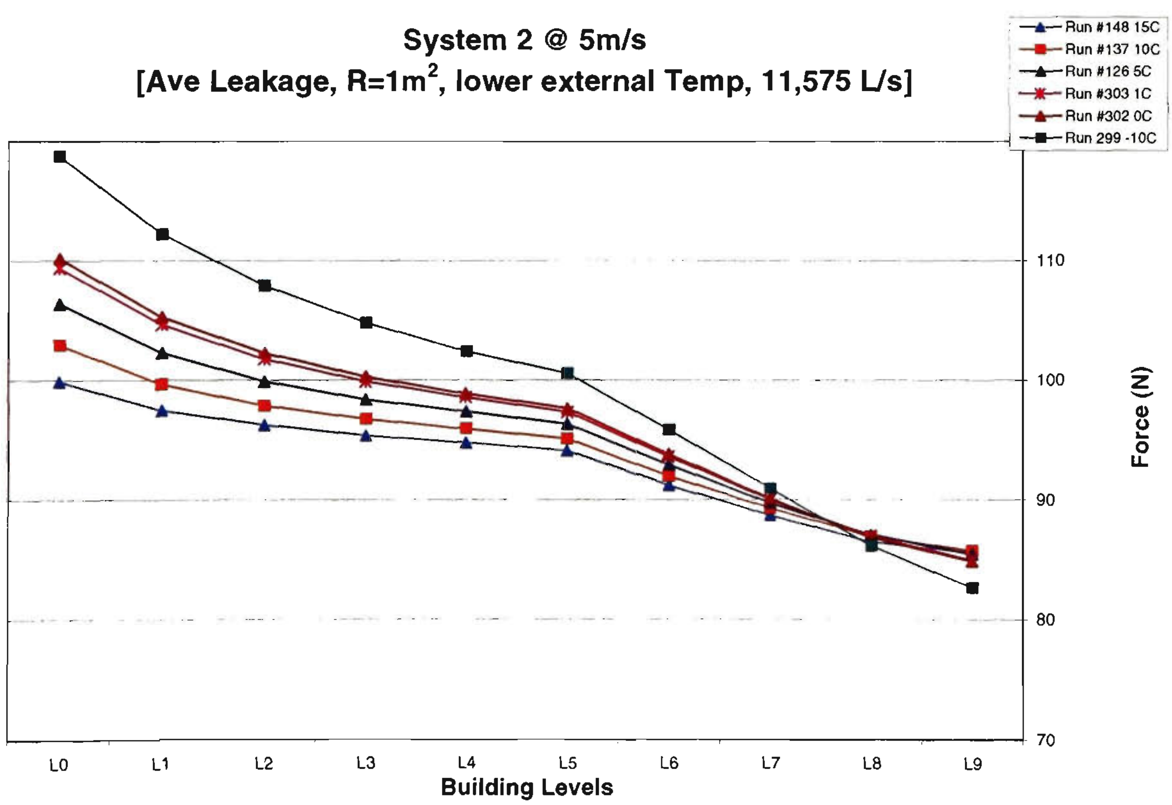


Figure 37. System 2 - Door Opening Forces when the Normal Stack Effect Condition Occurs

7.5.2.4.2. Airflow Velocities

System 2 *[fan speed 11,575 L/s, relief 0.01 m^2]* was modelled using the same range of temperatures adopted in section 7.5.2.4.1. of this thesis. Figure 38 illustrates that as the external temperatures decrease, the airflow velocity on a nominated fire floor (with open stairwell doors on L0, the fire floor and the floor above the fire floor) also decreases. The simulation results of Runs #308 (1°C), #355 (0°C) and #365 (-10°C) in Figure 38 show that on L0, the airflow velocity satisfies the performance condition of 1 m/s. Reducing the effective relief opening to 0 m^2 (as opposed to 0.01 m^2) was found to have some effect of increasing the airflow velocity at L0. However, as explained previously, it is not possible for a barometric damper to have a zero relief opening area.

Figure 38 also shows that when the external temperature is -10°C and the nominated fire floor is L8, the required airflow velocity only *just* passes.

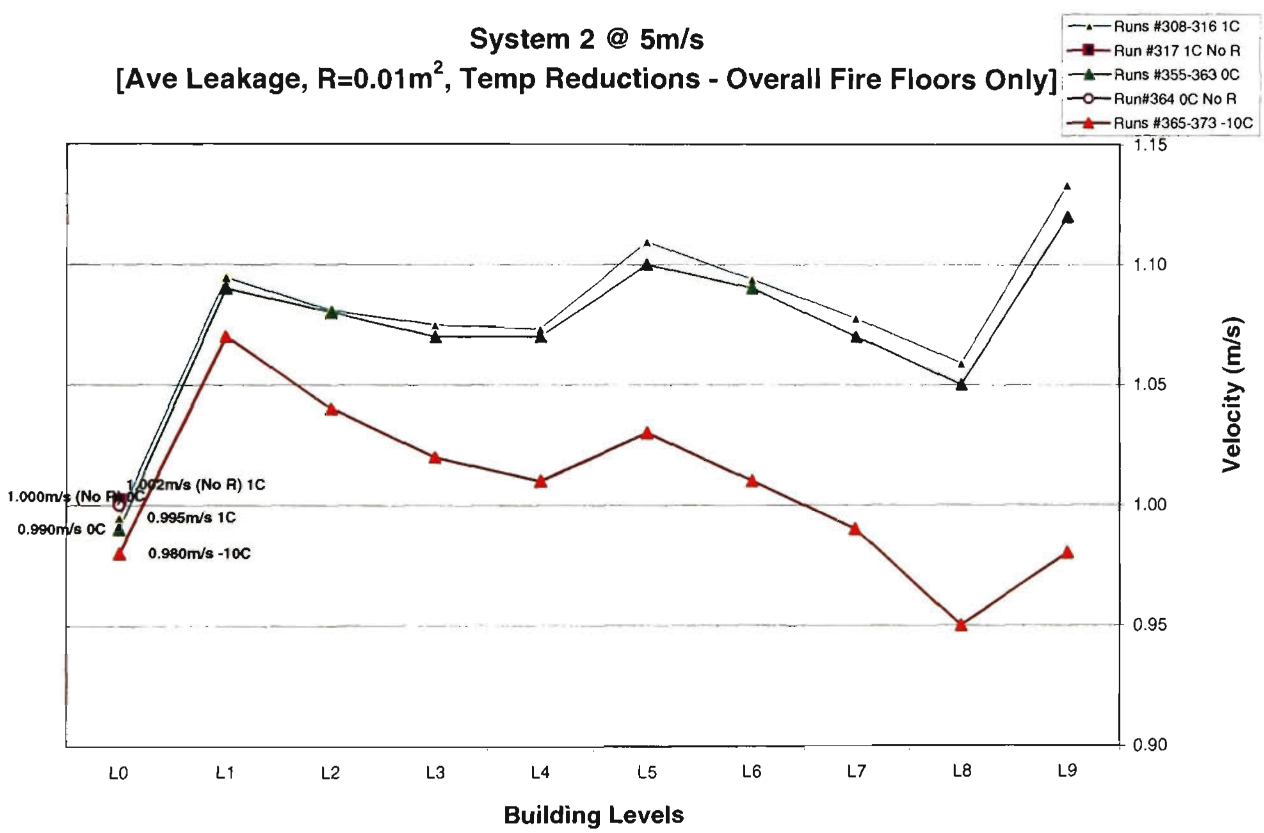


Figure 38. System 2 - Airflow Velocities for Fire Floor building levels using SEW and Reduced Temperatures

Evaluation of System 1 *[fan speed 11,575 L/s, fixed relief 0.06 m^2]* at 0°C shows that the airflow velocity *just* passes on L0 (airflow velocity 0.96 m/s [1.0 m/s]); Run #420, Appendix I. A selection of other fire floors were also assessed under the same conditions and it was found that System 1 can achieve the airflow velocity conditions during the normal stack effect simulations modelled when the external temperature is 0°C (Appendix M, Table M2).

7.5.3. *Combination (Hot and Windy)*

A hot (30°C) and windy (15 m/s) condition was modelled to assess the SPS's sensitivity in terms of the door opening forces and airflow velocities for this situation.

7.5.3.1. Effect of Combination (Hot and Windy) Conditions

7.5.3.1.1. Door Opening Forces

The results for System 1 *[fan speed 3,472 L/s, fixed relief 0.06 m^2]* are presented in Figure 39. The results show that when an external temperature of 30°C and wind speed of 15 m/s was used, the maximum door opening force marginally exceeds the 110 N force conditions on L9 (i.e. Run #204, maximum door opening force 110.6 N). However, if the relief area could have been increased to 0.075 m^2 at the said fan speed, the maximum door opening force would have passed (i.e. Run #205, door opening force 103.2 N); alternatively the fan speed could have been reduced. When the SPF speed was 10% - 20% of the maximum fan supply rate, a relief opening area was not required.

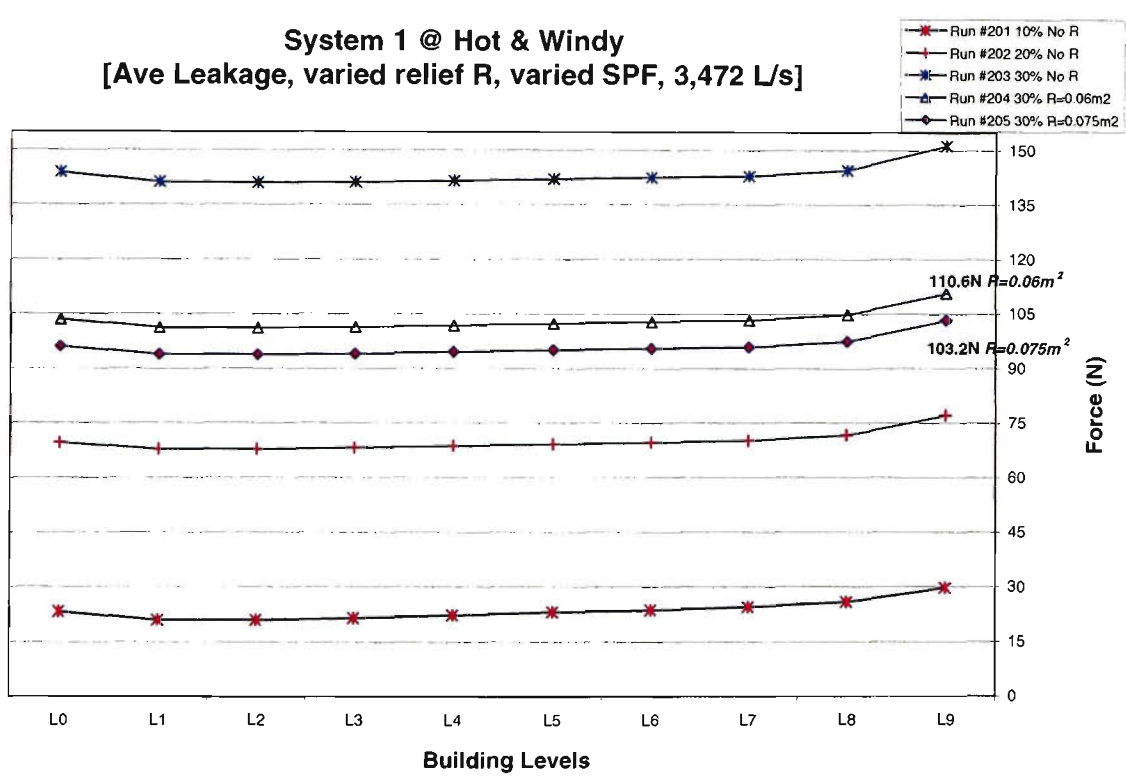


Figure 39. System 1 - Door Opening Forces using a Hot and Windy Condition

In the case of System 2 *[fan speed 11,575 L/s, relief 1 m²]*, Figure 40 shows that the maximum door opening force of 97.6 N was achieved on L0. This is less than the maximum limit (110 N) of the Australian Standard and therefore, System 2 is considered to pass this hot (30°C) and windy (15 m/s) simulation.

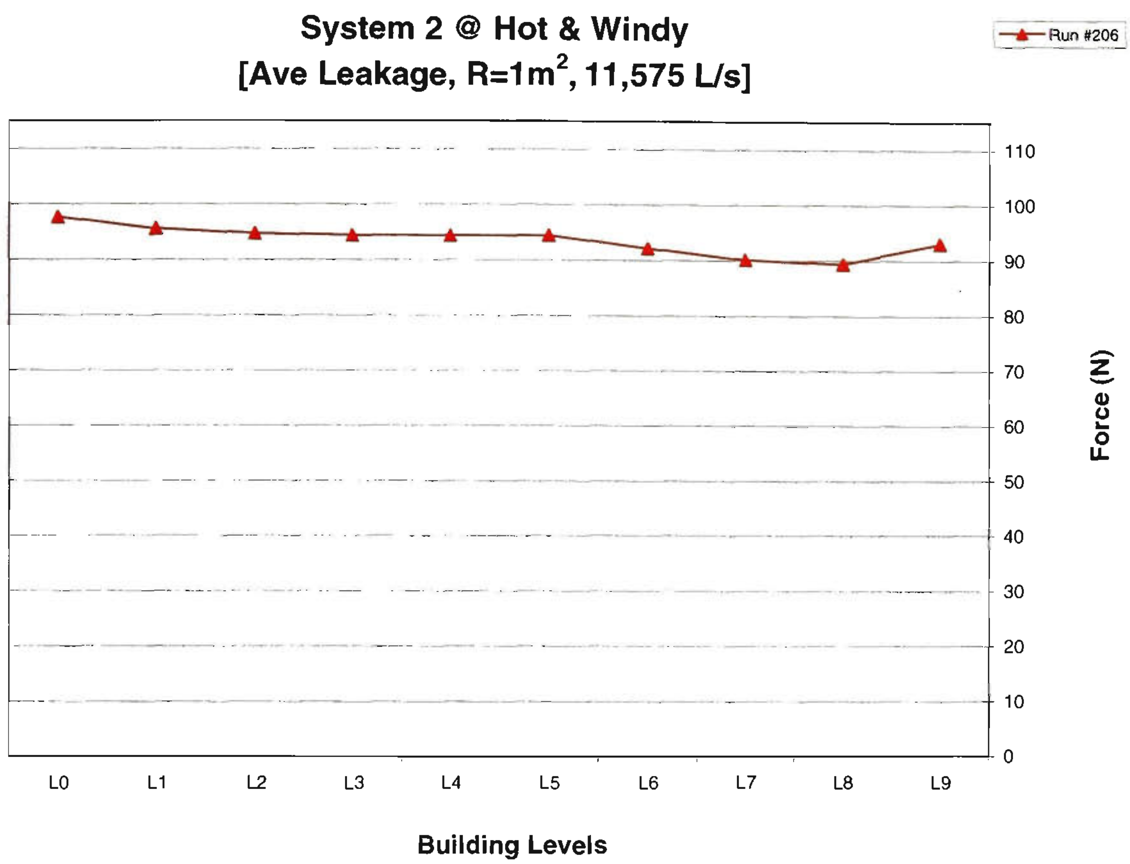


Figure 40. System 2 - Door Opening Forces using a Hot and Windy Condition

<u>7.5.3.1.2. Airflow Velocities</u>

Runs #207-215 in Figure 41 show the airflow velocity results for System 2 *[fan speed 11,575 L/s, relief 0.01 m²]*. In this figure, each floor in turn is nominated as the fire floor and the results show that the airflow performance condition is achieved for each floor. The airflow velocity increased with increasing building level, going from 1.1 m/s on L0 to 1.5 m/s on L9. This is consistent with the airflow velocity diagrams shown previously, showing that the closer the fire floor is to the SPF, the higher the airflow velocities through the nominated fire floor door.

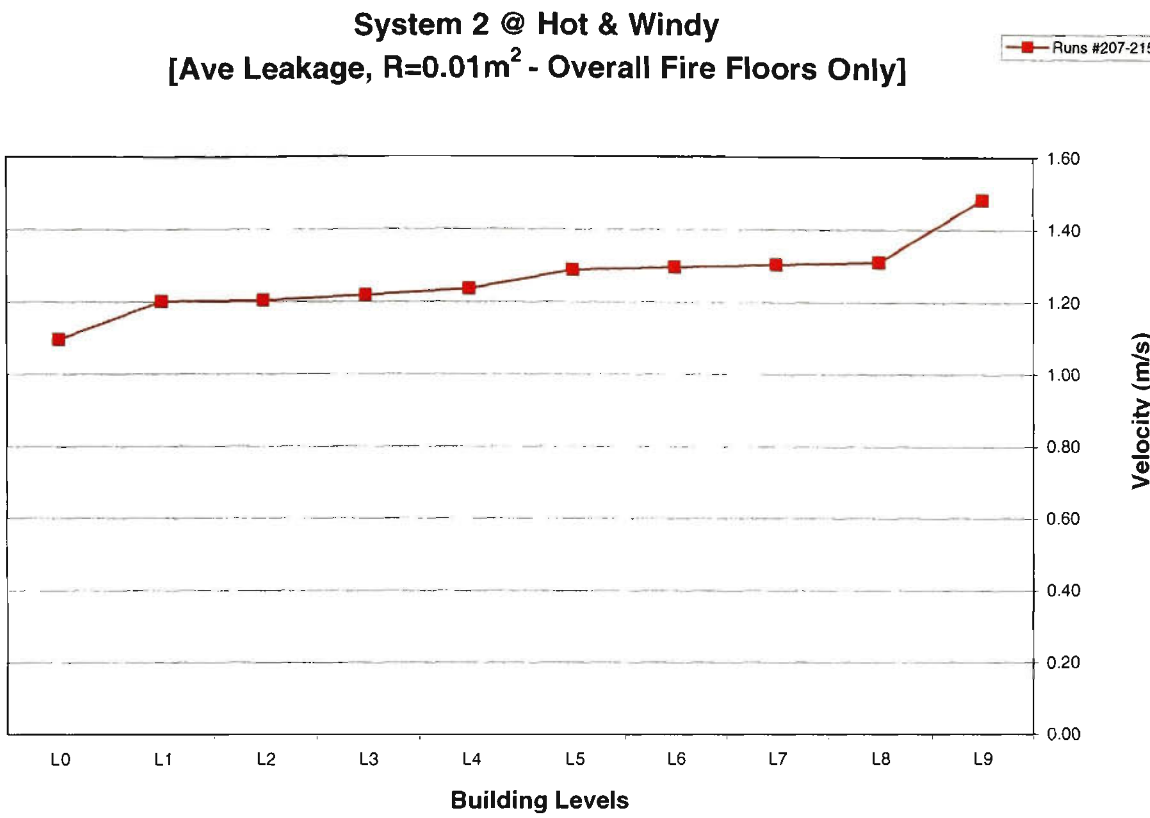


Figure 41. System 2 - Airflow Velocities for Fire Floor building levels using a Hot and Windy Condition

When System 1 *[fan speed 11,575 L/s, fixed relief 0.06 m^2]* was assessed the airflow velocity passed on L0 for the hot and windy condition modelled. This outcome was not analysed directly but interpolated from other analysis results (see Appendix M, Table M2).

7.5.4. Sensitivity to Leakage

The leakage values for both Systems 1 and 2 were modified from being 'Average' values to ranging between 'Average' and 'Loose' values as defined by Klote and Milke (2002). In addition, values '1000% Leakier than the 'Average' values' were considered for some of the simulations. The remaining building variables were set to SETW. Appendix N details how the following leakage values were obtained and Table 20 illustrates the leakage values used for the various building elements.

Table 20. Sensitivity Analysis - Leakage Data

Element Name	(Quart) Leakage Coefficient[56]	(Half) Leakage Coefficient[56]	(3Quart) Leakage Coefficient[56]	(Loose) Leakage Coefficient[57]
Wallext1	2.15×10^{-4}	2.6×10^{-4}	3.05×10^{-4}	0.35×10^{-3}
Wallext2	2.15×10^{-4}	2.6×10^{-4}	3.05×10^{-4}	0.35×10^{-3}
Stwallext	1.7×10^{-4}	2.3×10^{-4}	2.9×10^{-4}	0.35×10^{-3}
Stwallin1	1.7×10^{-4}	2.3×10^{-4}	2.9×10^{-4}	0.35×10^{-3}
Stwallin2	1.7×10^{-4}	2.3×10^{-4}	2.9×10^{-4}	0.35×10^{-3}
Floorleak	8.15×10^{-5}	1.11×10^{-4}	1.405×10^{-4}	0.17×10^{-3}
StrRooflek	1.7×10^{-4}	2.3×10^{-4}	2.9×10^{-4}	0.35×10^{-3}

For some simulations, the leakages of the various building elements were modified consistently (i.e. by the same proportion - hereafter referred to as '**consistent**' changes). The effects of these changes on the door opening forces and airflow velocities are considered in section 7.5.4.1. of this thesis.

Although such changes to leakage may occur over time, it is also possible that changes to leakage may occur to the stair shaft *or* the outside building façade to varying degrees. These effects are referred to as '**selected**' changes and are detailed in section 7.5.4.2. of this thesis.

7.5.4.1. Effect of 'Consistent' Changes to Leakage

Although the leakage values in a building cannot be easily modified or altered once the building is constructed (eg. tightening the construction), the influence of increasing the leakage values from the 'Average' values originally used, has been modelled. Initially, the building element leakage values were proportionally increased from 'Average', 'Quart', 'Half', 3Quart' to 'Loose' values, as listed by Klote and Milke (2002) for all building elements containing leakage with the exception of the *lift wall* leakage (Lftwallint), the *injection shaft roof* leakage (InjSRflek) and the *lift roof* leakage (LftRflek[58]). Table 21 lists the simulation combinations performed.

---

[56] 'Quart', 'Half' and '3Quart' leakage values for *building walls, internal stair walls, external stair walls, internal lift walls, floor leaks,* obtained from Klote and Milke (2002), i.e. between 'Average' and 'Loose' values.

[57] 'Loose' leakage values for *building walls, internal stair walls, external stair walls, internal lift walls, floor leaks,* obtained from Klote and Milke (2002).

[58] For this research, it was assumed that there was no leakage between the stairwell walls and the adjacent injection shaft, or the injection shaft and the occupied space (or the exterior of the building).

Table 21. 'Consistent' Leakage Combinations

Main Building Façade Leakage	Stairwell Wall Leakage
Average Leakage	Average Leakage
Quart (25% Leakier)	Quart (25% Leakier)
Half (50% Leakier)	Half (50% Leakier)
3Quart (75% Leakier)	3Quart (75% Leakier)
Loose (100% Leakier)	Loose (100% Leakier)

7.5.4.1.1. Door Opening Forces

Figure 42 illustrates the results obtained when System 1 *[fan speed 3,472 L/s, fixed relief 0.06 m^2]* was assessed in terms of '**consistent**' leakage increases using the SETW conditions. This figure shows that in all cases modelled, the door opening forces comply with the performance condition of 110 N. The door opening forces actual reduce as the leakage areas increase.

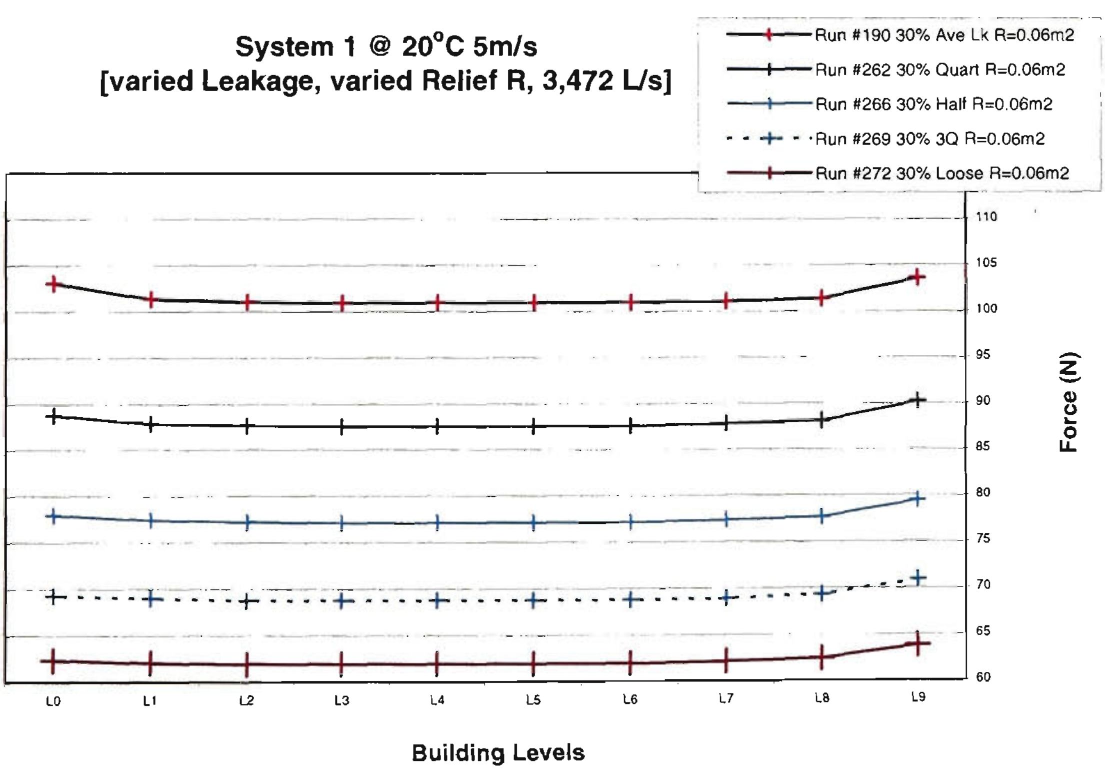


Figure 42. System 1 - Door Opening Forces using SETW and Varied Leakage

For System 2 *[fan speed 11,575 L/s, relief 1 m²]* the results presented in Figure 43 also show compliance with the door opening force conditions of the Australian Standards. In particular, the door opening forces decreased in proportion to the increase in leakage from 'Average' to 'Loose'. For example, the door opening forces for an 'Average' to a 'Quart' leakage increase, have reduced by approximately 2 N, however, when the door opening forces are varied between 'Average' to 'Half' leakage conditions, the results reduce by approximately 5 N.

When System 2 was modelled in terms of the maximum door opening forces for increased leakage values, the resulting pattern displayed in Figure 43 is representative of previous door opening force illustrations for System 2.

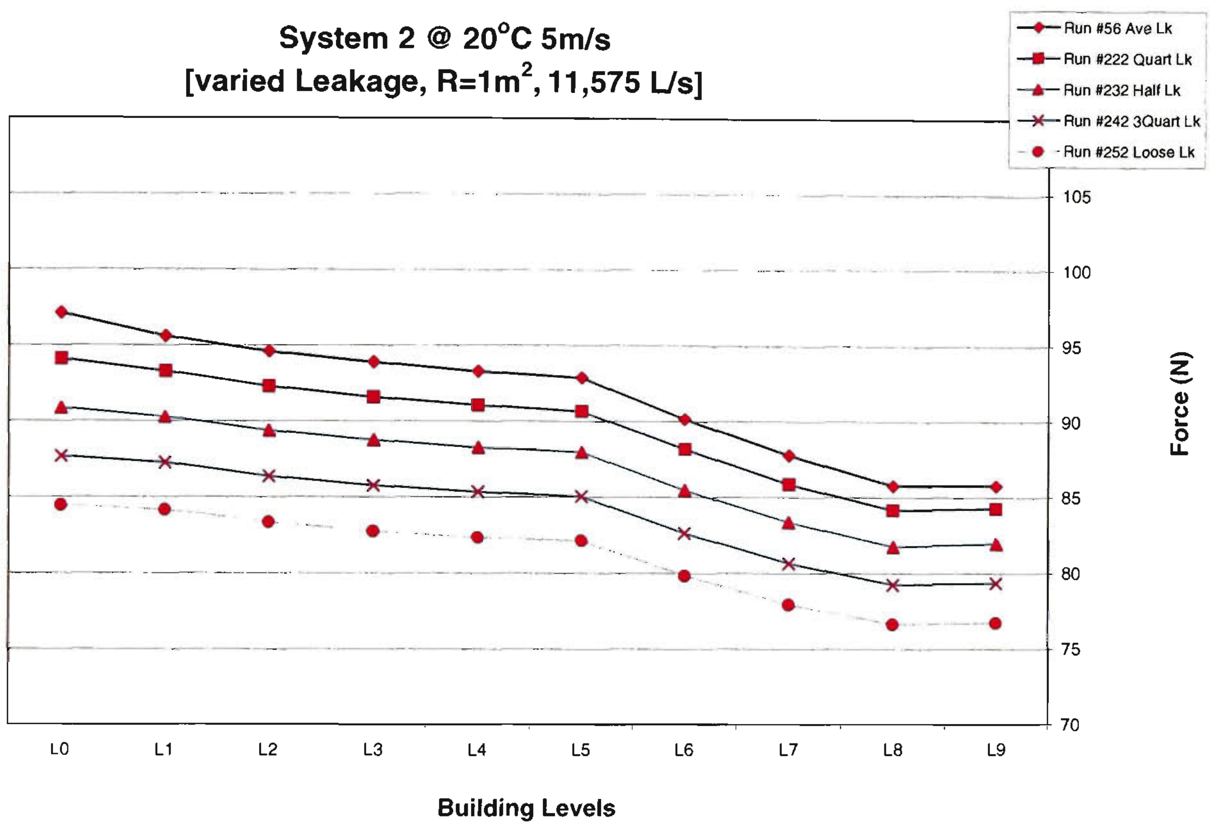


Figure 43. System 2 - Door Opening Forces using SETW and Varied Leakage

7.5.4.1.2. Airflow Velocities

The results for System 2 *[fan speed 11,575 L/s, relief 0.01 m²]* at SETW conditions are presented in Figure 44, where each floor in turn is nominated as the fire floor. For all the '**consistent**' leakage variations modelled, the minimum airflow velocity of 1 m/s was achieved at each fire floor door. Also, the airflow velocities were found to increase per level as the leakage proportionally increases from 'Average' to 'Loose'.

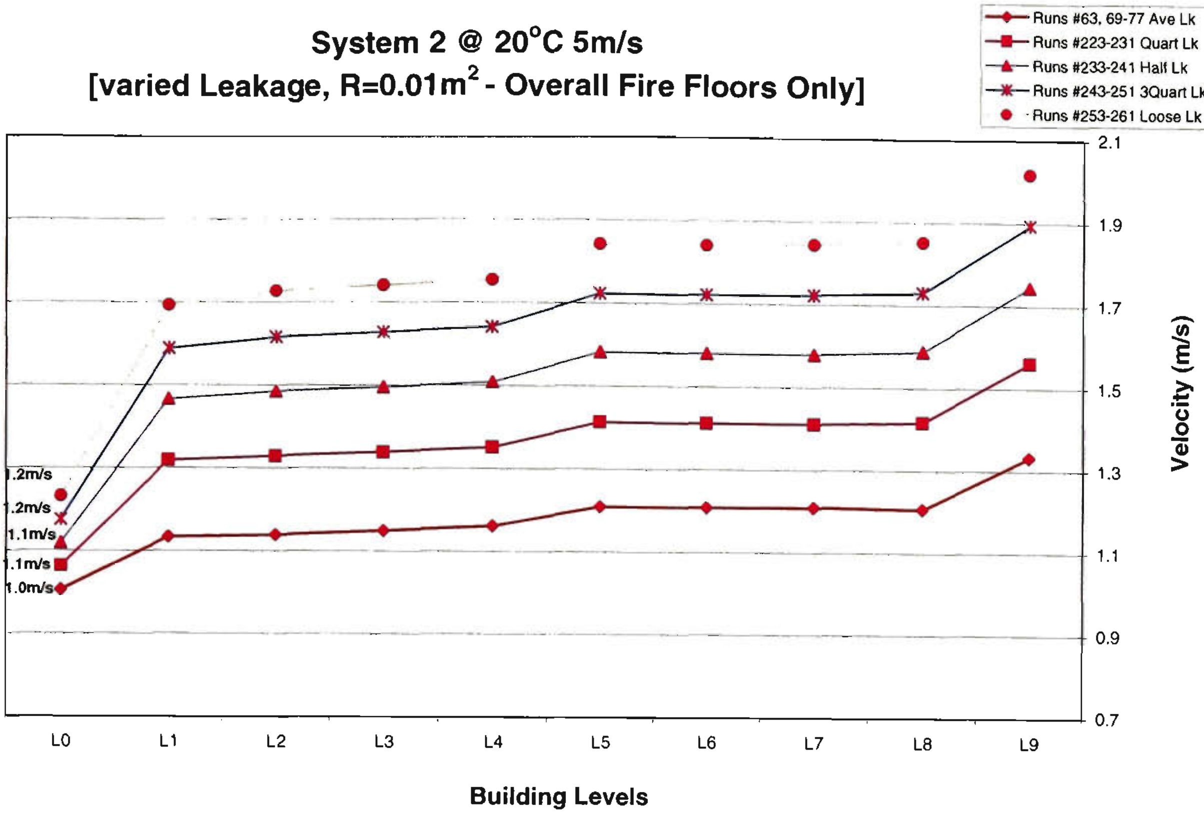


Figure 44. System 2 - Airflow Velocities for Fire Floor building levels using SETW and Varied Leakage

When System 1 *[fan speed 11,575 L/s, fixed relief 0.06 m^2]* was modelled with '**consistent**' leakage increases for the various building elements, the airflow velocity is shown to pass on the nominated fire floor modelled, i.e. L0 (refer to Runs #439, 447-449 listed in Appendix I).

7.5.4.2. *Effect of 'Selected' Changes to Leakage*

For '**selected**' changes to leakage, two situations were considered. The first was where the *stairwell walls* had their leakage values modified whilst those of the *main building façade* elements remained as per the 'base' building model. In this case, the stairwell leakage values were varied between 'Quart' Leakier, 'Half' Leakier and 'Loose' (100% Leakier). The second situation considered was where the *stairwell wall* elements remained as per the 'base' building model, while the *main building façade* leakage elements were varied using only 'Loose' (100% Leakier) and '1000% Leakier than 'Average' values'.

These analyses were performed as the leakage associated with the *stairwell walls* and the *main building façade* elements may change independently of each other. Figure 45 shows the '**selected**' building elements, where the *stairwell wall* elements (in green) were varied independently to the *main building façade* elements (considered in black) and vice-versa. The elements noted with an asterisk (*) in Figure 45 did not have their leakage values varied from the 'base' building model, i.e. 'Average' leakage.

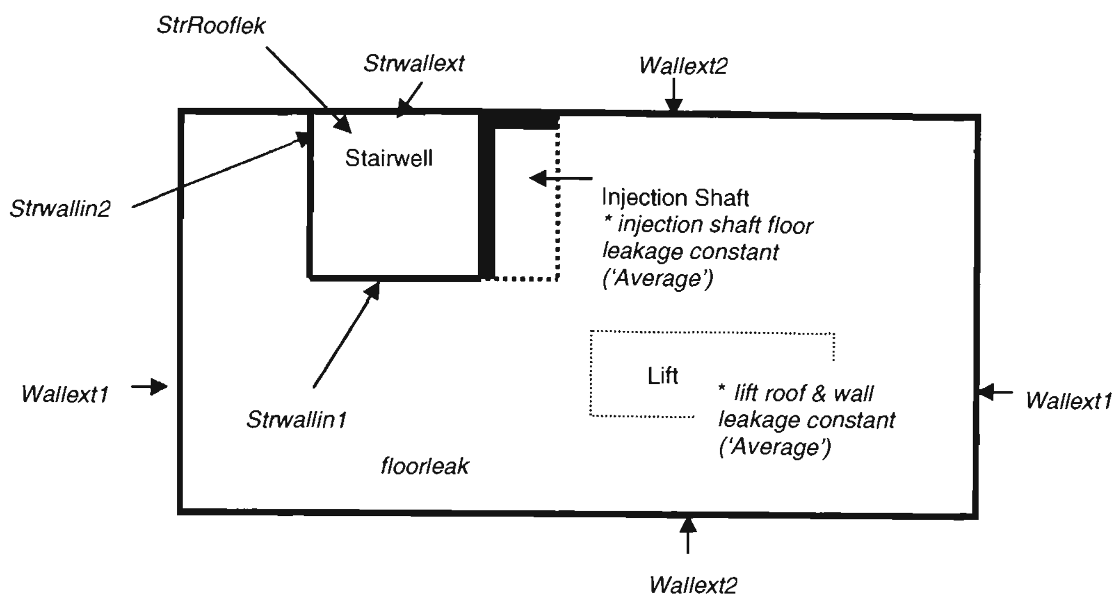


Figure 45. L5 Leakage Boundaries, Stairwell in Green (not to scale)

Table 22 below shows the leakage combinations modelled for '**selected**' leakage variations and the performance conditions modelled for door opening forces and airflow velocities.

Table 22. 'Selected' Leakage Combinations

Main Building Façade Leakage	Main Building Façade Total Leakage Area (m^2)	Stairwell Wall Leakage	Stairwell Wall Total Leakage Area (m^2)	Door Opening Forces Modelled (Y/N)	Airflow Velocities Modelled (Y/N)
Average Leakage	0.1175	Quart (25% Leakier)	0.0233	Y	Y
Average Leakage	0.1175	Half (50% Leakier)	0.0249	Y	Y
Average Leakage	0.1175	Loose (100% Leakier)	0.0281	Y	Y
1000% Leakier than 'Average' values	117.534	Average Leakage	0.0217	N	Y
Average Leakage	0.1175	1000% Leakier than 'Average' values	2.9448	N	Y
Loose (100% Leakier)	0.2434	Average Leakage	0.0217	N	Y
Average Leakage	0.1175	Loose (100% Leakier)	0.0281	N	Y

The simulation combinations noted in Table 22, were modelled using the environmental conditions of SETW. Appendix O describes how the leakage areas were calculated.

7.5.4.2.1. Door Opening Forces

When the door opening forces (with no doors open) were assessed for both Systems 1 and 2, it was identified that as the *stairwell leakage* increased (from 'Quart' to 'Half' to 'Loose') the door opening forces consistently reduced and this performance condition passed. However, the flow through the gaps around the door to the outside at the bottom of the stairwell (i.e. L0) increased. The pressure on the Eastern exterior building wall at this level (L0) also increased. The results are listed in Appendix I.

7.5.4.2.2. Airflow Velocities

In considering the effect on airflow for '**selected**' leakage changes, two floors were nominated as potential fire floors, L0 and L9. L0 was chosen as the simulations thus far have shown that if L0 passes the airflow velocity conditions, then the floors above this level would also pass these conditions and L9 was chosen to confirm this. The simulation results for both SPS are presented in Table 23, where the values in blue show a pass (minimum of 1 m/s), in terms of the airflow velocity performance condition.

In brief, at SETW for System 2 *[fan speed 11,575 L/s, relief 0.01 m^2]* the airflow velocity passes for all levels when the *stairwell* leakage is tighter than the *main building façade* (Runs #463, 465, 494, 534). The exception to this finding is when the *main building façade* or the *stairwell leakage* is extremely leaky (i.e. '1000% Leakier than 'Average' values', Run #455, 467); or when the *stairwell* leakage is 'Loose' (100% Leakier) (Run # 459) and the *main building façade* is 'Average.'

For System 1 *[fan speed 11,575 L/s, relief 0.06 m^2]*, the airflow velocity only passes for each floor when the *stairwell* leakage is considered to have 'Average' leakage while the *main building façade* is considered 'Loose' (100% Leakier). Refer to the simulation Runs #464 and #466 in Table 23.

These simulations also found that if the external façade is extremely leaky then the outside wind (as Easterly wind) will have a much greater influence on airflows within the building.

Table 23. Airflow Velocities for 'Selected' Changes to Leakage

Fire Floor		System 1 (S1)/ System 2 (S2)	Airflow Velocity (m/s)	CONTAM Simulation Run #	Leakage Combinations: Stairwell Walls	Leakage Combinations: Main Building Façade
L0		S2	0.9	459	Loose (100% Leakier)	Average Leakage
L0		S1	0.9	460		
	L9	S2	1.2	461		
	L9	S1	1.2	462		
L0		S2	1.3	463	Average Leakage	Loose (100% Leakier)
L0		S1	1.2	464		
	L9	S2	2.1	465		
	L9	S1	2.0	466		
L0		S2	0.2	467	1000% Leakier	Average Leakage
L0		S1	0.2	468		
	L9	S2	0.3	469		
	L9	S1	0.3	470		
L0		S2	0.8	455	Average Leakage	1000% Leakier
L0		S1	0.8	456		
	L9	S2	1.0	451		
	L9	S1	1.0	458		
L0		S2	1.0	494	Quart (25% Leakier)	Average Leakage
L0		S1	0.9	508		
	L9	S2	NS	NS		
	L9	S1	NS	NS		
L0		S2	1.0	534	Half (50% Leakier)	Average Leakage
L0		S1	0.9	545		
	L9	S2	NS	NS		
	L9	S1	NS	NS		

NS refers to No Simulation, i.e. no CONTAM simulation conducted

7.6. Overview of Building Models Analysed

Table 24 summarises the cases analysed and the results obtained for each Study Group described in section 7.5. of this thesis. These results are discussed further in section 7.6.1. of this thesis.

The 'base' building model developed incorporated the typical features of Systems 1 and 2 (refer to Chapter 3.) and was created such that the performance conditions, specifically in terms of door opening forces and airflow velocities, complied with the design standard AS1668.1. In brief, System 1 has a VSD to control the SPF speed as well as a fixed relief opening. System 2 has a dump-back damper for the constant speed SPF. Both forms of stairwell relief were modelled via a grille/vent in the stairwell shaft located on L9. This relief (exhaust) grille vented air from the stairwell shaft to the outside of the building.

Appendix I lists all of the CONTAM simulations performed and the airflow and maximum door opening force results obtained. In total, more than 600 CONTAM simulations were conducted in order to obtain the results presented in this thesis.

Table 24. Study Group Simulations and Associated Variables

Study Group	Wind (m/s)	Wind Direction	Temperature (°C)		Fan Speed (L/s)	Leakage	(Effective) Relief Damper (m²)
			Internal	External			
1 (Sys 2 set-up-SETW) Runs #56, 63, 69 – 77	5	East	20	20	11,575	*Constant* for external building wall, stairwell wall & door gap (closed)	Door Force = 1 Airflow Velocity = 0.01
2 (Sys 1 set-up, SETW) Runs #275 – 298, 322, 329	"	"	"		Varies (from 1,157 to 5,787)	"	Door Force = 0.06 Airflow Velocity = 0.06 (for fan 11.5 i.e. like Sys 2)
3 (Sys 2, Vary Wind) Runs #56, 63, 69 – 77, 79 – 121, 122 – 123, 124	Varies (from 5 to 15, 30)	"	"	"	11,575	"	Door Force = 1, 1.1 Airflow Velocity = 0.01
(Sys 1, Vary Wind) Runs #190, #194 – 200, 318 - 321	"	"	"	"	Varies (from 1,157 to 3,472)	"	Door Force = 0.06, 0.075 Airflow Velocity = 0.06 (for fan 11.5 i.e. like Sys 2)
4 (Sys 2, Vary Temp Up/Down) Runs #126 – 180/ #299 – 373	5	"	"	Varies (from -10, -8, -5, 0, 1, 5, 10 to 15) / 25, 30	11,575	"	Door Force = 1 Airflow Velocity = 0.01 (upper relief limit at 25°C #169, < 0.05)
(Sys 1, Vary Temp Up/Down) Runs #181 – 193 /#305 - 307	"	"	"	Varies (from -10, 0, 1, 2, 5, 10 to 15) / 25, 30	3,472	"	Door Force = 0.06 Airflow Velocity = 0.06 (for fan 11.5 i.e. like Sys 2)
5 (Sys 2, Hot & Windy) Runs #206 - 215	15	"	"	30	11,575	"	Door Force = 1 Airflow Velocity = 0.01
(Sys 1, Hot & Windy) Runs #201 - 205	"	"	"	"	Varies (from 1,157 to 3,472)	"	Door Force = between 0.06-0.075 Airflow Velocity = 0.06 (for fan 11.5 i.e. like Sys 2)
6 (Sys 1 & 2, Vary Wind Direction) Runs #56, 190, 216 - 221	"	Varies (from North, South, East and West)	"	20	Bldg 1 = 3,472 Bldg 2 = 11,575	"	Sys 1, Door Force = 0.06 Sys 2, Door Force = 1
7 'consistent' changes (Sys 2, Leakages) Runs #56, 63, 69-77, 222 – 261, 381 - 418	"	East	"	"	11,575	*Increases* for external building wall, stairwell wall & door gap (closed)	Door Force = 1 Airflow Velocity = 0.01
(Sys 1, Leakages) Runs #262 – 274, 374 - 397, 419 - 453	"	"	"	"	3,472	"	Varies Door Force = 0.06 Varies Airflow Velocity = 0.01, 0.06)
7 'selected' changes (Sys 2, Leakages) Runs #482 - 507, 526 - 570	"	East	"	"	11,575	*Increases* for external building wall, stairwell wall & door gap (closed)	Door Force = 1 Airflow Velocity = 0.01
(Sys 1, Leakages) Runs #455 – 481, 508 - 575	"	"	"	"	3,472	"	Varies Door Force = 0.06 Varies Airflow Velocity = 0.01, 0.06

7.6.1. Results – Building Models Analysed

As presented previously in section 7.4.4. of this thesis, the 'base' building model at SETW conditions of 20°C and 5 m/s, resulted in the following SPS designs:

- System 1 Door Opening Forces (no doors open), Fan speed 3,472 L/s, Relief 0.06 m^2

  Airflow Velocity (three doors open), Fan speed 11,575 L/s, Relief 0.06 m^2

- System 2 Door Opening Forces (no doors open), Fan speed 11,575 L/s, Relief 1 m^2

  Airflow Velocity (three doors open), Fan speed 11,575 L/s, Relief 0.01 m^2 (i.e. effectively closed)

From the sensitivity studies conducted (Study Groups 3-7) and the 'base' building system simulations developed (Study Groups 1 and 2), the following can be concluded:

- If the **external wind speed increases** from 5 m/s to 15 m/s, the door opening forces and airflow velocity conditions pass for both Systems;

  The maximum door opening force was 106.7 N at 15 m/s for System 1. Wind speed increases assisted in achieving an airflow velocity of 1 m/s on the nominated fire floor, the door opening forces also increased as the wind speed increased.

  For the maximum wind speed of 30 m/s, the door opening forces only pass for System 1 on L1-L8. If the fan speed could have been reduced to less than 3,472 L/s (or the relief increased), then the door opening forces for this particular assessment would have passed. For System 2, the door opening forces were excessive on L0. For the airflow velocity assessment, both Systems pass when the fire floor is considered to be on L0.

- For **varied wind directions** the door opening force conditions pass for both Systems.

  Note: Only the Easterly wind direction was (generally) considered in terms of the CONTAM simulations.

- If the **external temperature increases** from 5°C to 30°C **(and for the reverse stack effect)**, the door opening forces and airflow velocity conditions pass for both Systems. The maximum door opening force obtained was for System 1 (108.3 N at 5°C). Overall, increases in external temperatures assisted in achieving 1 m/s on the fire floor.

- If the **external temperature reduces (and for the normal stack effect)** from 1°C to -10°C (i.e. wintry conditions), the door opening forces pass for temperatures down to 1°C for System 2, while for System 1 the door opening forces pass down to 2°C. For the airflow velocity assessment, System 2 passes at a minimum external temperature of 1°C and System 1 *just* passes at 0°C (i.e. 0.97 m/s became 1 m/s).

- For a **hot and windy condition,** the door opening force did not pass for System 1 (on L9) at the lowest fan speed setting of 3,472 L/s. The door opening forces pass for System 2 with all doors closed. The airflow velocity conditions pass for both Systems.
- For '**consistent' leakage increases** the door opening forces and airflow velocities pass for both Systems.

  Note: The *stairwell* leakage is approximately 1/5th of the *main building façade* leakage when both are at 'Average' leakage conditions (refer to Appendix O for calculations).
- For '**selected**' **leakage increases** the door opening forces pass for System 1 and generally for System 2 (with some temperature limitations), however the limited airflow velocities modelled generally do not pass for all nominated fire floor levels.

Table 25 summarises these findings.

Table 25. Summary of Findings

Study Group	Variable	Door Opening Force Performance Achieved (max 110 N) & 0.06 m² — System 1	Door Opening Force Performance Achieved (max 110 N) & 1 m² — System 2	Airflow Velocity Performance Achieved (1 m/s) System 1 & 0.06 m² (fixed)	Airflow Velocity Performance Achieved (1 m/s) System 2 & 0.01 m² (barometric)
1. System 2	SETW		✓		✓
2. System 1	SETW	✓		✓	
3. Wind Increase	5 m/s	✓	✓	✓ L0 just passes (0.967 m/s)	✓
	7.5 m/s	✓	✓	✓	✓
	10 m/s	✓	✓	✓	✓
	12.5 m/s	✓	✓	✓	✓
	15 m/s	✓	✓	✓	✓
	30 m/s	L0, L9 does not pass	L0 does not pass	✓ L0 only floor modelled	✓ L0 only floor modelled (Main discharge door force high)
4. External Temperature Increase	5°C	✓	✓	just passes on L0 (0.962 m/s)	just passes on L0 (0.997 m/s)
	10°C	✓	✓	✓	✓
	15°C	✓	✓	✓	✓
	20°C	✓	✓	✓	✓
	25°C	✓	✓	✓	✓
	30°C	✓	✓	✓	✓
Stack Effect – Reverse	25°C	✓	✓	✓	✓
	30°C	✓	✓	✓	✓

Table 25. Summary of Findings (continued)

Study Group	Variable	Door Opening Force Performance Achieved (max 110 N) & 0.06 m² System 1	Door Opening Force Performance Achieved (max 110 N) & 1 m² System 2	Airflow Velocity Performance Achieved (1 m/s) System 1 & 0.06 m² (fixed)	Airflow Velocity Performance Achieved (1 m/s) System 2 & 0.01 m² (barometric)
4. External Temperature Reduction	2°C	✓	NT	✓	NS
	1°C	L0 does not pass (110.080 N)	✓	✓	just passes on L0 (0.995 m/s)
	0°C	L0 does not pass	L0 does not pass	just passes on L0 (0.959 m/s)	L0 does not pass
	-5°C	NS	L0 does not pass	NS	NS
	-8°C	NS	L0, L1 does not pass	NS	NS
	-10°C	L0 does not pass	L0, L1 does not pass	X	L0, L7, L8, L9 does not pass
	-15°C	NS	L0, L1, L2 does not pass	NS	NS
Stack Effect – Normal	15°C	✓	✓	✓	✓
	10°C	✓	✓	✓	✓
	5°C	✓	✓	✓	just passes on L0 (0.997 m/s)
	2°C	✓	NS	✓	NS
	1°C	L0 does not pass (110.080 N)	✓	✓	just passes on L0 (0.995 m/s)
	0°C	L0 does not pass	L0 does not pass	just passes on L0 (0.959 m/s)	L0 does not pass
	-5°C	NS	L0 does not pass	NS	NS
	-8°C	NS	L0, L1 does not pass	NS	NS
	-10°C	L0 does not pass	L0, L1 does not pass	X	L0, L7, L8, L9 does not pass
5. Combination Hot & Windy	30°C & 15 m/s	L9 does not pass	✓	✓	✓
6. Wind Directions	N	✓	✓	NS	NS
	S	✓	✓	NS	NS
	E	✓	✓	✓	✓
	W	✓	✓	NS	NS
7. Leakage Increase ('consistent' changes)	Quart Half 3Quart Loose	X X X X	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓
7. Leakage Increase ('selected' changes) @ high stairwell leakage with respect to 'Average' main building façade leakage	Quart Half 3Quart Loose 1000%	✓ ✓ NS ✓ NS	✓ (>= 15°C) ✓ (>= 10°C) NS ✓ (>= 0°C) NS	X X NS ✓ limited analysis	✓ (>= 0°C) X NS X limited analysis

NS refers to No Simulation, i.e. no CONTAM simulation conducted

X refers to Does Not Pass

✓ refers to Simulation passes performance condition

7.7. Discussion of Findings (E-factors)

In this section of the effectiveness evaluation, it has been assumed that the SPS has been properly designed and commissioned with respect to the 'base' building. The probability that a SPS does not work is considered as part of the effectiveness assessment in the next chapter.

In order to assess the effectiveness of the SPS with respect to variations in wind and temperature, it was necessary to also take into account the probability of having particular values of wind and temperature. These have been calculated, based on the data obtained from the Bureau of Meteorology (http://www.bom.gov.au/climate) over a 12-month period for Melbourne (see Appendix M, Table M1). In brief, if the door opening forces or airflow velocity results obtained using CONTAM satisfied the performance conditions, then the SPS was considered to pass for the condition modelled. If the simulation modelled passed, the probability of occurrence in terms of the external weather data was then used so that this component of the effectiveness assessment could be calculated. The temperature and wind speeds were assumed to be independent of each other.

It was not possible to determine how likely and to what extent the building leakage would change with time therefore, no attempt was made to determine the likelihood of any such changes.

The results of these calculations, in terms of SPS effectiveness, considering the wind, temperature and leakage variations (i.e. the E-factors) are presented in Tables 26a and 26b.

In the Table, an effectiveness of '1' indicates that the performance condition has been achieved. The effectiveness values for '1000% Leakier than 'Average' values' were not calculated in detail as only two levels, L0 and L9, were assessed in order to obtain an *indication* of its influence.

Table 26a. Effectiveness at Varied Conditions with 'Consistent' Leakage Changes

LEAKAGE	EFFECTIVENESS at Varied Conditions (consistent)			
	SYSTEM 1		SYSTEM 2	
	Door Opening Force	Airflow Velocity	Door Opening Force	Airflow Velocity
AVERAGE (as assumed)	0.9981	1	0.9971	1
Quart (25% Leakier)	1	1	0.9998	1
Half (50% Leakier)	1	1	1	1
3/4Quart (75% Leakier)	1	1	1	1
Loose (100% Leakier)	1	1	1	1

Table 26b. Effectiveness at Varied Conditions with 'Selected' Leakage Changes

LEAKAGE for Stairwell walls *(while main bldg remains at Ave Leakage)*	**EFFECTIVENESS at Varied Conditions (selected)**			
	SYSTEM 1		**SYSTEM 2**	
	Door Opening Force	**Airflow Velocity**	**Door Opening Force**	**Airflow Velocity**
AVERAGE (as assumed)	0.9981	1	0.9971	1
Quart (25% Leakier)	1	0.3379	1	1
Half (50% Leakier)	1	0.1300	1	0.8435
Loose (100% Leakier)	1	0.0400	1	0.1300

As should have been noted throughout this chapter, it appears to be extremely rare that changes to environmental conditions (wind and temperature) have any significant effect on the CONTAM results for door opening forces or the ability to achieve the airflow velocity conditions at a door. Accordingly, the effectiveness values with respect to temperature and wind speed variations are '1' or very close to this number.

This outcome appears to be in conflict with anecdotal evidence and personal experience associated with SPS.

In Chapter 5, it was noted that it is common to avoid the testing of SPS on windy (gusting) days as the system may be unstable and it may be difficult to obtain stable readings. These effects appear to be related to the positioning of air intakes or dampers such that wind gusting has a direct impact on their performance creating pressure fluctuations within the shaft. Such effects could not be modelled with CONTAM and therefore, have not been assessed in this thesis. Clearly if such effects are common, the effectiveness on windy days will be less than that suggested in this chapter.

The location and shielding of the SPS equipment would appear to be an important design consideration. This aspect is noted by Klote and Milke (2002) and should be seen as a topic for future research.

Table 26b shows that increased leakage of the stairwell can have a significant effect on the ability of the SPS to achieve the airflow velocity criteria of 1 m/s. The apparently inferior performance of System 1 compared with System 2 is due to the fact that System 1 has a fixed vent size of 0.06 m^2 whereas for System 2, the damper can close to 0.01 m^2.

8. THE INFLUENCE OF OTHER FACTORS ON EFFECTIVENESS (F-factors)

8.1. Introduction

The impact of 'other factors' (F-factors) on the effectiveness of stair pressurisation systems (SPS) is now considered. Specifically, the influence of the uncertainties associated with these factors on whether the SPS will achieve each of the performance conditions of Australian Standard (AS) AS1668.1 is determined.

The evaluation presented in this chapter does not, of course, consider the impact of the factors considered in the previous chapter as these were considered in that chapter. As noted in Chapter 6, the effectiveness of SPS associated with the F-factors will be influenced by the design of the SPS (adequate or not), the installation (addressed as part of commissioning) and faults with the equipment which may develop over time (addressed as part of maintenance).

This chapter explains the development of a technical survey, how the fault tree (presented originally in Chapter 6) was expanded and used as the basis for the effectiveness assessment, as well as presenting the effectiveness results.

8.2. Survey Development

In general, reliability data is obtained as a result of testing whether or not a component will work. This data is usually presented as a result of numerous tests on a component eg. a switch, within a controlled environment, such as a laboratory. In order to obtain real 'industry' data associated with the operational aspects and specific components of a SPS, a survey approach was adopted. This was because such 'industry' knowledge associated specifically with (complex) SPS is not readily available via (traditional) published means such as reference books, eg. Lees (1980b).

The survey questions used were based on the problems identified within the history profiles for Systems 1 and 2 (refer to section 5.5 of this thesis) and the fault tree presented in the forthcoming section. The survey was completed (via correspondence) by industry personnel such as designers, maintenance contractors, etc., from organisations that are intimately associated with SPS.

The aim of the survey was to try and obtain as much 'industry' knowledge as possible, in terms of failure probabilities for all aspects of a SPS eg. faults associated with wiring, relays, dampers, pressure sensors, variable speed drives (VSD), programming, etc.

Since the survey was to be completed by industry participants experienced in visiting buildings with SPS to undertake commissioning or maintenance,[59] the results are therefore, only applicable to buildings which are visited for such purposes. Consequently, the data would be expected to present an optimistic view for buildings that have never been commissioned and are not maintained.

Once the survey was completed, it was returned to the author and the data was analysed (for inclusion into the fault tree given in section 8.3. of this thesis). In total, 12 people responded to the survey (out of a possible 51).

8.2.1. Survey Description

The survey questions relate to the 'other factors' (the F-factors), which could influence the effectiveness of a SPS. The survey itself was divided into the following general categories, for ease of data collection:

- Section A Power
- Section B Components
- Section C Commissioning
- Section D Other (i.e. Miscellaneous)

Each part of the survey had questions related to the probability of failure of an item or component. This probability of failure was determined by requesting the survey respondent to identify 'how many times out of 100 inspections of a component (eg. the fire indicator panel [FIP]), would the component fail'. By requesting the data in this manner, the benchmark was always consistent (eg. 100 inspections) and the results could be averaged if required, and collated in terms of a percentage. The data was based on "expert opinion" as opposed to reviewing documentation related to failures, as such detailed information was not available via the literature.

Section A (Power) of the survey, was concerned with the types of primary and secondary power used for various components eg. the FIP, VSD, etc., as well as an assessment of their failure probability.

[59] In terms of maintenance, this could either refer to routine (programmed) maintenance as per AS1851.6 or 'soon to be maintained' systems, where the latter refers to a SPS which may not have been maintained previously, however a contractor has recently been employed to start maintaining the system.

Section B (Components) was further divided into:

- Wiring/Cabling issues
- Relays
- Pressure sensors
- Dampers
- Stair pressurisation fans (SPF)
- The FIP
- Unimods/High level interfaces (HLI)
- Damper Motors/Actuators
- VSD
- Doors

Each of the sub categories listed above were assessed in terms of the types of faults which may render the SPS inoperable of achieving the particular performance conditions of AS1668.1. The survey respondents were also asked when the faults were identified (eg. after installation, during commissioning, during routine maintenance, during testing, by others, etc).

Section C of the survey related to Commissioning. Questions were related to how commissioning is undertaken and what may/may not work for a non-commissioned system.

The final section of the survey, Section D (Other), was the smallest part of the survey and questioned the respondent as to the frequency of occurrence for specific activities eg. additional holes/leakages being identified in the stairwell shaft, etc., as well as a description of the most reliable SPS (based on their experience). The actual survey responses are given in Appendix P.

8.3. Fault Trees

Due to the complexity of a SPS, and in order to identify the various components of a SPS, a fault tree was used to illustrate the operation of a SPS. Fault tree analysis represents a deductive process where the basic underlying components related to the operation of a complex system are represented. Each node in the tree represents an outcome. The top outcome is then decomposed to sub outcomes, which have their own sub outcomes and so on. These sub outcomes may either contribute solely to resulting in a failure (where they are considered as an 'OR' outcome) or may only result in failure if other parallel sub outcomes also fail (where they are considered as 'AND' outcomes).

Once the probability data was obtained for the various components of the fault tree through the survey and other sources (see section 8.4. of this thesis), the Gate-by-Gate (Guidelines for Chemical Process Quantitative Risk Analysis 2000) technique was used to calculate the various branches of the fault tree, culminating with the top outcome or event, for which the overall probability of failure can be calculated for the SPS associated with Systems 1 and 2. The end outcomes considered in this chapter are the specific performance conditions of AS1668.1.

8.3.1. *Fault Trees for Each System*

The stair pressurisation and alarm systems in both Buildings 1 and 2 have been studied in great detail in order to construct diagrams showing the interrelationship between the various components associated with activating and operating a SPS. The interrelationship diagrams were first presented in Chapter 3 (Figures 13 and 14) and are essential if potential fault sources are to be identified for a complex SPS. The fault tree presented in Chapter 6, when the concept of effectiveness was discussed is expanded in Figure 46 and represents the possible combined elemental faults associated with both Systems 1 and 2. Each of the boxes in the fault tree identifies a possible fault with the SPS, which could prevent the Australian Standard performance conditions from being met. A description of each of the fault tree boxes is provided in Appendix F.

The dotted boxes/lines shown in Figure 46 illustrate the components related to a building's smoke control system (SCS) if a zone smoke control system (ZSCS) is installed (as per Building 2). This information has been included for completeness however, for the purposes of this research and as previously stated, the building's SCS has been ignored and therefore, the dotted boxes/lines are not incorporated in the fault tree calculations to follow (or subsequent fault tree diagrams).

The boxes highlighted in grey relate to the factors considered in Chapter 7 (E-factors) where their exclusive influence on effectiveness was considered on the basis of the CONTAM analysis. As noted previously, this chapter only considers the influence of the F-factors.

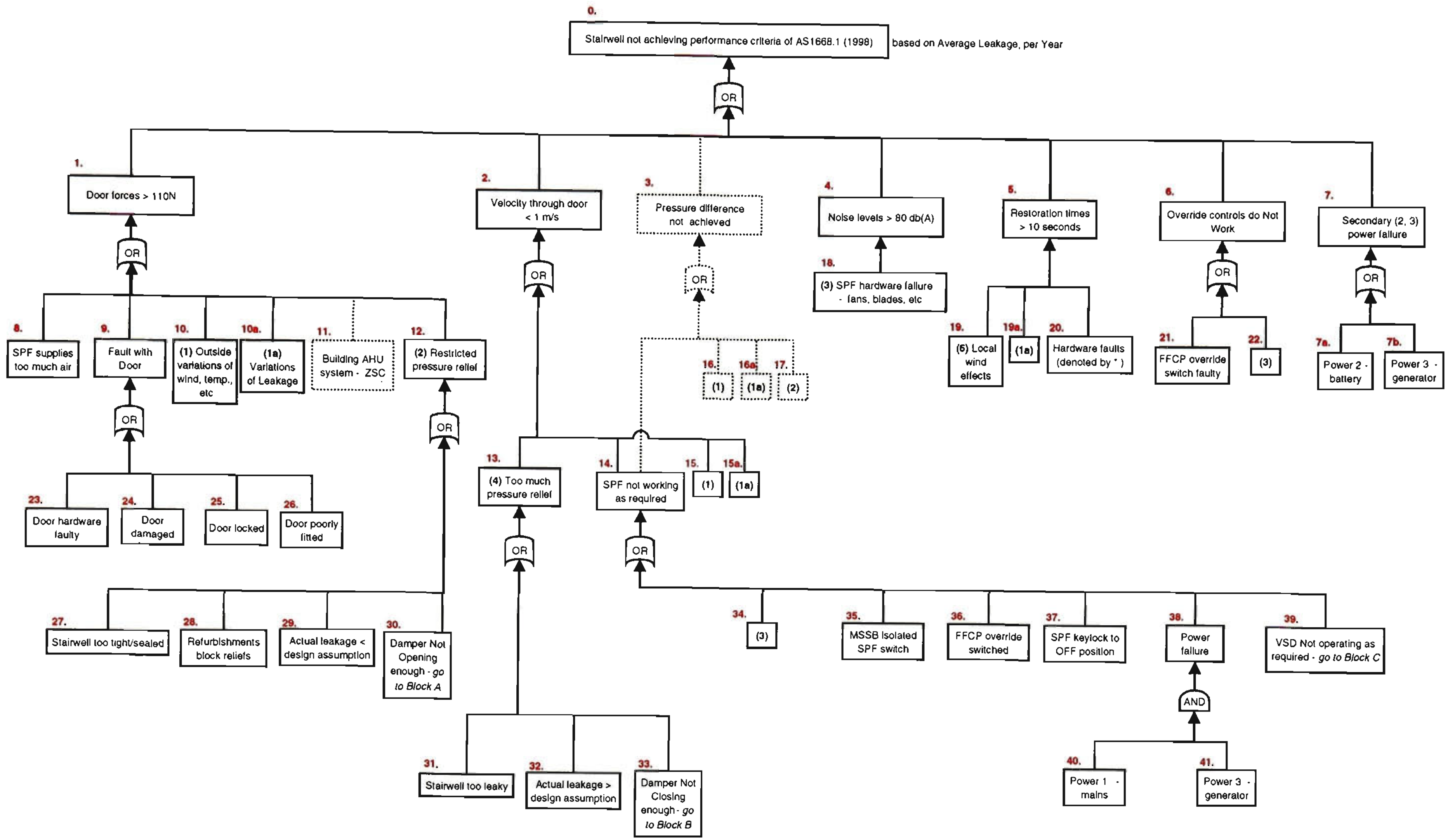


Figure 46. Entire Fault Tree for Systems 1 and 2

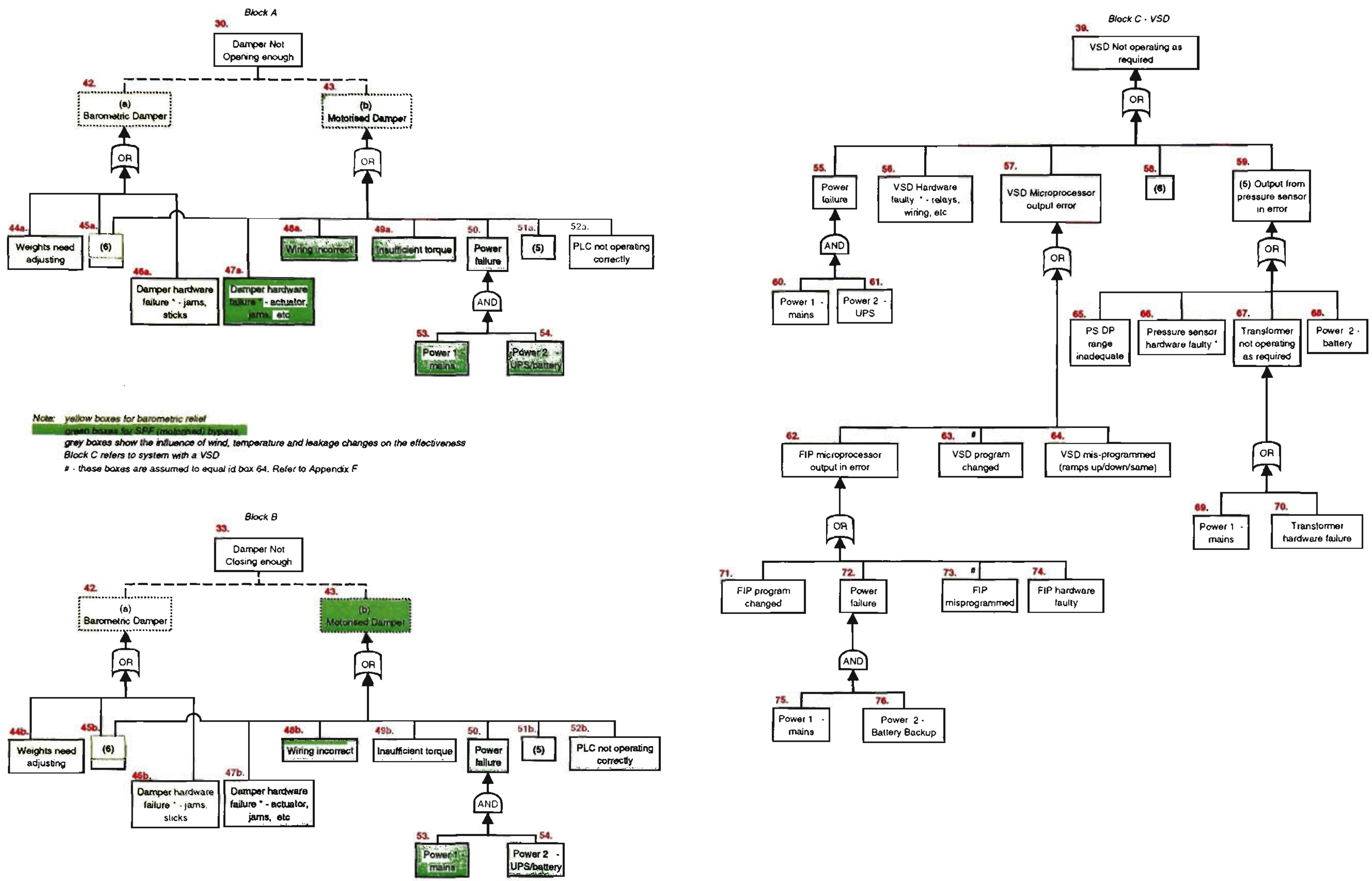


Figure 46. Entire Fault tree for Systems 1 and 2 (continued)

8.4. Fault Data

The following sections detail how the data associated with the failure probabilities was obtained and subsequently calculated.

8.4.1. Published Data

Where reliability data could not be sourced directly from the survey results, published literature (Cerward 1992, Lees 1980b) was consulted. In particular, published data was used for the following components identified in the fault tree, which have been also referenced on the fault tree diagram to follow (Figure 47):

- Power 1 failure (associated with mains power supply)
- Power 2 failure (associated with secondary power supplies eg. batteries, uninterruptible power supplies [UPS])
- Power 3 failure (associated with secondary power supplies eg. generator)
- Transformer hardware failure

8.4.2. Survey Results

It is important to note that the answers for the survey were highly variable and only a limited number of industry personnel responded. An example of the variability of the results is now given:

Question B2 of the survey relates to the frequency of wiring faults associated with FIP and the data obtained varied from 1, 2, 5 up to 60 times out of 100 cases. Due to the large variation of results[60] *from some of the respondents, and because only 20% of the possible respondents completed the survey (i.e. 12 out of 51), there is some degree of uncertainty associated with the data obtained. Therefore, when calculating the probability of a fault for a component, if there were extreme results for a question, the mean response was based on* ***all*** *of the 'industry' results for that question. Another calculation was then undertaken where apparent outliers were ignored. An outlier was taken to be one which was extremely high or low in value as compared to the respondent answers for each question.*

The survey results were analysed (specifically for Sections A, B and D of the survey) such that the mean failure probability and the failure probability ignoring 'extreme' responses were assessed. This information was then added to the fault tree diagrams in the following section.

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[60] Some respondents answered 'N', 'NA', 'blank, '-' or provided word answers such as 'monthly', 'annual', etc., where a numerical answer was required. Therefore, for non-numerical responses (where one was required), the answers were not included in the mean calculations.
Note: Respondents may have written 'N' because either they do not come across this fault or maybe that item is not part of what they are contracted to maintain and therefore, they do not inspect it and are not aware of the item having a fault.

8.4.3. Fault Tree Results

For each survey question requiring a numerical response, all the answers were collated and the mean answer, with and without the outliers, was determined. The mean results calculated were then used to determine probabilities of failure. The information gained from these data analyses were added to the various branches of the fault tree using the Gate-by-Gate technique (as detailed in Appendix P).

The factors in Figure 46 that are not considered in this thesis (such as the impact of the smoke control system [SCS] on the SPS) have been removed, thereby creating Figure 47. There is also no direct consideration of faults arising from inadequate design or during initial installation in Figure 47.

The relevant probabilities of failure presented in Figure 47 cover the following:

- Systems 1 and 2 response (all survey data, shown in light blue)
- Systems 1 and 2 response (calculated using all survey data, shown in grey)
- System 1 response ('extreme' responses ignored, shown in orange/pink)
- System 2 response ('extreme' responses ignored, shown in orange)
- System 2 response (calculated barometric damper response, shown in green)
- System 2 response (calculated motorised damper response, shown in dark blue)

As mentioned earlier, the calculations for the fault tree shown in Figure 47 are presented such that the failures due to wind, temperature or leakage variations are ignored (the E-factors, denoted by a grey box), as they were assessed in Chapter 7.

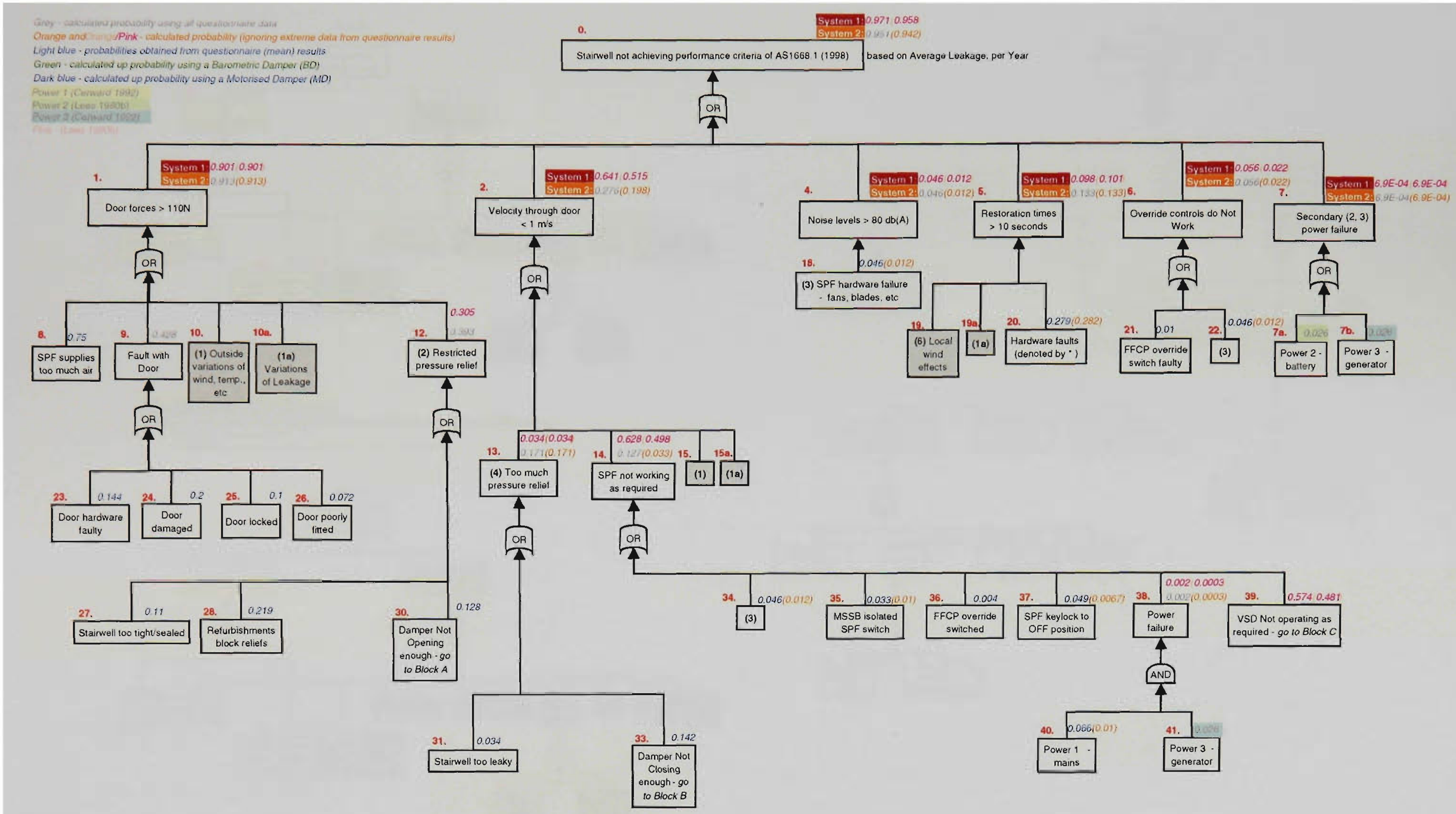

Figure 47. Modified Fault tree for Systems 1 and 2

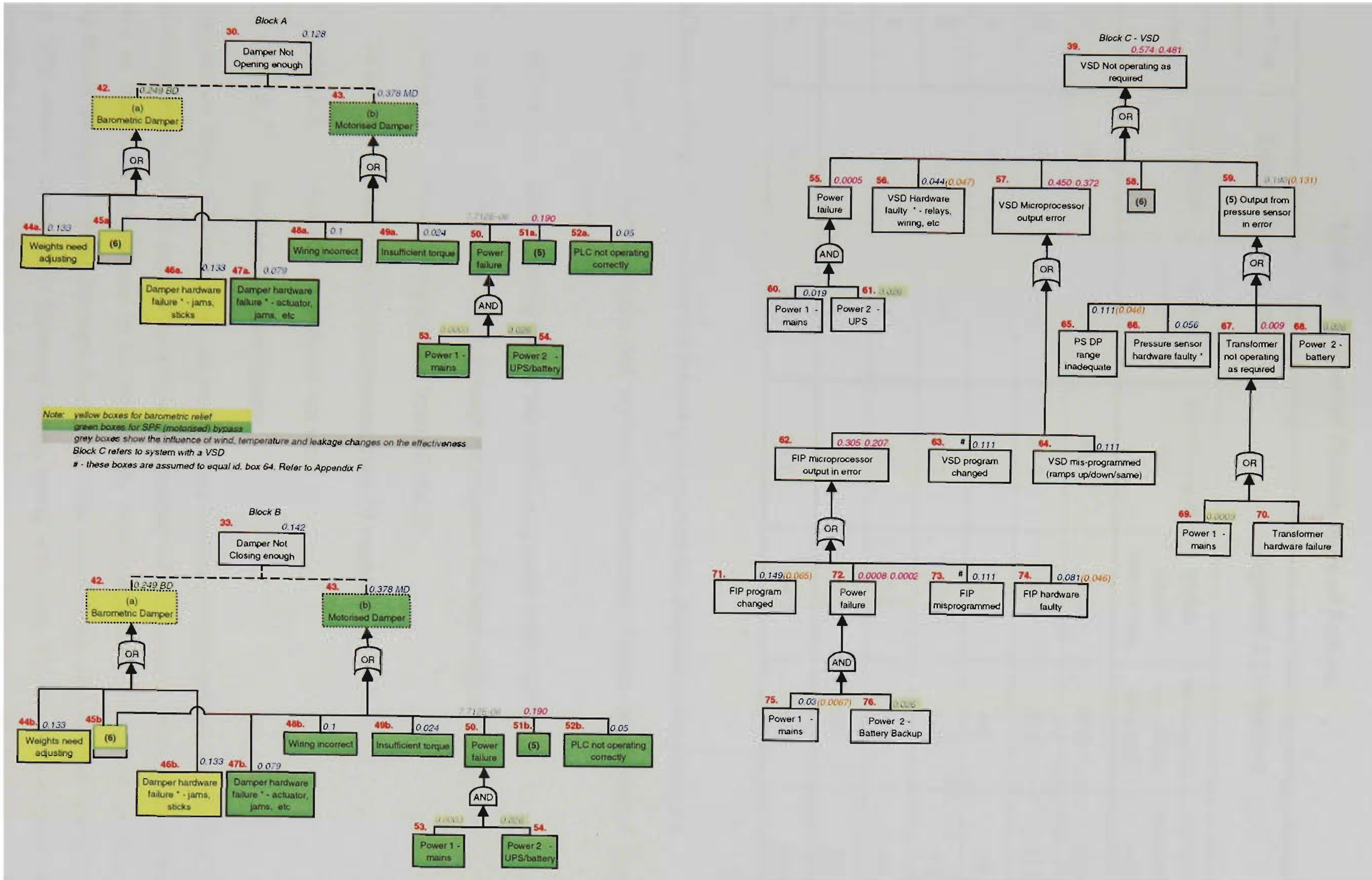

Figure 47. Modified Fault tree for Systems 1 and 2 (continued)

The probability of failure calculations are summarised in Table 27. The overall main fault tree branches associated with the performance conditions of a SPS (including commissioning [i.e. id boxes 6. and 7.]) are also included in this table.

Table 27. Overall Probabilities of Failure

Fault Tree Branch (id box number.)	System 1 (% failure)		System 2 (% failure)			
	Using all data	Ignoring 'extreme' data	BD/MD using all data	BD/MD ignoring 'extreme' data	BD calculated from all data (id box 42.)	MD calculated from all data (id box 43.)
1	90.1	90.1	91.3	91.3	92.5	93.8
2	64.1	51.5	27.6	19.8	36.6	47.5
4	4.6	1.2	4.6	1.2	4.6	4.6
5	9.8	10.1	13.3	13.3	13.3	7.9
6	5.6	2.2	5.6	2.2	5.6	5.6
7	0.1	0.1	0.1	0.1	0.1	0.1
0	**97.1**	**95.8**	**95.1**	**94.2**	**96.3**	**97.3**

The id boxes in Table 27 represent the following outcomes (as detailed in Appendix F):

- Id box 0. Stairwell does not achieve performance criteria of AS1668.1 (i.e. top outcome)
- Id box 1. Door opening forces too high (i.e. greater than 110 N)
- Id box 2. Airflow velocities through nominated fire floor door less than 1 m/s
- Id box 4. Noise levels greater than 80 dB(A)
- Id box 5. Restoration times greater than 10 seconds
- Id box 6. Override controls do not work
- Id box 7. Secondary power failure

It can be seen in Table 27 that for the two most critical performance conditions of AS1668.1 (the door opening forces and the airflow velocities, associated with id boxes 1. and 2., respectively), the rates of failure would appear to be alarmingly high, particularly in relation to the door opening forces being exceeded for both Systems. The calculations suggest that there is only about a 1/10 chance of the door opening forces being less than 110 N. In the case of the airflow velocities at the fire floor door, the failure rates vary from approximately 20% to 65% depending on the System and whether extreme responses are ignored. System 2 is consistently better than System 1 with respect to the airflow velocities though.

8.5. Discussion of Findings (F-factors)

The terms "commissioning" and "maintenance" are interpreted a couple of different ways, where:

- a 'commissioned' system is one which has been tested and any deficiencies identified have been corrected, so that the (whole) SPS complies with the performance conditions of AS1668.1 [a 'maintained' system would be corrected in terms of the requirements of AS1851.6]; or
- a system which has been tested and deficiencies identified have <u>*not necessarily been*</u> corrected prior to occupancy (in the case of 'commissioning') or before the next maintenance routine; and in fact, may never be completely fixed.

If systems were commissioned in accordance with the first definition, then it can be assumed that the SPS will operate as required after commissioning. That is, the SPS would have an effectiveness of close to '1'. If the latter definition was used however, the SPS may not necessarily result in a compliant/operational SPS as required by AS1668.1 even though the system is "commissioned" or "maintained".

The fault tree results in Figure 47 imply that faults identified during those processes are not being addressed to a high level, since they are based on responses from the industry involved with buildings that have or are being "commissioned' and "maintained". Ideally, after commissioning a SPS should have an effectiveness of close to '1', i.e. it should work at the completion of either commissioning or maintenance, if sufficiently exhaustive.

Using Figure 47, the commissioning and maintenance aspects described in the Australian Standards have been colour-coded and presented in terms of the activities involved in identifying and/or correcting (identified) faults.[61] This information has been detailed in Figure 48 and both the *mandatory* (Level 1) and non-mandatory maintenance routines have been detailed. This figure therefore, illustrates the extent of checking that is theoretically undertaken for these systems.

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[61] Note: The ability to detect a fault, is highly dependent on the thoroughness of the maintenance person. Therefore, even if a system is being maintained, there is the possibility that the fault may not be identified.

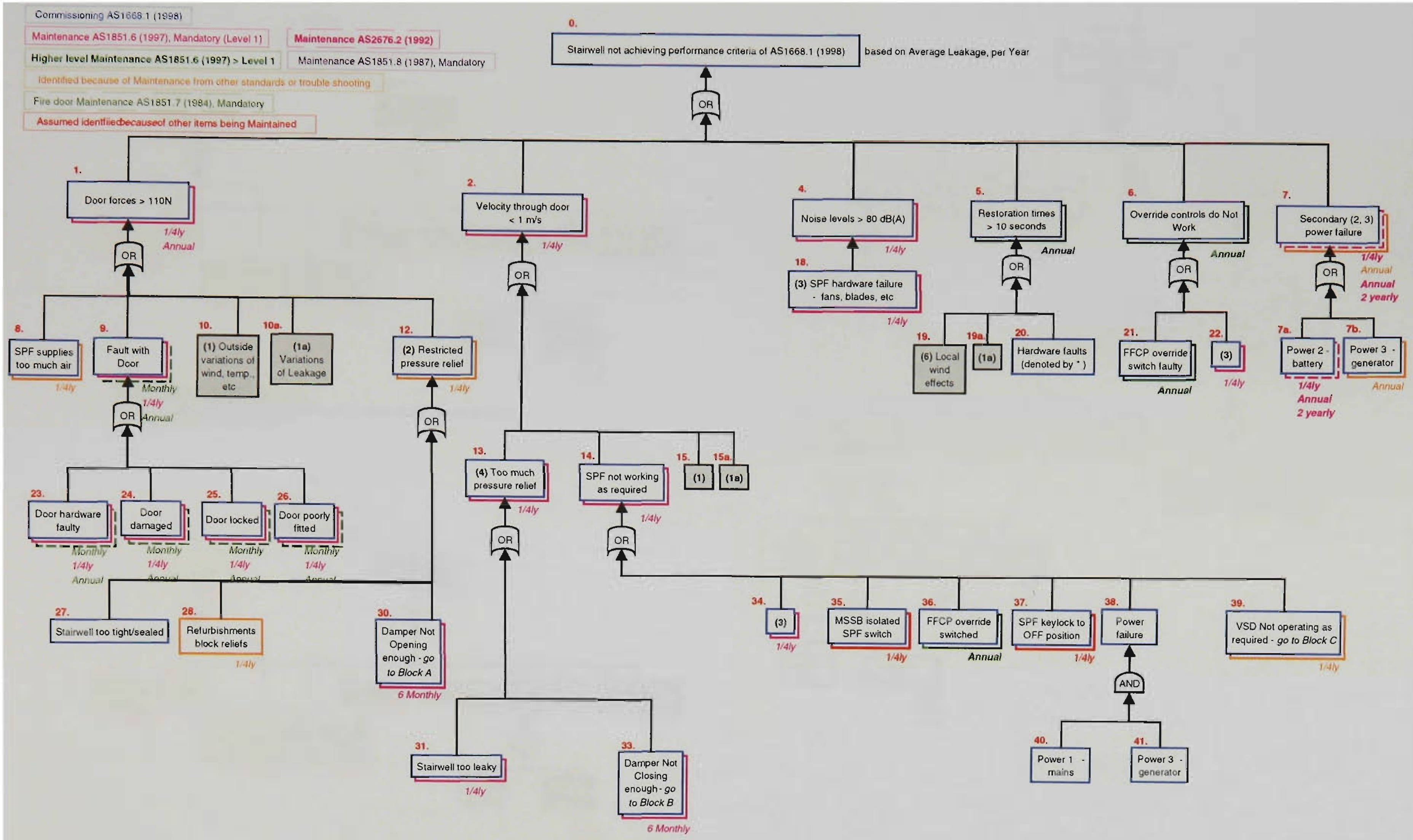

Figure 48. Commissioning and Maintenance routines associated with identified Faults

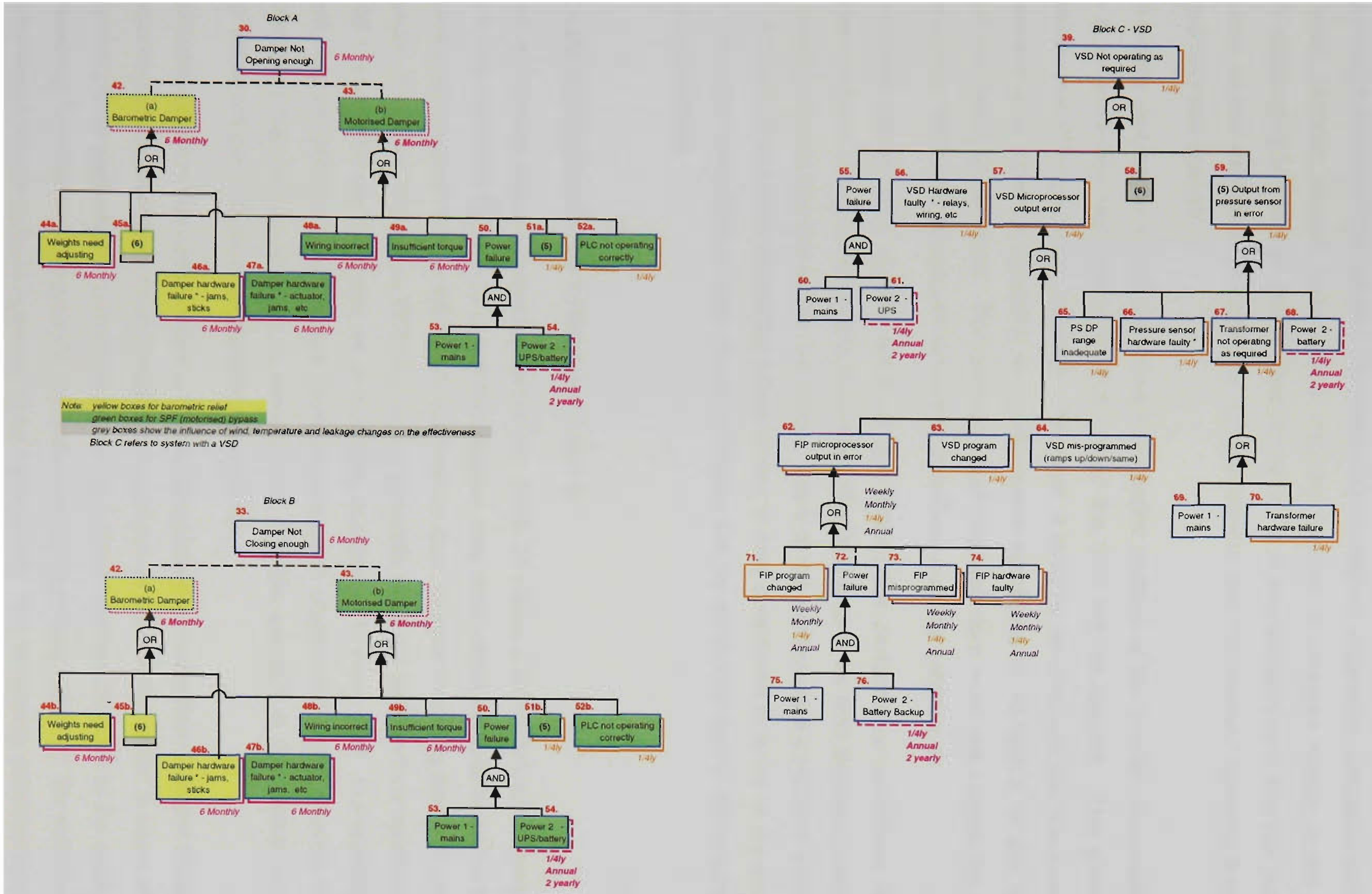

Figure 48. Commissioning and Maintenance routines associated with identified Faults (continued)

When asked (see Question C5 of the survey, in Appendix P) to rank the factors likely to lead to failure of a SPS which has not been commissioned, contractors ranked the causes in the following order: high door opening forces, low airflow velocities, excessive restoration times, faulty sensors, incorrect VSD controls, excessive pressurisation, incorrectly configured electrical interfaces, incorrect damper motor travel, incorrect location of pressure sensor, outlet grille needs rebalancing and the set points need adjusting. It is interesting to note that this order is the same as that identified for nominally "commissioned" and "maintained" systems from the detailed fault tree analysis.

When initially viewing the results presented in the earlier sections of this chapter, it appears that there is an extremely high probability that *overall* the SPS will not operate. This gives the impression that SPS are highly unreliable. However, it must be remembered that this research assessment is in terms of achieving the performance conditions of AS1668.1 for the whole system (i.e. every single door). For example, each stairwell door must not exceed the door opening force requirements, the airflow velocity conditions must be satisfied, etc.

As presented earlier (see section 8.4.3. of this thesis) the performance conditions which dominate in terms of not achieving the Australian Standard criteria for both Systems, were the door opening forces and the airflow velocities. Each of the performance conditions (detailed within AS1668.1) and their associated effectiveness is now considered in terms of the leading causes of failure and whether these causes of failure can be addressed during commissioning and/or maintenance.

<u>Door Opening Forces</u> (id box 1.) Systems 1 and 2:

The risk with having high door opening forces (eg. Table 27 shows a 90.1% failure for System 1 and a 91.3% failure for System 2), is that the situation may arise where occupants cannot enter the pressurised stairwell due to difficulty in opening the door, thereby impairing the safety of the occupants. However, in reality a SPS may in fact generally pass the performance conditions of AS1668.1, except for say two doors, as an example, as opposed to every door. In this case, the stairwell *may* still provide a safe egress route for occupants (depending on the severity of the non compliant two doors), however in terms of the criterion adopted in this thesis, such a system would not pass, because every door did not pass.

It should also be noted that initially when a SPS is commissioned, every door is tested however, subsequent (annual) maintenance only requires a selection of doors to be tested in terms of the door opening force performance criteria (providing there have been no changes to the system in the preceding 12 months). The selection of doors chosen is usually based on the extremes of the performance criteria (refer to Appendix D for more detail). The responses obtained from the survey assume that the above has occurred. This means that the doors not tested as part of the maintenance inspections, may not necessarily fail.

In reference to Figure 47, in terms of door opening forces for both Systems, the main causes in order of dominance are:

- the SPF supplies too much air (id box 8.)
- there are faults with the stairwell door (id box 9.)
- there is restricted pressure relief within the stairwell (id box 12.) and
- refurbishments block the relief (id box 28.)

All of the above sub outcomes are considered as part of the commissioning process (see Figure 48) except for id box 28. (refurbishments blocking the relief). Therefore, if commissioning is correctly performed, then initially there should not be a fault with these items. However, if commissioning is not performed correctly or if a fault presents itself after commissioning, then it is possible that branch 9. (fault with the door) for example, may be identified during maintenance, as part of a maintenance routine. For the item mentioned in id box 9. the fire door standard (AS1851.7 1984) requires monthly inspections and AS1851.6 (1997) requires quarterly inspections.[62]

Id boxes 12. (restricted pressure relief within the stairwell), 8. (SPF supplies too much air) and 28. (refurbishments blocking the relief), might be identified on a quarterly basis when other systems are being maintained or during trouble-shooting activities. Noting that the latter id box would generally only be an issue once the building has been occupied and during the life of the building (as opposed to necessarily being a concern at the commissioning stage).

Once faults are identified it is important that they be corrected as quickly as possible. It appears in Table 27 that this may not be the case, due to the high door opening force failure rates (eg. 90.1%, id box 1.).

<u>Door Opening Forces</u> (id box 1.) System 2:

In addition to the above noted causes for high door opening forces (for System 1), id box 43. (motorised damper not opening enough – which is also a sub outcome of id box 12.) is also identified as a dominant factor for System 2. This item is part of the commissioning process. Six-monthly inspections are also recommended for the dampers when these dampers are considered as 'fire mode air dampers ....', as in AS1851.6, however, if the damper is not considered as such then the damper may not be inspected until a much later date (i.e. the two-yearly non-mandatory maintenance).

Assuming that the door opening failure causes listed above for both Systems are each independently effective (i.e. 100% reliable), the resulting influence on the door opening force

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[62] These inspections are more or less visual and operational inspections, i.e. door forces are not actually measured during this maintenance routine.

effectiveness can be calculated (refer to Appendix P; Note, for System 2, the barometric damper [BD] data has been used for the calculations).

As seen in Table 28, the most significant improvement with regard to the door opening forces for both Systems is when the SPF is not over pressurising the stairwell.

Table 28. Door Opening Force Effectiveness with Dominant Causes Removed

Door Opening Force Effectiveness	Using all fault tree branches – using all data	Ignore id box 8. – using all data SPF not over pressurising	Ignore id box 9. – using all data No faulty doors	Ignore id box 12. – using all data No restricted pressure relief	Ignore id box 28. – using all data Refurbishments do not block relief	Ignore id box 43. – using all data No motorised damper problems
System 1	0.10	<u>0.40</u>	0.17	0.14	0.13	NA
System 2 with BD	0.08	<u>0.30</u>	0.13	0.14	0.10	0.10

NA refers to Not Applicable

<u>Airflow Velocities</u> (id box 2.) System 1:

As shown in Figure 47, the main causes for System 1's airflow velocity failures, in order of dominance are:

- the SPF is not working as required (id box 14.)
- the VSD is not operating as required (id box 39.)
- there is a VSD microprocessor output error (id box 57.)
- the FIP microprocessor output is in error (id box 62.) and
- the output from the pressure sensor is in error (id box 59.)

Referring to Figure 47, the above listed causes are part of the commissioning process so if commissioning is conducted correctly then ideally there should be no initial problems and the effectiveness should be '1'. However, these causes could also result in a fault at some time after commissioning. There is regular maintenance for two of the above five causes, so ideally these faults would be identified and corrected during maintenance. For example, id box 14. (associated with the SPF) requires quarterly maintenance (as per AS1851.6), while id box 62. (associated with the FIP) requires weekly, monthly and annual maintenance in accordance with AS1851.8. However, there is no formal maintenance associated with the remaining three faults (i.e. the VSD and the pressure sensor), unless specified in the manufacturer's instructions. Therefore, these items may become faulty after commissioning or during the life cycle of the system. It is possible however, that these faults may be addressed on a quarterly basis when other components are being maintained or during trouble-shooting activities.

Each of the failure causes listed were then considered to be 100% reliable. Table 29 shows the modified effectiveness associated with the airflow velocities. For example, when the highest failure item (id box 14.) contributing to low reliability of the airflow velocities, was considered 100% reliable, the dominant cause for this particular high failure was due to the VSD (i.e. id box 39.), as shown in Figure 47. When the faults related to the VSD were removed (i.e. id boxes 56., 63. and 64.) so that the VSD was effectively 100% reliable, the reliability associated with the airflow velocities improved. For example, the failure probability for id box 2. was originally 64.1% and it reduced to 52.5% for System 1 (refer to calculations in Appendix P).

As seen in Table 29, the most significant improvement with regard to the airflow velocities is when the FIP microprocessor output is not in error (for System 1).

Table 29. Airflow Velocity Effectiveness with id boxes removed

Airflow Velocity Effectiveness	Using all fault tree branches – using all data	Ignore id box 14. – using all data SPF working as required (i.e. VSD is reliable)	Ignore id box 62. – using all data FIP microprocessor output not in error	Ignore id box 59. – using all data Pressure sensor output not in error	Ignore id box 13. – using all data Not too much pressure relief (i.e. dampers effective)
System 1	0.36	0.48	<u>0.52</u>	0.44	NA
System 2 with BD	0.63	NA	NA	NA	<u>0.84</u>

NA refers to Not Applicable
BD refers to Barometric Damper

<u>Airflow Velocities</u> (id box 2.) System 2:

For System 2 and referring to Figure 47, the main causes for non compliant airflow velocities at the nominated the fire floor door, in order of dominance are:

- motorised damper not closing enough (id box 43.)
- barometric damper not closing enough (id box 42.) and
- having too much pressure relief (id box 13.)

All of the above listed causes are part of commissioning. They also have routine maintenance activities associated with the items eg. the dampers (id box 43. and id box 42.) require six-monthly inspections (when they are considered as 'fire mode air dampers' as detailed in

AS1851.6), while having excessive pressure relief (id box 13.) would be inspected as part of AS1851.6 on a quarterly basis (it is important to note that having too much pressure relief [id box 13.] is a result of the damper not closing enough, independent of the type of damper). Therefore, should a fault occur subsequent to commissioning, it should be identified and corrected as part of routine maintenance practices.

When the dominant causes listed above are assumed to be 100% reliable, the resulting effect on the airflow velocity effectiveness is increased. When the damper is considered effective, the effectiveness increased from 0.63 to 0.84 (see Table 29).

High Restoration Times (id box 5.) System 1:

Using the survey data for System 1, high restoration times are due to sub outcome id boxes 66. (PS hardware is faulty) and id box 56. (VSD hardware is faulty) in Figure 47. Both of these sub outcomes are part of the commissioning process, so there should not be any problems if commissioning is conducted correctly. If these faults were to occur at a later stage, they may not be identified as there is no formal maintenance for these items.

High Restoration Times (id box 5.) System 2:

Using the survey data for System 2 (with a barometric relief damper), high restoration times are due to the dominant sub outcome id box 46. (barometric damper hardware failure) in Figure 47. This item is inspected as part of commissioning however, a fault could occur some time after commissioning. The maintenance associated with this item should identify subsequent faults, during the six monthly maintenance (as per AS1851.6), providing the damper is associated with the maintenance frequency of 'fire mode air dampers ....' as stated in the standard.

Override Controls do not work (id box 6.) Systems 1 and 2:

The dominant factor contributing to the override controls not working is predominantly due to sub outcome id box 22. (SPF hardware failure). This item is to be checked as part of the commissioning process and should a fault occur during the life of the system, the maintenance contractor could correct defects on a quarterly basis as per AS1851.6.

<u>High noise levels</u> (id box 4.) Systems 1 and 2:

The dominant factor contributing to high noise levels is id box 18. (SPF hardware failure). This item is to be checked as part of the commissioning process, however, this fault could occur at some time after successful commissioning. The maintenance inspection conducted on a quarterly basis (AS1851.6) should correct any deficiencies identified with the hardware associated with the SPF. Actual noise measurements are not recorded as part of this maintenance, therefore noise corrections would only be performed on an intuitive basis.

<u>Secondary power failure</u> (id box 7.) Systems 1 and 2:

The dominant factors contributing to secondary power failure are equally due to sub outcome id boxes 7a. (battery failure) and id box 7b. (generator failure). Both of these items are part of the commissioning process and therefore, if commissioning is performed correctly, then initially, there should not be a fault with these power supplies. Although both secondary power supplies have equal failure probabilities, the generator is only inspected annually while the batteries are maintained on a quarterly, annual and two-yearly basis (AS2676.2 1992). Therefore, it is more likely that a fault with the batteries would be identified earlier as the maintenance routine is more frequent than that of the generator.

8.6. Other Findings

During the assessment of the F-factors, the following additional findings were noted (refer to the fault trees, Figures 47 and 48, associated with the commissioning and maintenance activities).

<u>Airflow Velocities (Systems 1 and 2)</u>:

Two additional faults identified which could influence the airflow velocities for both Systems 1 and 2 are id boxes 37. (SPF switch locked off) and id box 35. (SPF switch isolated by MSSB). These items are addressed as part of the commissioning process, however there is no formal subsequent maintenance for these items (the keylock devices or isolations associated with the switches are a direct result of human intervention). Therefore, if switches are turned to the isolate or "OFF" position and are not inspected, it may be some time before these faults are identified and could result in the SPS not operating when required.

Dampers

A barometric damper was shown to be more reliable than motorised dampers, where a barometric damper had a failure probability of 24.9% while a motorised damper was shown to have a failure probability of 37.8%. This finding is consistent with the theory that motorised dampers have more components and therefore, more potential fault items than barometric (simpler design) dampers.

8.7. Conclusions

Overall, System 2 was found to be marginally more reliable than System 1 (refer to Table 27). Using all of the 'industry' survey results (which assumed a maintained or soon to be maintained system), the lowest *overall* failure probability for System 1 was calculated to be 97.1% (for a SPS with a VSD) as compared with 95.1% for System 2 (independent of the type of relief damper).

These results illustrate that there needs to be a stronger focus on *correctly* commissioning the SPS as many of the potential faults could be corrected at this stage of the process. The maintenance program (in terms of actually rectifying problems) also needs to be considered more seriously, as items identified as requiring corrective action, need to be corrected soon after identification, so that the faults do not remain for extended periods of time. The majority of the branches presented in Figure 48 are associated with the *mandatory* (Level 1) maintenance routines and therefore, should be detected. Other faults may only be identified during the non-mandatory maintenance routines (eg. the override control switches for the FFCP, the restoration time, etc.) whereby if these higher levels of maintenance are not conducted, a fault may be present for a long period of time, before it is identified, if ever.

Some of the faults identified may also go unchecked as they are only assessed during the commissioning stage after which time there is no formal maintenance, for example, the keylock switches associated with the SPF and the MSSB. Therefore, if the item is not commissioned correctly then the component may never work as intended. It is important then, to be reminded that currently the design standard (AS1668.1) details more criteria for compliance than the maintenance (or even commissioning criteria), as illustrated earlier in Table 4. Therefore, any item listed as part of the design should really have a maintenance routine associated with it.

9. EFFECTIVENESS OF STAIR PRESSURISATION SYSTEMS

The *effectiveness* of a Stair Pressurisation System (SPS) can now be assessed since the wind, temperature and leakage influences, referred to as the E-factors, as well as the 'other factors' (the F-factors) presented in Chapters 7 and 8, have been evaluated.

Chapter 7 considered the effect of environmental (wind and temperature) influences and potential leakage variations on the effectiveness of SPS in relation to achieving the AS1668.1 performance conditions that could be affected by these factors (i.e. door opening forces and airflow velocities). These 'E-factors' were evaluated assuming that hardware faults ('F-factors') had no influence.

In Chapter 8, the influence of the F-factors on effectiveness, in relation to all of the performance conditions of AS1668.1 was determined.

The above factors (i.e. the E- and F-factors) were considered separately in order to assess the impact of each. A complete assessment of effectiveness would utilise the complete fault tree (see Figure 47) with the calculated failure rates for all factors (E- and F-factors) being considered. However, such a more complete analysis is not necessary due to the dominant influences of the F-factors.

Chapter 7 found that the variations in wind speed, temperature and leakage had little effect on reducing SPS effectiveness. This was evidenced by the high effectiveness results calculated in Table 26a, which were close to '1'. It is only if the stairwell leakage increases with respect to the main building façade, that the effectiveness associated more specifically with the airflow velocities, reduces (see Table 26b).

The findings of Chapter 8, which considered the influence of the F-factors, showed that these factors appear to significantly impact the ability of SPS to achieve the AS1668.1 performance conditions. The performance conditions least likely to be achieved were the door opening force and the airflow velocity conditions. The overall effectiveness (i.e. considering all performance conditions) was found to be 0.03 and 0.05 for System 1 and System 2, respectively.

Due to the dominance of the F-factors, if the results associated with the E-factors were added to the grey boxes in the fault tree presented in Figure 47, and the Gate-by-Gate technique was used to calculate the combined overall failure probability, it is found that the effectiveness results presented in Chapter 8 do not vary significantly as the variations to wind, temperature and leakage [generally] do not influence the effectiveness of the SPS.

The poor effectiveness associated with SPS is dominated by the door opening forces being excessive and to a lesser extent by an inability to achieve the airflow velocities required by AS1668.1.

In a real fire situation, doors may be opened by more than one person or a stronger person but the fact that excessive door opening forces is a dominant cause of failure is of great concern because it may not be possible for occupants to enter the stairs.

As concluded in Chapter 8, there needs to be a stronger focus on correctly commissioning and maintaining SPS such that problems identified are addressed as soon as possible and not merely deferred. The other conclusions of Chapter 8 should be noted.

10. CONCLUSIONS

The aim of this research was to study the *effectiveness* of Stair Pressurisation Systems (SPS) appropriate for multi-storey office buildings, by considering component uncertainty and the uncertainties associated with construction, commissioning, maintenance and variations in external weather conditions. An assessment considering SPS and their components, interrelationships, etc., has been considered whereby detailed fault tree diagrams illustrating the complex sub components and their relationship to a SPS achieving the Australian Standard (AS), AS1668.1 performance conditions, has been presented. The design criteria for these systems (such as pressures, flows, etc.); as well as the commissioning and maintenance requirements have also been presented in a unique manner. This was done by considering the Australian Standard requirements as well as historical data associated with two representative SPS, one of which has a variable speed drive (VSD) to adjust the pressure within the stairwell (i.e. System 1), while the other has barometric dampers to enable pressure relief within the stairwell (System 2).

The *effectiveness* assessment for the SPS was conducted considering the influence of wind, temperature and leakage variations, as well as 'other factors', associated with reliability. The former three aspects (referred to as the E-factors in this thesis), were investigated using the CONTAM computer software such that the performance conditions of AS1668.1 were achieved for the whole system i.e. every door. The 'other factors' (F-factors) were assessed where commissioning and maintenance are the norm. The data associated with assessing the F-factors was obtained through a survey completed by industry personnel who are intricately associated and involved with SPS (typically, with the maintenance of these systems).

An attempt to look at SPS reliability in relation to whether a signal is received by the fan and damper, was undertaken by Zhao (1998) who used simplified fault trees to assess the reliability of a single fan system. He endeavoured to look at the effects of commissioning and maintenance on system reliability even though there was limited data available at that time. Zhao, however, did not consider whether the door opening forces were likely to be excessive, the airflow through the doors adequate or whether any of the AS1668.1 performance conditions would be achieved. This research utilises a more complex approach where wind, temperature and leakage variations, as well as equipment reliability, and the inherent influences of design, commissioning and maintenance are considered; for more complex SPS found in high-rise office buildings.

The buildings chosen, and the SPS associated with these buildings, are representative of those within the Melbourne Central Business District (CBD) and consequently their historical profiles can be used as a tracking mechanism for problems/issues associated with SPS.

CONTAM was used to develop the design characteristics for both types of SPS (i.e. one with a VSD and one without) which complied with the performance conditions of AS1668.1 (i.e. the door opening forces and airflow velocity conditions). In particular, System 1 (with a VSD) and System 2 (with an adjustable relief damper) were modelled as follows:

- System 1 Door Opening Forces (no doors open), Fan speed 3,472 L/s, Relief 0.06 m^2

  Airflow Velocity (three doors open), Fan speed 11,575 L/s, Relief 0.06 m^2

- System 2 Door Opening Forces (no doors open), Fan speed 11,575 L/s, Relief 1 m^2

  Airflow Velocity (three doors open), Fan speed 11,575 L/s, Relief 0.01 m^2 (i.e. effectively closed)

When assessing the effect of E-factors on the effectiveness of a SPS, a sensitivity study was conducted modelling variations to wind speed (including a high wind condition), temperature changes (predominantly and external to the building), and building leakage (such as leakage increases across the façade of the building versus the stairwell shaft). These influencing factors have been identified in the literature (Klote and Fothergill 1983) and from anecdotal evidence, as likely to effect the performance of SPS. Due to the extreme difficulty in utilising real test data to investigate the influence of variations of the E-factors alone, it was decided to utilise the computer program CONTAM to analyse these effects.

The results of the CONTAM analyses found that variations in temperature or wind had little effect on system effectiveness. Accordingly, the effectiveness values with respect to temperature and wind speed variations were '1' or very close to this number. However, it is known from anecdotal evidence and personal experience that SPS are not tested on windy (gusting) days, as the system may be unstable, making it difficult to obtain stable readings. These effects would appear to be related to the positioning of air intakes or dampers such that wind gusting has a direct impact on their performance creating pressure fluctuations within the shaft. Such effects were not modelled with CONTAM. The location of shielding for the SPS would appear to be an important consideration and should be seen as a topic for future research.

Increases in stairwell leakage were, however, found to have a significant impact on the ability of a SPS to achieve the airflow velocity criteria of 1 m/s. This is a direct result of the design and standard of construction (i.e. workmanship) of the SPS but also of future changes to the building. For example, for Systems 1 and 2, the effectiveness (with respect to airflow velocity) reduced to 0.04 and 0.13 respectively, when the stairwell leakage was increased from 'Average' leakage conditions to 'Loose' (100% Leakier) conditions. The inferior performance of System 1, compared with System 2, is due to the fact that System 1 has a fixed vent size of 0.06 m^2, whereas for System 2 the damper could close to 0.01 m^2.

The majority of the results associated with the F-factors influencing effectiveness, were obtained through a survey completed by industry personal directly involved in a "hands-on" sense with the detailed aspects of SPS. This survey considered the parts and potential faults of a SPS in detail. This approach differed from the previous approach of Zhao (1998), which utilised a greatly simplified model and used failure rate data only from the literature.

It was found that the order of dominance in terms of not achieving the performance conditions of AS1668.1 was generally:

- high door opening forces,
- low airflow velocities,
- override controls not working,
- restoration times being excessive,
- high noise levels and
- secondary power failure.

The issues identified during the historical review also correlated with the data obtained from the detailed survey, in terms of the most likely components to not achieve the performance conditions (prior to commissioning).

For System 1 (with a VSD) the dominant factors generating high failure probabilities associated with the door opening forces and airflow velocities were, respectively:

- The stair pressurisation fan (SPF) supplying too much air into the stairwell
- The fire indicator panel (FIP) microprocessor output being in error

For System 2 (with a barometric damper) the dominant factors generating high failure probabilities associated with the door opening forces and airflow velocities were, respectively:

- The SPF supplying too much air into the stairwell
- The relief damper not closing enough, resulting in too much pressure relief and therefore, low airflow velocities in the stairwell (Zhao also had identified the damper as the key cause of uncertainty)

Table 30 illustrates the effect of removing the above-noted dominant factors when all the survey data is used and also when the ‘extreme’ (outlier) data is ignored. System 2 is considered with a barometric damper (BD).

Table 30. Effectiveness associated with Door Opening Forces and Airflow Velocities For Systems 1 and 2

Effectiveness	Door Opening Force			Airflow Velocity			
	Using all fault tree branches – using all data	Ignoring 'extreme 'data	SPF not over pressurising – using all data	Using all fault tree branches – using all data	Ignoring 'extreme' data	FIP microprocessor output not in error – using all data	Relief damper operating correctly – using all data
System 1	0.10	0.10	0.40	0.36	0.49	0.52	NA
System 2 with BD	0.08	0.08	0.30	0.63	0.30	NA	0.84

NA refers to Not Applicable

As can be seen from Table 30, the effectiveness values are low, especially when compared with Zhao's (1998) conclusion that the reliability of a signal being received by the fan and damper is 90%. However, Zhao merely considered whether the signal would be received for the above-noted components, not whether the specific performance conditions of AS1668.1 could be achieved. Moreover, Zhao's model of the complexity of the SPS and its operation is quite limited.

Referring again to Table 30, when the dominant factor associated with the performance condition of door opening forces (i.e. the SPF not over pressurising) was considered 100% reliable for both Systems, the effectiveness improves from 0.01 to 0.40 for System 1 and 0.08 to 0.30 for System 2. In terms of the airflow velocities, when the dominant factors were removed the effectiveness for this performance condition also significantly improved.

Many of the sub outcomes presented in the fault tree diagrams leading to high door opening forces or low airflow velocities, are inspected as part of commissioning, however there are no subsequent maintenance inspections for many of these items (eg. the VSD, the pressure sensor, etc.). Therefore, if the component is not commissioned correctly, these items may never work as required. Alternatively, these items may become faulty at some stage after commissioning (eg. the override switches, the isolation switches, etc.) rendering the SPS inadequate. The latter fault is also a direct result of human intervention and as it is not required to be inspected as part of the *mandatory* maintenance routine this fault could go uncorrected. Therefore, the items currently lacking a maintenance program should have a maintenance program devised and adhered to, as maintenance is designed to identify (and correct) faults.

In the case of relief dampers, if these dampers are considered as the dampers listed in AS1851.6, then their faults may be identified during the six-monthly maintenance routine, however if not, then faulty dampers may go unnoticed for quite some time, thereby reducing the effectiveness of the SPS.

The reason for the high probabilities of component failure (and therefore, low effectiveness values) could be attributed to either one, or combination of, the following:

- The SPS may not have been commissioned;
- The SPS may not have been maintained previously (i.e. only now has a maintenance program been developed for the system); or
- The faulty item(s) identified may not be fixed prior to the next maintenance inspection, if ever.

If the system is not commissioned (correctly), this will have one of the greatest influences on the probability of failure, especially as some of the dominant factors effecting the reliability do not have specified maintenance protocols (i.e. they are only addressed/assessed as part of the commissioning process). This aligns with Moore and Timms' (1997) findings as well as those obtained as part of the survey (i.e. where door opening forces and airflow velocities were identified as being the dominant factors which may not work after installation of the SPS components).

To improve the overall reliability of the SPS, maintenance contractors and personnel need to be familiar with, and aware of, potential issues associated with the equipment as a fault may be left undetected for some time and therefore, the SPS may not operate in accordance with AS1668.1. If faults identified during commissioning and maintenance are properly fixed rather than just being noted, it would be expected that the effectiveness of the SPS would be significantly improved. Commissioning also must be performed *completely* and *correctly* prior to maintenance so that the SPS has the best chance of functioning as per the design and performance conditions of AS1668.1.

In terms of the effectiveness of the SPS, the F-factors (issues related to commissioning, maintenance and operation of the SPS, etc.), were identified as being the dominant factors leading to failure as compared with the E-factors (i.e. influence of wind, temperature and leakage variations). Having said this, the results generated indicate that *overall* SPS are not very effective in terms of achieving the performance conditions of AS1668.1 for the whole system.

It should be noted that failure to meet AS1668.1's performance conditions may not always mean that the SPS will not operate satisfactorily in a real fire. It may not be necessary to achieve an airflow velocity of at least 1 m/s to keep smoke out and the stairwell doors may still be able to be opened even when the force required is greater than 110 N. However, the performance of SPS with respect to real fire scenarios is outside the scope of this thesis.

As demonstrated in this thesis, the key factors associated with the successful performance of SPS have been known since the first Australian Standard related to SPS was published in 1974. These factors have been integrated into the commissioning and maintenance protocols incorporated in latter versions of AS1668.1 and AS1851.6. To assist in the conduct of meaningful commissioning and later maintenance, particular information is meant to be provided at the building and be accessible to persons undertaking the work. Such information includes the instructions on how SPS and their associated equipment operate and are designed to function in fire mode, but is rarely provided; thereby making it more difficult to undertake successful commissioning and maintenance.

The commissioning and maintenance procedures, if followed correctly and acted upon, should result in a significant improvement in the effectiveness of SPS compared with that found in this thesis.

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13. TABLE OF APPENDICES

Appendix A Nomenclature associated (Figures 13 and 14)

BMS	Building Management System
DDC	Direct Digital Control
FAR	Fire Alarm Relay
HLI	High Level Interface
OAD	Outside Air Damper
PID	Proportional-Integral-Derivative control(ler)
RA	Return Air
sd	Smoke Detector
setpt	Setpoint
Spill D	Spill Damper
spr	Sprinkler
VAV D	Variable Air Volume Damper
UPS	Uninterrupted Power Supply – a form of emergency power

Appendix B Anomalies with Australian Standards

Discrepancies exist between the airflow velocity and door opening force test requirements as detailed within the design standard AS1668.1 (1998) and the maintenance standard AS1851.6 (1997); specifically for zone smoke control systems (ZSCS) (eg. as per Building 2). That is, the design standard states one approach (which is what a designer designs in accordance with) and then the maintenance standard contradicts and offers another approach. This makes maintenance/testing confusing as the system *should* be tested in accordance with how it has been designed, i.e. not tested against different requirements.

For example; the design standard AS1668.1 (1998) specifies requirements for ZSCS vs Purge/Shut down systems, while the maintenance standard does not discriminate between these two types of systems (refer to the underlined items in the table below):

Table B1. Differences between the Design and Maintenance Standards

Type of Test	Design AS1668.1:1998	Maintenance AS1851.6:1997 (Level 2 – Annual)
Airflow Velocity Testing	Section 9.3.1 a) ii)	Section B10.2 b i)
Purge/Shut down	**3 doors** open (main door + test door (ff) + adjacent door)	- not stated
ZSCS	<u>**2 doors**</u> open (main door + test door (ff))	'implied' same as Purge i.e. <u>**3 doors**</u> open, though neither system type is specified
Door Force Testing	Section 9.3.1 b) ii)	Section B10.2 b ii)
Purge/Shut down	**1 door** open (test door)	- not stated
ZSCS	**2 doors** open (adjacent door+ test door (ff)) OR **1 door** (test door (ff))	'implied' same as Purge i.e. **1 door** open, though neither system type is specified

ff refers to 'fire floor'

Appendix C AS1851.6 (1983) Maintenance Levels

The information below relates to the levels of maintenance to be performed, depending on the results of a Level 1 maintenance inspection, as well as the frequency intervals for the level of inspection associated with SPS, detailed within the standard.

Table C1. Maintenance frequencies (1983)

Item	Description	Routine	Frequency			
			Level 1	Level 2❦	Level 3❦	Level 4❦
Fans	Air pressurisation	B2	Quarterly	Half-yearly	Two-yearly	Only if necessary
Motors, induction	Fan drives, test and emergency use only	B3	Quarterly	Half-yearly	Two-yearly	Only if necessary
Batteries for fire/smoke control services	Lead-acid or Alkaline	♣	Refer to Australian Standard ASXXXX			
Fire mode air dampers for smoke-spill, fresh air and recycle air, complete with their automatic gear		B5	Half-yearly	Yearly	NA	Only if necessary
Air-handling changeover under fire/smoke conditions		B12	Monthly	Yearly	NA	Only if necessary
Fire-isolated escape routes protected by air-pressurisation systems		B13	Monthly	Yearly	Two-yearly	Only if necessary

❦ Levels 2, 3 and 4 maintenance routines are for information only

♣ refers to Australian Standard ASXXXX

NA denotes Not Applicable

More specifically, the various routines identified in Table C1 above, have been detailed below.

Fans **Routine B2**

Level 1
- check bearings for noise and overheating
- check fans for excessive vibration
- check guards and other safety features for satisfactory condition
- check fan belts for wear
- check flexible connections, where fitted, for leaks, tearing or fraying

Level 2
- check lubrication of bearings and apply as necessary
- check fan belts for correct tension
- check couplings for tightness
- on fan energisation, operation and de-energisation, check that the flexible connections are not overstressed owing to fan movement

Level 3
- check pulley wheels for alignment
- check couplings for alignment
- measure and record fan output

Level 4
- check casing and impeller for corrosion and treat as necessary
- check balance of impeller if work carried out on it
- regrease bearings if applicable
- check fan belts if applicable
- check reassembled unit for excessive vibration
- check that guards and other safety features are satisfactory
- check for correct rotation
- measure and record fan output
- repair or replace flexible connections as necessary

Motors, Induction **Routine B3**

Level 1
- check for noisy running
- check for excessive vibration
- check for excessive heating

Level 2
- check that external ventilation airways are clear
- apply lubrication if necessary

Level 3
- measure and record insulation resistance of stator windings
- measure and record running current
- check starter, protection settings and contact where appropriate

Level 4 - overhaul or replace with exchange unit
- measure and record thermistor resistances where fitted
- test run
- measure and record insulation resistance of stator windings

Fire mode dampers **<u>Routine B5</u>**

Level 1 - inspect for obstructions
- ensure drive force is available to motors

Level 2 - ensure damper(s) moves to its fire mode position upon removal of drive force
- check that there is no excessive leakage past dampers when in the closed position
- check and adjust all motor drive linkages and ensure no 'slippage' or excessive hysteresis is occurring
- check linkage and damper bearings and lubricate as necessary
- ensure that any damper position indicators are operational and correctly positioned where fitted
- if motors are pneumatic, check for air leaks in the air lines and connections

Level 3 Not applicable

Level 4 - replace as appropriate

Air-handling changeover under fire/smoke conditions **<u>Routine B12</u>**

Level 1 - simulate[63] fire/smoke situation (for each system when separate) to effect changeover
- check that there is an appropriate direction of airflow between designated areas (if applicable)
- switch system back to 'normal' and check that all equipment is in the correct designated mode
- check that appropriate indicating lights signify normal operation

[63] 'Simulate' refers to replicating an alarm eg. smoke detector activation, without physically triggering the alarm i.e. with smoke. This simulated alarm could be performed at the FIP in order to check the functioning of the air-handling equipment and associated dedicated smoke detector circuits, as opposed to the smoke detector itself.

Level 2 During simulation of fire/smoke conditions, check that:

- each item of equipment and any associated indicators have operated correctly and that fans are running or are shut down in accordance with the correct operational sequence for the air-handling system(s) concerned
- motorised dampers and their associated motorised outside-air, recycle-air and spill-air dampers are operating correctly
- the operation of the manual switch provided for fire brigade personnel de-energises supply-air fans

Level 3 Not applicable

Level 4
- adjust or repair as necessary
- carry out the Level 2 routines

Fire-isolated escape routes protected by air-pressurisation systems **Routine B13**

Level 1
- simulate[63] initiation of operation of all systems
- while air-pressurisation systems are operating, check the following for each system:
  - excessive noise
  - ease of opening doors
  - movement of air from each pressurised area through a selected open door

    Note: Use the same door every time
- switch all systems back to normal

Level 2
- check that the fans of all air-pressurisation systems start when:
  - the building fire alarm is actuated by the automatic fire sprinkler system of the building, or by any smoke/thermal alarm group forming part of the building automatic fire detection system
  - any recycle-air sensor group, or any supply-air sensor group is actuated and
  - any recycle-air sensor group *and* supply-air sensor group are actuated
- check that when the smoke sensor group of any air-pressurisation system is actuated, the associated pressurisation fan is shut down
- check that operation of the manual switch provided for fire brigade personnel de-energises fans supplying air to the pressurised fire-isolated escape routes

Level 3 - with all air-pressurisation and other systems required to operate in the smoke-spill mode operating simultaneously, measure and record for each air-pressurisation system:

- the average flowrate through a selected open door, when the doors leading from every stairway to two selected successive storeys and the main discharge doors are fully open simultaneously

  Note: Use the same door every time
- the force required to open each door
- the time taken for conditions in the first two bullet points above to be restored after opening and reclosing up to three doors and
- the noise level at doorways identified as subject to the highest noise level, at the relevant points of entry into fire-isolated escape routes, with the associated door open

- with all air-pressurisation and other systems operating simultaneously, check that any specific air relief is fully operational and enables the required airflow from pressurised areas to be sustained

Level 4 - repair or replace any items not capable of being adjusted for satisfactory performance

Appendix D AS1851.6 (1997) Maintenance Levels

The information below relates to the levels of maintenance to be performed, depending on the results of a Level 1 maintenance inspection, as well as the frequency intervals for the level of inspection associated with SPS, detailed within the standard.

Note: The B2, B3 and Level 4 routines of maintenance are identical to those detailed in Appendix C.

The table below only illustrates the changes from the previous 1983 maintenance standard employed (i.e. AS1851.6). These changes predominantly refer to frequency changes.

Table D1. Maintenance frequencies (1997)

Item	Description	Routine	Frequency			
			Level 1	**Level 2❧**	**Level 3❧**	**Level 4❧**
Fans	Air pressurisation			Yearly	Yearly	
Motors, induction	Fan drives, test and emergency use only					
Batteries for fire/smoke control services	Vented cells Sealed cells	Refer to Australian Standard AS2676.1 Refer to Australian Standard AS2676.2				
Fire mode air dampers for smoke-spill, fresh air and recycle air, complete with their automatic gear		B5				
Air-handling changeover under fire/smoke conditions		B9	Quarterly			
Fire-isolated escape routes protected by air-pressurisation systems		B10	Quarterly			

❧ Levels 2, 3 and 4 maintenance routines are for information only

More specifically, the various routines or variations identified in Table D1 above, have been detailed below.

Fire mode dampers **Routine B5**

Level 2 - if control system is pneumatic, check for correct operation of air compressors, filters, dryers and pressure reducing systems (additional item)

Air-handling changeover under fire/smoke conditions **Routine B9**

Level 1
- simulate[64] fire/smoke situation (for each system when separate) to effect changeover or shut down as appropriate
- switch system back to 'normal' and check that all equipment is in the correct designated mode
- check that appropriate indicating lights signify normal operation

Level 2 During automatic[65] activation of the fire/smoke conditions, check that:
- each item of equipment and any associated indicators have operated correctly and that fans are running or are shut down in accordance with the correct operational sequence for the air-handling system(s) concerned
- motorised outside-air, recycle-air, air-control and spill-air dampers and their associated motors are operating correctly
- the operation of the manual switch provided for fire brigade personnel de-energises supply-air fans
- the system performance criteria of zone smoke control systems should be verified between each zone

Note: If there have been no building changes since the last test, approval may be given to testing less than all zones and if a standby power generator is provided, this level of maintenance should also include testing of the standby power to verify fire mode performance

Level 3 Not applicable

Level 4
- adjust or repair as necessary
- carry out the Level 2 routines

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[64] 'Simulate' refers to replicating an alarm eg. smoke detector activation, without physically triggering the alarm i.e. with smoke. This simulated alarm could be performed at the FIP in order to check the functioning of the air-handling equipment and associated dedicated smoke detector circuits, as opposed to the smoke detector itself.

[65] 'Automatic' activation refers to checking the functioning of the air-handling changeover system via activation of a field device. That is, a heat, flame or smoke source is used to activate a detector or flow water to reduce the pressure to operate a flow/pressure switch, for the sprinkler system.

Fire-isolated escape routes protected by air-pressurisation systems **Routine B10**

Level 1
- simulate[64] initiation of operation of all systems
- while air-pressurisation systems are operating, check the following for each system:
  - excessive noise (refer to AS1168.1)
  - ease of opening doors
  - movement of air from each pressurised area through a selected open door

    Note: Use the same door every time
- switch all systems back to normal

Level 2
- check that the fans of all air-pressurisation systems start under automatic[65] activation when:
  - the building fire alarm is actuated by the automatic fire sprinkler system of the building, or by any smoke/thermal alarm group forming part of the building automatic fire detection system
  - any recycle-air sensor group, or any supply-air sensor group is actuated and
  - any recycle-air sensor group *and* supply-air sensor group are actuated
- with all air-pressurisation and other systems, required to operate in the fire mode, operating simultaneously, measure and record for each air-pressurisation system:
  - the average flowrate through a selected open door, when the doors leading from every stairway to two selected successive storeys and the main discharge doors are fully open simultaneously
  - the force required to open each door
  - the time taken for conditions found in the first two bullet points above to be restored after opening and reclosing up to three doors and
  - the noise level at doorways identified as subject to the highest noise level, at the relevant points of entry into fire-isolated escape routes, with the associated door open
- check that when the smoke sensor group of any air-pressurisation system is automatically actuated, the associated pressurisation fan is shut down
- check that operation of the manual switch provided for fire brigade personnel de-energises fans supplying air to the pressurised fire-isolated escape routes

Level 3 - simulate[64] activation of all air-pressurisation and other systems required to operate in the fire mode, and while operating simultaneously measure and record the following for every door:

- ambient noise level
- door opening force
- air velocity through door

Note: *If there have been no building changes since the last test, approval may be given to testing less than all doors and these test doors should be selected based on the extremes of the performance criteria*

- with all air-pressurisation and other systems operating simultaneously, check that any specific air relief is fully operational and enables the required airflow from pressurised areas to be sustained

Level 4 - repair or replace any items not capable of being adjusted for satisfactory performance

Appendix E Measurement of Air Velocity Through a Doorway

When measuring the air velocity, a time averaged reading is taken as opposed to spot readings of a few measurements. Also, obstructions of an open doorway either by people or other objects are not permitted; as it is also possible to increase the air velocity across a stair door by blocking off other doors (eg. people standing in the doorway of an adjacent door).[66]

The two main approaches are described below:

Time average method

Equipment:

A vane anemometer or other digital device (capable of averaging wind speed over a period of time).

Optional

A watch with a readout in seconds.

The air velocity is to be in metres per second (m/s). And as such, the test is to take not less than 1 minute when traversing the open doorway. To time-average the air velocity through the door opening, make traverses of the open doorway by:

- making a steady (i.e. 0.5 m/s) horizontal serpentine sweep traverse of the doorway and then
- make a steady (i.e. 0.5 m/s) vertical serpentine sweep traverse of the doorway.

If after completion of these two sweeps, one minute has not expired, continue the horizontal and vertical sweeps until one minute has elapsed.

Instantaneous readout average method

Equipment:

A device providing an instantaneous air velocity at the point of use eg. hot wire anemometer.

Divide the doorway into a minimum of 18 imaginary squares and take a reading in the centre of each square. Add all the readings together and divide by 18 for the average measured instantaneous air velocity.[67]

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[66] This is especially relevant to the ground floor doors for base-injected fire-isolated exit pressurisation systems in buildings with a 'Purge' system.

[67] In some instances there will be a negative air velocity which must be deducted from the total, therefore this method is not as accurate or reliable as the time average method, especially where the air velocity probe used is not sensitive to the direction of air movement.

Appendix F Description of Id Boxes in Fault Tree

The acronyms are detailed in the Nomenclature at the start of the thesis.

0. The stairwell performance criteria, has been assessed against the current standard's performance conditions i.e. Australian Standard 1668.1 (1998). This is because when stairwells are assessed now days, more often than not, they are assessed against the most recent standard (i.e. the 1998 edition), as this standard is said to be more stringent than the standard at the time of construction and therefore, if the stairwell passes the 1998 performance conditions, it more than likely will also pass the (possible) requirements at the time of construction. The only exception to this rule is noted with id box 3. below.

1. The door opening force performance condition of 110 N (i.e. 11.2 kg) has not been achieved, that is, the door opening force is greater than 110 N.

2. The airflow velocity performance condition through an open door of 1 m/s has not been achieved, that is, the airflow velocity through an open door is less than 1 m/s.

3. The pressure difference performance condition (i.e. between the stairwell and the occupied space, with the door closed), is a performance condition of the design standard AS1668.1 for ZSCS. Therefore, it has not been considered as part of this research and is presented for background information only, hence the dotted boxes/lines.

4. The noise performance condition of below 80 dB(A) within a stairwell (with the stairwell doors closed) and the occupied spaces (with the stairwell door open on the fire floor) has not been achieved.

5. The reduced restoration time of less than 10 seconds, as stated in AS1668.1 has been exceeded. This is a performance condition of the standard to ensure that the system is sufficiently responsive and therefore, has been included in the fault tree assessment.

   Note 1: The 1979 edition of this standard required a 15 – 60 second restoration time.

   Note 2: This id box has been included as it required as part of design and commissioning.

6 The override controls for the FFCP do not work and/or are faulty and therefore, the SPF cannot be manually controlled on/off. Non-compliance may result in the fire brigade not being able to control the SPF.

   Note 1: This id box has been included as it required as part of commissioning.

7. The secondary power supply fails (eg. either the batteries, UPS or generators).

   Note 1: The requirement for secondary power supply functionality is a requirement for commissioning only.

7 (a). The secondary power supply to the pressure sensor i.e. the battery, fails.

7 (b). The generator is also a form of secondary power and been denoted with a '3'. In this case, the generator fails.

8. The SPF supplies too much air into the stairwell i.e. this may be because the SPF has been oversized for the design resulting in a fan of greater capacity than required. That is, the assumed fan size was too large for what is required.

9. Faults with the stairwell door are attributed to the door itself and/or the door attachments, hardware faults, etc., resulting in door opening forces exceeding the 110 N maximum force.

10. External outside conditions, eg. variations in wind speed, temperature variations (across the height of the stairwell), etc., result in fluctuating pressure variations within the stairwell which can cause the door opening forces to exceed 110 N.

10 (a). Leakage associated with the building walls may change (over time) eg. service holes may (inadvertently) be cut into the stairwell walls, increasing the leakage or existing leakage may be blocked due to refurbishment works thereby reducing the available leakage so the door opening forces are exceeded.

11. The building's AHU in the remainder of the building and/or the ZSCS operation can influence the performance of the SPS. This influence can sometimes result in either a positive or negative effect. However, the influences of these additional mechanical ventilation systems installed within the building have not been considered as part of this research i.e. these systems are assumed to be non-operational for this study and has been presented for background information only, hence the dotted boxes/lines.

12. If the pressure within the stairwell cannot be relieved, the pressure inside the stairwell will build up, resulting in the door opening forces being excessive, i.e. greater than 110 N.

13. Too much pressure relief within a stairwell may result due to cracks in the stairwell construction, service holes being cut into the stairwell shaft, (closed) door gaps being larger than required, etc., or because the stairwell is leakier than the assumed value. In this case, because of 'high' leakage, the airflow velocity of 1 m/s across an open door cannot be achieved, as too much air is 'escaping' from the stairwell.

14. The SPF is not operating as required in terms of supplying sufficient air and therefore, the stairwell is not pressurising adequately as per the design, in terms of achieving the required airflow velocity of 1 m/s.

15. External outside conditions, eg. variations in wind speed, temperature variations (over the height of the stairwell), etc., result in fluctuating pressure variations within the stairwell which can cause the airflow velocity conditions of 1 m/s, not being achieved.

15 (a). Leakage associated with the building walls, may change (increase) over time eg. service holes may (inadvertently) be cut into the stairwell walls, increasing the leakage so that the airflow velocities are not achieved.

16. External outside conditions, eg. variations in wind speed, temperature variations throughout the height of the stairwell, etc., result in fluctuating pressure variations within the stairwell, such that the required pressure difference is exceeded. This id box has been presented for background information only, hence the dotted boxes/lines.

16 (a). Leakage associated with the building walls, may change over time eg. existing leakage may be blocked due to refurbishment works thereby increasing the pressure differential for a ZSCS. This has been included for background information only, hence the dotted lines/boxes.

17. If the pressure within the stairwell cannot be relieved, the pressure inside the stairwell will build up, resulting in differential pressures exceeding the design limit, i.e. refer to id box 12. and its associated dependents. This means that the performance condition required as part of standard has not been achieved. This has been included for background information only, hence the dotted lines/boxes.

18. Hardware faults of the SPF (eg. faulty belts, blades break, mechanical fan faults, etc.), may result in excessive noise limits being exceeded within the stairwell.

Note 1: The building's AHU is not considered to work and therefore, it's potential noise contributions are not included in this research.

Note 2: The noise occupants may make is not considered as part of the noise level, as noise measurements are conducted when the building is not occupied.

19. The local wind effects such as gusting may result in fluctuating pressure variations within the stairwell, whereby the restoration times (i.e. stabilisation times) are exceeded.

19 (a). Leakage associated with the building walls, may change (over time) eg. service holes may (inadvertently) be cut into the stairwell walls, increasing the leakage so that the restoration times are exceeded.

20. Hardware faults denoted by '*' i.e. for the VSD, the pressure sensor and the dampers, could contribute to the restoration times being exceeded also.

21. The FFCP override switch (which can be used to turn the SPF on or off) is faulty, and so the SPF does not correctly respond when this switch is used. This means that the performance condition specified in the Australian Standard is not achieved and the fire brigade personnel may not be able to control the SPF if required.

22. Hardware faults of the SPF (eg. faulty belts, blades break, mechanical fan faults, etc.), may result in the SPF not working as required when the override switch is turned either on or off.

23. Hardware faults associated with the stairwell doors eg. the latches, door handles, the self-closing mechanism of the door, door strikes, etc., result in the door not being able to be opened without a force exceeding 110 N.

24. The stairwell door is damaged in service over time (eg. contractors carry equipment up the stairwell and damage/knock the stairwell doors, latches, hinges, etc.), such that the force required to open the door is greater than 110 N.

25. The stairwell door is locked, so occupants cannot get inside the stairwell at all, again resulting in a force of greater than 110 N while trying to open the door.

26. The door fitting itself may initially interfere with the opening of the stairwell door or when a stairwell door is replaced, eg. it could be jamming, etc., and therefore, the force required to open the door is greater than 110 N.

27. The stairwell construction, form of construction, workmanship and/or material used results in a stairwell being 'tighter' (i.e. not very leaky), than the design of the stairwell allowed. Therefore, the pressure cannot be relieved and the pressure builds up, contributing to excessive door opening forces.

28. The relief required in the occupied spaces has been blocked/(excessively) restricted and therefore, the pressure builds up within the stairwell, resulting in excessive door opening forces.

29. The actual leakage within the stairwell is significantly less than the design assumption, and therefore, the pressure in the stairwell increases and the pressurised air cannot escape, resulting in excessive door opening forces. This factor is considered as part of design and for simplification, is considered to have an effectiveness of '1' for this study.

30. The Bypass/Relief dampers do not operate as required for the design i.e. the damper does not open enough to relieve the pressure. As dampers can be either barometric or motorised, there are two possible paths which can be followed from this id box. Refer to Block A for more detail.

    Note: If following path for System 1 with No Relief dampers (i.e. fixed opening), then id box 30. and its dependents is ignored.

31. The stairwell construction, form of construction, workmanship, large door gaps and/or material used results in a stairwell being 'leakier' (i.e. not very tight/sealed), than the design of the stairwell allowed as compared with the main building leakage. Therefore, the pressurised air is 'lost' from the stairwell and the airflow velocity of 1 m/s cannot be achieved.

32. The actual leakage within the stairwell is significantly greater than the design assumption, and therefore, the pressurised air escapes from the stairwell and the airflow velocity of 1 m/s cannot be achieved. This factor is considered as part of design and for simplification, is considered to have an effectiveness of '1' for this study.

33. The Bypass/Relief dampers do not operate as required for the design i.e. the damper does not close enough to restrict the pressure loss. As dampers can be either barometric or motorised, there are two possible paths, which can be followed from this id box. Refer to Block B for more detail.

    Note: If following path for System 1 with No Relief dampers (i.e. fixed opening), then id box 33. and its dependents is ignored.

34. Hardware faults of the SPF (eg. faulty belts, blades break, mechanical fan faults, etc.), may result in the SPF not operating as required for its design.

35. The SPF switch on the MSSB has been switched to OFF/isolate and therefore, the SPF does not start/operate when required.

36. The SPF switch on the FFCP has been switched to OFF/isolate and therefore, the SPF does not start/operate when required.

37. The SPF keylock switch adjacent to the actual SPF, has been locked OFF and therefore, the SPF does not start/operate when required.

38. There is complete (i.e. primary and secondary) power failure to the SPF and therefore, the SPF does not operate as required.

39. The VSD is not operating as required, and therefore, the SPF does not respond and operate/start when required. Refer to Block C for more detail.

40. The primary power supply to the SPF i.e. the mains fails, however, there is the option of the secondary power supply.

41. The secondary power supply to the SPF i.e. the generator, fails.

    Note: It is assumed that if the secondary power supply is being used, the primary power supply has failed, unless the secondary power is only being used for testing purposes.

42. If the Bypass/Relief damper installed (eg. either within the stairwell or as part of the SPF bypass) is a barometric damper, follow the dependent boxes with yellow highlights.

43. If the Bypass/Relief damper installed (eg. either within the stairwell or as part of the SPF bypass) is a motorised damper, follow the dependent boxes with green highlights.

44. (a). The weights on the barometric damper need adjusting so that the damper is lighter and opens more easily, as the damper was not opening enough to be able to relieve the pressure.

44 (b). The weights on the barometric damper need adjusting so that the damper is heavier and is therefore, harder to open, as the damper was not closing enough to be able to maintain the pressure.

45. (a). The local wind effects such as gusting may result in fluctuating pressure variations within the stairwell, whereby the opening operation of the barometric damper is restricted and therefore, pressure cannot be adequately relieved.

45 (b). The local wind effects such as gusting may result in fluctuating pressure variations within the stairwell, whereby the closing operation of the barometric damper is restricted and therefore, excessive pressure is lost.

46. (a). Hardware faults associated with the barometric damper results in the damper jamming and/or sticking and so the damper does not open enough to relieve the pressure inside the stairwell.

46 (b). Hardware faults associated with the barometric damper results in the damper jamming and/or sticking and so the damper does not close enough to maintain the pressure inside the stairwell.

47. (a). Hardware faults associated with the motorised damper (eg. the blades stick/jam, the actuator is faulty, the actuator has not been adjusted correctly, the motor runs backwards, the fuse is incorrect and/or has been installed incorrectly, etc.), result in the damper not opening enough to relieve the pressure inside the stairwell.

47 (b). Hardware faults associated with the motorised damper (eg. the blades stick/jam, the actuator is faulty, the actuator has not been adjusted correctly, the motor runs backwards, the fuse is incorrect and/or has been installed incorrectly, etc.), result in the damper not closing enough to maintain the pressure inside the stairwell.

48. (a). The motorised damper wiring is incorrect eg. it may be wired back-to-front, resulting in the damper closing more when it should be opening more and so the pressure cannot be relieved.

48 (b). The motorised damper wiring is incorrect eg. it may be wired back-to-front, resulting in the damper opening more when it should be closing more and so the pressure cannot be maintained.

49. (a). The motor for the motorised damper is not large enough to control the damper and therefore, there is insufficient torque to open the damper more and relieve the pressure.

49. (b). The motor for the motorised damper is not large enough to control the damper and therefore, there is insufficient torque to close the damper more and maintain the pressure.

50. There is complete (i.e. primary and secondary) power failure to the motorised damper and therefore, the damper does not open more when required, to relieve the pressure.

Note: *There is no 50 (b). specifically, because it is assumed that if there was absolute power failure, the damper would revert to the closed (failure) position, as described in AS1668.1.*

51. (a). The output from the pressure sensor is in error that is, the pressure reading is incorrect i.e. reading a lower pressure than what is in the stairwell and so the motorised damper does not open more, to relieve the pressure.

51 (b). The output from the pressure sensor is in error that is, the pressure reading is incorrect i.e. reading a higher pressure than what is in the stairwell and so the motorised damper does not close more, to maintain the pressure.

52. (a). The programming (as part of the programmable logic circuit, PLC) between the pressure sensor and the motorised damper is incorrect/faulty and therefore, the damper does not open more, to relieve the pressure.

52 (b). The programming (as part of the programmable logic circuit, PLC) between the pressure sensor and the motorised damper is incorrect/faulty and therefore, the damper does not close more, to maintain the pressure.

53. The primary power supply to the motorised damper i.e. the mains, fails, however, there is the option of the secondary power supply.

54. The secondary power supply to the motorised damper i.e. the UPS or battery, fails.

Note: *It is assumed that if the secondary power supply is being used, the primary power supply has failed, unless the secondary power is only being used for testing purposes.*

55. There is complete (i.e. primary and secondary) power failure to the VSD and therefore, the VSD does not operate as required, in terms of altering the speed of the SPF.

56. Hardware failure faults associated with the VSD eg. faulty relays, incorrect wiring, microprocessor faults, etc., result in the VSD not operating as required, in terms of altering the speed of the SPF.

57. The VSD microprocessor output is in error and therefore, the VSD does not operate as required, in terms of altering the speed of the SPF.

58 The local wind effects such as gusting may result in fluctuating pressure variations within the stairwell, such that the VSD cannot respond in time when required.

59 The output from the pressure sensor is in error that is, the pressure reading is incorrect i.e. reading either too high or low than what is actually in the stairwell and so the VSD 'sees' the incorrect pressure from the pressure sensor, and the resulting fan speed is incorrect also.

60. The primary power supply to the VSD i.e. the mains, fails, however, there is the option of the secondary power supply.

61. The secondary power supply to the VSD i.e. the uninterruptible power supply (UPS), fails.

Note: *It is assumed that if the secondary power supply is being used, the primary power supply has failed, unless the secondary power is only being used for testing purposes. In terms of probability of failure, data related to battery failure has been used as UPS have batteries.*

62. Incorrect signal from the FIP (eg. the wrong detector alarms, refer to Figures 13 and 14 or the ACF microprocessor is in fault), whereby the corresponding signal to the VSD is incorrect, resulting in the wrong SPF speed.

63. The VSD program has been changed/altered from the original design/commissioning information, without approval, and so the resulting VSD speed is incorrect for the SPF.

Note: *This box is assumed to equal id box 64. in terms of the probability of failure, due to the wording of the questionnaire.*

64. The VSD has been mis-programmed i.e. the program was incorrect from the beginning, and so the VSD is sending the incorrect message/signal to the SPF in terms of the required speed.

65. The differential pressure (DP) seen by the pressure sensor (PS) is either not established (eg. the pressure inside the stairwell fluctuates too much) or the range of the PS is incorrect (eg. the range is too large for the available pressures inside the stairwell resulting in the pressure sensor being insensitive, etc.), resulting in incorrect readings from the pressure sensor.

66. The hardware associated with the pressure sensor is faulty (eg. the sensing tubing is blocked, there is an electrical malfunction, the supply voltage has been applied to the output of the sensor, instead of the input, the pressure reading is non-repeatable, there has been a calibration shift, etc.), and so the pressure sensor does not 'see' the correct pressures.

67. The transformer for the pressure sensor is faulty and therefore, does not operate as required.

68. The secondary power supply to the pressure sensor i.e. the battery, fails.

Note: *It is assumed that if the secondary power supply is being used, the primary power supply has failed, unless the secondary power is only being used for testing purposes.*

69. The primary power supply to the transformer for the pressure sensor i.e. the mains, fails, however, there is the option of the secondary power supply.

70. Hardware faults associated with the transformer, result in the transformer not operating as required, in terms of 'transforming' the mains power supply.

71. The FIP program has been changed/altered from the original design/commissioning information, without approval and therefore, the resulting signal/message for a particular operation for the VSD, is incorrect.

72. There is complete (i.e. primary and secondary) power failure to the FIP and therefore, the FIP does not operate as required, in terms of sending a signal to the VSD and other associated equipment for smoke control.

73. The FIP has been mis-programmed i.e. the program was incorrect from the beginning, and so the FIP is sending the incorrect message/signal to the VSD.

Note: *This box is assumed to equal id box 64. in terms of the probability of failure, even though VSD were agreed to be difficult to set up (especially in the past), the FIP despite its long existence has multiple areas which need to be configured also, therefore, adding to its complexity.*

74. Hardware failure faults associated with the FIP (eg. faulty microprocessor, incorrect wiring, faulty fuses/relays, etc.), result in the FIP not operating as required, in terms of sending the correct signal/message to the VSD and other associated equipment for smoke control.

75. The primary power supply to the FIP i.e. the mains, fails, however, there is the option of the secondary power supply.

76. The secondary power supply to the FIP i.e. the battery backup, fails.

Note: *It is assumed that if the secondary power supply is being used, the primary power supply has failed, unless the secondary power is only being used for testing purposes.*

Appendix G Conversion of Mass Flow Rate to Airflow Velocity

Computation example for converting the mass flow rate in kg/s to an airflow velocity in m/s.

$$Velocity,\ m/s \ x\ Crack\ area\ for\ cross\ sectional\ opening\ in\ door,\ m^2\ x\ Density,\ kg/m^3 = Mass\ Flow\ Rate,\ kg/s$$

Equation G1

Since 1 kg of air is $\approx$ 1 m^3, the expression above becomes:

$$Velocity,\ m/s = \frac{Mass\ Flow\ Rate,\ kg/s}{Crack\ area\ for\ cross\ sectional\ opening\ in\ door,\ m^2\ x\ Density,\ kg/m^3}$$

So, where the crack area for the cross sectional opening of the door is 0.96915 m^2 (for an open door) and 0.023 m^2 (for a closed door) (refer to Chapter 7, Table 9), the equivalent airflow velocity (i.e. in m/s) to a said mass flow rate of 1.1907 kg/s is:

$$\begin{aligned}
Velocity,\ m/s &= \frac{Mass\ Flow\ Rate,\ kg/s}{Crack\ area\ for\ cross\ sectional\ opening\ in\ door,\ m^2\ x\ Density,\ kg/m^3} \\
&= \frac{1.1907,\ kg/s}{0.96915,\ m^2\ x\ 1\ kg/m^3} \\
&= \frac{1.1907,\ m/s}{0.96915} \\
&= 1.2286\ m/s
\end{aligned}$$

This methodology described above, was then used throughout the mass flow rate conversion segment of this research in order to assess compliance with the airflow velocity condition of 1 m/s in AS1668.1. That is, the mass flow rates generated by CONTAM for the various simulations were converted as above, to enable comparison with the Australian Standard requirements.

Appendix H Door Opening Force Calculations

The maximum door opening force was calculated in terms of pressures using Klote and Milke (2002).

Firstly, the variables listed in Equations H1 and H2 below, have the following values:

F_r	= 5.65 N[68]	K_d	= 1
W	= 2.13 m	A	= 2.13 m x 0.91 m = 1.9383 m^2
d	= 0.0762 m	F	= 110 N

In order to find the maximum door opening force in terms of pressure (i.e. Δp), Equation H1 is rearranged to find the moment of the door closure and friction:

$$F_r = \frac{M_r}{(W-d)} \qquad \textbf{Equation H1}$$

$$\begin{aligned} M_r &= F_r(W-d) \\ &= 5.65(2.13-0.0762) \\ &= 5.65(2.0538) \\ &= 11.6040\ Nm \end{aligned}$$

Substituting this value M_r into Equation H2 gives:

$$M_r + K_d\, A\, \Delta p\left(\frac{W}{2}\right) - F(W-d) = 0 \qquad \textbf{Equation H2}$$

$$11.6040 + (1 \times 1.9383 \times \Delta p)\cdot\left(\frac{2.13}{2}\right) - 110\cdot(2.13-0.0762) = 0$$

$$11.6040 + (1.9383 \times \Delta p)\cdot(1.065) - 225.918 = 0$$

$$\begin{aligned} 2.0643 \times \Delta p &= 225.918 - 11.6040 \\ 2.0643 \times \Delta p &= 214.314 \\ \Delta p &= 103.8197 \\ &= 103.82\ Nm^2\ (or\ Pa) \end{aligned}$$

Therefore, the maximum pressure differential across the door (i.e. between the stairwell and the occupied space) using a door closure moment force of 11.6040 Nm (i.e. M_r) is 103.82 Nm^2 (Pa). Providing this pressure differential value is not exceeded means that the door opening forces within the stairwell comply with the performance conditions of AS1668.1. In practical terms, when performing the CONTAM simulations with all stairwell doors closed, if the upper pressure

[68] Klote and Milke (2002) state that the force at the door knob (F_r), needed to overcome the hinge friction, is between 2.3 to 9 N, therefore, the median value was chosen for this calculation.

limit of 103.82 Pa (inside the stairwell) is not exceeded, this means that the door opening force is not greater than 110 N and so the occupants could enter the stairwell when the SPS was operational in fire mode, i.e. pressurising the stairwell, as per the Australian Standard requirements.

Appendix I CONTAM Simulations Performed

Below is the list of all of the CONTAM simulations performed, including the door opening forces and airflow velocity results. The file names are also listed for each simulation. The list below is referred to as Table I1.

Note: kg/s = m3/s Pressure limit (max) in stairwell to exceed 110N dr force, calculated as 103.82Pa (for a door moment, Mr = 11.6Nm)

CONTAM Press in stairs = 97.9 Pa, so **F = 104 N**

With correction of m/s for open door x-sectional areas on the fire floor, see column P

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) *m/s* Min	Limits (kg/s) *m/s* Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	*File saved as*
1	**5** **E**	**20**	M - L9, 5, 1 A=0.54m2	5.525	0.5525	5.525	6.64725	Y	Y	Y	0.023 *1*	0.2 *8.7*	0	N	all drs shut	N		try controls 21 fan limits a1
2	"	"	"	"	"	"	"	"	"	"	"	"	"	N	all drs shut	0.6x0.4	L9 str shft	try controls 21g fan limits ag
3	"	"	"	"	"	"	"	"	"	"	"	"	3 Grd-StM, StRm, L1	N	FF=GF **Y=1.2m/s**	N		VelC P_S 3 drs
4	"	"	"	7	0.7	7	8.42106	"	"	"	N	N	3 Grd-StM, StRm, L1	N	FF=GF **Y=1.43m/s**	N		VelC P_S 3 drs F1
5	"	"	"	2.7625	0.2763	2.763	3.32363	"	"	"	N	N	3 Grd-StM, StRm, L1	N	FF=GF N	N		VelC P_S 3 drs Fhalf
6	"	"	S - L9 A=0.54m2	5.525			6.64725	"	"	"	N	N	3 Grd-StM, StRm, L1	N	FF=GF **Y=1.57m/s**	N		VelC P_S 3 drs 1Inj
7	"	"	"	7			8.42106	"	"	"	N	N	3 Grd-StM, StRm, L1	N	FF=GF **Y=1.89m/s**	N		VelC P_S 3 drs 1Inj F1
8	"	"	"	2.7625			3.32363	"	"	"	N	N	3 Grd-StM, StRm, L1	N	FF=GF N=0.96m/s	N		VelC P_S 3 drs 1Inj Fhalf
9	"	"	"	1.3813			1.66181	"	"	"	N	N	3 Grd-StM, StRm, L1	N	FF=GF N=0.71m/s	N		VelC P_S 3 drs 1Inj Fquart
10	"	"	"	0				"	"	"	N	N	3 Grd-StM, StRm, L1	N	FF=GF N	N		VelC P_S 3 drs 1Inj Fnone
11	"	"	"	1.3813			1.66181	"	"	"	N	N	3 Grd-StM, L1, L2	N	FF=L1 N=0.03m/s	N		VelC P_S 3 drs_a 1Inj Fquart
12	"	"	"	1.3813			1.66181	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N=0.002m/s	N		VelC P_S 3 drs_b 1Inj Fquart

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
13	"	"	"	5.525			6.64725	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N=0.01m/s	N		VelC P_S 3 drs_b 1Inj
14	"	"	"	7			8.42106	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N=0.01m/s	N		VelC P_S 3 drs_b 1Inj F1
15	"	"	M - L9, 5, 1 A=0.54m2	7			8.42106	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N	N		VelC P_S 3 drs_b F1
16	"	"	S - L9 A=0.54m2	9			10.8281	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N=0.01m/s	N		VelC P_S 3 drs_b 1Inj F2
17	"	"	"	11.575			13.9261	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N=0.02m/s	N		VelC P_S 3 drs_b 1Inj F3
18	"	"	"	30			36.0937	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N=0.06m/s	N		VelC P_S 3 drs_b 1Inj F4
19	"	"	"	20			24.0625	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 N=0.03m/s	N		VelC P_S 3 drs_b 1Inj F5
20	"	"	"	"			24.0625	"	"	"	N	N	3 Grd-StM, L1, L2	N	FF=L1 N=0.23m/s	N		VelC P_S 3 drs_a 1Inj F5
21	"	"	M - L9, 5, 1 A=0.54m2	5.525			6.64725	"	"	"	N	N	3 Grd-StM, L1, L2	N	FF=L1 N=0.006m/s	N		VelC P_S 3 drs_a
22	"	"	"	7			8.42106	"	"	"	N	N	3 Grd-StM, L1, L2	N	FF=L1 N=0.001m/s	N		VelC P_S 3 drs_a F1
23	"	"	"	9			10.8281	"	"	"	N	N	3 Grd-StM, L1, L2	N	FF=L1 N=0.002m/s	N		VelC P_S 3 drs_a F2
24	"	"	"	20			24.0625	"	"	"	N	N	3 Grd-StM, L1, L2	N	FF=L1 N=0.03m/s	N		VelC P_S 3 drs_a F5
25	"	"	S - L9 A=0.54m2	5.525			6.64725	"	"	"	N	N	3 Grd-StM, L1, L2	N	FF=L1 N=0.07m/s	N		VelC P_S 3 drs_a 1Inj
26	"	"	"	"			6.64725	"	"	"	N	N	3 Grd-StM, L9, L8	N	FF=L9 N	N		VelC P_S 3 drs_i 1Inj
27	"	"	"	"			6.64725	"	"	"	N	N	3 Grd-StM, L9, L8	N	FF=L9 N	N		VelC P_S 3 drs_ib 1Inj_Sltd

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
28	"	"	"	"			6.64725	"	"	"	N	N	3 Grd-StM, L8, L7	N	FF=L8 **Y=1.58m/s**	N		VelC P_S 3 drs_hb 1Inj_Sltd
29	"	"	"	"			6.64725	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N=0.03m/s	N		VelC P_S 3 drs_gb 1Inj_Sltd
30	"	"	"	"			5.525	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N=0.02m/s	N		VelC P_S 3 drs_gb 1Inj_Sltd_x
31	"	"	"	"			5.525	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N	N		VelC P_S 3 drs_gb 1Inj_Sltd_x_noSflrlek
32	"	"	"	"			5.525	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N	N		VelC P_S 3 drs_gb 1Inj_Sltd_x_noSflrlek_1
33	"	"	"	100			100	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N=0.03m/s	N		VelC P_S 3 drs_gb 1Inj F6_Sltd_x_noSflrlek_1
34	"	"	"	"			100	"	"	"	N	N	3 Grd-StM, L7, L6	Y 200+	FF=L7 **Y=18.26m/s**	N		VelC P_S 3 drs_gb 1Inj F6_Sltd_x_noSflrlek_2
35	"	"	"	5.525			5.525	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N=0.63m/s	N		VelC P_S 3 drs_gb 1Inj_Sltd_x_noSflrlek_2
36	"	"	"	7			7	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N=0.83m/s	N		VelC P_S 3 drs_gb 1Inj F1_Sltd_x_noSflrlek_2
37	"	"	"	9			9	"	"	"	N	N	3 Grd-StM, L7, L6	**N max ~ 66**	FF=L7 **Y=1.12m/s**	N		VelC P_S 3 drs_gb 1Inj F2_Sltd_x_noSflrlek_2
38	"	"	M - L9, 5, 1 A=0.54m2	"			9	"	"	"	N	N	3 Grd-StM, L7, L6	N	FF=L7 N=0.93m/s	N		VelC P_S 3 drs_gb F2_x_2
39	"	"	"	11.575			11.575	"	"	"	N	N	3 Grd-StM, L7, L6	**N max ~ 71**	FF=L7 **Y=1.25m/s**	N		VelC P_S 3 drs_gb F3_x_2
40	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	**N max ~ 64**	FF=L7 **Y=1.22m/s**	N		VelC P_S 3 drs_g F3_x_2
41	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	**N max ~ 64**	FF=L9 **Y=1.34m/s**	N		VelC P_S 3 drs_i F3_x_2
42	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 82**	FF=GF **Y=1.02m/s**	N		VelC P_S 3 drs F3_x_2

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
43	"	"	" A=0.27m2	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N, FF=6.8 max ~ 83**	FF=GF **Y=1.02m/s**	N		VelC P_S 3 drs H F3_x_2
44	"	"	"	15			15	"	"	"	N	N	3 Grd-StM, StRm, L1	Y, FF=7.7 L4=113+	FF=GF **Y=1.35m/s**	N		VelC P_S 3 drs H F7_x_2
45	"	"	" A=0.54m2	"			15	"	"	"	N	N	3 Grd-StM, StRm, L1	Y L4=113+	FF=GF **Y=1.35m/s**	N		VelC P_S 3 drs F7_x_2
46	"	"	" A=0.27m2	"			15	"	"	"	N	N	1 StRm	**N, FF=59 L1+ >700**	FF=GF	N		DrFC P_S H F7_x_2
47	"	"	"	11.575			11.575	"	"	"	N	N	1 StRm	**N, FF=36 L1+ >448**	FF=GF	N		DrFC P_S H F3_x_2
48	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N, FF=6.6 max ~ 69**	FF=GF N=0.92m/s	.6x.4x.5 =0.12m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR
49	"	"	"	15			15	"	"	"	N	N	3 Grd-StM, StRm, L1	**N, FF=7.3 max ~ 111**	**FF=GF Y=1.23m/s**	.6x.4x.5 =0.12m2	L9 str shft	VelC P_S 3 drs H F7_x_2 StR
50	"	"	"	11.575			11.575	"	"	"	N	N	1 StRm	**N, FF=39 L1+ >300**	FF=GF	.6x.4x.5 =0.12m2	L9 str shft	DrFC P_S H F3_x_2 StR
51	"	"	"	15			15	"	"	"	N	N	1 StRm	**N, FF=24 L1+ >486**	FF=GF	.6x.4x.5 =0.12m2	L9 str shft	DrFC P_S H F7_x_2 StR
52	"	"	"	11.575			11.575	"	"	"	N	N	0	Y > 1200	all drs shut	N		DrFC P_S H F3_x_2_0
53	"	"	"	15			15	"	"	"	N	N	0	Y > 2100	all drs shut	N		DrFC P_S H F7_x_2_0
54	"	"	"	11.575			11.575	"	"	"	N	N	0	**N max ~ 86**	all drs shut	1.05x1.05 =1.1m2	L9 str shft	DrFC P_S H F3_x_2 StR1_0
55	"	"	"	"			11.575	"	"	"	N	N	0	Y max 127	all drs shut	.894x.894 =0.8m2	L9 str shft	DrFC P_S H F3_x_2 StR2_0
56	"	"	"	"			11.575	"	"	"	N	N	0	**N max ~ 97**	**all drs shut @ GF**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0
57	"	"	"	15			15	"	"	"	N	N	0	Y max 158	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F7_x_2 StR3_0

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
58	"	"	"	11.575			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N,FF=6 max ~ 30	FF=GF N=0.55m/s	1x1 =1m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR3
59	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N,FF=6	FF=GF N=0.72m/s	.71x.71 =0.5m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR4
60	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N,FF=6	FF=GF N=0.84m/s	.5x.5 =0.25m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR5
61	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N,FF=6	FF=GF N=0.94m/s	.32x.32 =0.1m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR6
62	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N,FF=6	FF=GF N=0.97m/s	.22x.22 =0.05m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR7
62A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 76**	**FF=GF N=0.97m/s**	**.245x.245 =0.06m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_62A
63	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N,FF=6.8 max ~ 82	**FF=GF Y=1.01m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8
64	"	"	"	"			11.575	"	"	"	N	N	**2** Grd-StM, StRm	**N,FF=8 max ~ 91**	**FF=GF Y=1.46m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 2 drs H F3_x_2 StR8
65	"	"	"	"			11.575	"	"	"	N	N	1 StRm	Y > 500	**FF=GF Y=5.05m/s**	.1x.1 =0.01m2	L9 str shft	VelC P_S 1 drs H F3_x_2 StR8
66	"	"	"	"			11.575	"	"	"	N	N	2 Grd-StM, StRm	N,FF=8 max ~ 29	FF=GF N=0.77m/s	1x1 =1m2	L9 str shft	VelC P_S 2 drs H F3_x_2 StR3
67	"	"	"	"			11.575	"	"	"	N	N	1 StRm	N,FF=6 max ~ 69	**FF=GF Y=1.5m/s**	**1x1 =1m2**	L9 str shft	VelC P_S 1 drs H F3_x_2 StR3
68	"	"	"	"			11.575	"	"	"	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0
69	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 79	**FF=L1 Y=1.13m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8
69A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	**N**	**FF=L1 Y=1.09m/s**	**.245x.245 =0.06m2**	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR10_69A
70	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 78	**FF=L2 Y=1.14m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) m/s Min	Limits (kg/s) m/s Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	File saved as
70A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N	FF=L2 Y=1.09m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR10_070A
71	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 76	FF=L3 Y=1.15m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8
71A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N	FF=L3 Y=1.10m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR10_071A
72	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 75	FF=L4 Y=1.16m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8
72A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N	FF=L4 Y=1.11m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR10_072A
73	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 73	FF=L5 Y=1.21m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8
73A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N	FF=L5 Y=1.16m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR10_073A
74	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 70	FF=L6 Y=1.21m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8
74A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N	FF=L6 Y=1.16m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR10_074A
75	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 63	FF=L7 Y=1.21m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8
75A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N	FF=L7 Y=1.16m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR10_075A
76	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~ 64	FF=L8 Y=1.21m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8
76A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N	FF=L8 Y=1.16m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR10_076A
77	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 64	FF=L9 Y=1.33m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_ib H F3_x_2 StR8
77A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 60	FF=L9 Y=1.27m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_ib H F3_x_2 StR10_77A

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
78	7.5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_078
79	"	"	"	"			11.575	"	"	"	N	N	0	N max ~ 98	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_079
80	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 82	FF=GF Y=1.02m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_080
80a	"	"	"	"			11.575	"	"	"	N	N	1 StRm	N max ~ 67	FF=GF Y=1.49m/s	1x1 =1m2	L9 str shft	VelC P_S 1 drs H F3_x_2 StR3_080a
81	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 80	FF=L1 Y=1.14m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_081
82	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 78	FF=L2 Y=1.15m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_082
83	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 77	FF=L3 Y=1.16m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_083
84	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 75	FF=L4 Y=1.17m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_084
85	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 74	FF=L5 Y=1.22m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_085
86	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 71	FF=L6 Y=1.22m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_086
87	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 63	FF=L7 Y=1.22m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_087
88	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~ 64	FF=L8/L9 Y=1.21m/s Y=1.35m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_088
89	10 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_089

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
90	"	"	"	"			11.575	"	"	"	N	N	0	N max ~ 99	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_090
91	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 84	FF=GF Y=1.04m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_091
91a	"	"	"	"			11.575	"	"	"	N	N	1 StRm	N max ~ 78	FF=GF Y=1.48m/s	1x1 =1m2	L9 str shft	VelC P_S 1 drs H F3_x_2 StR3_091a
92	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 81	FF=L1 Y=1.15m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_092
93	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 80	FF=L2 Y=1.16m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_093
94	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 78	FF=L3 Y=1.17m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_094
95	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 76	FF=L4 Y=1.18m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_095
96	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 75	FF=L5 Y=1.22m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_096
97	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 73	FF=L6 Y=1.22m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_097
98	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 64	FF=L7 Y=1.23m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_098
99	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~ 64	FF=L8/L9 Y=1.22m/s Y=1.36m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_099
100	12.5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_100
101	"	"	"	"			11.575	"	"	"	N	N	0	N max ~ 101	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_101
102	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 85	FF=GF Y=1.07m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_102

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
103	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 83	FF=L1 Y=1.17m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_103
104	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 81	FF=L2 Y=1.17m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_104
105	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 80	FF=L3 Y=1.18m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_105
106	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 78	FF=L4 Y=1.19m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_106
107	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 77	FF=L5 Y=1.23m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_107
108	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 74	FF=L6 Y=1.23m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_108
109	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 64	FF=L7 Y=1.24m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_109
110	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~64	FF=L8/L9 Y=1.23m/s Y=1.38m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_110
111	15 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_111
112	"	"	"	"			11.575	"	"	"	N	N	0	N max ~104	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_112
113	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~87	FF=GF Y=1.1m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_113
114	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~85	FF=L1 Y=1.18m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_114
115	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~83	FF=L2 Y=1.18m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_115
116	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~82	FF=L3 Y=1.19m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_116

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
117	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~79	FF=L4 Y=1.2m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_117
118	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~78	FF=L5 Y=1.25m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_118
119	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~76	FF=L6 Y=1.25m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_119
120	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~66	FF=L7 Y=1.25m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_120
121	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~66	FF=L8/L9 Y=1.25m/s Y=1.41m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_121
122	30 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	"	"	"	N	N	0	Y max ~114	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_122
123	"	"	"	"			11.575	"	"	"	N	N	0	N max ~104	all drs shut	1.05x1.05 =1.1m2	L9 str shft	DrFC P_S H F3_x_2 StR1_0_123
124	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~96	FF=GF Y=1.32	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_124
125	5 E	5	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y max >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_125
126	"	"	"	"			11.575	Y	Y	Y	N	N	0	N max ~106	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_126
127	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, StRm, L1	N max ~67	FF=GF N/Y=0.997	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_127
128	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L1, L2	N max ~65	FF=L1 Y=1.1	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_128
129	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L2, L3	N max ~63	FF=L2 Y=1.09	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_129

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
130	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L3, L4	N max ~62	FF=L3 Y=1.09	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_130
131	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L4, L5	N max ~60	FF=L4 Y=1.09	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_131
132	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L5, L6	N max ~59	FF=L5 Y=1.13	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_132
133	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L6, L7	N max ~59	FF=L6 Y=1.12	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_133
134	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L7, L8	N max ~59	FF=L7 Y=1.1	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_134
135	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L8, L9	N max ~59	FF=L8/L9 Y=1.09 Y=1.18	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_135
136	5 E	10	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_136
137	"	"	"	"			11.575	Y	Y	Y	N	N	0	N max ~103	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_137
138	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, StRm, L1	N max ~72	FF=GF Y=1	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_138
139	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L1, L2	N max ~69	FF=L1 Y=1.11	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_139
140	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L2, L3	N max ~68	FF=L2 Y=1.11	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_140
141	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L3, L4	N max ~67	FF=L3 Y=1.11	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_141
142	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L4, L5	N max ~65	FF=L4 Y=1.12	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_142
143	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L5, L6	N max ~64	FF=L5 Y=1.16	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_143

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
144	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L6, L7	N max ~62	FF=L6 Y=1.15	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_144
145	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L7, L8	N max ~60	FF=L7 Y=1.14	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_154
146	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L8, L9	N max ~60	FF=L8/L9 Y=1.13 Y=1.24	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_146
147	5 E	15	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_147
148	"	"	"	"			11.575	Y	Y	Y	N	N	0	N max ~100	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_148
149	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, StRm, L1	N max ~77	FF=GF Y=1	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_149
150	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L1, L2	N max ~75	FF=L1 Y=1.12	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_150
151	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L2, L3	N max ~73	FF=L2 Y=1.12	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_151
152	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L3, L4	N max ~72	FF=L3 Y=1.13	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_152
153	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L4, L5	N max ~70	FF=L4 Y=1.14	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_153
154	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L5, L6	N max ~68	FF=L5 Y=1.19	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_154
155	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L6, L7	N max ~66	FF=L6 Y=1.18	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_155
156	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L7, L8	N max ~61	FF=L7 Y=1.18	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_156

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
157	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L8, L9	N max ~61	FF=L8/L9 Y=1.17 Y=1.28	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_157
158	5 E	25	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_158
159	"	"	"	"			11.575	Y	Y	Y	N	N	0	N max ~95	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_159
160	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, StRm, L1	N max ~87	FF=GF Y=1.01	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_160
161	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L1, L2	N max ~84	FF=L1 Y=1.15	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_161
162	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L2, L3	N max ~82	FF=L2 Y=1.15	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_162
163	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L3, L4	N max ~81	FF=L3 Y=1.17	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_163
164	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L4, L5	N max ~79	FF=L4 Y=1.18	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_164
165	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L5, L6	N max ~77	FF=L5 Y=1.23	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_165
166	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L6, L7	N max ~75	FF=L6 Y=1.24	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_166
167	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L7, L8	N max ~65	FF=L7 Y=1.24	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_167
168	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L8, L9	N max ~66	FF=L8/L9 Y=1.24 Y=1.38	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_168
169	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L6, L7	N max ~42	FF=L6 N=0.84	.71x.71 =0.5m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR4_169

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) m/s Min	Limits (kg/s) m/s Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	*File saved as*
170	5 E	30	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y >1200	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3_x_2 StR8_0_170
171	"	"	"	"			11.575	Y	Y	Y	N	N	0	N max ~93	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_171
172	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, StRm, L1	N max ~92	FF=GF Y=1.01	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_172
173	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L1, L2	N max ~89	FF=L1 Y=1.15	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_173
174	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L2, L3	N max ~87	FF=L2 Y=1.16	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_174
175	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L3, L4	N max ~85	FF=L3 Y=1.18	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_175
176	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L4, L5	N max ~83	FF=L4 Y=1.2	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_176
177	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L5, L6	N max ~82	FF=L5 Y=1.25	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_177
178	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L6, L7	N max ~78	FF=L6 Y=1.26	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_178
179	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L7, L8	N max ~67	FF=L7 Y=1.27	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_179
180	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L8, L9	N max ~67	FF=L8/L9 Y=1.27 Y=1.42	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_180
181	5 E	30	M - L9, 5, 1 A=0.27m2	1.1575			1.1575	Y	Y	Y	N	N	0	N max ~27	all drs shut	N		DrFC P_S H F3a_x_2 _0_181
182	"	"	"	2.315			2.315	Y	Y	Y	N	N	0	N max ~74	all drs shut	N		DrFC P_S H F3b_x_2 _0_182
182A	"	"	"	2.315			2.315	Y	Y	Y	N	N	0	N max ~70.2	all drs shut	.1x.1 =0.01m2		DrFC P_S H F3b_x_2 StR8_0_182A

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
183	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	Y max~148	all drs shut	N		DrFC P_S H F3c_x_2 _0_183
184	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	Y max~140	all drs shut	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3c_x_2 StR8_0_184
185	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	Y max~112	all drs shut	.22x.22 =0.05m2	L9 str shft	DrFC P_S H F3c_x_2 StR7_0_185
186	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~100**	**all drs shut**	**.274x.274 =0.075m2**	L9 str shft	DrFC P_S H F3c_x_2 StR9_0_186
187	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~107**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_187 **better than 186**
188	5 E	25	"	3.4725			3.4725	Y	Y	Y	N	N	0	Y max~147	all drs shut	N		DrFC P_S H F3c_x_2 _0_188
189	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~105**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_189
190	"	**20**	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~104**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_190
191	"	15	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~105**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_191
192	"	10	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~106**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_192
193	"	5	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~108**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_193
194	7.5 E	20	"	1.1575			1.1575	Y	Y	Y	N	N	0	**N max ~24**	**all drs shut**	**N**		DrFC P_S H F3a_x_2 _0_194
195	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	Y max~145	all drs shut	N		DrFC P_S H F3c_x_2 _0_195
196	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	**N max ~110**	**all drs shut**	**.22x.22 =0.05m2**	L9 str shft	DrFC P_S H F3c_x_2 StR7_0_196

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) *m/s* Min	Limits (kg/s) *m/s* Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	*File saved as*
197	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	N max ~104	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_197 better than 196
198	10 E	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	N max ~105	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_198
199	12.5 E	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	N max ~106	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_199
200	15 E	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	N max ~107	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_200
201	15 E	30	M - L9, 5, 1 A=0.27m2	1.1575			1.1575	Y	Y	Y	N	N	0	N max ~29	all drs shut	N		DrFC P_S H F3a_x_2 _0_201
202	"	"	"	2.315			2.315	Y	Y	Y	N	N	0	N max ~77	all drs shut	N		DrFC P_S H F3b_x_2 _0_202
203	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	Y max~151	all drs shut	N		DrFC P_S H F3c_x_2 _0_203
204	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	Y max ~110.6	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_204
205	"	"	"	3.4725			3.4725	Y	Y	Y	N	N	0	N max ~103	all drs shut	.274x.274 =0.075m2	L9 str shft	DrFC P_S H F3c_x_2 StR9_0_205
206	15 E	30	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	N max ~98	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_206
207	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, StRm, L1	N max ~96	FF=GF Y=1.1	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_207
208	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L1, L2	N max ~94	FF=L1 Y=1.2	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_208
209	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L2, L3	N max ~93	FF=L2 Y=1.21	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_209
210	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L3, L4	N max ~91	FF=L3 Y=1.22	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_210

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) m/s Min	Limits (kg/s) m/s Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	*File saved as*
211	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L4, L5	N max ~89	FF=L4 Y=1.24	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_211
212	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L5, L6	N max ~87	FF=L5 Y=1.29	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_212
213	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L6, L7	N max ~84	FF=L6 Y=1.3	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_213
214	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L7, L8	N max ~69	FF=L7 Y=1.3	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_214
215	"	"	"	"			11.575	Y	Y	Y	N	N	3 Grd-StM, L8, L9	N max ~69	FF=L8/L9 Y=1.31 Y=1.48	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_215
216	5 N	20	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	0	N max ~102	all drs shut	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_216
217	"	"	"	11.575			11.575	"	"	"	N	N	0	N max ~94	all drs shut	.274x.274 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_217
218	5 S	20	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	0	N max ~103	all drs shut	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_218
219	"	"	"	11.575			11.575	"	"	"	N	N	0	N max ~96	all drs shut	.274x.274 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_219
220	5 W	20	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	0	N max ~104	all drs shut	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_220
221	"	"	"	11.575			11.575	"	"	"	N	N	0	N max ~97	all drs shut	.274x.274 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_221
The following scenarios are with a 25% increased leakage rate (i.e. b/w average to loose) QUARTER Increase in Leakage																		
222	5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	"	"	"	N	N	0	N max ~ 94	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_222 Quart

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) m/s Min	Limits (kg/s) m/s Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	*File saved as*
223	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 78	FF=GF Y=1.06	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_223 Quart
224	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 74	FF=L1 Y=1.32	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_224 Quart
225	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 73	FF=L2 Y=1.33	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_225 Quart
226	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 71	FF=L3 Y=1.34	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_226 Quart
227	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 69	FF=L4 Y=1.35	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_227 Quart
228	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 67	FF=L5 Y=1.41	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_228 Quart
229	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 64	FF=L6 Y=1.41	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_229 Quart
230	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 57	FF=L7 Y=1.41	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_230 Quart
231	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 58	FF=L8/L9 Y=1.42 Y=1.56	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_231 Quart
HALF Increase in Leakage (I.e. 50%)																		
232	5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	"	"	"	N	N	0	N max ~ 91	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_232 Half
233	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 74	FF=GF Y=1.12	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_233 Half
234	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 69	FF=L1 Y=1.47	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_234 Half
235	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 68	FF=L2 Y=1.49	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_235 Half
236	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 66	FF=L3 Y=1.56	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_236 Half

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
237	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 64	FF=L4 Y=1.51	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_237 Half
238	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 62	FF=L5 Y=1.58	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_238 Half
239	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 59	FF=L6 Y=1.58	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_239 Half
240	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 53	FF=L7 Y=1.58	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_240 Half
241	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 53	FF=L8/L9 Y=1.59 Y=1.75	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_241 Half
3 QUARTER Increase in Leakage (I.e. 75%)																		
242	5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	"	"	"	N	N	0	N max ~ 87	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_242 3Quart
243	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 70	FF=GF Y=1.18	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_243 3Quart
244	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 65	FF=L1 Y=1.59	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_244 3Quart
245	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 63	FF=L2 Y=1.62	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_245 3Quart
246	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 61	FF=L3 Y=1.63	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_246 3Quart
247	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 58	FF=L4 Y=1.64	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_247 3Quart
248	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 57	FF=L5 Y=1.72	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_248 3Quart
249	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 54	FF=L6 Y=1.72	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_249 3Quart
250	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 49	FF=L7 Y=1.72	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_250 3Quart

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
251	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 49	FF=L8/L9 Y=1.73 Y=1.89	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_251 3Quart
LOOSE Increase in Leakage (i.e. 100%)																		
252	5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	"	"	"	N	N	0	N max ~ 84	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_252 Loose
253	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 66	FF=GF Y=1.23	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_253 Loose
254	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 64	FF=L1 Y=1.69	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_254 Loose
255	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 59	FF=L2 Y=1.73	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_255 Loose
256	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 57	FF=L3 Y=1.74	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_256 Loose
257	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 55	FF=L4 Y=1.75	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_257 Loose
258	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 53	FF=L5 Y=1.84	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_258 Loose
259	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 50	FF=L6 Y=1.84	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_259 Loose
260	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 45	FF=L7 Y=1.85	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_260 Loose
261	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 45	FF=L8/L9 Y=1.85 Y=2.02	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_261 Loose
The following scenarios are with a 25%-100% increased leakage rate (i.e. b/w average to loose) Increases in Leakage for VSD setting																		
262	5 E	20	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	0	N max ~90	all drs shut @ GF	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_262 Quart

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
263	"	"	"	11.575			11.575	"	"	"	N	N	0	N max ~94	all drs shut @ GF	.1x.1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_263 Quart *same as #222*
264	"	"	"	3.473			3.4725	"	"	"	N	N	0	Y max ~114	all drs shut @ GF	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3c_x_2 StR8_0_264 Quart
265	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~93	all drs shut @ GF	.22x.22 =0.05m2	L9 str shft	DrFC P_S H F3c_x_2 StR7_0_265 Quart
266	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~79	all drs shut @ GF	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_266 Half
267	"	"	"	11.575			11.575	"	"	"	N	N	0	N max ~91	all drs shut @ GF	.1x.1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_267 Half *same as #232*
268	"	"	"	3.473			3.4725	"	"	"	N	N	0	N max ~98.5	all drs shut @ GF	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3c_x_2 StR8_0_268 Half
269	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~70	all drs shut @ GF	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_269 3Quart
270	"	"	"	11.575			11.575	"	"	"	N	N	0	N max ~87	all drs shut @ GF	.1x.1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_270 3Quart *same as #242*
271	"	"	"	3.473			3.4725	"	"	"	N	N	0	N max ~86	all drs shut @ GF	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3c_x_2 StR8_0_271 3Quart
272	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~63	all drs shut @ GF	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_272 Loose
273	"	"	"	11.575			11.575	"	"	"	N	N	0	N max ~84	all drs shut @ GF	.1x.1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_273 Loose *same as #252*
274	"	"	"	3.473			3.4725	"	"	"	N	N	0	N max ~76	all drs shut @ GF	.1x.1 =0.01m2	L9 str shft	DrFC P_S H F3c_x_2 StR8_0_274 Loose
Back to average leakages																		
275	5	20	M - L9, 5, 1 A=0.27m2	1.1575			1.1575	Y	Y	Y	N	N	0	N max ~18	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3a_x_2 StR10_0_275
276	"	"	"	"			1.1575	"	"	"	"	"	0	N max ~23	all drs shut	N		DrFC P_S H F3a_x_2 _0_276 **better than 275**

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
277	"	"	"	"			1.1575	"	"	"	"	"	3 Grd-StM, StRm, L1	N	FF=GF N=0.14	N		VelC P_S 3 drs H F3a_x_2_277
278	"	"	"	2.315			2.315	"	"	"	"	"	0	**N max ~51**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3b_x_2 StR10_0_278
279	"	"	"	"			2.315	"	"	"	"	"	0	**N max ~70**	**all drs shut**	**N**		DrFC P_S H F3b_x_2 _0_279 **better than 278**
280	"	"	"	"			2.315	"	"	"	"	"	3 Grd-StM, StRm, L1	N	FF=GF N=0.21	N		VelC P_S 3 drs H F3b_x_2_280
281	"	"	"	3.4725			3.4725	"	"	"	"	"	0	**N, L9 max ~104**	**all drs shut**	**.245x.245 =0.06m2**	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_281 **exactly like #190**
282	"	"	"	3.4725			3.4725	"	"	"	"	"	0	**N, L9 max ~109**	**all drs shut**	**.22x.22 =0.05m2**	L9 str shft	DrFC P_S H F3c_x_2 StR7_0_282
283	"	"	"	"			3.4725	"	"	"	"	"	3 Grd-StM, StRm, L1	N max ~13	FF=GF N=0.3	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3c_x_2 StR8_283
284	"	"	"	"			3.4725	"	"	"	"	"	3 Grd-StM, L5, L6	N max ~13	FF=L5 N=0.3	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3c_x_2 StR8_284
285	"	"	"	4.63			4.63	"	"	"	"	"	0	Y max ~175	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_285
286	"	"	"	"			4.63	"	"	"	"	"	0	Y max ~163	all drs shut	.274x.274 =0.075m2	L9 str shft	DrFC P_S H F3d_x_2 StR9_0_286
287	"	"	"	"			4.63	"	"	"	"	"	0	Y max ~144	all drs shut	.32x.32 =0.1m2	L9 str shft	DrFC P_S H F3d_x_2 StR6_0_287
288	"	"	"	"			4.63	"	"	"	"	"	0	**N max ~42**	**all drs shut**	**.71x.71 =0.5m2**	L9 str shft	DrFC P_S H F3d_x_2 StR4_0_288
289	"	"	"	"			4.63	"	"	"	"	"	0	**N max ~80**	**all drs shut**	**.5x.5 =0.25m2**	L9 str shft	DrFC P_S H F3d_x_2 StR5_0_289
290	"	"	"	"			4.63	"	"	"	"	"	0	**N max ~96**	**all drs shut**	**.447x.447 =0.2m2**	L9 str shft	DrFC P_S H F3d_x_2 StR11_0_290 **better than 288 and 289**
291	"	"	"	"			4.63	"	"	"	"	"	0	Y max ~116	all drs shut	.387x.387 =0.15m2	L9 str shft	DrFC P_S H F3d_x_2 StR12_0_291

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
292	"	"	"	"			4.63	"	"	"	"	"	3 Grd-StM, StRm, L1	N max ~13	FF=GF N=0.4	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3d_x_2 StR8_292
293	"	"	"	5.7875			5.7875	"	"	"	"	"	0	Y max ~264	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3e_x_2 StR10_0_293
294	"	"	"	"			5.7875	"	"	"	"	"	0	**N max ~62**	**all drs shut**	**.71x.71 =0.5m2**	L9 str shft	DrFC P_S H F3e_x_2 StR4_0_294
295	"	"	"	"			5.7875	"	"	"	"	"	0	Y max ~120	all drs shut	.5x.5 =0.25m2	L9 str shft	DrFC P_S H F3e_x_2 StR5_0_295
296	"	"	"	"			5.7875	"	"	"	"	"	0	**N max ~89**	**all drs shut**	**.592x.592 =0.35m2**	L9 str shft	DrFC P_S H F3e_x_2 StR13_0_296
297	"	"	"	"			5.7875	"	"	"	"	"	0	**N max ~103**	**all drs shut**	**.547x.547 =0.3m2**	L9 str shft	DrFC P_S H F3e_x_2 StR14_0_297
298	"	"	"	"			5.7875	"	"	"	"	"	3 Grd-StM, StRm, L1	N max ~25	FF=GF N=0.48	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3e_x_2 StR8_298
298A	"	"	"	"			5.7875	"	"	"	"	"	3 Grd-StM, StRm, L1		FF=GF N=0.49	N	L9 str shft	VelC P_S 3 drs H F3e_x_2_298A
299	5	-10	M - L9, 5, 1 A=0.27m2	11.575			11.575	Y	Y	Y	N	N	0	Y max ~119	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_299
300	"	-8	"	"			11.575	"	"	"	"	"	0	Y max ~117	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_300
301	"	-5	"	"			11.575	"	"	"	"	"	0	Y max ~114	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_301
302	"	0	"	"			11.575	"	"	"	"	"	0	Y max ~110.2	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_302
303	"	1	"	"			11.575	"	"	"	"	"	0	**N max ~109**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_303
304	"	-15	"	"			11.575	"	"	"	"	"	0	Y max ~123	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_304

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
305	"	-10	"	3.4725			3.4725	"	"	"	"	"	0	Y max ~116	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_305
306	"	0	"	"			3.4725	"	"	"	"	"	0	Y max ~110.6	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_306
307	"	1	"	"			3.4725	"	"	"	"	"	0	Y max ~110.1	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3_x_2 StR10_0_307 just does not pass
307A	"	2	"	"			3.4725	"	"	"	"	"	0	N max ~109.6	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3_x_2 StR10_0_307A passes
308	"	1	"	"			11.575	"	"	"	"	"	3 Grd-StM, StRm, L1	N max ~62	FF=GF N=0.99	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_308 just passes
309	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~ 60	FF=L1 Y=1.09m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_309
310	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~ 59	FF=L2 Y=1.14m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_310
311	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~ 58	FF=L3 Y=1.07m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_311
312	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~ 57	FF=L4 Y=1.07m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_312
313	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~ 58	FF=L5 Y=1.11m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_313
314	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~ 59	FF=L6 Y=1.09m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_314
315	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~ 59	FF=L7 Y=1.08m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_315
316	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~ 59	FF=L8/L9 Y=1.06 Y=1.13	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_316
317	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~64	FF=GF N=1.00	N		VelC P_S 3 drs H F3_x_2_317

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
318	30 E	20	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	0	Y max ~35	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3c_x_2 StR3_0_318
319	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~152	all drs shut	N		DrFC P_S H F3c_x_2_0_319
320	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~98	all drs shut	.32x.32 =0.1m2	L9 str shft	DrFC P_S H F3c_x_2 StR6_0_320
320A	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~114.7	all drs shut	.32x.32 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_320A
321	"	"	"	"			3.4725	"	"	"	N	N	0	N max ~108	all drs shut	.274x.274 =0.075m2	L9 str shft	DrFC P_S H F3c_x_2 StR9_0_321
Trying to find relief for Bldg A when no. of doors increases																		
322	5 E	20	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	1 StRm	N max ~58	FF=GF Y=1.28m/s	.22x.22 =0.05m2	L9 str shft	VelC P_S 1 drs H F3c_x_2 StR7_322
323	"	"	"	"			3.4725	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 13	FF=GF N=0.38m/s	.22x.22 =0.05m2	L9 str shft	VelC P_S 2 drs H F3c_x_2 StR7_323
324	"	"	"	"			3.4725	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 14	FF=GF N=0.39m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 2 drs H F3c_x_2 StR8_324
325	"	"	"	4.63			4.63	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 19	FF=GF N=0.51m/s	.22x.22 =0.05m2	L9 str shft	VelC P_S 2 drs H F3d_x_2 StR7_325
326	"	"	"	"			4.63	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 20	FF=GF N=0.53m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 2 drs H F3d_x_2 StR8_326
327	"	"	"	5.7875			5.7875	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 26	FF=GF N=0.65m/s	.22x.22 =0.05m2	L9 str shft	VelC P_S 2 drs H F3e_x_2 StR7_327
328	"	"	"	"			5.7875	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 28	FF=GF N=0.67m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 2 drs H F3e_x_2 StR8_328
329	"	"	"	9.260			9.260	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 57	FF=GF Y=1.1m/s	.22x.22 =0.05m2	L9 str shft	VelC P_S 2 drs H F3f_x_2 StR7_329
330	"	"	"	8.103			8.1025	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 45	FF=GF Y=0.94m/s	.22x.22 =0.05m2	L9 str shft	VelC P_S 2 drs H F3g_x_2 StR7_330

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) m/s Min	Limits (kg/s) m/s Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	*File saved as*
331	"	"	"	"			8.1025	"	"	"	N	N	2 Grd-StM, StRm	N max ~ 48	FF=GF Y=0.98m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 2 drs H F3g_x_2 StR8_331
Finding ambient stair shaft pressures with No SPF on (I.e. before fire alarm sounds)																		
332	5 E	20	M - L9, 5, 1 A=0.27m2	0.0001			0.0001	"	"	"	N	N	0 AMBIENT-NO SPF	**N** **max ~6**	**all drs shut**	**.22x.22** **=0.05m2**	L9 str shft	DrFC P_S H F0_x_2 StR7_0_332 AMBIENT-NO SPF
333	"	"	"	"			"	"	"	"	N	N	0 AMBIENT-NO SPF	**N** **max ~6**	**all drs shut**	**1x1** **=1m2**	L9 str shft	DrFC P_S H F0_x_2 StR7_0_332 AMBIENT-NO SPF
Redoing Bldg A with relief of 0.06m2 I.e. runs #322-332																		
334	5 E	20	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	1 StRm	**N** **max ~56**	**FF=GF** **Y=1.28m/s**	**.245x.245** **=0.06m2**	L9 str shft	VelC P_S 1 drs H F3c_x_2 StR10_334
335	"	"	"	"			3.4725	"	"	"	N	N	2 Grd-StM, StRm	**N** **max ~ 13**	FF=GF N=0.38m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 2 drs H F3c_x_2 StR10_335
336	"	"	"	5.7875			5.7875	"	"	"	N	N	2 Grd-StM, StRm	**N** **max ~ 26**	FF=GF N=0.64m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 2 drs H F3e_x_2 StR10_336
337	"	"	"	9.260			9.260	"	"	"	N	N	2 Grd-StM, StRm	**N** **max ~ 56**	**FF=GF** **Y=1.09m/s**	**.245x.245** **=0.06m2**	L9 str shft	VelC P_S 2 drs H F3f_x_2 StR10_337
338	"	"	"	8.103			8.1025	"	"	"	N	N	2 Grd-StM, StRm	**N** **max ~ 45**	FF=GF Y=0.93m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 2 drs H F3g_x_2 StR10_338
339	"	"	"	0.0001			0.0001	"	"	"	N	N	0 AMBIENT-NO SPF	**N** **max ~6**	**all drs shut**	**.245x.245** **=0.06m2**	L9 str shft	DrFC P_S H F0_x_2 StR10_0_339 AMBIENT-NO SPF
340	"	"	"	11.575			11.575	"	"	"	N	N	0	**N** **max ~39**	**all drs shut**	**=2.43m2**	L9 str shft	DrFC P_S H F0_x_2 Stbigger relief_0_340
Damper r/ship check																		
341	5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N** **max ~66**	FF=GF N=0.85m/s	=0.1492m2		VelC P_S 3 drs H F3_x_2_341
342	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N** **max ~80.5**	FF=GF N=0.94m/s	=0.0206m2		VelC P_S 3 drs H F3_x_2_342
343	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N** **max ~80.6**	**FF=GF** **Y=0.998m/s**	**=0.02m2**		VelC P_S 3 drs H F3_x_2_343

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
344	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~81.3	FF=GF Y=1m/s	=0.015m2		VelC P_S 3 drs H F3_x_2_344
345	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~29	FF=GF N=0.57m/s	=0.94m2		VelC P_S 3 drs H F3_x_2_345
346	"	"	"	"			11.575	"	"	"	N	N	0	N max ~104	all drs shut	=0.94m2		DrFC P_S H F0_x_2 StR3_0_346
347	"	"	"	"			11.575	"	"	"	N	N	0	N max ~109	all drs shut	=0.91m2		DrFC P_S H F0_x_2 StR3_0_347 lower limit for baro relief to pass DFs
Testing A and B formulae																		
348	5 E	20	M - L9, 5, 1 A=0.27m2	11.575			11.575	"	"	"	N	N	0	N max ~34	all drs shut	=2.88m2		DrFC P_S H F0_x_2 StR3_0_348
349	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~80	FF=GF Y=0.995m/s	=0.026m2		VelC P_S 3 drs H F3_x_2_349
350	"	"	"	"			11.575	"	"	"	N	N	0	N max ~34	all drs shut	=2.94m2		DrFC P_S H F0_x_2 StR3_0_350
351	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~80	FF=GF Y=0.991m/s	=0.029m2		VelC P_S 3 drs H F3_x_2_351
352	"	"	"	"			11.575	"	"	"	N	N	0	Y max ~110.6	all drs shut	=0.9m2		DrFC P_S H F0_x_2 StR3_0_352
353	"	"	"	"			11.575	"	"	"	N	N	0	Y max ~380.6	all drs shut	=0.3m2		DrFC P_S H F0_x_2 StR3_0_353
354	"	"	"	"			11.575	"	"	"	N	N	0	N max ~35	all drs shut	=2.7m2		DrFC P_S H F0_x_2 StR3_0_354
Velocitiy Test for Sys 1 & 2 from Runs #308-316, 355-363																		
355	5	0	"	"			11.575	"	"	"	"	"	3 Grd-StM, StRm, L1	N max ~61	FF=GF N=0.99	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_355
356	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~59	FF=L1 Y=1.09m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_356
357	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~58	FF=L2 Y=1.08m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_357

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
358	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~57	FF=L3 Y=1.07m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_358
359	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~58	FF=L4 Y=1.07m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_359
360	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~58	FF=L5 Y=1.1m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_360
361	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~59	FF=L6 Y=1.09m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_361
362	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~59	FF=L7 Y=1.07m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_362
363	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~59	FF=L8/L9 Y=1.05m/s Y=1.12m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_363
364	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~62	FF=GF N=1.00	N		VelC P_S 3 drs H F3_x_2_364
365	5	-10	"	"			11.575	"	"	"	"	"	3 Grd-StM, StRm, L1	N max ~51	FF=GF N=0.98	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_365
366	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L1, L2	N max ~51	FF=L1 Y=1.07m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_a H F3_x_2 StR8_366
367	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L2, L3	N max ~54	FF=L2 Y=1.04m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_b H F3_x_2 StR8_367
368	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L3, L4	N max ~59	FF=L3 Y=1.02m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_c H F3_x_2 StR8_368
369	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L4, L5	N max ~57	FF=L4 Y=1.01m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_d H F3_x_2 StR8_369
370	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L5, L6	N max ~58	FF=L5 Y=1.03m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_e H F3_x_2 StR8_370
371	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L6, L7	N max ~59	FF=L6 Y=1.01m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_f H F3_x_2 StR8_371

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
372	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L7, L8	N max ~59	FF=L7 N=0.99m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_g H F3_x_2 StR8_372
373	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L8, L9	N max ~60	FF=L8/L9 N=0.95m/s N=0.98m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR8_373
Filling in gaps for IB Table, interpolations (22.09.05)																		
374	30	-10	"	"			3.4725	"	"	"	N	N	0	Y max~129.4	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_374
375	0	0	"	"			3.4725	"	"	"	N	N	0	N max ~109.8	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_375
376	15	0	"	"			3.4725	"	"	"	N	N	0	Y max ~115.5	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_376
377	12.5	5	"	"			3.4725	"	"	"	N	N	0	Y max ~111.5	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_377
378	0	35	"	"			3.4725	"	"	"	N	N	0	N max ~108.8	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_378
379	12.5	35	"	"			3.4725	"	"	"	N	N	0	Y max ~111.5	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_379
380	30	15	"	"			3.4725	"	"	"	N	N	0	Y max ~115	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_380
381	30	-10	"	"			11.575	"	"	"	N	N	0	Y max ~141.9	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_381
382	0	0	"	"			11.575	"	"	"	N	N	0	N max ~108.9	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_382
383	12.5	1	"	"			11.575	"	"	"	N	N	0	Y max ~114.9	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_383
384	15	10	"	"			11.575	"	"	"	N	N	0	Y max ~110.3	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_384
385	30	30	"	"			11.575	"	"	"	N	N	0	N max ~108.3	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_385

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
386	30	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~67	FF=GF Y=1.42	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_386
387	0	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~60	FF=GF N=0.98	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_387
388	12.5	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~64	FF=GF Y=1.06	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_388
389	15	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~71	FF=GF Y=1.09	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_389
389A	30	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~81	FF=GF Y=1.33	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_389A
390	0	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~81	FF=GF N=0.99	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_390
391	2.5	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~53	FF=GF Y=1.00	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_391
392	0	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~53	FF=GF N=0.967	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_392
392A	15	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~56	FF=GF Y=1.08	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_392A
393	2.5	1	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~59	FF=GF N=0.984	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_393
394	2.5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~53	FF=GF N=0.97	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_394
Filling gaps for IB Table continued (with increased leakages)																		
395	5	-10	M - L9, 5, 1 A=0.27m2	3.4725			3.4725	"	"	"	N	N	0	N max ~102.8	all drs shut @ GF	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_395 Quart
396	15	0	"	"			3.4725	"	"	"	N	N	0	N max ~101.1	all drs shut @ GF	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_396 Quart
397	30	10	"	"			3.4725	"	"	"	N	N	0	N max ~102.3	all drs shut @ GF	.274x.274 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_397 Quart

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) m/s Min	Limits (kg/s) m/s Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	File saved as
398	0	-10	"	11.575			11.575	"	"	"	N	N	0	Y max ~115	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_398 Quart
399	2.5	-5	"	"			11.575	"	"	"	N	N	0	Y max ~110.8	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_399 Quart
400	0	-5	"	"			11.575	"	"	"	N	N	0	Y max ~110.5	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_400 Quart
401	12.5	0	"	"			11.575	"	"	"	N	N	0	Y max ~112.3	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_401 Quart
402	7.5	0	"	"			11.575	"	"	"	N	N	0	**N max ~108.8**	**all drs shut @ GF**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_402 Quart
403	30	25	"	"			11.575	"	"	"	N	N	0	**N max ~107.6**	**all drs shut @ GF**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_403 Quart
404	0	-10	"	"			11.575	"	"	"	N	N	0	Y max ~112.4	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_404 Half
405	10	-5	"	"			11.575	"	"	"	N	N	0	Y max ~111.7	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_405 Half
406	12.5	0	"	"			11.575	"	"	"	N	N	0	**N max ~109**	**all drs shut @ GF**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_406 Half
407	30	20	"	"			11.575	"	"	"	N	N	0	**N max ~108**	**all drs shut @ GF**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_407 Half
407A	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 93**	**FF=GF Y=1.48**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_407A Half
408	15	1	"	"			11.575	"	"	"	N	N	0	**N max ~109.9**	**all drs shut @ GF**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_408 Half
409	30	0	"	"			11.575	"	"	"	N	N	0	Y max ~119.9	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_409 Half
410	30	10	"	"			11.575	"	"	"	N	N	0	Y max ~111	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_410 Half
411	2.5	-10	"	"			11.575	"	"	"	N	N	0	**N max ~109.9**	**all drs shut @ GF**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_411 3Quart

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
412	12.5	-5	"	"			11.575	"	"	"	N	N	0	Y max ~110.2	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_412 3Quart
413	15	0	"	"			11.575	"	"	"	N	N	0	N max ~107.3	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_413 3Quart
414	30	5	"	"			11.575	"	"	"	N	N	0	Y max ~110.7	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_414 3Quart
415	10	-10	"	"			11.575	"	"	"	N	N	0	Y max ~110.4	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_415 Loose
416	15	-10	"	"			11.575	"	"	"	N	N	0	Y max ~113.6	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_416 Loose
417	5	-5	"	"			11.575	"	"	"	N	N	0	N max ~103	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_417 Loose
418	30	1	"	"			11.575	"	"	"	N	N	0	Y max ~110.08	all drs shut @ GF	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_418 Loose
419	30	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~59	FF=GF Y=1.29	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_419
420	5	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~56.5	FF=GF N=0.96	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_420
421	0	1	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~56.8	FF=GF N=0.94	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_421
422	5	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~61	FF=GF N=0.96	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_422
423	15	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~64	FF=GF Y=1.06	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_423
424	2.5	10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~63	FF=GF N=095	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_424
425	12.5	10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~69	FF=GF Y=1.02	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_425
426	0	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~75	FF=GF N=0.95	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_426

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
427	15	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~80	FF=GF Y=1.05	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_427
428	2.5	1	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~80	FF=GF N=0.95	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_428
429	10	1	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~59	FF=GF N=0.99	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_429
430	15	15	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~75	FF=GF Y=1.05	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_430
431	30	15	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~83	FF=GF Y=1.28	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_431
432	15	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~94	FF=GF Y=1.05	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_432
433	12.5	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~58	FF=GF Y=1.025	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_433
434	15	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~58	FF=GF Y=1.05	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_434
435	30	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~101	FF=GF Y=1.26	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_435
436	0	1	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 53	FF=GF Y=1.00	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_436 Quart
437	12.5	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 54	FF=GF Y=1.09	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_437 Quart
438	0	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 72	FF=GF Y=1.01	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_438 Quart
439	**5**	**20**	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 72	FF=GF Y=1.02	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_439 Quart
440	15	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 76	FF=GF Y=1.12	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_440 Quart
441	30	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 100.7	FF=GF Y=1.12	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_441 Quart

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
442	0	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 52	FF=GF Y=1.01	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_442 Quart
443	2.5	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 52	FF=GF Y=1.01	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_443 Quart
444	15	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 55	FF=GF Y=1.12	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_444 Quart
445	30	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 59.8	FF=GF Y=1.38	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_445 Quart
446	2.5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 40	FF=GF Y=1.00	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_446 Quart
447	5	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 69	FF=GF Y=1.08	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_447 Half
448	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 65	FF=GF Y=1.18	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_448 3Quart
449	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 61	FF=GF Y=1.23	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_449 Loose
450	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 55	FF=L9 Y=1.50	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR10_450 Quart
451	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 50	FF=L9 Y=1.68	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR10_251 Half
452	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 46	FF=L9 Y=1.83	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR10_452 3Quart
453	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, L9, L8	N max ~ 43	FF=L9 Y=1.95	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_h H F3_x_2 StR10_453 Loose
Main Bldg 1000% Leakier than Ave Leakage value and st walls Ave L																		
455	5	20	"	11.575			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 7.2	FF=GF N=0.77m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_455
456	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 6.7	FF=GF N=0.77m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_456

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
457	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 6.8	FF=L9 Y=1.04m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR8_457
458	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 6.7	FF=L9 Y=1.03m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR10_458
Main Bldg Ave L and st walls 100% Leakier than Ave Leakage value																		
459	5	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 68	FF=GF N=0.92m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_459
460	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 63	FF=GF N=0.90m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_460
461	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 52	FF=L9 Y=1.25m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR8_461
462	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 49	FF=L9 Y=1.19m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR10_462
Main Bldg 100% Leakier and st walls Ave L																		
463	5	20	"	11.575			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 71	FF=GF Y=1.29	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_463 Loose
464	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 67	FF=GF Y=1.25m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_464 Loose
465	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 49	FF=L9 Y=2.09	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR8_465 Loose
466	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 47	FF=L9 Y=2.02	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR10_466 Loose
Main Bldg Ave L and st walls 1000% Leakier																		
467	5	20	"	11.575			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 5.9	FF=GF N=0.18m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_467
468	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 5.9	FF=GF N=0.179m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_468
469	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 5.8	FF=L9 N=0.29m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR8_469

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
470	"	"	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 5.9	FF=GF N=0.287m/s	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs_i H F3_x_2 StR10_470
Stwalls 25% Q leakier than the main bldg (which is set to Ave Leakage)																		
471	5	20	"	3.4725			3.4725	"	"	"	"	"	0	N, L9 max ~83.9	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_471SQ
472	-10	5	"	"			3.4725	"	"	"	"	"	0	N, L0 max ~96.2	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_472SQ
473	-10	30	"	"			3.4725	"	"	"	"	"	0	N, L0 max ~109	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_473SQ
474	0	0	"	"			3.4725	"	"	"	"	"	0	N, L0 max ~90	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_474SQ
475	5	5	"	"			3.4725	"	"	"	"	"	0	N, L0 max ~88.4	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_475SQ
476	12.5	5	"	"			3.4725	"	"	"	"	"	0	N, L0 max ~91.3	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_476SQ
477	30	20	"	"			3.4725	"	"	"	"	"	0	N, L9 max ~94	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_477SQ
478	15	30	"	"			3.4725	"	"	"	"	"	0	N, L9 max ~90.2	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_478SQ
479	0	35	"	"			3.4725	"	"	"	"	"	0	N, L9 max ~88.6	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_479SQ
480	12.5	35	"	"			3.4725	"	"	"	"	"	0	N, L9 max ~91	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_480SQ
481	0	-10	"	"			3.4725	"	"	"	"	"	0	N, L9 max ~95.5	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_481SQ
482	5	20	"	11.575			11.575	"	"	"	"	"	0	N, L0 max ~88.7	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_482SQ
483	0	-10	"	"			11.575	"	"	"	"	"	0	N, L0 max ~108.3	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_483SQ

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s) Min	Limits (kg/s) Max	Speed Calc Rf kg/s	Leakage (Y/N) Bldg	Leakage (Y/N) Rm Flrs	Leakage (Y/N) Str Drs	Limits (kg/s) *m/s* Min	Limits (kg/s) *m/s* Max	Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille Size	Relief Grille Location	*File saved as*
484	12.5	-10	"	"			11.575	"	"	"	"	"	0	Y, L0 max ~115.4	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_484SQ
485	5	0	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~101**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_485SQ
486	12.5	1	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~106**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_486SQ
487	15	5	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~105**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_487SQ
488	30	15	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~109.4**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_488SQ
489	10	-10	"	"			11.575	"	"	"	"	"	0	Y, L0 max ~113.1	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_489SQ
490	12.5	0	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~106.7**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_490SQ
491	30	10	"	"			11.575	"	"	"	"	"	0	Y, L0 max ~113.4	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_491SQ
492	30	1	"	"			11.575	"	"	"	"	"	0	Y, L0 max ~121.3	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_492SQ
493	15	0	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~109**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_493SQ
494	5	**20**	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N **max ~ 76.8**	FF=GF **N=0.9782m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_494SQ
495	0	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 49.6	FF=GF N=0.943m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_495SQ
496	2.5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 49.6	FF=GF N=0.943m/s	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_496SQ
497	15	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 51.9**	**FF=GF Y=1.06m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_497SQ
498	30	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 54.2**	**FF=GF Y=1.32m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_498SQ

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
499	15	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 66.5**	**FF=GF Y=1.07**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_499SQ
500	30	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 76.5**	**FF=GF Y=1.306**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_500SQ
501	10	15	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 73.9**	**FF=GF Y=1.013**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_501SQ
502	0	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 76.1**	**FF=GF N=0.9656**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_502SQ
503	5	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 62.3**	**FF=GF N=0.972**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_503SQ
504	10	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 49.2**	**FF=GF N=0.999**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_504SQ
505	0	1	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 57.7**	**FF=GF N=0.9556**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_505SQ
506	30	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 104.3**	**FF=GF Y=1.277**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_506SQ
507	5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 49.2**	**FF=GF N=0.999**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_507SQ
508	**5**	**20**	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 70.9	FF=GF N=0.94	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_508SQ
509	30	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 55.5**	**FF=GF Y=1.27**	**.245x.245 =0.06m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_509SQ
510	5	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 52.7	FF=GF N=0.936	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_510SQ
511	15	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 55.1**	**FF=GF Y=1.03**	**.245x.245 =0.06m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_511SQ
512	0	1	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 53	FF=GF N=0.923	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_512SQ
513	12.5	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 59.7**	**FF=GF Y=1.001**	**.245x.245 =0.06m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_513SQ

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
514	0	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 70.3	FF=GF N=0.927	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_514SQ
515	15	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 88	FF=GF Y=1.025	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_515SQ
516	30	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~95.9	FF=GF Y=1.231	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_516SQ
517	30	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~79.7	FF=GF N=0.942	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_517SQ
518	10	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~95.9	FF=GF N=0.975	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_518SQ
519	12.5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~47.5	FF=GF N=0.9969	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_519SQ
520	10	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~72.6	FF=GF N=0.9754	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_520SQ
521	5	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~59	FF=GF N=0.942	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_521SQ
522	10	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~59	FF=GF N=0.9753	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_522SQ
523	10	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~47	FF=GF N=0.9692	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_523SQ
Stwalls 50% H leakier than the main bldg (which is set to Ave Leakage)																		
524	5	20	"	3.4725			3.4725	"	"	"	"	"	0	N, L9 max ~74	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_524SH
525	20	-10	"	"			3.4725	"	"	"	"	"	0	N, L0 max ~99	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_525SH
526	5	20	"	11.575			11.575	"	"	"	"	"	0	N, L0 max ~84	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_526SH
527	10	-10	"	"			11.575	"	"	"	"	"	0	N, L0 max ~107.7	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_527SH

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
528	12.5	-10	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~109.98**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_528SH
529	30	1	"	"			11.575	"	"	"	"	"	0	Y max ~116	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_529SH
530	30	10	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~108**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_530SH
531	15	-10	"	"			11.575	"	"	"	"	"	0	Y max ~112	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_531SH
532	30	5	"	"			11.575	"	"	"	"	"	0	Y max ~112	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_532SH
533	15	0	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~103.75**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_533SH
534	**5**	**20**	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 74**	**FF=GF N=0.961**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_534SH
535	0	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 54	FF=GF N=0.939	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_535SH
536	2.5	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 55	FF=GF N=0.943	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_536SH
537	20	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 73.5**	**FF=GF Y=1.291**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_537SH
538	5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 47	FF=GF N=0.944	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_538SH
539	0	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 59	FF=GF N=0.947	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_539SH
540	0	15	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 68	FF=GF N=0.947	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_540SH
541	0	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 81.7**	**FF=GF N=0.9517**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_541SH
542	2.5	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 73**	**FF=GF N=0.9516**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_542SH

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) m/s		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		File saved as
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
543	5	10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 64	FF=GF N=0.9577	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_543SH
544	10	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 48.6	FF=GF N=0.985	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_544SH
545	5	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 68	FF=GF N=0.924	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_545SH
546	10	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 45	FF=GF N=0.956	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_546SH
547	12.5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 45	FF=GF N=0.984	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_547SH
548	30	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 53	FF=GF Y=1.26	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_548SH
549	15	0	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 53	FF=GF Y=1.01	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_549SH
550	10	10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 61	FF=GF N=0.96	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_550SH
551	12.5	30	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 79	FF=GF N=0.982	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_551SH
552	10	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 82	FF=GF N=0.958	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_552SH
553	30	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 92.6	FF=GF Y=1.21	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_553SH
Stwalls 100% L leakier than the main bldg (which is set to Ave Leakage)																		
554	5	20	"	3.4725			3.4725	"	"	"	"	"	0	N, L9 max ~60	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_554SL
555	30	-10	"	"			3.4725	"	"	"	"	"	0	N, L0 max ~84.5	all drs shut	.245x.245 =0.06m2	L9 str shft	DrFC P_S H F3c_x_2 StR10_0_555SL
556	5	20	"	11.575			11.575	"	"	"	"	"	0	N, L0 max ~75.5	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_556SL

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
557	15	-10	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~102.6**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_557SL
558	30	5	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~103.2**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_558SL
559	30	-10	"	"			11.575	"	"	"	"	"	0	Y, L0 max ~118.7	all drs shut	1x1 =1m2	L9 str shft	DrFC P_S H F3_x_2 StR3_0_559SL
560	30	0	"	"			11.575	"	"	"	"	"	0	**N, L0 max ~108**	**all drs shut**	**1x1 =1m2**	L9 str shft	DrFC P_S H F3_x_2 StR3_0_560SL
561	10	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 44.5**	**FF=GF N=0.96m/s**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_561SL
562	5	10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 59.6	FF=GF N=0.928	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_562SL
563	2.5	20	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 67.6	FF=GF N=0.9205	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_563SL
564	0	30	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 75.6	FF=GF N=0.918	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_564SL
565	5	15	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 63.8	FF=GF N=0.929	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_565SL
566	2.5	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 81.8	FF=GF N=0.9226	.1x.1 =0.01m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_566SL
567	10	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 81.8**	**FF=GF N=0.9647**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_567SL
568	10	25	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 74**	**FF=GF N=0.9653**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_568SL
569	15	5	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 59**	**FF=GF Y=1.023**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_569SL
570	30	15	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N max ~ 77**	**FF=GF Y=1.249**	**.1x.1 =0.01m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR8_570SL
571	10	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 41.5	FF=GF N=0.932	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_571SL

Run	Wind m/s	o/s Temp C	Injection Sing/Multi	Fan Speed kg/s	Limits (kg/s)		Speed Calc Rf kg/s	Leakage (Y/N)			Limits (kg/s) *m/s*		Drs Open	Newtons Dr Force High (Y/N)	Test Dr Velocity >1 (Y/N)	Relief Grille		*File saved as*
					Min	Max		Bldg	Rm Flrs	Str Drs	Min	Max				Size	Location	
572	10	10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 56.6	FF=GF N=0.933	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_572SL
573	10	35	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	N max ~ 76	FF=GF N=0.927	.245x.245 =0.06m2	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_573SL
574	12.5	-10	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N** **max ~ 41.8**	**FF=GF** **N=0.9602**	**.245x.245** **=0.06m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_574SL
575	12.5	30	"	"			11.575	"	"	"	N	N	3 Grd-StM, StRm, L1	**N** **max ~ 73.6**	**FF=GF** **N=0.9519**	**.245x.245** **=0.06m2**	L9 str shft	VelC P_S 3 drs H F3_x_2 StR10_575SL

Appendix J 'Element' Name Descriptions

The 'Element Name' columns listed in Tables 9-14 and used as part of the CONTAM model, refer to the following:

MBldgexitdrc	main building foyer exit/entrance door (on east side of building) and is closed
Stdropin	stairwell door open between the occupancy and the stairwell
Stdrclin	stairwell door closed between the occupancy and the stairwell
Stdropext	stairwell door open between the stairwell and the outside of the building, Ground Floor (L0)
Stdrclext	stairwell door closed between the stairwell and the outside of the building, Ground Floor (L0)
Lftdrcl	lift door closed
StReliefGr1	the relief/bypass damper between the stairwell shaft and the outside of the building, Level 9
InjGrille_H	the injection grille between the (air) injection shaft (which supplies air via the SPF) and the stairwell: Levels 1, 5 and 9
Wallext1	the short length of the external building wall
Wallext2	the long length of the external building wall
Stwallext	the short length of the stairwell shaft external to the building
Stwallin1	the short length of the stairwell shaft inside the building near the occupancy area
Stwallin2	the long length of the stairwell shaft inside the building near the occupancy area
Lftwallint	the internal lift wall near the occupancy area
Floorleak	the leakage between the occupancy floors
StrRooflek	the stairwell shaft roof leakage
InjSRflrek	the roof leakage from the (air) injection shaft
LftRflek	the roof leakage from the lift shaft
Lftfloorlek	the floor leakage within the lift shaft
InjSflrlk	the floor leakage within the (air) injection shaft
Stfloorlek	the floor leakage within the stairwell shaft
SPF_x	the SPF located on the Roof Level, Level 10

Appendix K Calculation of Leakage and Cross-Sectional Areas

The leakage areas were obtained from Klote and Milke (2002) and are detailed in the table below.

Table K1. Typical Leakage Areas of Commercial Buildings for C = 0.65

Construction Element	Tightness	Area Ratio A/A_w
Exterior Building Walls *includes construction cracks, cracks around windows and doors*	Tight	0.50×10^{-4}
	Average	0.17×10^{-3}
	Loose	0.35×10^{-3}
	Very Loose	0.12×10^{-2}
Stairwell Walls *includes construction cracks, but not cracks around windows or doors*	Tight	0.14×10^{-4}
	Average	0.11×10^{-3}
	Loose	0.35×10^{-3}
Elevator Shaft Walls *includes construction cracks, but not cracks around doors*	Tight	0.18×10^{-3}
	Average	0.84×10^{-3}
	Loose	0.18×10^{-2}
		A/A_f
Floors *includes construction cracks and gaps around penetrations*	Tight	0.66×10^{-5}
	Average	0.52×10^{-4}
	Loose	0.17×10^{-3}

A refers to flow area

A_f refers to floor area

A_w refers to wall area

The subsequent cross-sectional areas for the various components specified in CONTAM were then calculated using (Equation K1) the above 'Average' values and the measurements detailed within Table 11 of this thesis. For example:

Length x Width x Leakage Coefficient = Area (m^2) per item **Equation K1**

Wallext1 Length x Width x Leakage Coefficient $= 20 \times 3.8 \times 0.17 \times 10^{-3}$
$= 0.01292\ m^2$ per item

Wallext2 Length x Width x Leakage Coefficient $= 70 \times 3.8 \times 0.17 \times 10^{-3}$
$= 0.04522\ m^2$ per item

Stwallin1 Length x Width x Leakage Coefficient $= 3 \times 3.8 \times 0.11 \times 10^{-3}$
$= 0.001254\ m^2$ per item

Stwallin2 Length x Width x Leakage Coefficient $= 4 \times 3.8 \times 0.11 \times 10^{-3}$
$= 0.001672\ m^2$ per item

Stwallext Length x Width x Leakage Coefficient $= 3 \times 3.8 \times 0.11 \times 10^{-3}$
$= 0.001254\ m^2$ per item

Lftwallint Length x Width x Leakage Coefficient $= 3 \times 3.8 \times 0.84 \times 10^{-3}$
$= 0.009575\ m^2$ per item

Floorleak Length x Width x Leakage Coefficient $= 70 \times 20 \times 0.52 \times 10^{-4}$
$= 0.0728\ m^2$ per item

StrRooflek Length x Width x Leakage Coefficient $= 3 \times 4 \times 0.11 \times 10^{-3}$
$= 0.00132\ m^2$ per item

InjSRflek Length x Width x Leakage Coefficient $= 1.5 \times 2 \times 0.17 \times 10^{-3}$
$= 0.00051\ m^2$ per item

LftRflek Length x Width x Leakage Coefficient $= 3 \times 3 \times 0.84 \times 10^{-3}$
$= 0.00756\ m^2$ per item

Stdropin Length x Width $= \dfrac{0.91 \times 2.13}{2} = 0.96915\ m^2$

Appendix L Weather Data from the Bureau of Meteorology

The external weather values were obtained from the Bureau of Meteorology website (http://www.bom.gov.au/climate) in terms of the temperature and wind data.

Both the daily temperature and wind data were collected for the months of July 2003 to June 2004, inclusive, in order to identify typical annual averages. The temperate daily values were collected from the Melbourne Regional Office {i.e. station 086071}, which is equivalent to the Melbourne CBD as the elevation of this weather observation station is 31.2 m (which is very close to the height of the 'base' building model i.e. 34.2 m used for the CONTAM analysis). The wind observation values were taken from the Essendon Airport {i.e. station 086038}, with an elevation of 78.4 m (as wind data is not collected at the Melbourne Regional Office and the Melbourne CBD has poor wind exposure because of the buildings).[69] The longitude and latitude values are presented below for both weather stations.

Table L1. Weather Station Location Details

Station Location.	Latitude	Longitude
Regional Office - station 086071	- 37.8075 S	144.9700 E
Essendon Airport - station 086038	- 37.7278 S	144.9064 E

The weather data collected at the stations is subdivided into 9 am and 3 pm readings, as opposed to an average value over a day. The mean (average), maximum and minimum values were then calculated for each month in terms of the wind and temperatures for both 9 am and 3 pm values. The wind speed data (including directions) collected by the Bureau of Meteorology is measured and averaged over the 10 minutes prior to 9 am and 3 pm. The maximum wind gust[70] data was also analysed.

Table L2 lists the data collected for the various months and shows how the average, maximum and minimum values were chosen for each month. The temperature and wind speed values are presented for the 9 am and 3 pm readings, and so too is the wind gust data (referred to in the thesis as the maximum wind speed).

[69] 'The city site has poor wind exposure because of the city buildings' (correspondence from climate.vic@bom.gov.au, 14/07/2004).

[70] The Bureau of Meteorology defines 'wind gust' in terms of the speed of the strongest wind gust in the 24 hours to midnight. More specifically, the maximum wind gusts are measured using rolling 3 second wind gusts, which are then calculated every minute. The maximum wind gust is usually the maximum gust in the 10 minutes before the hour (correspondence from climate.vic@bom.gov.au, 26/07/2004).

Table L2. Weather Station Wind and Temperature Data

Date		Minimum temperature (°C)	Maximum temperature (°C)	Speed of maximum wind gust (km/h)	Gust m/s'	9am Temperature (°C)	9am wind speed (km/h)	9 am m/s'	9am MSL pressure (hPa)	3pm Temperature (°C)	3pm wind speed (km/h)	3 pm m/s'	3pm MSL pressure (hPa)
July 03	MEAN	7.2	14.7	48.4	13.4	9.1	19.5	5.4	1021.7	13.6	23.2	6.5	1019.8
	Lowest	4.1	11.2	19.0	5.3	4.3	Calm	0.6	998.8	9.3	Calm	0.6	1003.7
	Highest	11.3	17.4	83.0	23.1	12.2	46.0	12.8	1034.4	16.1	52.0	14.4	1032.5
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	1.8	1.6	18.9	5.2	1.9	11.7	3.2	7.7	1.6	10.7	3.0	7.5
August 03	MEAN	7.3	15.0	52.0	14.0	9.7	20.8	5.6	1017.7	13.9	25.8	6.9	1015.8
	Lowest	2.0	12.2	22.0	0.0	3.7	7.0	0.0	986.9	10.0	11.0	0.0	991.6
	Highest	12.4	17.4	93.0	25.8	15.6	41.0	11.4	1028.6	17.1	54.0	15.0	1027.3
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	2.7	1.6	17.4	5.4	2.5	9.1	2.7	9.8	1.9	9.9	3.0	8.9
Sept 03	MEAN	8.3	17.4	57.9	16.1	12.1	23.4	6.5	1013.4	16.0	28.8	7.7	1011.5
	Lowest	3.2	13.7	20.0	5.6	7.9	6.0	1.7	995.2	12.3	4.0	0.0	994.7
	Highest	14.1	22.3	107.0	29.7	17.9	46.0	12.8	1027.9	22.1	57.0	15.8	1027.8
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	2.6	2.5	19.3	5.4	2.5	11.0	3.1	9.6	2.6	12.6	3.7	9.7
Oct 03	MEAN	9.5	17.7	45.0	12.5	13.2	20.0	5.6	1015.4	16.4	23.1	6.4	1013.7
	Lowest	5.2	12.6	20.0	5.6	9.0	2.0	0.6	995.0	12.5	4.0	1.1	996.0
	Highest	15.1	27.3	76.0	21.1	21.3	43.0	11.9	1030.3	26.6	46.0	12.8	1029.0
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	2.2	3.3	14.2	4.0	2.8	10.3	2.8	8.4	3.6	8.9	2.5	8.0

Table L2. Weather Station Wind and Temperature Data (continued)

Date		Minimum temperature (°C)	Maximum temperature (°C)	Speed of maximum wind gust (km/h)	Gust m/s'	9am Temperature (°C)	9am wind speed (km/h)	9 am m/s'	9am MSL pressure (hPa)	3pm Temperature (°C)	3pm wind speed (km/h)	3 pm m/s'	3pm MSL pressure (hPa)
Nov 03	MEAN	12.8	23.7	46.0	12.8	17.1	19.0	5.3	1019.1	21.8	23.3	6.5	1017.6
	Lowest	6.8	15.1	31.0	8.6	11.0	4.0	1.1	1006.8	13.7	7.0	1.9	1006.4
	Highest	21.8	39.1	74.0	20.6	27.6	41.0	11.4	1026.6	36.8	46.0	12.8	1025.7
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	3.3	6.6	11.7	3.3	4.5	10.2	2.8	5.0	6.4	8.0	2.2	5.1
Dec 03	MEAN	15.9	27.2	45.9	12.7	20.4	18.8	5.2	1013.3	25.4	23.2	6.4	1011.6
	Lowest	11.6	19.1	31.0	8.6	14.6	4.0	1.1	998.1	17.2	11.0	3.1	1000.6
	Highest	26.4	40.3	69.0	19.2	30.2	44.0	12.2	1022.4	39.6	41.0	11.4	1020.3
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	3.5	5.9	10.6	2.9	4.3	11.2	3.1	5.6	6.1	6.7	1.8	5.2
Jan 04	MEAN	14.3	24.6	46.3	12.8	17.6	16.7	4.7	1011.9	22.5	22.2	6.2	1010.5
	Lowest	9.3	19.9	33.0	9.2	13.1	4.0	1.1	993.2	17.2	11.0	3.1	992.6
	Highest	18.9	36.5	72.0	20.0	29.4	35.0	9.7	1024.3	33.6	41.0	11.4	1025.8
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	2.0	4.1	9.4	2.6	3.3	9.2	2.6	6.4	3.9	6.3	1.8	6.3
Feb 04	MEAN	15.5	26.0	41.8	11.6	18.4	15.4	4.3	1013.7	24.7	20.5	5.7	1012.3
	Lowest	11.6	18.0	28.0	7.8	14.1	6.0	1.7	1005.5	16.7	9.0	2.5	1000.7
	Highest	20.0	40.4	61.0	16.9	29.2	30.0	8.3	1022.6	39.2	33.0	9.2	1020.2
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	1.9	6.2	8.6	2.4	3.0	5.4	1.5	4.6	6.1	7.0	1.9	5.1

Table L2. Weather Station Wind and Temperature Data (continued)

Date		Minimum temperature (°C)	Maximum temperature (°C)	Speed of maximum wind gust (km/h)	Gust m/s'	9am Temperature (°C)	9am wind speed (km/h)	9 am m/s'	9am MSL pressure (hPa)	3pm Temperature (°C)	3pm wind speed (km/h)	3 pm m/s'	3pm MSL pressure (hPa)
Mar 04	MEAN	14.1	23.8	41.5	11.5	16.6	15.6	4.3	1018.2	22.5	23.2	6.4	1016.5
	Lowest	10.6	18.0	26.0	7.2	13.7	6.0	1.7	1005.4	17.6	11.0	3.1	1003.6
	Highest	19.1	34.8	65.0	18.1	24.4	37.0	10.3	1025.1	32.7	37.0	10.3	1024.0
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	1.6	4.4	11.2	3.1	2.3	8.1	2.3	5.4	4.4	6.9	1.9	5.1
Apr 04	MEAN	12.3	21.5	41.0	11.4	15.5	16.1	4.5	1022.7	20.2	22.2	6.2	1020.5
	Lowest	6.9	14.4	20.0	5.6	9.7	2.0	0.6	1004.1	12.8	9.0	2.5	1003.8
	Highest	23.0	32.5	76.0	21.1	25.6	39.0	10.8	1031.4	31.9	37.0	10.3	1028.4
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	3.0	4.7	14.8	4.1	3.8	9.3	2.6	5.6	4.6	7.4	2.1	5.6
May 04	MEAN	9.2	17.4	39.1	10.9	11.7	17.3	4.8	1020.5	16.3	21.5	6.0	1018.7
	Lowest	5.1	13.2	17.0	4.7	7.6	6.0	1.7	1007.2	10.7	4.0	1.1	1009.5
	Highest	15.3	21.7	69.0	19.2	16.5	30.0	8.3	1028.3	20.4	39.0	10.8	1026.5
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	2.3	2.2	14.5	4.0	2.3	5.7	1.6	5.1	2.5	8.7	2.4	4.6
June 04	MEAN	8.7	14.9	56.3	15.6	10.4	22.8	6.3	1018.3	13.8	26.2	7.3	1016.5
	Lowest	3.8	12.0	19.0	5.3	5.1	4.0	1.1	996.0	10.3	7.0	1.9	997.4
	Highest	13.4	20.2	87.0	24.2	14.0	43.0	11.9	1031.1	19.3	43.0	11.9	1029.0
	TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	STD DEV	2.3	1.7	18.3	5.1	2.0	10.1	2.8	8.8	1.8	8.5	2.4	8.4
		Min Temp	*Max Temp*		*Gust m/s'*	*9am Temp*		*9am m/s'*		*3pm Temp*		*3pm m/s'*	
Annual	MEAN	11.3	20.3	46.8	13.0	14.3	18.8	5.2	1017.1	18.9	23.6	6.5	1015.4
Annual	Lowest	2.0	11.2	17.0	0.0	3.7	2.0	0.0	986.9	9.3	4.0	0.0	991.6
Annual	Highest	26.4	40.4	107.0	29.7	30.2	46.0	12.8	1034.4	39.6	57.0	15.8	1032.5

Table L2. Weather Station Wind and Temperature Data (continued)

		Minimum temperature (°C)	Maximum temperature (°C)	Speed of maximum wind gust (km/h)	Gust m/s'	9am Temperature (°C)	9am wind speed (km/h)	9 am m/s'	9am MSL pressure (hPa)	3pm Temperature (°C)	3pm wind speed (km/h)	3 pm m/s'	3pm MSL pressure (hPa)
Summer													
Dec/Jan/Feb													
Annual	MEAN	15.2	25.9	44.6	12.4	18.8	17.0	4.7	1013.0	24.2	21.9	6.1	1011.5
Annual	Lowest	9.3	18.0	28.0	7.8	13.1	4.0	1.1	993.2	16.7	9.0	2.5	992.6
Annual	Highest	26.4	40.4	72.0	20.0	30.2	44.0	12.2	1024.3	39.6	41.0	11.4	1025.8
Winter													
June/Jul/Aug													
Annual	MEAN	7.8	14.9	52.2	14.4	9.8	21.0	5.8	1019.2	13.8	25.1	6.9	1017.4
Annual	Lowest	2.0	11.2	19.0	0.0	3.7	4.0	0.0	986.9	9.3	7.0	0.0	991.6
Annual	Highest	13.4	20.2	93.0	25.8	15.6	46.0	12.8	1034.4	19.3	54.0	15.0	1032.5

		TOTALS	%
N=	73	354	21
S=	62	354	18
E=	4	354	1
W=	23	354	6

Although the data for the 12-month period of July 2003-June 2004 shows that there is more likely to be a Northerly (21%), closely followed by a Southerly (18%), then Westerly (6%) and finally Easterly (4%) chance in wind direction, the CONTAM scenarios were modelled with an Easterly wind. This was because when the wind directions were varied for the 'base' building (i.e. with an internal and external temperature of 20°C and a wind speed of 5 m/s), the simulation results indicated, that in relation to the door opening forces, the Easterly and Westerly wind directions had (marginally) the greatest influence (that is, these wind directions resulted in higher door opening forces due to higher differential pressures in the stairwell), followed then by a Southerly and then Northerly wind. This was seen in the CONTAM simulations #56, #190 and #216-221 (refer to Appendix I). Therefore, it is considered that by modelling the scenarios with an Easterly wind, a more conservative analysis was obtained.

Table L3. CONTAM Wind Direction Influences on Door Opening Forces

Wind Direction	Fan Speed 3,472 L/s (System 1) Relief = 0.06 m^2			Fan Speed 11,575 L/s (System 2) Relief = 1 m^2		
	Maximum Pressure (Pa)	Maximum Door Opening Force (N)	Run Id	Maximum Pressure (Pa)	Maximum Door Opening Force (N)	Run Id
East	97.4	104	#190	91.0	97	#56
North	96.2	102	#216	87.5	94	#217
South	97.3	103	#218	90.5	96	#219
West	97.5	104	#220	90.6	97	#221

The table below, details the data for the 12-month period which was used to identify realistic temperature and wind ranges, so that the sensitivity study could be conducted. The winter and summer average temperatures were also then analysed resulting in 15°C and 25°C, respectively.

Table L4. Annual External Weather Data

	Min Temp (°C)	Max Temp (°C)	Max Gust (m/s)	9 am Temp (°C)	9 am Wind (m/s)	3 pm Temp (°C)	3 pm Wind (m/s)
Mean	11.3	20.3	13	14.3	5.2	18.9	6.5
Lowest	2	11.2	0	3.7	0	9.3	0
Highest	26.4	40.4	29.7	30.2	12.8	39.6	15.8

Based on Table L4 (and more specifically the highlighted cells), the following range of external temperatures and wind conditions were adopted and used in the sensitivity study. Such a sensitivity study was performed (as opposed to only performing analyses with a single external temperature and wind of 20°C and 5 m/s, respectively), as the building's SCS may be activated at any time and therefore, the conditions may be different to that observed during commissioning or testing. Therefore, a range of values were modelled and are detailed in Chapter 7 of this thesis.

Table L5. Sensitivity Data Ranges for Temperature and Wind

Comments	Temperature (°C)	Wind (m/s)	Comments
	- 10		
	- 8		
	- 5		
	0		
	1		
Close to the minimum value	5	**5**	Note 2
	10	7.5	
	15	10	
Mean maximum value	**20**	12.5	
	25	15	Maximum gust at 3pm
Value occurred more often than maximum value	30		

Notes 1: It was assumed that the temperatures and wind speeds were constant over the height of the building.

2: The minimum wind speed of 5 m/s was chosen at 9 am as commissioning is typically performed early in the morning preferably on a calm/still day. Therefore, a wind speed of 5 m/s (which is representative of a calm day) was realistic.

Throughout this thesis the wind values obtained from the Bureau of Meteorology have not been modified/adjusted as detailed within AS1170.2 (2002), which is the standard designers of structures use when the structure is subject to wind action. The aforementioned standard states in the preface that at the time of drafting, there was "insufficient evidence to indicate any trend in wind speeds due to climatic change" and that the values of wind speed are determined using the annual probability of exceedance (i.e. the probability that a value will be exceeded in any one year).

The other reason for not modifying/adjusting the wind data, is because based on the interpolations in Table 4.1(A) of AS1170.2 (2002), the modifier for a Category 4 terrain (i.e. comparable to the Melbourne CBD) is 80% of what the modifier would be for a Category 2 terrain (which would be the terrain for where the wind data was actually obtained, i.e. at the airport) for the height of the wind data collection station. Therefore, it was determined that the data obtained from the airport weather station for wind, was representative of the data which could have been obtained from the regional weather station (if such data was available), and in any case, the airport wind data provided a more conservative analysis for this research, therefore, the values were not modified.

Appendix M Probability of Occurrence (E-factors)

Based on the data obtained from the Bureau of Meteorology and as presented in Appendix L, it was calculated that the following probabilities of occurrence would occur for the various wind speeds and temperatures over the 12-month period (July 2003 – June 2004). Refer to Table M1.

Notes:
1. A temperature of 20°C refers to a temperature range of greater than or equal to 17.5°C and less than or equal to 22.4°C.
2. A wind speed of 12.5 m/s includes wind speeds in the range of greater than or equal to 11.3 m/s and less than or equal to 13.7 m/s.

Table M1. External Conditions and their Probability of Occurrence

For a 12 month period July 2003-June 2004

TOTAL NUMber of days = 366 — TOTAL Number of winds = 696

TOTAL NUMber of days = 366 — TOTAL Number of temps = 732 *(2 temps/day)*

Temp (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Freq/ Yr 03/04	% (out of poss. total data)
No. of days	*31*	*29*	*31*	*30*	*31*	*30*	*31*	*31*	*30*	*31*	*30*	*31*		
-15	0	0	0	0	0	0	0	0	0	0	0	0	*0*	0.00
-10	0	0	0	0	0	0	0	0	0	0	0	0	*0*	0.00
-5	0	0	0	0	0	0	0	0	0	0	0	0	*0*	0.00
<= 0	0	0	0	0	0	0	0	0	0	0	0	0	*0*	0.00
5	0	0	0	0	0	2	5	5	0	0	0	0	*12*	0.02
10	0	0	0	6	20	29	32	30	20	13	3	0	*153*	0.21
15	22	12	24	26	33	27	25	27	29	37	25	10	*297*	0.41
20	25	28	28	18	9	2	0	0	11	10	15	26	*172*	0.23
25	9	12	5	8	0	0	0	0	0	2	10	13	*59*	0.08
30	5	2	4	2	0	0	0	0	0	0	4	8	*25*	0.03
>=35	1	4	1	0	0	0	0	0	0	0	3	5	*14*	0.02
TOTAL	***62***	***58***	***62***	***60***	***62***	***60***	***62***	***62***	***60***	***62***	***60***	***62***	***732***	***1.00***

Table M1. External Conditions and their Probability of Occurrence (continued)

Wind (m/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Freq/ Yr 03/04*	% (out of poss. total data)
0	1	0	0	2	1	1	5	2	3	6	2	1	*24*	0.03
2.5	15	18	20	14	11	7	12	10	8	5	7	11	*138*	0.20
5	28	29	22	24	25	17	16	19	11	22	21	24	***258***	0.37
7.5	11	9	11	13	11	23	15	19	22	24	15	15	*188*	0.27
10	6	2	6	5	3	8	7	8	8	3	2	4	***62***	0.09
12.5	1	0	0	0	0	3	3	2	6	2	2	3	*22*	0.03
15	0	0	0	0	0	0	1	1	2	0	0	0	*4*	0.01
>=17.5	0	0	0	0	0	0	0	0	0	0	0	0	*0*	0.00
TOTAL	***62***	***58***	***59***	***58***	***51***	***59***	***59***	***61***	***60***	***62***	***49***	***58***	***696***	***1.00***
* Gust of 30m/s	0	0	0	0	0	0	0	0	1	0	0	0	*1*	0.001
Not Calm winds > 5 m/s	18	11	17	18	14	34	26	30	38	29	19	22	*276*	0.38

****

**** __*NOTE:*__ __*AND even rarer to get 20°C and a 5 m/s wind condition concurrently!*__

The information in Table M1 shows that the occurrence of a temperature less than 5°C within the 12-month data range is zero. The results of Table M1 are graphically represented as follows.

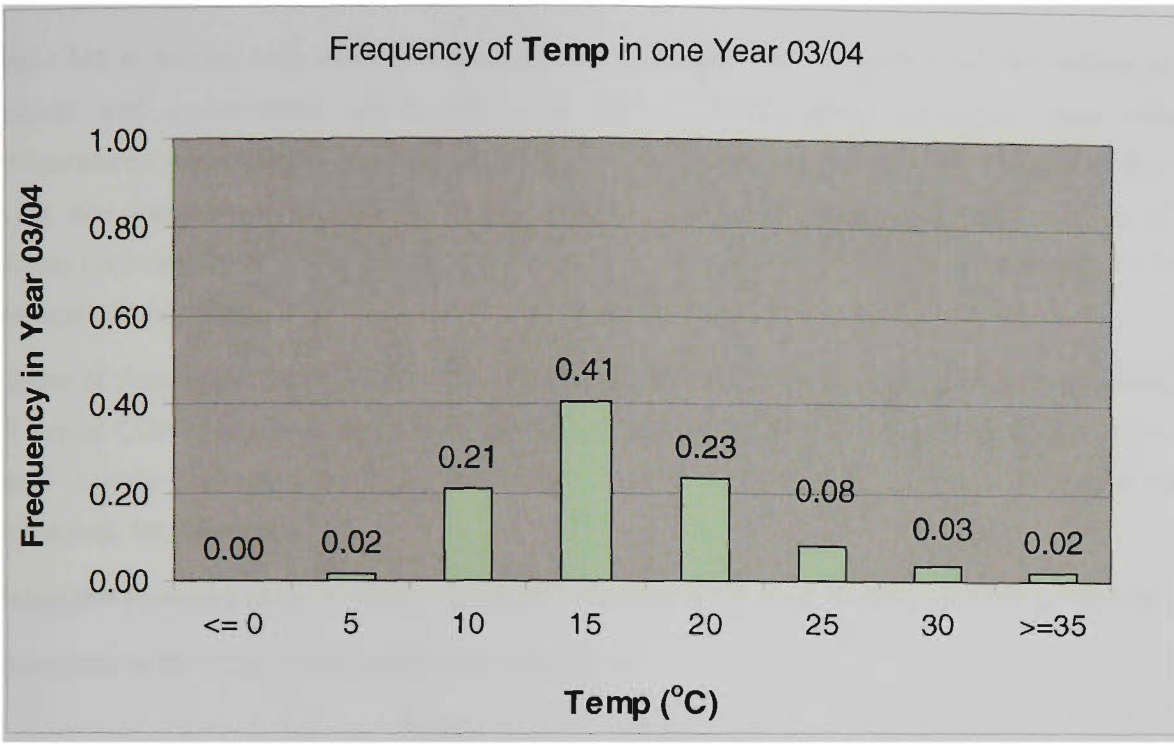

Figure M1. Temperature Probability

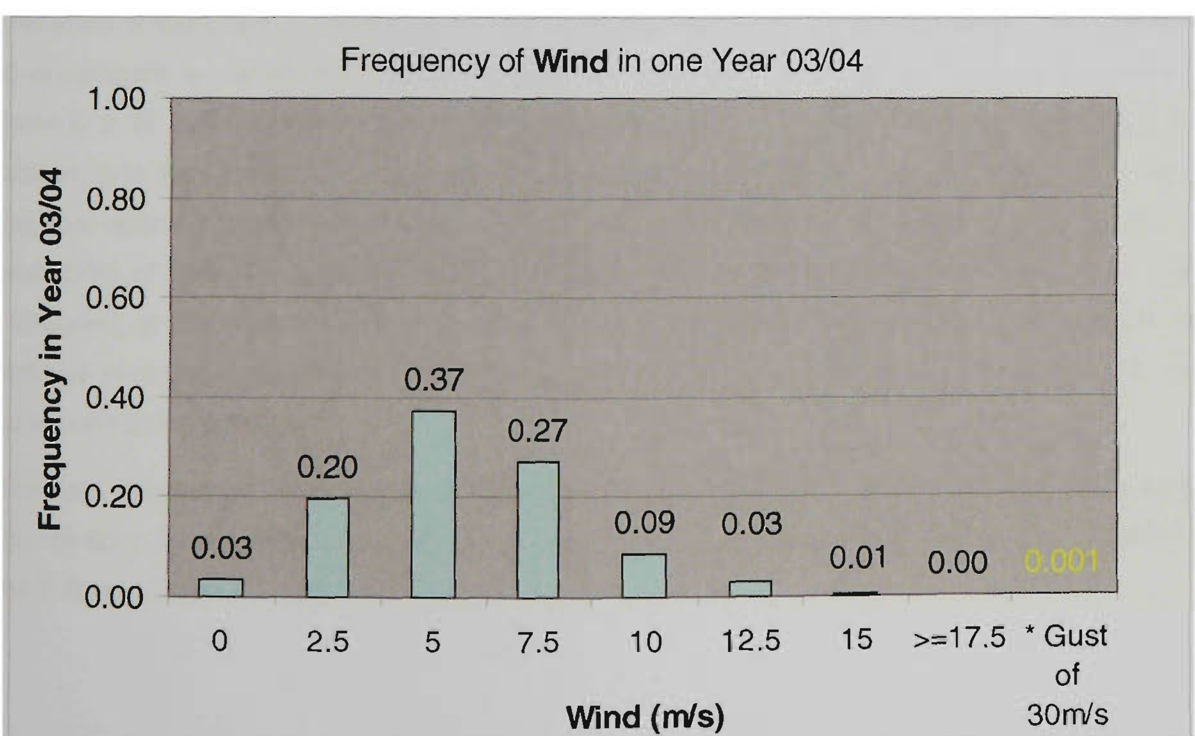

Figure M2. Wind Speed Probability

Referring to Figures M2 and M3, the probability of having a 5°C and a wind speed of 10 m/s is:

$$= 0.02x0.09$$
$$= 0.18\%$$

Table M2 to follow, was used to calculate the probability of occurrence for the various wind speeds and temperature combinations for the 12-month study period of data (where temperatures were greater than or equal to 5°C (as temperatures less than this value did not occur and have therefore not been represented). This table also incorporates the pass/fail results (denoted by a 'Y' for passes and a 'N' for fails) for the CONTAM simulations at varied leakage combinations.

Values of 'Average', 'Quart', 'Half', '3Quart' and 'Loose' results are indicated in bold and refer to an actual CONTAM simulation, while results not in bold have been interpolated based on the trend in data and the neighbouring results. The probabilities of success have then been calculated, for example:

Using the Average (Ave) Leakage data (for the Stairwell and the Main Building Façade) –

Probability of 20°C and 5 m/s at SETW conditions

$$\text{Prob}_{20^{\circ}C, 5\,m/s} = 0.23x0.37$$
$$= 0.0851\%$$

Therefore, if there is a 'Y' in the column for door opening forces and/or velocities, the probability of occurrence is carried through to its associated probability of success column, however, if there is a 'N' in the column, the probability of success is 0. Table M2 helps to illustrate that according to the CONTAM simulations, the performance conditions could be achieved for either the door opening forces only, the wind speed only, both conditions, or neither. Accordingly, the probability of success columns are then added whereby, the effectiveness values have been calculated, at the base of the column. That is, effectiveness in terms of wind, temperature and leakage changes have been calculated for the door opening forces, the velocities and both conditions being achieved.

The data detailed in Table M2 are applicable for when the Ground Floor (L0) is considered as the fire floor, for the airflow velocity assessment. This table details the effectiveness results for the E-factors.

TEMP	WIND	Prob. Of Occurrence from graphs	Pass or Fail - System 1 (L=AVE)			Pass or Fail - System 2 (L=AVE)			Prob of Success - System 1 (L=AVE)			Prob of Success - System 2 (L=AVE)			Pass or Fail - System 1 (L=Qrt)			Pass or Fail - System 2 (L=Qrt)		
			Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both
5	0	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y
	2.5	0.004	Y	Y	Y	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y	Y	Y	Y
	5	0.0074	Y	Y	Y	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	Y	Y	Y
	7.5	0.0054	Y	Y	Y	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	Y	Y	Y
	10	0.0018	Y	Y	Y	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	Y	Y	Y
	12.5	0.0006	N	Y	N	N	Y	N	0	0.0006	0	0	0.0006	0	Y	Y	Y	Y	Y	Y
	15	0.0002	N	Y	N	N	Y	N	0	0.0002	0	0	0.0002	0	Y	Y	Y	N	Y	N
	30	0.00002	N	Y	N	N	Y	N	0	0.00002	0	0	0.00002	0	Y	Y	Y	N	Y	N
10	0	0.0063	Y	Y	Y	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	Y	Y	Y
	2.5	0.042	Y	Y	Y	Y	Y	Y	0.042	0.042	0.042	0.042	0.042	0.042	Y	Y	Y	Y	Y	Y
	5	0.0777	Y	Y	Y	Y	Y	Y	0.0777	0.0777	0.0777	0.0777	0.0777	0.0777	Y	Y	Y	Y	Y	Y
	7.5	0.0567	Y	Y	Y	Y	Y	Y	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	Y	Y	Y	Y	Y	Y
	10	0.0189	Y	Y	Y	Y	Y	Y	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	Y	Y	Y	Y	Y	Y
	12.5	0.0063	Y	Y	Y	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	Y	Y	Y
	15	0.0021	Y	Y	Y	N	Y	N	0.0021	0.0021	0.0021	0	0.0021	0	Y	Y	Y	Y	Y	Y
	30	0.00021	N	Y	N	N	Y	N	0	0.00021	0	0	0.00021	0	Y	Y	Y	N	Y	N
15	0	0.0123	Y	Y	Y	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	Y	Y	Y
	2.5	0.082	Y	Y	Y	Y	Y	Y	0.082	0.082	0.082	0.082	0.082	0.082	Y	Y	Y	Y	Y	Y
	5	0.1517	Y	Y	Y	Y	Y	Y	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	Y	Y	Y	Y	Y	Y
	7.5	0.1107	Y	Y	Y	Y	Y	Y	0.1107	0.1107	0.1107	0.1107	0.1107	0.1107	Y	Y	Y	Y	Y	Y
	10	0.0369	Y	Y	Y	Y	Y	Y	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	Y	Y	Y	Y	Y	Y
	12.5	0.0123	Y	Y	Y	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	Y	Y	Y
	15	0.0041	Y	Y	Y	Y	Y	Y	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	Y	Y	Y	Y	Y	Y
	30	0.00041	N	Y	N	N	Y	N	0	0.00041	0	0	0.00041	0	Y	Y	Y	N	Y	N
20	0	0.0069	Y	Y	Y	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	Y	Y	Y
	2.5	0.046	Y	Y	Y	Y	Y	Y	0.046	0.046	0.046	0.046	0.046	0.046	Y	Y	Y	Y	Y	Y
	5	0.0851	Y	Y	Y	Y	Y	Y	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	Y	Y	Y	Y	Y	Y
	7.5	0.0621	Y	Y	Y	Y	Y	Y	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	Y	Y	Y	Y	Y	Y
	10	0.0207	Y	Y	Y	Y	Y	Y	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	Y	Y	Y	Y	Y	Y
	12.5	0.0069	Y	Y	Y	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	Y	Y	Y
	15	0.0023	Y	Y	Y	Y	Y	Y	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	Y	Y	Y	Y	Y	Y
	30	0.00023	N	Y	N	N	Y	N	0	0.00023	0	0	0.00023	0	Y	Y	Y	N	Y	N
25	0	0.0024	Y	Y	Y	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	Y	Y	Y
	2.5	0.016	Y	Y	Y	Y	Y	Y	0.016	0.016	0.016	0.016	0.016	0.016	Y	Y	Y	Y	Y	Y
	5	0.0296	Y	Y	Y	Y	Y	Y	0.0296	0.0296	0.0296	0.0296	0.0296	0.0296	Y	Y	Y	Y	Y	Y
	7.5	0.0216	Y	Y	Y	Y	Y	Y	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	Y	Y	Y	Y	Y	Y
	10	0.0072	Y	Y	Y	Y	Y	Y	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	Y	Y	Y	Y	Y	Y
	12.5	0.0024	Y	Y	Y	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	Y	Y	Y
	15	0.0008	Y	Y	Y	Y	Y	Y	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	Y	Y	Y	Y	Y	Y
	30	0.00008	N	N	N	N	N	N	0	0	0	0	0	0	Y	Y	Y	Y	Y	Y
30	0	0.0009	Y	Y	Y	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	Y	Y	Y
	2.5	0.006	Y	Y	Y	Y	Y	Y	0.006	0.006	0.006	0.006	0.006	0.006	Y	Y	Y	Y	Y	Y

	5	0.0111	Y	Y	Y	Y	Y	Y	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	Y	Y	Y	Y	Y	Y
	7.5	0.0081	Y	Y	Y	Y	Y	Y	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	Y	Y	Y	Y	Y	Y
	10	0.0027	Y	Y	Y	Y	Y	Y	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	Y	Y	Y	Y	Y	Y
	12.5	0.0009	Y	Y	Y	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	Y	Y	Y
	15	0.0003	N	Y	N	Y	Y	Y	0	0.0003	0	0.0003	0.0003	0.0003	Y	Y	Y	Y	Y	Y
	30	0.00003	N	Y	N	Y	Y	Y	0	0.00003	0	0.00003	0.00003	0.00003	Y	Y	Y	Y	Y	Y
>=35	0	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y
	2.5	0.004	Y	Y	Y	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y	Y	Y	Y
	5	0.0074	Y	Y	Y	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	Y	Y	Y
	7.5	0.0054	Y	Y	Y	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	Y	Y	Y
	10	0.0018	Y	Y	Y	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	Y	Y	Y
	12.5	0.0006	N	Y	N	Y	Y	Y	0	0.0006	0	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y
	15	0.0002	N	Y	N	Y	Y	Y	0	0.0002	0	0.0002	0.0002	0.0002	Y	Y	Y	Y	Y	Y
	30	0.00002	N	Y	N	Y	Y	Y	0	0.00002	0	0.00002	0.00002	0.00002	Y	Y	Y	Y	Y	Y
	Probability	1.0000							0.9981	1.0000	0.9981	0.9971	1.0000	0.9971						
									Sys 1 - Effectiveness with AVE Leak. :			Sys 2 - Effectiveness with AVE Leak. :								

			Prob of Success - System 1 (L=Qrt)			Prob of Success - System 2 (L=Qrt)			Pass or Fail - System 1 (L=Half)			Pass or Fail - System 2 (L=Half)			Prob of Success - System 1 (L=Half)			Prob of Success - System 2 (L=Half)			Pass or Fail - System 1 (L=3Qrt)		
TEMP	WIND	Prob. Of Occurrence from graphs	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both
5	0	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y
	2.5	0.004	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y
	5	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y
	7.5	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y
	10	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y
	12.5	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y
	15	0.0002	0.0002	0.0002	0.0002	0	0.0002	0	Y	Y	Y	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y
	30	0.00002	0.00002	0.00002	0.00002	0	0.00002	0	Y	Y	Y	N	Y	N	0.00002	0.00002	0.00002	0	0.00002	0	Y	Y	Y
10	0	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y
	2.5	0.042	0.042	0.042	0.042	0.042	0.042	0.042	Y	Y	Y	Y	Y	Y	0.042	0.042	0.042	0.042	0.042	0.042	Y	Y	Y
	5	0.0777	0.0777	0.0777	0.0777	0.0777	0.0777	0.0777	Y	Y	Y	Y	Y	Y	0.0777	0.0777	0.0777	0.0777	0.0777	0.0777	Y	Y	Y
	7.5	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	Y	Y	Y	Y	Y	Y	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	Y	Y	Y
	10	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	Y	Y	Y	Y	Y	Y	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	Y	Y	Y
	12.5	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y
	15	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	Y	Y	Y	Y	Y	Y	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	Y	Y	Y
	30	0.00021	0.00021	0.00021	0.00021	0	0.00021	0	Y	Y	Y	N	Y	N	0.00021	0.00021	0.00021	0	0.00021	0	Y	Y	Y
15	0	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y
	2.5	0.082	0.082	0.082	0.082	0.082	0.082	0.082	Y	Y	Y	Y	Y	Y	0.082	0.082	0.082	0.082	0.082	0.082	Y	Y	Y
	5	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	Y	Y	Y	Y	Y	Y	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	Y	Y	Y
	7.5	0.1107	0.1107	0.1107	0.1107	0.1107	0.1107	0.1107	Y	Y	Y	Y	Y	Y	0.1107	0.1107	0.1107	0.1107	0.1107	0.1107	Y	Y	Y
	10	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	Y	Y	Y	Y	Y	Y	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	Y	Y	Y
	12.5	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y
	15	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	Y	Y	Y	Y	Y	Y	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	Y	Y	Y
	30	0.00041	0.00041	0.00041	0.00041	0	0.00041	0	Y	Y	Y	Y	Y	Y	0.00041	0.00041	0.00041	0.00041	0.00041	0.00041	Y	Y	Y
20	0	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y
	2.5	0.046	0.046	0.046	0.046	0.046	0.046	0.046	Y	Y	Y	Y	Y	Y	0.046	0.046	0.046	0.046	0.046	0.046	Y	Y	Y
	5	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	Y	Y	Y	Y	Y	Y	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	Y	Y	Y
	7.5	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	Y	Y	Y	Y	Y	Y	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	Y	Y	Y
	10	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	Y	Y	Y	Y	Y	Y	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	Y	Y	Y
	12.5	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y
	15	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	Y	Y	Y	Y	Y	Y	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	Y	Y	Y
	30	0.00023	0.00023	0.00023	0.00023	0	0.00023	0	Y	Y	Y	Y	Y	Y	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	Y	Y	Y
25	0	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y
	2.5	0.016	0.016	0.016	0.016	0.016	0.016	0.016	Y	Y	Y	Y	Y	Y	0.016	0.016	0.016	0.016	0.016	0.016	Y	Y	Y
	5	0.0296	0.0296	0.0296	0.0296	0.0296	0.0296	0.0296	Y	Y	Y	Y	Y	Y	0.0296	0.0296	0.0296	0.0296	0.0296	0.0296	Y	Y	Y
	7.5	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	Y	Y	Y	Y	Y	Y	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	Y	Y	Y
	10	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	Y	Y	Y	Y	Y	Y	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	Y	Y	Y
	12.5	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y
	15	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	Y	Y	Y	Y	Y	Y	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	Y	Y	Y
	30	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	Y	Y	Y	Y	Y	Y	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	Y	Y	Y

30	*0*	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y
	2.5	0.006	0.006	0.006	0.006	0.006	0.006	0.006	Y	Y	Y	Y	Y	Y	0.006	0.006	0.006	0.006	0.006	0.006	Y	Y	Y
	5	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	Y	Y	Y	Y	Y	Y	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	Y	Y	Y
	7.5	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	Y	Y	Y	Y	Y	Y	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	Y	Y	Y
	10	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	Y	Y	Y	Y	Y	Y	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	Y	Y	Y
	12.5	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y
	15	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	Y	Y	Y	Y	Y	Y	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	Y	Y	Y
	30	* 0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	Y	Y	Y	Y	Y	Y	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	Y	Y	Y
>=35	0	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y
	2.5	0.004	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y
	5	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y
	7.5	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y
	10	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y
	12.5	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y
	15	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y
	30	* 0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	Y	Y	Y	Y	Y	Y	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	Y	Y	Y
Probability		***1.0000***	1.0000	1.0000	1.0000	0.9998	1.0000	0.9998							1.0000	1.0000	1.0000	1.0000	1.0000	1.0000			
			Sys 1 - Effectiveness QUART L.:			Sys 2 - Effectiveness QUART L:									Sys 1 - Effectiveness HALF L. :			Sys 2 - Effectiveness HALF L:					

			Pass or Fail - System 2 (L=3Qrt)			Prob of Success - System 1 (L=3Qrt)			Prob of Success - System 2 (L=3Qrt)			Pass or Fail - System 1 (Loose)			Pass or Fail - System 2 (Loose)			Prob of Success - System 1 (Loose)		
TEMP	WIND	Prob. Of Occurrence from graphs	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both
5	0	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006
	2.5	0.004	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y	Y	Y	Y	0.004	0.004	0.004
	5	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	Y	Y	Y	0.0074	0.0074	0.0074
	7.5	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	Y	Y	Y	0.0054	0.0054	0.0054
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	Y	Y	Y	0.0018	0.0018	0.0018
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	Y	Y	Y	0.0002	0.0002	0.0002
	30	0.00002	N	Y	N	0.00002	0.00002	0.00002	0	0.00002	0	Y	Y	Y	Y	Y	Y	0.00002	0.00002	0.00002
10	0	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	Y	Y	Y	0.0063	0.0063	0.0063
	2.5	0.042	Y	Y	Y	0.042	0.042	0.042	0.042	0.042	0.042	Y	Y	Y	Y	Y	Y	0.042	0.042	0.042
	5	0.0777	Y	Y	Y	0.0777	0.0777	0.0777	0.0777	0.0777	0.0777	Y	Y	Y	Y	Y	Y	0.0777	0.0777	0.0777
	7.5	0.0567	Y	Y	Y	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	Y	Y	Y	Y	Y	Y	0.0567	0.0567	0.0567
	10	0.0189	Y	Y	Y	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	Y	Y	Y	Y	Y	Y	0.0189	0.0189	0.0189
	12.5	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	Y	Y	Y	0.0063	0.0063	0.0063
	15	0.0021	Y	Y	Y	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	Y	Y	Y	Y	Y	Y	0.0021	0.0021	0.0021
	30	0.00021	Y	Y	Y	0.00021	0.00021	0.00021	0.00021	0.00021	0.00021	Y	Y	Y	Y	Y	Y	0.00021	0.00021	0.00021
15	0	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	Y	Y	Y	0.0123	0.0123	0.0123
	2.5	0.082	Y	Y	Y	0.082	0.082	0.082	0.082	0.082	0.082	Y	Y	Y	Y	Y	Y	0.082	0.082	0.082
	5	0.1517	Y	Y	Y	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	Y	Y	Y	Y	Y	Y	0.1517	0.1517	0.1517
	7.5	0.1107	Y	Y	Y	0.1107	0.1107	0.1107	0.1107	0.1107	0.1107	Y	Y	Y	Y	Y	Y	0.1107	0.1107	0.1107
	10	0.0369	Y	Y	Y	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	Y	Y	Y	Y	Y	Y	0.0369	0.0369	0.0369
	12.5	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	Y	Y	Y	0.0123	0.0123	0.0123
	15	0.0041	Y	Y	Y	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	Y	Y	Y	Y	Y	Y	0.0041	0.0041	0.0041
	30	0.00041	Y	Y	Y	0.00041	0.00041	0.00041	0.00041	0.00041	0.00041	Y	Y	Y	Y	Y	Y	0.00041	0.00041	0.00041
20	0	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	Y	Y	Y	0.0069	0.0069	0.0069
	2.5	0.046	Y	Y	Y	0.046	0.046	0.046	0.046	0.046	0.046	Y	Y	Y	Y	Y	Y	0.046	0.046	0.046
	5	0.0851	Y	Y	Y	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	Y	Y	Y	Y	Y	Y	0.0851	0.0851	0.0851
	7.5	0.0621	Y	Y	Y	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	Y	Y	Y	Y	Y	Y	0.0621	0.0621	0.0621
	10	0.0207	Y	Y	Y	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	Y	Y	Y	Y	Y	Y	0.0207	0.0207	0.0207
	12.5	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	Y	Y	Y	0.0069	0.0069	0.0069
	15	0.0023	Y	Y	Y	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	Y	Y	Y	Y	Y	Y	0.0023	0.0023	0.0023
	30	0.00023	Y	Y	Y	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	Y	Y	Y	Y	Y	Y	0.00023	0.00023	0.00023
25	0	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	Y	Y	Y	0.0024	0.0024	0.0024
	2.5	0.016	Y	Y	Y	0.016	0.016	0.016	0.016	0.016	0.016	Y	Y	Y	Y	Y	Y	0.016	0.016	0.016
	5	0.0296	Y	Y	Y	0.0296	0.0296	0.0296	0.0296	0.0296	0.0296	Y	Y	Y	Y	Y	Y	0.0296	0.0296	0.0296
	7.5	0.0216	Y	Y	Y	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	Y	Y	Y	Y	Y	Y	0.0216	0.0216	0.0216
	10	0.0072	Y	Y	Y	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	Y	Y	Y	Y	Y	Y	0.0072	0.0072	0.0072
	12.5	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	Y	Y	Y	0.0024	0.0024	0.0024
	15	0.0008	Y	Y	Y	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	Y	Y	Y	Y	Y	Y	0.0008	0.0008	0.0008
	30	0.00008	Y	Y	Y	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	Y	Y	Y	Y	Y	Y	0.00008	0.00008	0.00008
30	0	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	Y	Y	Y	0.0009	0.0009	0.0009

	2.5	0.006	Y	Y	Y	0.006	0.006	0.006	0.006	0.006	0.006	Y	Y	Y	Y	Y	Y	0.006	0.006	0.006
	5	0.0111	Y	Y	Y	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	Y	Y	Y	Y	Y	Y	0.0111	0.0111	0.0111
	7.5	0.0081	Y	Y	Y	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	Y	Y	Y	Y	Y	Y	0.0081	0.0081	0.0081
	10	0.0027	Y	Y	Y	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	Y	Y	Y	Y	Y	Y	0.0027	0.0027	0.0027
	12.5	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	Y	Y	Y	0.0009	0.0009	0.0009
	15	0.0003	Y	Y	Y	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	Y	Y	Y	Y	Y	Y	0.0003	0.0003	0.0003
	30	0.00003	Y	Y	Y	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	Y	Y	Y	Y	Y	Y	0.00003	0.00003	0.00003
>=35	0	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006
	2.5	0.004	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	Y	Y	Y	Y	Y	0.004	0.004	0.004
	5	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	Y	Y	Y	0.0074	0.0074	0.0074
	7.5	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	Y	Y	Y	0.0054	0.0054	0.0054
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	Y	Y	Y	0.0018	0.0018	0.0018
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	Y	Y	Y	0.0006	0.0006	0.0006
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	Y	Y	Y	0.0002	0.0002	0.0002
	30	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	Y	Y	Y	Y	Y	Y	0.00002	0.00002	0.00002
	Probability	1.0000				1.0000	1.0000	1.0000	1.0000	1.0000	1.0000							1.0000	1.0000	1.0000
						Sys 1 - Effectiveness 3/4QL:			Sys 2 - Effectiveness 3/4QL:									Sys 1 - Effectiveness LOOSE L		

TEMP	WIND	Prob. Of Occurrence from graphs	Prob of Success - System 2 (Loose): Door Force	Velocity with 0.01m2	Both	Pass or Fail - System 1 (L=Ave): Door Force	Velocity with 0.06m2	Both	Prob of Success - System 1 (L=Ave): Door Force	Velocity with 0.06m2	Both	Pass or Fail - System 1 (L=Qrt): Door Force	Velocity with 0.06m2	Both	Prob of Success - System 1 (L=Qrt): Door Force	Velocity with 0.06m2	Both	Surmised That ½, Qrt, Loose would also =1 b/c	Pass or Fail - System 1 (S/W=Qrt): Door Force	Velocity with 0.01m2	Both
5	0	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	Qrt did and	Y	Y	Y
	2.5	0.004	0.004	0.004	0.004	Y	Y	Y	0.004	0.004	0.004	Y	Y	Y	0.004	0.004	0.004	Gets better	Y	Y	Y
	5	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	As leakage	Y	Y	Y
	7.5	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	increases	Y	Y	Y
	10	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018		Y	Y	Y
	12.5	0.0006	0.0006	0.0006	0.0006	N	Y	N	0	0.0006	0	Y	Y	Y	0.0006	0.0006	0.0006		Y	Y	Y
	15	0.0002	0.0002	0.0002	0.0002	N	Y	N	0	0.0002	0	Y	Y	Y	0.0002	0.0002	0.0002		Y	Y	Y
	30	' 0.00002	0.00002	0.00002	0.00002	N	Y	N	0	0.00002	0	Y	Y	Y	0.00002	0.00002	0.00002		Y	Y	Y
10	0	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	Y	Y	Y	0.0063	0.0063	0.0063		Y	Y	Y
	2.5	0.042	0.042	0.042	0.042	Y	Y	Y	0.042	0.042	0.042	Y	Y	Y	0.042	0.042	0.042		Y	Y	Y
	5	0.0777	0.0777	0.0777	0.0777	Y	Y	Y	0.0777	0.0777	0.0777	Y	Y	Y	0.0777	0.0777	0.0777		Y	Y	Y
	7.5	0.0567	0.0567	0.0567	0.0567	Y	Y	Y	0.0567	0.0567	0.0567	Y	Y	Y	0.0567	0.0567	0.0567		Y	Y	Y
	10	0.0189	0.0189	0.0189	0.0189	Y	Y	Y	0.0189	0.0189	0.0189	Y	Y	Y	0.0189	0.0189	0.0189		Y	Y	Y
	12.5	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	Y	Y	Y	0.0063	0.0063	0.0063		Y	Y	Y
	15	0.0021	0.0021	0.0021	0.0021	Y	Y	Y	0.0021	0.0021	0.0021	Y	Y	Y	0.0021	0.0021	0.0021		Y	Y	Y
	30	' 0.00021	0.00021	0.00021	0.00021	N	Y	N	0	0.00021	0	Y	Y	Y	0.00021	0.00021	0.00021		Y	Y	Y
15	0	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	Y	Y	Y	0.0123	0.0123	0.0123		Y	Y	Y
	2.5	0.082	0.082	0.082	0.082	Y	Y	Y	0.082	0.082	0.082	Y	Y	Y	0.082	0.082	0.082		Y	Y	Y
	5	0.1517	0.1517	0.1517	0.1517	Y	Y	Y	0.1517	0.1517	0.1517	Y	Y	Y	0.1517	0.1517	0.1517		Y	Y	Y
	7.5	0.1107	0.1107	0.1107	0.1107	Y	Y	Y	0.1107	0.1107	0.1107	Y	Y	Y	0.1107	0.1107	0.1107		Y	Y	Y
	10	0.0369	0.0369	0.0369	0.0369	Y	Y	Y	0.0369	0.0369	0.0369	Y	Y	Y	0.0369	0.0369	0.0369		Y	Y	Y
	12.5	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	Y	Y	Y	0.0123	0.0123	0.0123		Y	Y	Y
	15	0.0041	0.0041	0.0041	0.0041	Y	Y	Y	0.0041	0.0041	0.0041	Y	Y	Y	0.0041	0.0041	0.0041		Y	Y	Y
	30	' 0.00041	0.00041	0.00041	0.00041	N	Y	N	0	0.00041	0	Y	Y	Y	0.00041	0.00041	0.00041		Y	Y	Y
20	0	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	Y	Y	Y	0.0069	0.0069	0.0069		Y	Y	Y
	2.5	0.046	0.046	0.046	0.046	Y	Y	Y	0.046	0.046	0.046	Y	Y	Y	0.046	0.046	0.046		Y	Y	Y
	5	0.0851	0.0851	0.0851	0.0851	Y	Y	Y	0.0851	0.0851	0.0851	Y	Y	Y	0.0851	0.0851	0.0851		Y	Y	Y
	7.5	0.0621	0.0621	0.0621	0.0621	Y	Y	Y	0.0621	0.0621	0.0621	Y	Y	Y	0.0621	0.0621	0.0621		Y	Y	Y
	10	0.0207	0.0207	0.0207	0.0207	Y	Y	Y	0.0207	0.0207	0.0207	Y	Y	Y	0.0207	0.0207	0.0207		Y	Y	Y
	12.5	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	Y	Y	Y	0.0069	0.0069	0.0069		Y	Y	Y
	15	0.0023	0.0023	0.0023	0.0023	Y	Y	Y	0.0023	0.0023	0.0023	Y	Y	Y	0.0023	0.0023	0.0023		Y	Y	Y
	30	' 0.00023	0.00023	0.00023	0.00023	N	Y	N	0	0.00023	0	Y	Y	Y	0.00023	0.00023	0.00023		Y	Y	Y
25	0	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	Y	Y	Y	0.0024	0.0024	0.0024		Y	Y	Y
	2.5	0.016	0.016	0.016	0.016	Y	Y	Y	0.016	0.016	0.016	Y	Y	Y	0.016	0.016	0.016		Y	Y	Y
	5	0.0296	0.0296	0.0296	0.0296	Y	Y	Y	0.0296	0.0296	0.0296	Y	Y	Y	0.0296	0.0296	0.0296		Y	Y	Y
	7.5	0.0216	0.0216	0.0216	0.0216	Y	Y	Y	0.0216	0.0216	0.0216	Y	Y	Y	0.0216	0.0216	0.0216		Y	Y	Y
	10	0.0072	0.0072	0.0072	0.0072	Y	Y	Y	0.0072	0.0072	0.0072	Y	Y	Y	0.0072	0.0072	0.0072		Y	Y	Y
	12.5	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	Y	Y	Y	0.0024	0.0024	0.0024		Y	Y	Y
	15	0.0008	0.0008	0.0008	0.0008	Y	Y	Y	0.0008	0.0008	0.0008	Y	Y	Y	0.0008	0.0008	0.0008		Y	Y	Y
	30	' 0.00008	0.00008	0.00008	0.00008	N	Y	N	0	0.00008	0	Y	Y	Y	0.00008	0.00008	0.00008		Y	Y	Y

30	0	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	Y	Y	Y	0.0009	0.0009	0.0009		Y	Y	Y
	2.5	0.006	0.006	0.006	0.006	Y	Y	Y	0.006	0.006	0.006	Y	Y	Y	0.006	0.006	0.006		Y	Y	Y
	5	0.0111	0.0111	0.0111	0.0111	Y	Y	Y	0.0111	0.0111	0.0111	Y	Y	Y	0.0111	0.0111	0.0111		Y	Y	Y
	7.5	0.0081	0.0081	0.0081	0.0081	Y	Y	Y	0.0081	0.0081	0.0081	Y	Y	Y	0.0081	0.0081	0.0081		Y	Y	Y
	10	0.0027	0.0027	0.0027	0.0027	Y	Y	Y	0.0027	0.0027	0.0027	Y	Y	Y	0.0027	0.0027	0.0027		Y	Y	Y
	12.5	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	Y	Y	Y	0.0009	0.0009	0.0009		Y	Y	Y
	15	0.0003	0.0003	0.0003	0.0003	N	Y	N	0	0.0003	0	Y	Y	Y	0.0003	0.0003	0.0003		Y	Y	Y
	30	0.00003	0.00003	0.00003	0.00003	N	Y	N	0	0.00003	0	Y	Y	Y	0.00003	0.00003	0.00003		Y	Y	Y
>=35	0	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006		Y	Y	Y
	2.5	0.004	0.004	0.004	0.004	Y	Y	Y	0.004	0.004	0.004	Y	Y	Y	0.004	0.004	0.004		Y	Y	Y
	5	0.0074	0.0074	0.0074	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	Y	Y	Y	0.0074	0.0074	0.0074		Y	Y	Y
	7.5	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	Y	Y	Y	0.0054	0.0054	0.0054		Y	Y	Y
	10	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018		Y	Y	Y
	12.5	0.0006	0.0006	0.0006	0.0006	N	Y	N	0	0.0006	0	Y	Y	Y	0.0006	0.0006	0.0006		Y	Y	Y
	15	0.0002	0.0002	0.0002	0.0002	N	Y	N	0	0.0002	0	Y	Y	Y	0.0002	0.0002	0.0002		Y	Y	Y
	30	0.00002	0.00002	0.00002	0.00002	N	Y	N	0	0.00902	0	Y	Y	Y	0.00002	0.00002	0.00002		Y	Y	Y
	Probability	1.0000	1.0000	1.0000	1.0000				0.9981	1	0.9981				1.0000	1.0000	1.0000				
			Sys 2 - Effectiveness LOOSE L:						Sys 1 - Effectiveness AVE L :						Sys 1 - Effectiveness QUART L.						

TEMP	WIND	Prob. Of Occurrence from graphs	Pass or Fail - System 2 (S/W=Qrt) Door Force	Velocity with 0.01m2	Both	Prob of Success - System 1 (S/W=Qrt) Door Force	Velocity with 0.01m2	Both	Prob of Success - System 2 (S/W=Qrt) Door Force	Velocity with 0.01m2	Both	Pass or Fail - System 1 (S/W=Qrt) Door Force	Velocity with 0.06m2	Both	Prob of Success - System 1 (S/W=Qrt) Door Force	Velocity with 0.06m2	Both	Pass or Fail - System 1 (S/W=Half) Door Force	Velocity with 0.01m2	Both
5	0	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	N	N	0.0006	0	0	Y	N	N
	2.5	0.004	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	N	N	0.004	0	0	Y	N	N
	5	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	N	N	0.0074	0	0	Y	Y	Y
	7.5	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	N	N	0.0054	0	0	Y	Y	Y
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	Y	Y	Y
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	Y	Y	Y
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	Y	Y	Y
	30	* 0.00002	N	Y	N	0.00002	0.00002	0.00002	0	0.00002	0	Y	Y	Y	0.00002	0.00002	0.00002	Y	Y	Y
10	0	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	N	N	0.0063	0	0	Y	N	N
	2.5	0.042	Y	Y	Y	0.042	0.042	0.042	0.042	0.042	0.042	Y	N	N	0.042	0	0	Y	N	N
	5	0.0777	Y	Y	Y	0.0777	0.0777	0.0777	0.0777	0.0777	0.0777	Y	N	N	0.0777	0	0	Y	Y	Y
	7.5	0.0567	Y	Y	Y	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	Y	N	N	0.0567	0	0	Y	Y	Y
	10	0.0189	Y	Y	Y	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	Y	Y	Y	0.0189	0.0189	0.0189	Y	Y	Y
	12.5	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	Y	Y	Y
	15	0.0021	Y	Y	Y	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	Y	Y	Y	0.0021	0.0021	0.0021	Y	Y	Y
	30	* 0.00021	N	Y	N	0.00021	0.00021	0.00021	0	0.00021	0	Y	Y	Y	0.00021	0.00021	0.00021	Y	Y	Y
15	0	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	N	N	0.0123	0	0	Y	N	N
	2.5	0.082	Y	Y	Y	0.082	0.082	0.082	0.082	0.082	0.082	Y	N	N	0.082	0	0	Y	N	N
	5	0.1517	Y	Y	Y	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	Y	N	N	0.1517	0	0	Y	Y	Y
	7.5	0.1107	Y	Y	Y	0.1107	0.1107	0.1107	0.1107	0.1107	0.1107	Y	Y	Y	0.1107	0.1107	0.1107	Y	Y	Y
	10	0.0369	Y	Y	Y	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	Y	Y	Y	0.0369	0.0369	0.0369	Y	Y	Y
	12.5	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	Y	Y	Y
	15	0.0041	Y	Y	Y	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	Y	Y	Y	0.0041	0.0041	0.0041	Y	Y	Y
	30	* 0.00041	Y	Y	Y	0.00041	0.00041	0.00041	0.00041	0.00041	0.00041	Y	Y	Y	0.00041	0.00041	0.00041	Y	Y	Y
20	0	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	N	N	0.0069	0	0	Y	N	N
	2.5	0.046	Y	Y	Y	0.046	0.046	0.046	0.046	0.046	0.046	Y	N	N	0.046	0	0	Y	Y	Y
	5	0.0851	Y	Y	Y	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	Y	N	N	0.0851	0	0	Y	Y	Y
	7.5	0.0621	Y	Y	Y	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	Y	Y	Y	0.0621	0.0621	0.0621	Y	Y	Y
	10	0.0207	Y	Y	Y	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	Y	Y	Y	0.0207	0.0207	0.0207	Y	Y	Y
	12.5	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	Y	Y	Y
	15	0.0023	Y	Y	Y	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	Y	Y	Y	0.0023	0.0023	0.0023	Y	Y	Y
	30	* 0.00023	Y	Y	Y	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	Y	Y	Y	0.00023	0.00023	0.00023	Y	Y	Y
25	0	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	N	N	0.0024	0	0	Y	N	N
	2.5	0.016	Y	Y	Y	0.016	0.016	0.016	0.016	0.016	0.016	Y	N	N	0.016	0	0	Y	Y	Y
	5	0.0296	Y	Y	Y	0.0296	0.0296	0.0296	0.0296	0.0296	0.0296	Y	N	N	0.0296	0	0	Y	Y	Y
	7.5	0.0216	Y	Y	Y	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	Y	Y	Y	0.0216	0.0216	0.0216	Y	Y	Y
	10	0.0072	Y	Y	Y	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	Y	Y	Y	0.0072	0.0072	0.0072	Y	Y	Y
	12.5	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	Y	Y	Y
	15	0.0008	Y	Y	Y	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	Y	Y	Y	0.0008	0.0008	0.0008	Y	Y	Y
	30	* 0.00008	Y	Y	Y	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	Y	Y	Y	0.00008	0.00008	0.00008	Y	Y	Y
30	0	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	N	N	0.0009	0	0	Y	Y	Y

	2.5	0.006	Y	Y	Y	0.006	0.006	0.006	0.006	0.006	0.006	Y	N	N	0.006	0	0	Y	Y	Y
	5	0.0111	Y	Y	Y	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	Y	N	N	0.0111	0	0	Y	Y	Y
	7.5	0.0081	Y	Y	Y	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	Y	Y	Y	0.0081	0.0081	0.0081	Y	Y	Y
	10	0.0027	Y	Y	Y	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	Y	Y	Y	0.0027	0.0027	0.0027	Y	Y	Y
	12.5	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	Y	Y	Y
	15	0.0003	Y	Y	Y	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	Y	Y	Y	0.0003	0.0003	0.0003	Y	Y	Y
	30	0.00003	Y	Y	Y	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	Y	Y	Y	0.00003	0.00003	0.00003	Y	Y	Y
>=35	0	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	N	N	0.0006	0	0	Y	Y	Y
	2.5	0.004	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	N	N	0.004	0	0	Y	Y	Y
	5	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	N	N	0.0074	0	0	Y	Y	Y
	7.5	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	Y	Y	Y
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	Y	Y	Y
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	Y	Y	Y
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	Y	Y	Y
	30	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	Y	Y	Y
	Probability	**1.0000**				1.0000	1.0000	**1.0000**	1.0000	1.0000	**1.0000**				1.0000	0.3379	**0.3379**			
						Sys 1 - Effectiveness with S/w QrtL:			Sys 2 - Effectiveness with S/w QrtL						Sys 1 - Effectiveness with S/w QrtL					

TEMP	WIND	Prob. Of Occurrence from graphs	Pass or Fail - System 2 (S/W=Half) Door Force	Velocity with 0.01m2	Both	Prob of Success - System 1 (S/W=Half) Door Force	Velocity with 0.01m2	Both	Prob of Success - System 2 (S/W=Half) Door Force	Velocity with 0.01m2	Both	Pass or Fail - System 1 (S/W=Half) Door Force	Velocity with 0.06m2	Both	Prob of Success - System 1(S/W=Half) Door Force	Velocity with 0.06m2	Both	Pass or Fail - System 1(S/W=Loose) Door Force	Velocity with 0.01m2	Both
5	0	0.0006	Y	N	N	0.0006	0	0	0.0006	0	0	Y	N	N	0.0006	0	0	Y	N	N
	2.5	0.004	Y	N	N	0.004	0	0	0.004	0	0	Y	N	N	0.004	0	0	Y	N	N
	5	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	N	N	0.0074	0	0	Y	N	N
	7.5	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	N	N	0.0054	0	0	Y	N	N
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	Y	Y	Y
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	Y	Y	Y
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	Y	Y	Y
	30	0.00002	N	Y	Y	0.00002	0.00002	0.00002	0	0.00002	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	Y	Y	Y
10	0	0.0063	Y	N	N	0.0063	0	0	0.0063	0	0	Y	N	N	0.0063	0	0	Y	N	N
	2.5	0.042	Y	N	N	0.042	0	0	0.042	0	0	Y	N	N	0.042	0	0	Y	N	N
	5	0.0777	Y	Y	Y	0.0777	0.0777	0.0777	0.0777	0.0777	0.0777	Y	N	N	0.0777	0	0	Y	N	N
	7.5	0.0567	Y	Y	Y	0.0567	0.0567	0.0567	0.0567	0.0567	0.0567	Y	N	N	0.0567	0	0	Y	N	N
	10	0.0189	Y	Y	Y	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	Y	Y	Y	0.0189	0.0189	0.0189	Y	Y	Y
	12.5	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	Y	Y	Y
	15	0.0021	Y	Y	Y	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	Y	Y	Y	0.0021	0.0021	0.0021	Y	Y	Y
	30	0.00021	Y	Y	Y	0.00021	0.00021	0.00021	0.00021	0.00021	0.00021	Y	Y	Y	0.00021	0.00021	0.00021	Y	Y	Y
15	0	0.0123	Y	N	N	0.0123	0	0	0.0123	0	0	Y	N	N	0.0123	0	0	Y	N	N
	2.5	0.082	Y	N	N	0.082	0	0	0.082	0	0	Y	N	N	0.082	0	0	Y	N	N
	5	0.1517	Y	Y	Y	0.1517	0.1517	0.1517	0.1517	0.1517	0.1517	Y	N	N	0.1517	0	0	Y	N	N
	7.5	0.1107	Y	Y	Y	0.1107	0.1107	0.1107	0.1107	0.1107	0.1107	Y	N	N	0.1107	0	0	Y	N	N
	10	0.0369	Y	Y	Y	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	Y	Y	Y	0.0369	0.0369	0.0369	Y	Y	Y
	12.5	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	Y	Y	Y
	15	0.0041	Y	Y	Y	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	Y	Y	Y	0.0041	0.0041	0.0041	Y	Y	Y
	30	0.00041	Y	Y	Y	0.00041	0.00041	0.00041	0.00041	0.00041	0.00041	Y	Y	Y	0.00041	0.00041	0.00041	Y	Y	Y
20	0	0.0069	Y	N	N	0.0069	0	0	0.0069	0	0	Y	N	N	0.0069	0	0	Y	N	N
	2.5	0.046	Y	Y	Y	0.046	0.046	0.046	0.046	0.046	0.046	Y	N	N	0.046	0	0	Y	N	N
	5	0.0851	Y	Y	Y	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	Y	N	N	0.0851	0	0	Y	N	N
	7.5	0.0621	Y	Y	Y	0.0621	0.0621	0.0621	0.0621	0.0621	0.0621	Y	N	N	0.0621	0	0	Y	N	N
	10	0.0207	Y	Y	Y	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	Y	Y	Y	0.0207	0.0207	0.0207	Y	Y	Y
	12.5	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	Y	Y	Y
	15	0.0023	Y	Y	Y	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	Y	Y	Y	0.0023	0.0023	0.0023	Y	Y	Y
	30	0.00023	Y	Y	Y	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	Y	Y	Y	0.00023	0.00023	0.00023	Y	Y	Y
25	0	0.0024	Y	N	N	0.0024	0	0	0.0024	0	0	Y	N	N	0.0024	0	0	Y	N	N
	2.5	0.016	Y	Y	Y	0.016	0.016	0.016	0.016	0.016	0.016	Y	N	N	0.016	0	0	Y	N	N
	5	0.0296	Y	Y	Y	0.0296	0.0296	0.0296	0.0296	0.0296	0.0296	Y	N	N	0.0296	0	0	Y	N	N
	7.5	0.0216	Y	Y	Y	0.0216	0.0216	0.0216	0.0216	0.0216	0.0216	Y	N	N	0.0216	0	0	Y	N	N
	10	0.0072	Y	Y	Y	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	Y	Y	Y	0.0072	0.0072	0.0072	Y	Y	Y
	12.5	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	Y	Y	Y
	15	0.0008	Y	Y	Y	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	Y	Y	Y	0.0008	0.0008	0.0008	Y	Y	Y
	30	0.00008	Y	Y	Y	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	Y	Y	Y	0.00008	0.00008	0.00008	Y	Y	Y

30	0	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	N	N	0.0009	0	0	Y	N	N
	2.5	0.006	Y	Y	Y	0.006	0.006	0.006	0.006	0.006	0.006	Y	N	N	0.006	0	0	Y	N	N
	5	0.0111	Y	Y	Y	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	Y	N	N	0.0111	0	0	Y	N	N
	7.5	0.0081	Y	Y	Y	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	Y	N	N	0.0081	0	0	Y	N	N
	10	0.0027	Y	Y	Y	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	Y	Y	Y	0.0027	0.0027	0.0027	Y	Y	Y
	12.5	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	Y	Y	Y
	15	0.0003	Y	Y	Y	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	Y	Y	Y	0.0003	0.0003	0.0003	Y	Y	Y
	30	0.00003	Y	Y	Y	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	Y	Y	Y	0.00003	0.00003	0.00003	Y	Y	Y
>=35	0	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	N	N	0.0006	0	0	Y	N	N
	2.5	0.004	Y	Y	Y	0.004	0.004	0.004	0.004	0.004	0.004	Y	N	N	0.004	0	0	Y	N	N
	5	0.0074	Y	Y	Y	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	Y	N	N	0.0074	0	0	Y	N	N
	7.5	0.0054	Y	Y	Y	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	Y	N	N	0.0054	0	0	Y	N	N
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	Y	Y	Y
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	Y	Y	Y
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	Y	Y	Y
	30	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	Y	Y	Y
	Probability	1.0000				1.0000	0.8435	0.8435	1.0000	0.8435	0.8435				1.0000	0.1300	0.1300			
						Sys 1 - Effectiveness S/w HalfL			Sys 2 - Effectiveness S/w HalfL						Sys 1 - Effectiveness S/w HalfL					

			Pass or Fail - System 2 (S/W=Loose)			Prob of Success - System 1 (S/W=Loose)			Prob of Success - System 2 (S/W=Loose)			Pass or Fail - System 1 (S/W=Loose)			Prob of Success - System 1 (S/W=Loose)		
TEMP	WIND	Prob. Of Occurrence from graphs	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.01m2	Both	Door Force	Velocity with 0.06m2	Both	Door Force	Velocity with 0.06m2	Both
5	0	0.0006	Y	N	N	0.0006	0	0	0.0006	0	0	Y	N	N	0.0006	0	0
	2.5	0.004	Y	N	N	0.004	0	0	0.004	0	0	Y	N	N	0.004	0	0
	5	0.0074	Y	N	N	0.0074	0	0	0.0074	0	0	Y	N	N	0.0074	0	0
	7.5	0.0054	Y	N	N	0.0054	0	0	0.0054	0	0	Y	N	N	0.0054	0	0
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	N	N	0.0018	0	0
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	0.0002	0.0002	0.0002
	30	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	Y	Y	Y	0.00002	0.00002	0.00002
10	0	0.0063	Y	N	N	0.0063	0	0	0.0063	0	0	Y	N	N	0.0063	0	0
	2.5	0.042	Y	N	N	0.042	0	0	0.042	0	0	Y	N	N	0.042	0	0
	5	0.0777	Y	N	N	0.0777	0	0	0.0777	0	0	Y	N	N	0.0777	0	0
	7.5	0.0567	Y	N	N	0.0567	0	0	0.0567	0	0	Y	N	N	0.0567	0	0
	10	0.0189	Y	Y	Y	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	Y	N	N	0.0189	0	0
	12.5	0.0063	Y	Y	Y	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	Y	Y	Y	0.0063	0.0063	0.0063
	15	0.0021	Y	Y	Y	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	Y	Y	Y	0.0021	0.0021	0.0021
	30	0.00021	Y	Y	Y	0.00021	0.00021	0.00021	0.00021	0.00021	0.00021	Y	Y	Y	0.00021	0.00021	0.00021
15	0	0.0123	Y	N	N	0.0123	0	0	0.0123	0	0	Y	N	N	0.0123	0	0
	2.5	0.082	Y	N	N	0.082	0	0	0.082	0	0	Y	N	N	0.082	0	0
	5	0.1517	Y	N	N	0.1517	0	0	0.1517	0	0	Y	N	N	0.1517	0	0
	7.5	0.1107	Y	N	N	0.1107	0	0	0.1107	0	0	Y	N	N	0.1107	0	0
	10	0.0369	Y	Y	Y	0.0369	0.0369	0.0369	0.0369	0.0369	0.0369	Y	N	N	0.0369	0	0
	12.5	0.0123	Y	Y	Y	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	Y	Y	Y	0.0123	0.0123	0.0123
	15	0.0041	Y	Y	Y	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	Y	Y	Y	0.0041	0.0041	0.0041
	30	0.00041	Y	Y	Y	0.00041	0.00041	0.00041	0.00041	0.00041	0.00041	Y	Y	Y	0.00041	0.00041	0.00041
20	0	0.0069	Y	N	N	0.0069	0	0	0.0069	0	0	Y	N	N	0.0069	0	0
	2.5	0.046	Y	N	N	0.046	0	0	0.046	0	0	Y	N	N	0.046	0	0
	5	0.0851	Y	N	N	0.0851	0	0	0.0851	0	0	Y	N	N	0.0851	0	0
	7.5	0.0621	Y	N	N	0.0621	0	0	0.0621	0	0	Y	N	N	0.0621	0	0
	10	0.0207	Y	Y	Y	0.0207	0.0207	0.0207	0.0207	0.0207	0.0207	Y	N	N	0.0207	0	0
	12.5	0.0069	Y	Y	Y	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	Y	Y	Y	0.0069	0.0069	0.0069
	15	0.0023	Y	Y	Y	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	Y	Y	Y	0.0023	0.0023	0.0023
	30	0.00023	Y	Y	Y	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	Y	Y	Y	0.00023	0.00023	0.00023
25	0	0.0024	Y	N	N	0.0024	0	0	0.0024	0	0	Y	N	N	0.0024	0	0
	2.5	0.016	Y	N	N	0.016	0	0	0.016	0	0	Y	N	N	0.016	0	0
	5	0.0296	Y	N	N	0.0296	0	0	0.0296	0	0	Y	N	N	0.0296	0	0
	7.5	0.0216	Y	N	N	0.0216	0	0	0.0216	0	0	Y	N	N	0.0216	0	0
	10	0.0072	Y	Y	Y	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	Y	N	N	0.0072	0	0
	12.5	0.0024	Y	Y	Y	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	Y	Y	Y	0.0024	0.0024	0.0024
	15	0.0008	Y	Y	Y	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	Y	Y	Y	0.0008	0.0008	0.0008
	30	0.00008	Y	Y	Y	0.00008	0.00008	0.00008	0.00008	0.00008	0.00008	Y	Y	Y	0.00008	0.00008	0.00008

30	0	0.0009	Y	N	N	0.0009	0	0	0.0009	0	0	Y	N	N	0.0009	0	0
	2.5	0.006	Y	N	N	0.006	0	0	0.006	0	0	Y	N	N	0.006	0	0
	5	0.0111	Y	N	N	0.0111	0	0	0.0111	0	0	Y	N	N	0.0111	0	0
	7.5	0.0081	Y	N	N	0.0081	0	0	0.0081	0	0	Y	N	N	0.0081	0	0
	10	0.0027	Y	Y	Y	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	Y	N	N	0.0027	0	0
	12.5	0.0009	Y	Y	Y	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	Y	Y	Y	0.0009	0.0009	0.0009
	15	0.0003	Y	Y	Y	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	Y	Y	Y	0.0003	0.0003	0.0003
	30	0.00003	Y	Y	Y	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	Y	Y	Y	0.00003	0.00003	0.00003
>=35	0	0.0006	Y	N	N	0.0006	0	0	0.0006	0	0	Y	N	N	0.0006	0	0
	2.5	0.004	Y	N	N	0.004	0	0	0.004	0	0	Y	N	N	0.004	0	0
	5	0.0074	Y	N	N	0.0074	0	0	0.0074	0	0	Y	N	N	0.0074	0	0
	7.5	0.0054	Y	N	N	0.0054	0	0	0.0054	0	0	Y	N	N	0.0054	0	0
	10	0.0018	Y	Y	Y	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	Y	N	N	0.0018	0	0
	12.5	0.0006	Y	Y	Y	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	Y	Y	Y	0.0006	0.0006	0.0006
	15	0.0002	Y	Y	Y	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Y	Y	Y	0.0002	0.0002	0.0002
	30	0.00002	Y	Y	Y	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	Y	Y	Y	0.00002	0.00002	0.00002
	Probability	**1.0000**				1.0000	0.1300	**0.1300**	1.0000	0.1300	**0.1300**				1.0000	0.0400	**0.0400**
						Sys 1 - Effectiveness S/w LooseL:			Sys 2 - Effectiveness S/w LooseL						Sys 1 - Effectiveness S/w LooseL		

Appendix N Leakage Calculations for Sensitivity Study

Detailed below are the calculations used for the varied building and stairwell leakages, as part of the sensitivity study. Using the 'Average' leakage values and knowing what the 'Loose'[71] values were (refer to Table K1 of Appendix K), the 'Quart', 'Half' and '3Quart' Leakier values were calculated, where:

- 'Quart' refers to 25% of the difference in value between 'Average' and 'Loose' leakage,
- 'Half' refers to 50% of the difference in value between 'Average' and 'Loose' leakage, and
- '3Quart' refers to 75% of the difference in value between 'Average' and 'Loose' leakage.

For example:

Table N1. Data for Sensitivity Study for Leakage

Element	Average Leakage Coefficient	Loose (100%) Leakage Coefficient	Difference between Average and Loose
Façade Walls	0.17×10^{-3}	0.35×10^{-3}	1.8×10^{-4}
Stair Walls/Stair Roof	0.11×10^{-3}	0.35×10^{-3}	2.4×10^{-4}
Floor	0.52×10^{-4}	0.17×10^{-3}	1.18×10^{-4}

Using the 'Difference' column in Table N1 and the façade wall element, 25% of the Difference value was added to the 'Average' value:

$$\begin{aligned}\text{Quart Coefficient} &= \text{Average Leakage} + (25\% x 1.8 x 10^{-4})\\ &= 0.17 x 10^{-3} + 4.5 x 10^{-5}\\ &= 2.15 x 10^{-4}\end{aligned}$$

And similarly for the 'Half' and '3Quart' values:

$$\begin{aligned}\text{Half Coefficient} &= \text{Average Leakage} + (50\% x 1.8 x 10^{-4})\\ &= 0.17 x 10^{-3} + 9 x 10^{-5}\\ &= 2.6 x 10^{-4}\end{aligned}$$

[71] Note: 'Loose' also refers to 100% leakage, i.e. maximum leakage, where the wording may be used interchangeably.

$$\begin{aligned}\text{3Quart Coefficient} &= \text{Average Leakage} + (75\% x 1.8 x 10^{-4})\\ &= 0.17 x 10^{-3} + 1.35 x 10^{-4}\\ &= 3.05 x 10^{-4}\end{aligned}$$

This process was continued throughout for the *stair* and *floor* elements (in Table N1), until all the coefficients were calculated, as presented in Table 20 of the thesis.

Appendix O Leakage Variations for 'Selected' Components

Assuming only one floor of the building eg. L5 (with all stairwell doors closed), and assessing the available leakage paths through the walls of one of the stairwells versus the main building façade elements, we have:

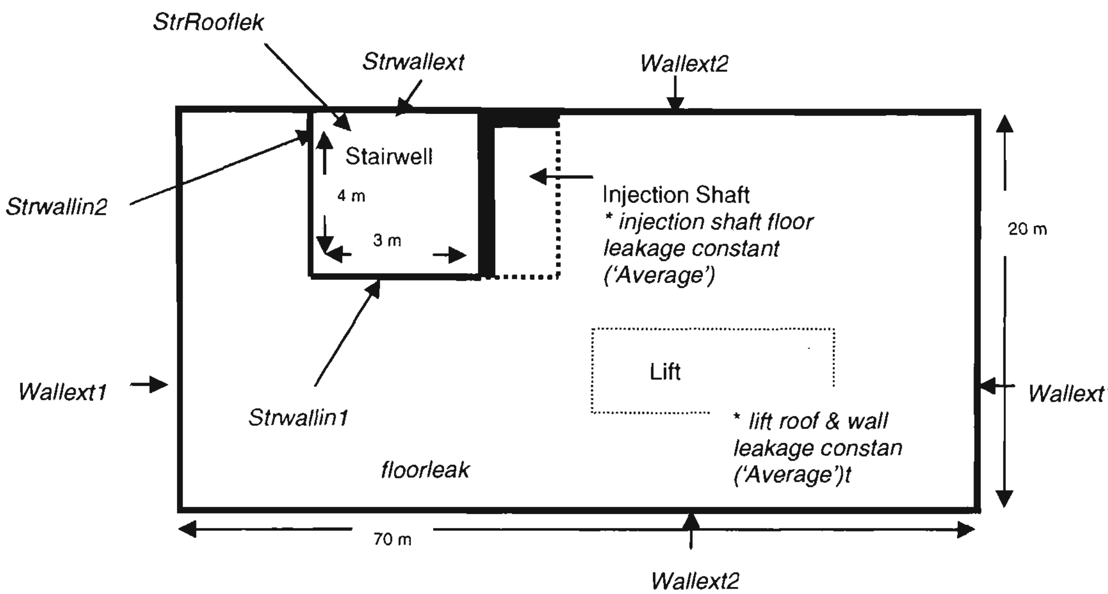

Figure O1. L5 Leakage Areas, not to scale (stairwell in green)

Notes:

1. For Figure O1 above, when the leakage values were increased only the values associated with the stairwell walls in green, were changed, as the assessment assumed there was no leakage between the stairwell wall and the adjacent injection shaft (see thickest lines in Figure O1 above).
2. The external stairwell wall (i.e. to the outside of the building) is part of the building's external construction and therefore, if the outside main building façade leakage changes, so too does the external wall of the stairwell (i.e. Strwallext).

<u>**Average Leakage Areas**</u>**:** **Stairwell**

Stwallin1 (x1side) → $0.11x10^{-3}x3x3.8 = 0.001254\ m^2$

Stwallin2 (x1 side) → $0.11x10^{-3}x4x3.8 = 0.001672\ m^2$

Door Leakage (closed) → $(0.00305x2)\ m^2 + (0.00636x2)\ m^2$

Adding the areas we get: **0.021746 m²**

Average Leakage Areas: **Main Building Façade**

Wallext1 (x2 sides) → $0.17x10^{-3}x20x3.8 = 0.01292\ m^2 x2$

Wallext2 (x2 sides) → $0.17x10^{-3}x70x3.8 = 0.04522\ m^2 x2$

Stwallext1 (x1 side) → $0.11x10^{-3}x3x3.8 = 0.001254\ m^2$

Adding the areas we get: **0.117534 m²**

Where the ratio between the 'Average' main building façade and one of the stairwells is:

$$\frac{\text{Main Building Facade}}{\text{Stairwell}} = \frac{0.117534\ m^2}{0.021746\ m^2}$$
$$= 5.4$$

i.e. approximately 1/5th. The stairwell leakage is approximately 1/5th of the main building façade leakage when both are at 'Average' leakage conditions.

Various other leakage combinations were assessed and as calculated below (where 1000% Leakage refers to the leakage being 1000 times leakier than the 'Average' leakage values used):

1000% Leakier Areas: **Stairwell**

Stwallin1 (x1 side) → $0.11x10^{-3}x1000x3x3.8 = 1.254\ m^2$

Stwallin2 (x1 side) → $0.11x10^{-3}x1000x4x3.8 = 1.672\ m^2$

Door Leakage (closed) → $(0.00305x2)\ m^2 + (0.00636x2)\ m^2$

Adding the areas we get: **2.94482 m²**

1000% Leakier Areas: **Main Building Façade**

Wallext1 (x2 sides) → $0.17x10^{-3}x1000x20x3.8 = 12.92\ m^2 x2$

Wallext2 (x2 sides) → $0.17x10^{-3}x1000x70x3.8 = 45.22\ m^2 x2$

Stwallext1 (x1 side) → $0.11x10^{-3}x1000x3x3.8 = 1.254\ m^2$

Adding the areas we get: **117.534 m²**

Loose (100% Leakier) Areas: **Stairwell**

Stwallin1 (x1 side) → $0.35x10^{-3}x3x3.8 = 3.99x10^{-3}\ m^2$

Stwallin2 (x1 side) → $0.35x10^{-3}x4x3.8 = 5.32x10^{-3}\ m^2$

Door Leakage (closed) → $(0.00305x2)\,m^2 + (0.00636x2)\,m^2$

Adding the areas we get: **0.02813 m^2**

Loose (100% Leakier) Areas: **Main Building Façade**

Wallext1 (x2 sides) → $0.35x10^{-3}x20x3.8 = 0.0266\ m^2x2$

Wallext2 (x2 sides) → $0.35x10^{-3}x70x3.8 = 0.0931\,m^2x2$

Stwallext1 (x1 side) → $0.35x10^{-3}x3x3.8 = 3.99x10^{-3}\ m^2$

Adding the areas we get: **0.24339 m^2**

Half (50% Leakier) Areas: **Stairwell**

Stwallin1 (x1 side) → $2.3x10^{-4}x3x3.8 = 2.622x10^{-3}\ m^2$

Stwallin2 (x1 side) → $2.3x10^{-4}x4x3.8 = 3.496x10^{-3}\ m^2$

Door Leakage (closed) → $(0.00305x2)\,m^2 + (0.00636x2)\,m^2$

Adding the areas we get: **0.024938 m^2**

Half (50% Leakier) Areas: **Main Building Façade**

Wallext1 (x2 sides) → $2.6x10^{-4}x20x3.8 = 0.01976\ m^2x2$

Wallext2 (x2 sides) → $2.6x10^{-4}x70x3.8 = 0.06916\ m^2x2$

Stwallext1 (x1 side) → $2.3x10^{-4}x3x3.8 = 2.622x10^{-3}\ m^2$

Adding the areas we get: **0.180462 m^2**

Quart (25% Leakier) Areas: **Stairwell**

Stwallin1 (x1 side) → $1.7x10^{-4}x3x3.8 = 1.938x10^{-3}\ m^2$

Stwallin2 (x1 side) → $1.7x10^{-4}x4x3.8 = 2.584x10^{-3}\ m^2$

Door Leakage (closed) → $(0.00305x2)\,m^2 + (0.00636x2)\,m^2$

Adding the areas we get: **0.023342 m²**

Quart (25% Leakier) Areas: **Main Building Façade**

Wallext1 (x2 sides) → $2.15x10^{-4}x20x3.8 = 0.01634\ m^2x2$

Wallext2 (x2 sides) → $2.15x10^{-4}x70x3.8 = 0.05719\ m^2x2$

Stwallext1 (x1 side) → $1.7x10^{-4}x3x3.8 = 1.938x10^{-3}\ m^2$

Adding the areas we get: **0.148998 m²**

The leakage ratio combinations assessed and modelled using CONTAM are detailed in Table O1.

Table O1. Leakage Ratio Combinations

Main Building Façade Leakage	Stairwell Wall Leakage	~ Ratio (Main Building Façade/ Stairwell)
Average Leakage	Average Leakage	5
1000% Leakier than 'Average' Leakage	Average Leakage	5,400
Average Leakage	Loose (100% Leakier)	4
Loose (100% Leakier)	Average Leakage	11
Average Leakage	1000% Leakier than 'Average' Leakage	0.04
Average Leakage	Half (50% Leakier)	5
Average Leakage	Quart (25% Leakier)	5

Appendix P Survey Results (including mean calculations and Gate-by-Gate Analysis)

Following is a copy of the survey and the raw data obtained from the industry survey participants.

QUESTIONNAIRE – Stair Pressurisation Systems (SPS) *Purge/Shutdown systems*

Section A POWER

A1. **Please nominate (tick) the power supplies, which are connected to the following for a general SPS:**

Item	MAINS	BATTERIES	GENERATOR	Other (please state)
FIP (fire indicator panel)	12	9	3 (+1 if avail/specified)	battery backup
SPF (stair pressurisation fan)	11		4 (essential power) (+1 if avail/specified)	
MSSB (mechanical services switch board for SPFs)	8		4 (+1 if avail/specified)	
VSD (variable speed drive)	11		5 (if avail) (+1 if avail/specified)	
Pressure Sensors (in stairwells, on bypass fans, etc)	10	UPS?	4	24V, maybe pneumatic, control circuit

A2a. **Is it normal to undertake steps to check other forms of power supply (eg. batter., etc) work?** Y x7 Nx5

If Y, what steps do you take? eg. how do you know that the batteries work? Generator tests, battery test buttons or switch off A/C power for short time while metering batteries, only if there are issues, load testingx2, operate with mains power isolated (check functions only)

For how long do you test the other forms of power supply? 120, variesx2, 60, as required minutes

When do you take these steps? Annuallyx2, as stipulated by Australian Standards/reg'n/owner's requirements x2, monthly, prior to testing, routine maintenance (monthly-1/4ly), at initial test if required, 3monthly or 6monthly

A2b. **For the Items listed in A1 above, please state what the secondary power supplies are (i.e. other than mains supply) AND if you test the items using only the secondary power supplies.**

Please also indicate the frequency that this might be done. Eg. if doing 100 checks of FIPs, how many times out of the 100 checks would the operation of the FIP be checked with secondary power sources <u>only</u>? and similarly for each of the other elements of hardware.

Note: If there is no secondary power supply for the Item, please write NA

Item	What is the Secondary Power Supply?	Tested using Secondary Power? (Y / N)	Frequency (out of 100 checks)	Tested • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm) i.e. AS1851.6, • other? (please state)
FIP (fire indicator panel)	Battery x 4, essential, Gen x 2	Y x 5	Annually, 20, 10, 99, 0	Rm x 5, bc, c
SPF (stair pressurisation fan)	Gen x4, essential,	Y x 4	20, 10, 0, annual, 25	Rm x 5, bc, c, annual test
MSSB (mechanical services switch board for SPFs)	Gen x3, essential,	Y x 4	20, 10, 25, 0	Rm x 5 (3times a yr), bc, c, annual test
VSD (variable speed drive)	Gen x4, essential,	Y x 4	20, 10, 0, monthly, 25	Rm x 5, bc, c, as part of SPF
Pressure Sensors (in stairwells, on bypass fans, etc)	Gen x3	Yx2	20, 25, 0	Rmx3, bc, c, as part of SPF

A3. Have you come across batteries being connected in reverse? Y N x10 (fire contractorx2)

If Y, out of 100 checks, how many times would this occur? ***eg. if checking 100 batteries how many times would the wires be reversed?***

Section B COMPONENTS

WIRING/CABLING

B1. **Do you come across loose wiring?** Y x8 N x 3

B2. **Indicate what the loose wiring is associated with, the frequency of occurrence AND when it's identified. Once again, frequency should be understood as follows:**

- **out of 100 checks of the wiring of FIPs, how many of these checks would identify loose wiring during routine maintenance? during commissioning? etc;**
- **in the case of SPFs, if you checked 100 SPFs, how many of these 100 checks would have loose wiring?, etc**

Note: If fault is identified during more than one testing routine, indicate frequency for each
Call separate trades as required (c and rm)

Wiring fault1 associated with ...	**Y / N**	**Frequency (out of 100 cases)**	**Identified** • after installation (before commissioning) (bc), • during commissioning (c), • during routine maintenance (rm) i.e. AS1851.6, • by others (bo), • other? (please state)
FIP (fire indicator panel)	Y x 7	5, 2, 2, 1, 10, 60, 2	Rm x3, bc, c
SPF (stair pressurisation fan)	Y x3	3, 50, 2	Rm x2, c
MSSB (mechanical services switch board for SPFs)	Y x8	2, 4, 2, 5, 10, 2, 80, 1	Rm x4, cx2 (b/c of moveable devices), bc
VSD (variable speed drive)	Y x6	1, 5, 5, 10, 2, 15	Rm x5, cx2 (internal failure of printed circuits)
Smoke/other detector	Y x2	2, 5, 5, 2	Rm x2, c
Other? (please state) DDC	Y	30-40	Rm x2 Rm x1 (poor terminations, all joins are possible failure points eg. screws)

RELAYS

B3. **Do you come across faulty[72] relays?** Y x 11 N x 1

B4. **Indicate what the faulty[1] relay is associated with, the frequency of identification AND when it is identified. If not applicable then write N/A.**

Note: If fault is identified during more than one testing routine, indicate frequency for each Very rare

[72] Faulty – this term refers to the item not working as designed to work.

Relay fault1 associated with ...	Y / N	Frequency (out of 100 cases)	Identified • after installation (before commissioning) (bc), • during commissioning (c), • during routine maintenance (rm) i.e. AS1851.6, • by others (bo), • other? (please state)
FIP (fire indicator panel)	Yx8	2, 2, 4, 4, 2, 1, 30, 10	Rm x4, relays not faulty only logic, t, cx2
SPF (stair pressurisation fan)	Yx3	1, 1, 30, 10	Rare, rm, c
MSSB (mechanical services switch board for SPFs)	Yx9	3, 2, 10, 1, 50 10, 80, 2	Rm x5, cx2
VSD (variable speed drive)	Yx2	1, 10	C
Other? (please state) DDC	Y	30-40	Rm (output modules)

PRESSURE SENSORS

B5. Do you come across faulty[1] pressure sensors? Y x 10 N x2

B6. In the following table, please note the frequency you would come across the following faults[1] associated with pressure sensors (given stable external conditions, eg. not windy, etc).

The above frequency should be interpreted as follows, Given 100 checks of transducers, estimate the number of times incorrect sensors have been identified?, blocked tubing has been identified?, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks there were no faults with the pressure sensor), then the number given against each possible fault listed in the table, should add up to the fault estimate in the shaded box. eg. for this example that would be 10.

Note: If fault is identified during more than one testing routine, indicate frequency for each

Fault[1] with pressure sensor	Frequency	Identified • after installation (before commissioning) (bc), • during commissioning (c), • during routine maintenance (rm) i.e. AS1851.6, • by others (bo), • other? (please state)
Incorrect pressure sensor installed (eg. out of range, low pressure sensitivity)	5, 1, 4, 2, 5, 3, 50, 30, 5	Rmx4, c, not capable of total fan disc static, bc
Blocked tubing	2, 2, 2, 10, 5, 0, 2, 10	Rmx2, usual after painting, holes not tagged in stair, because
Electrical malfunction	3, 4, 1, 5, 10, 10, 2, 10, 5	rm x5, bc
Supply voltage applied to output	4, 2, 0	Rm
Pressure reading not stable, non repetitive (*)	1, 2, 15, 15, 0, 10, 15	Rmx3, c
Calibration shift due to overpressure	10, 10, 5, 0	C
Differential pressure location not established/incorrect	8, 5, 2, 4, 1, 5, 17, 30, 50	Rm x5, c, bc (sensor located in wrong part of stair)
All of the above	Yes	
Other? (please state)	10	Rm
Total Fault *estimate* out of 100 cases	19%, 6%, 14%, 43%, 30%, 30%, 56%, 80%, 75%	

B7. **What would happen to the operation of the SPS if the faulty[1] pressure sensor was not detected/repaired?** not function to spec x4, operate at wrong pressure or not respond to airflow changes x2, door pulls too high stopping use as escape pathx2, test fails, no control set point, depends on fault eg. won't start or will start and it's not controllable, SPF doesn't achieve required airflow velocity, door-opening force

B8. (*) **Where 'non-repetitiveness' of the pressure sensor is an issue, does this cause a problem in relation to 'telling' the bypass/relief dampers to drive open/close?** Y x 6 N x1

If Y, Why?If N, Why? system operation not reliable, stair pressure too high or dampers not closing fully to achieve max airflow thru doors, if goes out of range - damper may overreact or not react enough, if pressure inside stairwell isn't stable then no part of test will be stable/repeatable, Y = VSD controlled fan or electrical controlled fan (won't be reliable operation b/c of inconsistency in response), damper or VSD output is erratic so performance of SPF is erratic

<u>DAMPERS</u> for Stair Pressurisation Systems (SPSs) only (i.e. not referring to dampers associated with a ZSCS)

B9. **Do you come across faulty[1]dampers in SPS's?** Y x 11 N x1

B10. **In the following table, please estimate the number of times (out of checking dampers 100 times) that you would come across the following faults[1] associated with dampers, also state the type of damper, its use (i.e. relief in stairwell or bypass for SPF) AND when the fault[1] is usually identified.**

The above frequency estimate should be interpreted as follows, Given 100 checks of dampers, estimate the number of times the damper does not close (more) when required?, the damper is jammed?, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks there were no faults with the pressure sensor), then the number given against each possible fault listed in the table, should add up to the fault estimate in the shaded box. eg. for this example that would be 10

Note: If fault is identified during more than one testing routine, indicate frequency for each

Fault[1] with damper	**Type of damper eg. barometric - weight adjusted (W), pneumatic (P) or electric motor (E)**	**Use of damper eg. relief (R) or fan bypass (F)**	**Frequency**	**Identified** • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm), i.e. AS1851.6; • testing (t), • by others (bo), • other?
Damper does not *close* (more) when required	E x 5, w x4, Px2	R x6, Fx4	20, 20, 15, 0, 10, 20	Rm x 7, c x3, t
Damper does not *open* (more) when required	E x 5, wx3, P	R x5, Fx4	15, 1, 15, 20	Rm x 5, c, t
Damper jammed/sticking	E x 5, W x7, Px2 Y	R x8, Fx3 Y	5, 10, 10, 10, 15, 20, 13, 20, 20, 10	Rm x 10, bc, t, c
Damper not operational because of actuator fault[1]	E x 8, P x4	R x7, F x6	10, 5, 5, 5, 1, 8, 2, 20	Rm x 8, bc, cx2, t
Damper does not open because installed motor has insufficient torque	E x 5	Rx2, Fx4	5, 5, 1, 1, 0	Cx2, bc, Rmx3, t
Damper weights need adjusting	E x 2, W x6	R x8, Fx3	5, 15, 15, 15, 20, 10	Cx2, Rm x5, t
Other? Wiring	E	R, F	10	rm
	Total Fault *estimate* out of 100 cases		50%, 20%, 20%, 40%, 48%, 44%, 45%, 70%, 80%, 10%	

B11. What would happen to the operation of the SPS if the faulty[1] damper/s was/were not detected/repaired?

Poor performance and not to code x4, overpressure or inadequate airflow x 2, lose control of pressurisation, doesn't pressurise as designed x2, test fails – Pressurisation would be too high if damper shut and too low if damper open x2, SPF would not achieve required performance – doorway airflow velocity or door opening force

SPFs

B12. **Do you come across faulty[1] SPFs?** Y x8 N x 4

B13. **In the following table, please estimate the number of times (out of 100 checks of SPFs) you would come across the following faults[1] associated with the SPF not operating when required.**

The above frequency estimate should be interpreted as follows, Given 100 checks of the SPFs, estimate the number of times the SPFs have broken blades?, the MSSB switch for the SPF has been isolated?, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks of the SPFs there were no faults with the SPF), then the number given against each possible fault listed in the table, should add up to the fault estimate in the shaded box. eg. for this example that would be 10.

Note: If fault is identified during more than one testing routine, indicate frequency for each

SPF does not work because	**Frequency**	**Identified** • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm), i.e. AS1851.6; • testing (t), • by others (bo), • other?
Broken fan blades	0, 0, 1, 0, 5, 0	Rm
MSSB has isolated the SPF to be off, so fan doesn't run	1, 1, 2, 1, rare, 1, 0, 10, 10	Rm x6, tx2, c
FFCP (fire fan control panel) has overridden the SPF to off/stop, so fan doesn't run	0, 1, 1, rare, 0, 0	Rm x3, t, c
Keylock switch (i.e. isolator switch) at SPF is off, so fan doesn't run	0, 0, 2, 0, 2, 30, 0	Rmx2
Power failure to SPF (note type of power)	0, 1, 1, 2, 2, 40, 0	Mainsx3, rmx3 blown fusesx2
SPS with VSDs and the VSD is faulty[1] (eg. not sending correct signal to SPF, so fan speed's not correct)	0, 1, 5, 1, 50, 4, 20, 20, 10	Rm x6, t, c
Slipped fan belts	0, 0, 2, 0, 0	Rm
SPF's shaft/keyway sheared	0, 0, 1, 0, 0	Rm
SPF's discharge damper/bypass damper closed (when should be open)	2, 0, 10, 1, 10, 2, 2, 15	Rm x5, t, c
Other?	75	Poor design, incorrectly located sensors, inadequate fan sizing, leaky shaft, leaky doors, etc
Total Fault *estimate* out of 100 cases	6/%, 1%, 17%, 11%, 60%, 9%, 41%, 100%, 100%	

<u>FIPs</u>

B14. **Do you come across faulty[1] FIPs?** Y x 9 N x2

B15. **In the following table, please estimate the number of times (out of 100 checks of FIPs) you would come across the following faults[1] associated with FIPs.**

The above frequency estimate should be interpreted as follows, Given 100 checks of the FIPs, estimate the number of times the FIPs have faulty[1]microprocessors?, no power to the FIP?, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks of the FIPs there were no faults with the FIP), then the number given against each possible fault listed in the table, should add up to the fault estimate in the shaded box. eg. for this example that would be 10.

Note: If fault is identified during more than one testing routine, indicate frequency for each

FIP does not work because	**Frequency**	**Identified** • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm), i.e. AS1851.6; • testing (t), • by others (bo), • other?
Microprocessor inside FIP does not work	2, 2, 5, 5, 15, 0, 10	Rm x 5, tx2, bo, cx2
FIP's program has changed since commissioning	3, 10, 5, 10, 1, 40, 40, 10	Rm x 6, tx2, cx2
No power to FIP	0, 1, 1, 10	Rm, c
Other? (please state) faulty override switch board faults water damage	1 10 1	rm bo rm
Total Fault *estimate* out of 100 cases	5%, 12%, 11%, 16%, 10%, 3%, 55%, 40%, 30%	

B16. **What would happen to the operation of the SPS if the faulty[1] FIP were not detected/repaired?**

Fan doesn't work x6 (no signal to HLI), depends on fault but system won't perform as expectedx2, fans may not initiate an alarm signal x2 (1668 & controls), failure

<u>UNIMODS/HLIs</u> (high level interface)

Function: *To provide an interface between the FIP and the incoming alarm/device signal. It is a 'translater' so that the FIP can 'see' the incoming alarm, in order to interpret what to do. It can also have pre-programmed functions.*

B17. **What power supplies (eg. mains, batteries, generator, other) normally power a Unimod/HLI?** All of above, mains x1, powered through FIP – mains/battery x3, essential mains x2, generator

B18. Can a Unimod/HLI become 'de-programmed'? i.e. lose its programming Y x3 N x 2

N = program contained in FIP's programming

If Y, How? not sure - memory held in eeprom, card shorted out/corroded, interference/power disruption, lose of power

DAMPER MOTORS/ACTUATORS

Function: *Can be either electrical or pneumatic in nature. Based on a signal from a pressure sensor, a relief damper (or fan bypass damper) is 'told' to open or close (more) via the operation of the actuator/motor.*

B19. In the table below, state whether or not the following are problems (also add to the list, if possible), when these problems are identified AND the frequency of occurrence out of 100 cases.

The above frequency estimate should be interpreted as follows, Given 100 checks of the Damper Motors/Actuators, estimate the number of times the Damper Motors/Actuators have motors running backwards?, fuses incorrectly installed?, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks of the Damper Motors/Actuators there were no faults with the Damper Motors/Actuators), then the number given against each possible fault listed in the table, should add up to the fault estimate in the shaded box. eg. for this example that would be 10.

Note: If fault is identified during more than one testing routine, indicate frequency for each

Damper/Actuator does not work because	**Motor Type eg. electrical (E) or pneumatic (P)**	**Frequency**	**Identified** • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm), i.e. AS1851.6; • testing (t), • by others (bo), • other?
Motor runs backwards	E x 8, P	1, 5, 2, 2, 2, 1, 15, 0, 50, 0	Rm x 5, cx2, bcx2, t
Fuses incorrectly installed	E x4, P	1, 2, 0, 5, 0	Rm x3, bcx2, c
Incorrect Fuses	E x5, P	2, 2, 1, 0, 5, 0	Rm x3, bcx2, c
Actuator mechanism has not been correctly adjusted	E x8, Px3 Y	10, 2, 2, 10, 1, 40, 5, 5, 30, 25	Rm x6, bcx2, t, c
Other? (please state) Seized damper No control signal Actuation time too slow, actuation at fault due to control fault	E x1 Y	2 5 75	Rm x 2 Bc
	Total Fault *estimate* out of 100 cases	**14%, 5%, 6%, 4%, 16%, 3%, 55%, 10%, 65%, 30%, 100%**	

<u>VSDs</u>

Function: *Provides power to the SPF to either ramp up (increase fan speed), ramp down (reduce fan speed) or stay at set speed.*

B20. **It is understood that the new VSDs need to have their input cables separated from the output cables because of the associated interference. Is this true?** Y x 8 N Don't know (x 2) - depends on manufacturer x2

B21. **Out of 100 checks of the VSDs, how many times would you come across this interference?** 1%x3, 5%, rare, 50%, (old site pre 2000, all of the time)

B22. **When would this type of fault[1] be identified*? i.e. by others, during routine maintenance, testing, commissioning, after installation (before commissioning), other?*** Commissioning x5, all of above x2, when it does not control, after installation, routine maintenancex2, testing after upgrade

B23. **In the following table, please estimate the number of times (out of 100 checks of VSDs) you would come across the following faults[1] associated with VSDs AND when they would be identified?**

The above frequency estimate should be interpreted as follows, Given 100 checks of the VSDs, estimate the number of times the VSDs have been mis-programmed/programmes altered?, faulty microprocessors?, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks of the VSDs there were no faults with the VSDs), then the number given against each possible fault listed in the table, should add up to the fault estimate in the shaded box. eg. for this example that would be 10.

Note: If fault is identified during more than one testing routine, indicate frequency for each

Find that when VSD has 'no power' in normal mode the programme reverts to default when powered up once a year. Can be a problem on certain model drives.

Fault[1] with VSD	**Frequency**	**Identified** • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm), i.e. AS1851.6; • testing (t), • by others (bo), • other?
Algorithm mis-programmed/altered in VSD	1, 5, 15, 30, 0, 10, 5	Rm x3, cx2, bc, t
Power failure to VSD (note type of power)	0, 0, 2, 1 (mains), 5, 5, 0	Rm, c
Microprocessor fault[1] with VSD	1, 0, 2, 2, 1, 3, 3, 5, 5	Rm x 3, c
Relays/contacts not operational in VSD	0, 0, 3, 5, 0	Rmx2, t, c
VSD faults[1] due to humidity of environment	0, 0, 1, 0, 70	Rm
VSD faults[1] due to high temperature environment	0, 0, 1, 0, 0	Rm
Other? Ramping time inappropriate Max speed limited	20	
Total Fault *estimate* out of 100 cases	**2%, 5%, 2%, 4%, 15%, 4%, 33%, 8%, 25%, 100%**	

B24. What would happen to the operation of the SPS if the faulty[1] VSD were not detected/repaired?

not operate as required x 8, may not bypass safeties in fire mode, SPS would not perform at required airflow/response time/door force

B25. Please list any problems you have encountered with VSDs:

- **during Commissioning?** Not properly commissioned for fire mode and AS1668 compliance, undersized for fan installedx2 and control not wired to correct terminals, faulty VSDs, incompatible BMS interface, no power, controls not working, op. parameter not setup/not setup correctly, incorrect speed limit (upper or lower) and incorrect ramping time to full speed
- **during Routine Maintenance?** Often when VSDs are replaced, different model/style used, sometimes wiring is altered or run modes accidentally lost/changed, fault trip, PLC cards have burned out, wiring sheared or disconnected and built up of dirt, fire signal not given to VSD and safety trips still active in fire mode and incorrect perimeters, blown units, non operation in fire mode/ramping time drifted/auto safety still in circuit/speed no longer correct, had 1.4 VSDs fail in 100 inspections.
- **Other?** Wrong VSD installed now b/c of bypass/lockout/safeties

<u>**DOORS**</u>

B26. Do you come across faulty[1] stairwell doors? Y x 11 N x1

B27. **In the following table, please estimate the number of times (out of 100 checks on the stairwell doors) you would come across the following faults[1] associated with stairwell doors AND when it would be identified?**

The above frequency estimate should be interpreted as follows, Given 100 checks of the stairwell doors, estimate the number of times these doors have been poorly fitted, have had faulty door closure devices, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks of the stairwell doors there were no faults with these doors), then the number given against each possible fault listed in the table, should add up to this fault estimate in the shaded box. eg. for this example that would be 10.

Note: If fault is identified during more than one testing routine, indicate frequency for each

Fault[1] with stairwell doors	**Frequency**	**Identified** • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm), i.e. AS1851.6; • testing (t), • by others (bo), • other?
Poorly fitted doors i.e. rubbing against door frame	10, 20, 10, 3, 0, 20, 1, 1, 0	Rmx4, c
Faulty[1] door closure device	10, 15, 20, 30, 15, 5, 5, 10, 13, 5, 4, 25	Cx2, rm x8, t
Door forces too high because of external environmental conditions (**)	10, 2, 20, 10, 0, 0, 3, 5, 3	C, rm x 6
Other? Faulty door hardware (strikes, handles, latches) Damaged Locked Gap too large under door	 15, 30 20 10, 10 5	Rm, bo Rm Rm T, c, rm rm
Total Fault *estimate* out of 100 cases	**20%, 57%, 80%, 50%, 55%, 8%, 5%, 27%, 15%, 8%**	

28. (**) **How do you know the door forces are too high because of external environmental conditions?**

Measurements, assumption based on previous experiments/results and observation of ambient conditions, Return Air on floor too high – press diff in stair high, visible

Never come across external problems – but control and building operational issues eg. SAF not supplying enough and SFs drawing insufficient or excess air (building (internal) pressure has large influence over the success of the test)

A test and operating the door *normally*, air intake on wrong side of building or on <u>one</u> side of building only. Door test results and observations outside

Section C COMMISSIONING

C1. **During commissioning Stair Pressurisation System (SPS) with VSD controlled SPFs, is it reasonable to assume that when all the stairwell doors are closed (i.e. maximum pressure in the stairwell), that the SPF's low speed setting is 30% of the maximum VSD fan setting? (i.e. doors can be opened in the stairwell)?** Y x3 N x 5

If N, what figure should be considered to be reasonable? Varies from stairwell to stairwell x4, depends on fan volumes, usually set to 20Pa in stairs, 5% min and 100 % max

C2. **How often out of 100 Commissioning cases) would you have to install a bigger relief grille/vent in the stair shaft (as a form of over pressure relief) than originally anticipated by the designer?** eg. for a SPS without a VSD some should have but never done – fan usually repatched, 20, 5, rare, never

C3. **Is it normal to fill out commissioning worksheets?** Y x 9 N

If Y, could you please provide a copy of the blank worksheet (and attach it)? Y x3 N x1

Standard NEBB sheet, see AS1668.1

C4. **In your experience (of 100 cases), if you Do Not commission a SPS, how often would the following items pass (i.e. in accordance with AS1668.1 and AS1851.6)?**

Eg. if doing 100 checks of SPS, how many times out of 100 would a Non-Commissioned SPS have door forces less than 110N?, velocities greater than 1ms?, and then similarly for each of the other elements listed below. All systems must be commissioned, variable (for all listed below), (we test during maintenance and assume all are commissioned)

Item	Frequency (out of 100 cases)
Door forces less than 110N	80, variable, 0, 30, 25, (20 est), 0
Airflow velocity at door greater than 1 m/s	30, variable, 0, 20, 25, (10 est), 0
Noise measurements within limits of AS1668.1	90, variable, 50, 5-10, 80, (10 est), 0
Restoration times within limits of AS1668.1	90, variable, 0, 30, 20, (1 est), 0
Manual fan override controls work	100, variable, 0, 5 (FFCP), (10 est), 0

C5. **Please list what might not work correctly on a day after installation of the SPS, but before commissioning?** door forces (high/low)x2, air velocities x3, restoration times, sensors, variable speed controllers, pressurisation, temp control, initiations, electrical interface not configured correctly, all of above (i.e. in C4), damper motor travel incorrect, VSD max/min speed incorrect, control pressure limits incorrect, pressure sensor in wrong place, controls not calibrated, door closers too strong, outlet grille needs re-balancing, set points

C6. **Do you measure and record external temperatures and wind speeds as part of Commissioning?** Yx1 Nx7 Not usually – unless readings are affected x2

If Y, what do you measure/record? Wind speeds, external temperatures but yes, if extremely windy or bleak day

C7. **Do you measure and record external environmental conditions as part of routine maint.?** Y Nx7

If Y, what do you measure/record?

Section D OTHER

D1. **How often (out of 100 cases) would you come across the following: when AND what effect would it have on the SPS's performance?**

The above frequency should be interpreted as follows, Given 100 checks of SPSs, estimate the number of times additional holes/leakages have developed in the stair shaft?, the stairwell has been tighter in construction than originally anticipated by the designer?, etc and place this number in the shaded box.

Eg. if the total fault number estimated is 10 (that means that on 90 occasions out of 100 checks there were no faults with the SPS as defined in the table below), then the number given against each possible fault listed in the table, should add up to the fault estimate in the shaded box. eg. for this example that would be 10.

Note: If fault is identified during more than one testing routine, indicate frequency for each

Item	**Frequency (out of 100 cases)**	**Identified** • after installation (before commissioning) (bc), • commissioning (c), • during routine maintenance (rm), i.e. AS1851.6; • testing (t), • by others (bo), • other?	**Effect on SPS performance?**
Additional holes/leakages in stair shaft	5, 2, 10, 2, 4, 10, 0, 20, 20, 15, 2	bc x2, c x3, rmx6, tx2 *- shear bolt hole into lift shaft*	Can't meet perform. With respect to press and flow x 2, failure, min, not able to meet KPIs, inadequate airflow velocity
Pressure too high in stairwell, tight stairwell	20, 5, 5, 15, 10	*- tenancy carpet fitted and no clearance under doors*, rmx3, but **o/c?** with VSD	Door opening force excessive
Relief on occupied floors blocked/restricted	50, 30, 1, 40, 5, 20, 20, 25, 6	Rm x7, tx2, *tenancy glass doors fitted*	Failure, profound, not able to meet KPIs, inadequate airflow velocities
Building itself, is too leaky for SPS	2, 5, 0, 10, 0	Rm x3, t	failure
Total Fault estimate out of 100 cases		5%, 80%, 12%, 55%, 10%, 40%, 40%, 55%, 18%	

D2. **In your experience, please describe the most reliable SPS you have come across and its components? eg. it has a VSD, supply air shaft, multiple injection, etc. Please attach extra paper if required.**

Consider 'reliable' in terms of maintenance, operation, etc.

1. VSD + supply air shaft + multiple injection + unitory controller
2. Barometric (due to lack of parts i.e. very little to go wrong), only problem is after time they tend too jam and need to be lubricated/adjusted. Also, need to be sized and positioned correctly (set and forget!).
3. Single speed axial fan supply ducted to grilles on each floor landing & balanced + barometric relief grille near fan to correct size (happened once – simple system).
4. Renaissance House – supply air shaft + SPF + exhaust fans (full 1668 controls initiated from FIP)
5. Reasonably tight stairwell + good door closing +VSD on fans +multiple injection and building system in correct mode under fire control (I believe that sandwich systems have too much complexity and too many moving parts to be a fail safe reliable system)
6. VSD (set at min speed to hold 25-30 Pa with all doors closed, thereby stopping 'hunting' of VSD in doors closed situation, i.e. stable system) + even air injection to stair + stair pressure set to 20Pa
7. Torn between barometric (70% and KISS) and motorised/electric dampers; VSD is a complicated device in terms of programming, as there are many VSDs on the market, maintenance personnel need to be competent in working with VDS equipment
8. VSD – 1 fan up to 8 levels and 2 fans 9-30 levels; Stair Pressurisation shaft desirable above 30 levels

THE END

& THANK YOU AGAIN FOR YOUR TIME

As seen from the survey answers on the preceding pages, each question has numerous responses. In order to actually use the information obtained from the industry respondents, the mean was calculated for each survey answer using all of the data for the specific question. As some questions had 'extreme' results compared with the other respondents who answered the question, another calculation was performed for each question, where the 'extreme' data was ignored, in order to avoid any bias.

Below is an example of how these mean results and the results ignoring the 'extreme' data were calculated.

Failure Rate Calculation (Mean)

Referring to Question B13. in the survey, we have the following 'industry' results for:

MSSB has isolated the SPF to be off

'industry' results (out of 100): 1, 1, 2, 1, 1, 0, 10, 10

Therefore, using all the data, the mean is calculated as:

$$\mu = \frac{n_1 + n_2 + \ldots}{n_n} \qquad \text{Equation P1}$$

where:

μ = mean

n_n = number of data points

Therefore, we have

$$\mu = \frac{1+1+2+1+1+0+10+10}{8}$$

$$\mu = \frac{26}{8}$$

$$\mu = 3.25$$

So, if the mean is 3.25; out of 100 cases (as stipulated in the question), we have a probability of failure of 0.0325 (rounded up to 0.033). This data is illustrated in light blue in Figure 47.

Ignoring the extreme 'industry' data results, i.e. data points which are approximately ten times greater or less than the highest or lowest 'industry' result, respectively, we have a modified mean of:

$$\mu = \frac{1+1+2+1+1+0}{6}$$

$$\mu = \frac{6}{6}$$

$$\mu = 1$$

So, if the modified mean is 1, out of 100 cases (as stipulated in the question), we have a probability of failure of 0.01. This data is illustrated in orange brackets in Figure 47.

In order to calculate the various 'OR' and 'AND' gate branches presented in the fault tree diagram (Figure 47), the Gate-by-Gate technique was used, whereby the following formulae were adopted.

Gate-by-Gate technique to Calculate Failure Probabilities along the Fault Tree Branches

OR gate: **P_A OR P_B**

$$P(A\ OR\ B) = 1-(1-P_A)(1-P_B) \quad \text{Equation P2}$$

$$= P_A + P_B - P_AP_B$$

$$= P_A + P_B$$

AND gate: **P_A AND P_B**

$$P(A\ AND\ B) = P_AP_B \quad \text{Equation P3}$$

Examples:

Referring to Figure 47, to calculate id box 9. we have an 'OR' gate made up of boxes 23., 24., 25. and 26. where the probability of failure using all the mean data is 0.144, 0.2, 0.1, 0.072, respectively. Using Equation P2 we have:

Probability of failure for id box 9. (using all data):

P9. →

$$P(23.\ OR\ 24.\ OR\ 25.\ OR\ 26.) = 1-(1-P_{23.})(1-P_{24.})(1-P_{25.})(1-P_{26.})$$

$$= 1-(1-0.144)(1-0.2)(1-0.1)(1-0.072)$$

$$= 0.428$$

Referring to Figure 47 as an example, to calculate id box 38. we have an 'AND' gate made up of id boxes 40. and 41. where the probability of failure using all the mean data is 0.066 and 0.026, respectively. Using Equation P3 we have:

Probability of failure for id box 38. (using all data):

P38. →

$$P(40.\ AND\ 41.) = P_{40.}P_{41.}$$

$$= 0.066 \times 0.026$$

$$= 0.002$$

However, if the extreme data results were not used, the probability of failure for id box 40. would be 0.01, not 0.06.

Probability of failure for id box 38 (ignoring extreme data):

$$\textbf{P38.} \rightarrow \quad P(40.\text{ AND } 41.) = P_{40.}P_{41.}$$

$$= 0.01 \times 0.026$$

$$= 0.0003$$

This methodology was then continued for all of the branches of the fault tree. Refer to the following spreadsheet for the probability of failure for the various branches.

Colour Codes:

All means from questionnaire $\boxed{}$ = calculated data from other loops

Removed extremes

Calc Baro Calc. up from means — No loop 28. (refurbs blocking reliefs)

Calc Motor Calc. up from means — No loop 28. (refurbs blocking reliefs) with BD cal'd up

System 2: No loop 8.(no excessive supply from SPF) & using BD data cal'd up

No loop 9. (no door force probs) & BD using data from quest., calc'd up

No loop 12. (no restricted pressure relief) & BD cal'd up

No loop 13. (no loop 42 or 43)

No loop 8. Using all data

System 1: **VSD & No Dampers i.e. fixed opening using means**

VSD & No Dampers i.e. fixed opening-not with extremes using means

No loop 8. (no excessive supply from SPF)

No loop 9. (no door faults)

No loop 12. (no restricted pressure relief)

No loop 14. (no 56, 63, 64) i.e. no VSD

No loop 62. (no FIP microprocessor output errors)

No loop 28. (refurbs blocking reliefs)

No loop 59. (pressure sensor output not in error)

Data From References:

Power 1 = 0.0002935(1) Failure Rate Estimate for Equipment Used in AOTC Critical Load Centers, George Cerward, May 1992

Power 2 = 0.02628(2) Lees, Volume 2, Table A9.3, pg 1007

Power 3 = 0.0264(1)

Transformer 0.00876(2)

Pr =>

OR	**12' restricted pressure relief (leading to doors)**						
27'	0.11	0.11	0.11	0.11	0.11	0.11	0.11
28'	0.2189	0.2189	0.2189	0.2189	0	0	0
30'	0.1275	0.248571	0.377501	0	0.1275	0.248571	0
Answer Pr =	**0.393456**	**0.477622**	**0.567252**	**0.304821**	0.223475	0.331228	0.110000

OR	**9' fault with door (leading to doors)**
23'	0.1443
24'	0.2
25'	0.1
26'	0.0722
Answer Pr =	**0.428379**

OR	**1' (high door forces)**											
8'	0.75	0.75	0.75	0	0	0.75	0.75	0.75	0.75	0	0.75	0.75
9'	0.428379	0.428379	0.428379	0.428379	0.428379	0	0.428379	0	0.428379	0.428379	0.428379	0.428379
12'	0.393456	**0.477622**	**0.567252**	**0.477622**	**0.304821**	**0.477622**	**0.304821**	**0.304821**	0	0.393456	0.223475	0.331228
Answer Pr =	**0.913322**	**0.925349**	**0.938158**	**0.701398**	**0.602621**	**0.869406**	**0.900655**	**0.826205**	0.857095	0.653287	**0.889030**	**0.904429**
										0.75		
										0.428379		
										0.110000		
										0.872814		

OR	**13' high pressure relief (leading to velocity)**			
31'	0.034	0.034	0.034	0.034
33'	0.1417	**0.248571**	**0.377501**	0
Answer Pr =	**0.170882**	**0.274120**	**0.398666**	**0.034000**

Block A/B

OR	**42' Baro. Damper calculated**
44a 44b'	0.1333
46a 46b'	0.133
Answer Pr =	**0.248571**

AND	**50' power failure for Motor. Damper**
53'	0.000293
54'	0.02628
Answer Pr =	**7.71E-06**

OR	**43' Motor. Damper calculated**
47a 47b'	0.0789
48a 48b'	0.1
49a 49b'	0.024
50'	7.71E-06
51a 51b'	0.190123
52a 52b'	0.05
Answer Pr =	**0.377501**

AND	**38' power failure for SPF (leading to low velocities)**	
40'	0.0657	0.01
41'	0.0264	0.0264
Answer Pr =	**0.00173**	**0.00026**

	4' high noise levels		
	18'	0.0461	0.0124
	Answer Pr =	**0.0461**	**0.0124**

OR	**5' high restoration times**						
20' is from:	46'	0.133	0	0	0	0
	47'	0	0.079	0	0	0
	56'	0	0	0.0438	0.047	0
	66'	0	0	0.0564	0.0564	0.0564
	Answer Pr =	**0.133000**	**0.079000**	**0.097730**	**0.100749**	0.056400

OR	**6' override controls not working**			
		21'	0.01	0.01
		22'	0.0461	0.0124
	Answer Pr =		**0.055639**	**0.022276**

AND	**7' secondary power failure**		
		7a'	0.02628
		7b'	0.0264
	Answer Pr =		**0.000694**

AND	72' power failure for FIP		
	75'	0.03	0.0067
	76'	0.02628	0.02628
Answer Pr =		**0.00079**	**0.000176**

	73' FIP misprogrammed (leading to FIP)
assumed to = 64	0.1106
Answer Pr =	**0.1106**

OR	62' FIP micro.output error (leading to VSD)		
	71'	0.1488	0.065
	72'	0.00079	0.00018
	73'	0.1106	0.1106
	74'	0.0809	0.0457
Answer Pr =		**0.304737**	**0.206554**

	63' VSD program changed (leading to VSD)
assumed to = 64	0.1106
Answer Pr =	**0.1106**

OR	57' (VSD micro.output error (leading to VSD)				
	62'	0.304737	0.206554	0	0.304737
	63'	0.1106	0.1106	0.1106	0
	64'	0.1106	0.1106	0.1106	0
Answer Pr =		**0.450025**	**0.372359**	[illegible]	**0.304737**

AND	**55' power failure for VSD**		
	60'	0.0186	
	61'	0.02628	
	Answer Pr =	**0.00049**	

70' transformer hardware fault, for pressure sensor (leading to VSD)		
Answer Pr =	**0.00876**	

68' power 2 fault, for pressure sensor (leading to VSD)	
Answer Pr =	**0.02628**

69' power 1 fault, for pressure sensor (leading to VSD)	
Answer Pr =	**0.000293**

OR	**67' transformer fault, for pressure sensor (leading to VSD)**		
	69'	0.000293	
	70'	**0.00876**	
	Answer Pr =	**0.00905**	

OR	**59' pressure sensor output fault (leading to VSD)**			
	65'	0.1105	0.0461	
	66'	0.0564	0.0564	
	67'	0.00905	0.00905	
	68'	0.02628	0.02628	
	Answer Pr =	**0.190123**	**0.131487**	

OR	39' VSD fault (leading to low velocities)				
55'	0.00049	0.00049	0.00049	0.00049	0.00049
56'	0.0438	0.047	0.0438	0	0.0438
57'	0.450025	0.372359	0.208968	0.304737	0.450025
59'	0.190123	0.131487	0.190123	0.190123	0
Answer Pr =	0.574305	0.480760	0.387720	0.437198	0.474371

OR	14' SPF fault (leading to low velocities)						
34'	0.0461	0.0124	0.0461	0.0124	0.0461	0.0461	0.0461
35'	0.0325	0.01	0.0325	0.0100	0.0325	0.0325	0.0325
36'	0.004	0.004	0.0040	0.0040	0.0040	0.0040	0.0040
37'	0.0486	0.0067	0.0486	0.0067	0.0486	0.0486	0.0486
38'	0.001734	0.000264	0.001734	0.000264	0.0017	0.0017	0.001734
39'	0.00000	0.00000	0.57430	0.48076	0.38772	0.43720	0.474371
Answer Pr =	0.12698	0.03297	0.62836	0.49788	0.46547	0.50866	0.54112

OR	2' low velocities										
13'	0.17088	0.17088	0.27412	0.27412	0.39867	0.034000	0.03400	0.034000	0.034000	0.034000	0.034000
14'	0.12698	0.03297	0.03297	0.12698	0.12698	0.62836	0.49788	0.46547	0.50866	0.12698	0.54112
Answer Pr =	0.27617	0.19822	0.298050	0.36629	0.47503	0.640997	0.51495	0.483644	0.525370	0.156666	0.556719

OR 0' overall chance of non-compliance with AS

	REF/ System 2				REF/ System 1	
	BD or MD- using All means	BD or MD- not with extremes	BD using data from quest., calc'd up	MD using data from quest., calc'd up	VSD & No Dampers i.e. fixed opening using means	VSD & No Dampers i.e. fixed opening-not with extremes using means
1'	0.913322	0.913322	0.925349	0.938158	0.900655	0.900655
2'	0.276167	0.198216	0.366295	0.475026	0.640997	0.514950
4'	0.0461	0.0124	0.0461	0.0461	0.0461	0.0124
5'	0.133000	0.133000	0.133000	0.079000	0.097730	0.100749
6'	0.055639	0.022276	0.055639	0.055639	0.055639	0.0223
7'	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04
Answer Pr =	0.951033	0.941859	0.963079	0.973083	0.971032	0.958187
	Using All means from contractors.	Ignoring extreme data	Using means to calc.up	Using means to calc.up	This is with VSD (its PS) and FIP, no dampers, i.e. VSD brings in errors.	Ignoring extreme data.

Deleting loops:

	REF/ System 2							REF/ System 1					
	No loop 8. & BD using data from quest., calc'd up	No loop 9. & BD using data from quest., calc'd up	No loop 13. (so no loops 42, 43) like no dampers, Using all means	No loop 8, Using means	No loop 12, and BD	No loop 28. Using means	No loop 28., and BD	No loop 8, No Dampers i.e. fixed opening using means	No loop 9, No Dampers i.e. fixed opening using means	No loop 12, No Dampers i.e. fixed opening using means	No loop 14 (so no loops 56, 63 & 64), No Dampers i.e. fixed opening using means	No loop 62, No Dampers i.e. fixed opening using means	No loop 28. Using means
1'	0.701398	0.869406	0.900655	0.653287	0.857095	0.889030	0.904429	0.602621	0.826205	0.857095	0.900655	0.900655	0.872814
2'	0.366295	0.366295	0.156666	0.276167	0.366295	0.276167	0.276167	*0.640997*	*0.640997*	*0.640997*	0.525370	0.483644	*0.640997*
4'	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461
5'	0.133000	0.133000	0.097730	0.133000	0.133000	0.133000	0.133000	0.097730	0.097730	0.097730	0.056400	0.097730	0.097730
6'	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639	0.055639
7'	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04	6.94E-04
Answer Pr =	0.852314	0.935409	0.943877	0.898901	0.958330	*0.967642*	*0.961469*	0.884128	0.949323	0.958330	*0.959948*	*0.958335*	0.962914

	REF/System 1
	No loop 59, No Dampers i.e. fixed opening using means
1'	0.900655
2'	*0.556719*
4'	0.0461
5'	0.097730
6'	0.055639
7'	0.000694
	0.964232

The probabilities of failure associated with Power 1, 2 and 3 were calculated as follow (using the previously listed reference material):

Power 1

Using a mains supply of less than 600 V, with a median failure probability of 0.0335 per million hours demand-kms, we have:

$$\text{Power 1} = \frac{0.0335}{1{,}000{,}000} \times \frac{8760\text{ hrs}}{\text{year}}$$

$$= 0.00029346$$

Power 2

Using a battery (wet), the probability that the battery will fail to provide the proper output in standby mode is $3\text{x}10^{-6}$/hr, resulting in:

$$\text{Power 2} = \frac{3\text{x}10^{-6}}{1\text{hrs}} \times \frac{8760\text{ hrs}}{\text{year}}$$

$$= 0.02628$$

Power 3

Using a standby diesel generator (with a range of 250 kW - 3.2 MW), operating 30 – 50[73] hours/year, the failure rate is 660 per million operating hours, resulting in:

$$\text{Power 3} = \frac{660}{1{,}000{,}000\text{ hrs}} \times \frac{40\text{ hrs}}{\text{year}}$$

$$= 0.0264$$

[73] Note: 40 operating hours was used for the calculation, as this is between 30 – 50 hours.