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FIRE RESPONSE OF HVAC SYSTEMS IN MULTISTOREY BUILDINGS: AN EXAMINATION OF THE NZBC ACCEPTABLE SOLUTIONS

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ABSTRACT

It is recognised that smoke is the major killer in most fires. In buildings with mechanical heating, ventilation or air conditioning (HVAC) systems the traditional reaction to a fire was to shut the HVAC system down, although in recent years some buildings have included a smoke management mode as part of their HVAC system, and/or have dedicated smoke management equipment (eg stair pressurisation).

The current Building Code Approved Documents give little guidance on the appropriate actions for HVAC systems to take in the event of a fire, and some requirements of the Acceptable Solutions are unclear. The objective stated in the Approved Documents is to avoid allowing smoke to spread to other firecells via the air conditioning system. HVAC systems can be utilised to actively manage smoke movement and can achieve this in a variety of ways.

This report attempts to provide some improvements to the Approved Documents and to give general guidelines to assist non-mechanical fire engineers and non-fire mechanical engineers in designing or specifying appropriate responses to a fire in a typical multistorey building. The report does not examine smoke control in atria or other large spaces.

The various generic classes of ventilation or air conditioning systems are described and the appropriate behaviour of each under fire conditions is discussed.

Results of some computer modelling of air (and cold smoke) flows around typical buildings are presented. The modelling indicates that the current levels at which active smoke control is invoked in the Acceptable Solutions are appropriate. It also suggests that the frequent practice of shutting off the ventilation system on a fire alarm may not be the best solution to managing smoke flows within the building.

Particular sections of the Acceptable Solutions relating to mechanical ventilation which are unclear or confusing are also discussed with suggested amendments proposed.

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Michael Dixon,
February 1999

Thought for the day:
"To steal ideas from one person is called plagiarism –
to steal from many is called research" - Anon

1. INTRODUCTION

It has long been recognised that the smoke and toxic gases produced during a fire are a frequent cause of the fatalities that occur in building fires. Often the victims are in parts of the building that are distant from the actual flaming fire, but are killed by effects of the smoke which has migrated large distances. Control of smoke movement is therefore vital to the safety of building occupants in the event of a fire.

The heating, ventilation and air conditioning (HVAC*) system can be an ideal means of transporting the smoke, either intentionally or unintentionally.

By design, the HVAC system that is installed in most commercial buildings moves large quantities of air from one part of the building to another. Air is the main constituent of smoke and so the HVAC system can also move smoke to areas far from the fire itself.

When operating as designed the HVAC can therefore be utilised to enhance the safety of the building as part of an integrated smoke management system - to remove smoke from the fire zone and discharge it safely, or to prevent smoke reaching particular areas by providing counteracting air flows. Conversely, if the behaviour of the HVAC under fire conditions is inappropriate it can add to the volume of smoke and perhaps even move it to areas where the smoke endangers the building occupants.

HVAC systems are not all alike. They come in a variety of configurations and types, and each has its own strengths and weaknesses in many aspects, including the ability to control smoke movement.

The NZ Building Code Acceptable Solutions do not specifically address the question of the behaviour of HVAC systems under fire conditions in a multi-storey building, other than to note that Australian Standard AS1668.1 is an acceptable method of compliance. A common alternative approach taken by many designers is simply to stop the HVAC system in the event of an alarm. Which action is better? Are there

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* The terms 'HVAC system' and 'Air Conditioning system' are used interchangeably in this report

circumstances where these reactions may unintentionally allow smoke to be spread around the building? This report discusses the various types of HVAC systems and the appropriate response of each type to a fire alarm.

AS1668 provides a prescriptive solution that, in the event of a fire alarm, selectively operates the HVAC plant in smoke control mode to achieve flows and pressures which actively restricts the smoke from endangering the occupied spaces. Whilst this may be an effective way of handling the problem with some types of systems, there are other HVAC system types which cannot operate effectively in a smoke control mode. There may also be solutions other than AS1668 that are equally valid under some circumstances and with some system types.

In addition, the standard is a prescriptive document which is difficult, if not impossible, to fully comply with in the case of a retrofit to an existing building and is inappropriate to some system types. An understanding of the general principles of HVAC systems and how they relate to smoke movement will assist the fire engineer in specifying appropriate reactions to a fire event.

This report looks at the types of air conditioning and ventilation systems that are typically found in New Zealand multi-storey buildings and assesses the appropriate response of the various system types to a fire event, as well as making some recommendations on aspects of specific sections of the existing Building Code Acceptable Solutions.

2. LITERATURE REVIEW

One of the performance requirements of New Zealand Building Code, clause C3 [BIA, 1995] states "*Air conditioning and mechanical ventilation systems shall be constructed to avoid circulation of smoke and fire between firecells*" (clause C3.3.7). Air conditioning system designers must therefore make conscious and informed decisions on the management of smoke from a fire and how the HVAC will affect the smoke flows within the building.

It is recognised that smoke is a major cause in fatalities in building fires. Semple [1977] reported that over 80% of fire deaths are attributed to smoke. Often the smoke migrates to areas remote from the actual source of the fire as has been well documented in the fires at the MGM Grand Hotel (1980), the Roosevelt Hotel (1963) and others [Klote & Milke, 1992], where the majority of the fatalities occurred many floors above the site of the fire and well away from the direct effect of the flames.

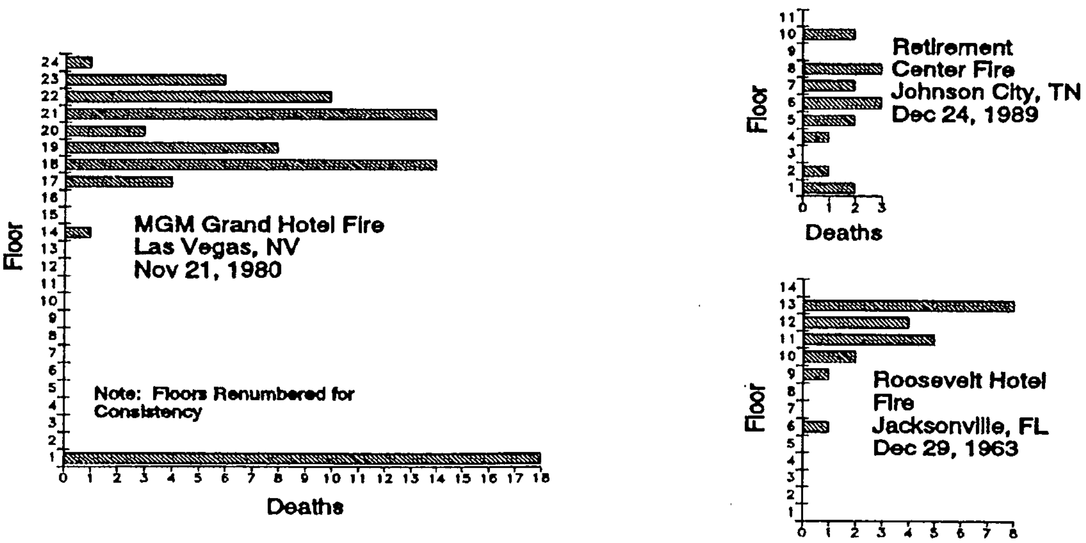

Fig 2.1, Locations of deaths on upper floors where the fire was located on floor 1*

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* Figure copyright 1992 by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Reprinted with permission from Klote & Milke, 1992.

The NZ Building Code Acceptable Solutions [BIA, 1995] include a statement that Australian Standard AS1668.1 [SAA, 1991] is an acceptable method for dealing with HVAC systems and how they should behave under fire conditions. However, the Acceptable Solutions do not make compliance with AS1668.1 mandatory and nor do they directly give any alternative means of compliance. In the USA, NFPA92A [NFPA, 1993] recommends responses which are similar in principle to the Australian Standard, although the NFPA document is not as prescriptive. There is no equivalent New Zealand standard covering the behaviour of HVAC systems. A draft joint AS/NZS standard [SAA/NZSA, 1996], based heavily on AS1668.1, was issued for public comment but was subsequently withdrawn.

The traditional reaction of the HVAC system under fire alarm conditions was to shut the system down [Klote, 1994; Klote & Clark, 1991, Chapman, 1983]. This reaction has been recommended since the 1930's with the intention of preventing the spread of smoke by the ventilation system and to stop the HVAC from feeding air to the fire. This is still the principal reaction in many buildings today. However, having the HVAC inoperative does not necessarily stop the smoke from migrating via the air duct systems to other parts of the building under the influences of stack effect, buoyancy or wind [Klote, 1988], with the stack effect being the dominant influence [Taylor, 1982].

Semple [1977] reported that all known smoke inhalation fatalities in US and Canadian high-rise buildings fitted with central plant HVAC had occurred when the HVAC system was shut down.

Klote [1993] noted that stopping the air system was in part also a reaction to a 1930's analysis that found a high proportion of building fires were located within the air systems themselves. This problem has largely been addressed by the use of components which are non-combustible or of limited combustibility (eg sheet metal ducts) but any system will contain some components which are at least in part combustible or are a source of smoke or ignition, such as electric motors, fabric air filters and insulation. There are also alternative products being introduced into the marketplace frequently which use non-traditional materials. However, any proposal to use alternative materials must recognise the consequences of potentially combustible components in an environment where the products of any fire will be rapidly spread to occupied areas.

The danger in not shutting down the HVAC is that, when operating as intended, the HVAC systems mix the air within the occupied space (which can create more smoke) and also transport large quantities of air around the building. HVAC systems can therefore easily increase the volume of smoke and/or carry it to remote parts of the building very quickly.

In the 1960's the use of pressurisation as a means of preventing smoke movement into stairways was introduced. Butcher & Parnell [1979] discussed tests carried out by the UK Fire Research Station which found that an excess pressure of 5Pa was sufficient to prevent smoke from intruding through door cracks in a stairway, and this pressure was also sufficient to stop smoke spread when the door was opened briefly (such as when it was opened to allow a person through). Further measurements on pressures due to wind effects found similar values. On the basis of these tests they recommended that pressure differentials of 25-50Pa should be used to prevent smoke movement.

In the early 1970's the concept of zoned smoke control was introduced (the "pressure sandwich") [Klote, 1994; Rye, 1984], using the HVAC to influence and control the smoke movement and overcome the natural smoke migration paths (buoyancy, wind and stack effects). The principle of operation was to make use of selective air supply and removal to create higher and lower pressure zones to contain the smoke in the region of the fire. By extracting air from the fire zone while restricting the supply path to the area, at the same time supplying air to adjacent zones, pressure differences are created at the zone boundaries which can be sufficient to prevent smoke from flowing out from the fire zone.

Taylor [1982] reports that the 'pressure sandwich' can be highly effective in limiting the movement of smoke and also protects lift shafts and stairways. It has also been reported by Semple [1977] to have contained the fire spread in an apartment fire. The concept is, however, relatively new and a consensus on "reasonable" design parameters has not been reached [Klote & Clark, 1991].

These methods of pressurisation and zone control are now regarded as part of the overall concept of a smoke management system.

The objectives of a smoke management system [Narayanan, 1996] include

- Maintaining the smoke layer interface above a particular height
- Maintaining a tenable environment in all exit access and refuge access paths for sufficient time to allow the safe evacuation of all occupants
- Limiting the spread of smoke from the fire/smoke zone into safe exit paths
- Providing adequate visibility to allow Fire Service personnel to conduct their fire fighting activities
- Exhausting accumulated smoke within a specified time
- Limiting the smoke layer temperature.

A smoke management system consists of a combination of active and passive systems which interact to achieve these objectives. A lack of understanding of this interaction can lead to excessive design or the failure of the systems to operate as intended.

Sprinklers are not an alternative to a smoke management system [Narayanan, 1993]. While sprinklers will control the fire size and hence influence the temperature and total volume of smoke released, they cannot influence the paths that the smoke will take as it moves away from the fire source.

Smoke removal (purging) alone, where air is supplied and smoke exhausted from the space containing the fire is not in itself effective in preventing smoke from being transported around the building [Klote & Budnick, 1989; Semple, 1977] unless it is also combined with pressurising of adjacent spaces. Smoke removal cannot control or extinguish the fire, however, it does remove hot gases which establish radiation feedback to the fire [Taylor, 1982].

Where the HVAC system is capable of operating in a smoke control mode, automatic initiation is regarded by Taylor [1982] as best, to gain maximum benefit as early as possible in the fire growth [Taylor, 1982; Klote & Milke, 1992].

Automatic initiation is not however universally advocated, as discussed by Chapman [1983] and there is no doubt that an incorrect or inappropriate response by the HVAC to a fire alarm signal can exacerbate the situation by unintentionally spreading smoke to other parts of the building. Manual activation by the attending Fire Service will probably be too late in the fire growth to be of use and could even spread the fire by moving combustible gases to other locations.

There is however general agreement that a manual override should be included for Fire Service use.

Where automatic initiation is used, the system designer must carefully consider what signals will be used to identify the fire location and initiate the smoke control mode. Manual call points should never be used as they may be operated far from the fire location. Similarly, Klote & Milke [1992] note that caution must be exercised if smoke detectors are used, as the smoke could have already spread some distance from the source before triggering a detector.

3. SMOKE MANAGEMENT OBJECTIVES

3.1 What is Smoke?

Smoke is defined by NFPA92A [NFPA, 1998] as airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with a quantity of air which is entrained or otherwise mixed into the mass.

The combustion products which are typically found include unburnt fuel, water vapour, carbon dioxide, carbon monoxide and other gases which may be toxic or corrosive. As the smoke moves away from the fire, air is entrained which dilutes and cools the smoke. The resulting mix is however still likely to be a hazard due to the temperature or concentration of gases. Effects on people can include the toxic effects due to the gases but also disorientation due to lack of visibility and high temperatures.

Particular fuels that are typically found in a building fire will produce their own specific combustion products. Plastics, polyurethane foams and PVC electrical insulation are found in significant quantities in any commercial or domestic occupancy and all produce quantities of various toxic substances when burnt.

Once the smoke is away from the immediate vicinity of the fire, the entrained air becomes the principal component and so for the purposes of fluid dynamic analysis of the smoke flows its physical properties may be taken as those of hot air. It should be noted, however, that the concentrations of hazardous products may still be substantial and the effects on a person may not be insignificant.

Smoke is generally thought of as being visible, but the definition above also includes invisible gases which are produced during a fire.

The temperature of the smoke will depend on a variety of factors, including the fire size, the ambient temperature, the thermal characteristics of the surrounding surfaces and how much air has been entrained. In the vicinity of the fire the smoke will be hot and will rise to form a layer below the ceiling above. As it moves away from the fire the smoke will be cooled by transfer of heat to surrounding surfaces and by dilution with cooler air.

If the hot smoke layer is above about 200°C, it is likely to be radiating sufficient heat to cause injury to persons below (the threshold is often taken as 2.5kW/m^2), even though they are not in direct contact with the smoke, and it will therefore prevent escape by any route passing below the smoke.

If the temperature is cooler, it may be possible for people to pass actually through the smoke but the ability to do so will depend on a variety of factors including the temperature, the distance to travel, the degree of visual obscuration as well as the presence of any other irritating or toxic components. Smoke above about 120°C (dry) or 100°C (humid) is probably too hot to allow passage through for any significant duration, regardless of any other factor that may be present. [Purser, 1995]

The prime objective is to prevent the escape routes becoming blocked by smoke. Evacuation of a building where the occupants pass through areas of some smoke contamination is feasible, but the conservative objective of most designers is to eliminate contact with smoke. To this end, smoke management systems usually aim to contain the smoke within the immediate zone of the fire (on the assumption that occupants in the immediate vicinity of the fire will escape early in its growth) and/or exhaust it to an area away from the building occupants.

3.2 Smoke Volumes

The volumes of smoke generated will be governed by a variety of factors, the most significant of which is the size of the fire itself. As discussed above, the smoke plume generated by the fire will contain the combustion products and also entrained air.

Smoke plume mass flows

A selection of plume flow correlations have been reported by Beyler [1986], among which there is a reasonable level of agreement. The correlations for mass flow (and hence the volume of smoke) in the plume are of the form

$$\frac{\dot{m}}{Q} = A\left(\frac{z}{Q^{2/5}}\right)^{n}$$

where $\dot{m}$ = smoke mass flow (kg/s)

z = clear height above the notional plume origin (m)

Q = fire heat release rate (kW)

A and n are constants

The correlations generally agree that the constant n has a value of 5/3, but a range of values for A are reported, from 0.066 to 0.138, with a majority favouring values around 0.08. Note that the height z is defined as being above the notional plume origin point, not above the plane of the actual fire itself. Applying the values above, the correlation reduces to

$$\dot{m} = 0.08z^{5/3}Q^{1/3}$$

A 'virtual origin' correction must be applied to the actual height which is derived from the fire diameter and heat output. The virtual origin z_o is the distance that the notional plume origin is above the actual fire location and is given by

$$z_o = -1.02D + 0.083Q^{2/5}$$

where D = fire diameter (m)

A negative value of z_o indicates the virtual origin is below the actual fire.

Buchanan [1994] also discussed a mass flow correlation from Hinkley, which (when typical ambient values are applied) reduces to

$$\dot{m} = 0.188 p Y^{3/2}$$

where p = fire perimeter (m)

Y = clear height above the fire (m)

Heskestad [1995] gives correlations for mass flow for the region below the mean flame height, as well as above the flaming region. The equations are:

(above the flame region) $\dot{m} = 0.071 Q_c^{1/3} z^{5/3} (1 + 0.027 Q_c^{2/3} z^{-5/3})$

(in flame region) $\dot{m} = 0.0056 Q_c \dfrac{z}{L}$

where Q_c = the fire convective heat release rate (kW, typically 70% of the total heat release rate)

L = flame height (m)

$= -1.02D + 0.235Q^{2/5}$

Hesestad's correlations appear to be similar to the ones used to calculate smoke plume volumes in the FPETool computer package, except for slight differences to the constants.

The three equations given above for the mass flow rates give similar results in the range of values under study here (fire diameters 1 to 3m, ceiling heights around 2.5 to 3m), as shown in figure 3.1.

Smoke plume temperatures

These mass flow rates can be converted to volume flows if the smoke temperature is known. As the smoke is mainly air, which has a density of 1.21kg/m^3 at 17°C (290K), a simple ideal gas law assumption can be used to estimate the smoke density from

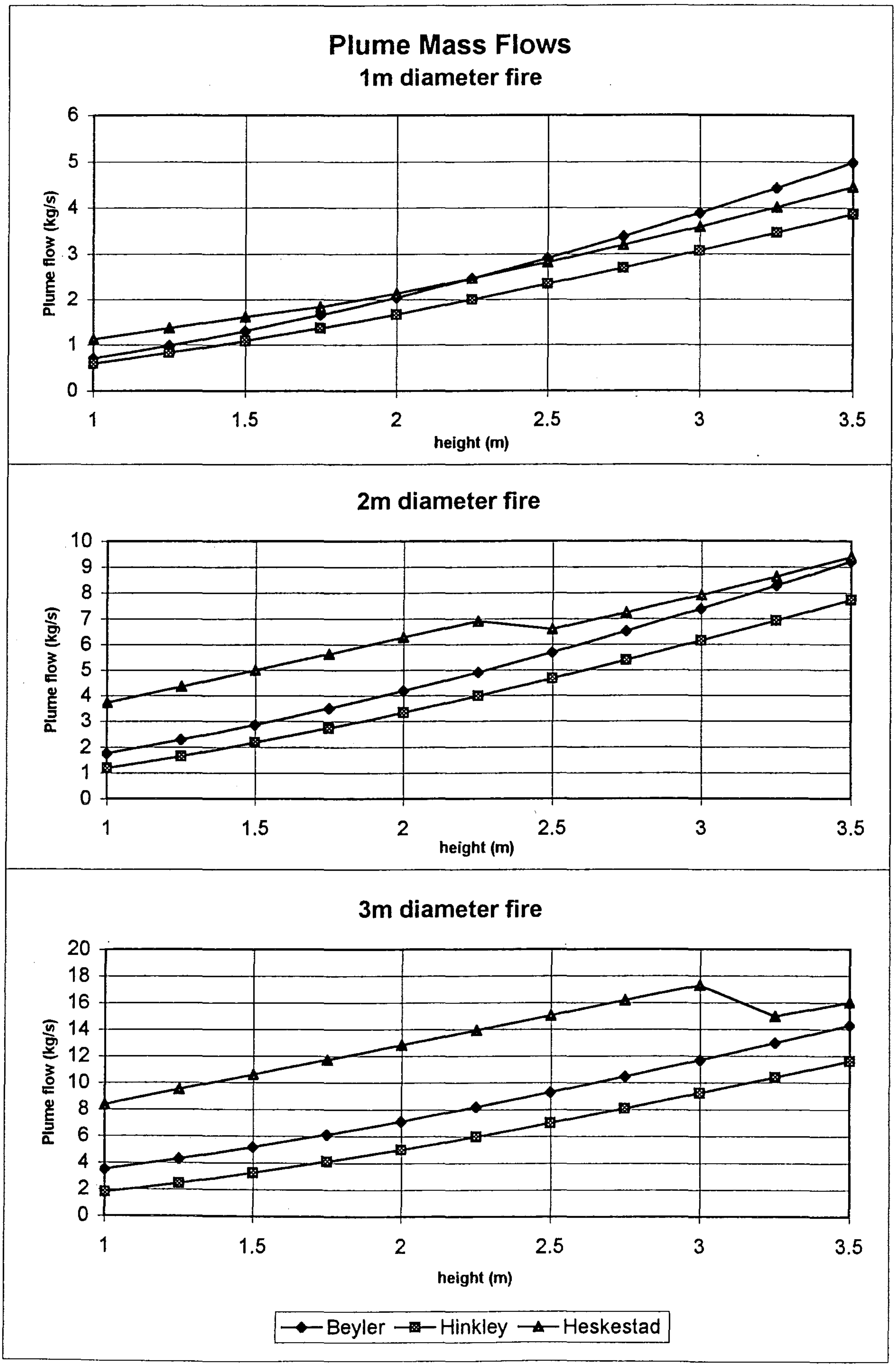

fig 3.1 - Comparison of plume mass flow correlations

$$\rho_s = 1.21\left(\frac{290}{T_s + 273}\right)$$

where T_s = smoke plume temperature (°C)

The average temperature of the smoke plume at any height can be estimated by assuming that all the heat convected away from the fire is contained within the plume, and that the plume is well mixed. From a simple heat balance, the convected heat must equal the energy in the plume fluid, ie

$$Q_c = \dot{m}c_p(T_s - T_o)$$

where c_p = specific heat of plume (kJ/kgK, assumed to be same as air)

T_o = ambient temperature (°C)

Which can be rearranged to become

$$T_s = \frac{Q_c}{\dot{m}c_p} + T_o$$

So using the equations above, the smoke volume can be calculated at a particular height above the fire for any given fire heat output.

However, for all of these calculations, an estimate must be made of the design fire size.

Design fire sizes

The fire load is not usually well defined in that the combustibles are not generally confined to specific areas but are dispersed throughout the building. This makes the estimation of an expected fire size difficult to determine with any degree of precision. However, in buildings fitted with sprinklers where the fire growth rate can be estimated (from knowledge of the typical fixtures and fittings in the occupied spaces), a calculation can be made of the fire size which will activate a sprinkler head and an assumption made that the fire will not grow any larger once the sprinkler is activated.

As an example, in a room with a 2.7m ceiling and a 3 by 4m grid of sprinklers with a response time index of 250 $(ms)^{1/2}$, the sprinklers will activate when a fast growing fire reaches about 1700kW, or about 2.1m diameter (based on a typical energy density of $0.5MW/m^2$), at which time it will be producing about 8 to $10m^3/s$ of smoke (8,000 to 10,000l/s) at temperatures of around 200 to 270°C immediately above the fire. For this design fire, the smoke control system must be designed to cope with temperatures and volumes of this magnitude. This calculation can be carried out by hand, but the more frequent approach is to use one of the commonly available computer programs such as FPETool and Fastlite to carry out these calculations.

As a comparison for this design fire size, the Acceptable Solution C3/AS1 includes design fires to be used for calculation of smoke volumes in certain sprinklered buildings containing 'intermediate floors'* where mechanical smoke control is required. Depending on the occupancy type the design fire could be either 1.5MW with a 7m perimeter (ie. 2.2m diameter and $0.38MW/m^2$), or 5MW with a 12m perimeter (3.8m diameter, 0.44 MW/m^2). Note that these values are suggested for larger spaces, such as atria, and not multistorey buildings. They are included here for comparison purposes.

An alternative for hand calculation, using the equations above, is to assume that the fire size will not grow past the point where it is controlled by the sprinklers, and therefore it's size will not exceed the sprinkler spacing (say 4.6x4.6m, for a 'extra light hazard'** occupancy). The smoke volume calculated in this scenario is over $30m^3/s$.

For unsprinklered buildings, the fire will not be controlled and will continue to grow, as will the volume of smoke produced. Any smoke control system will probably be overwhelmed quickly unless it is specifically designed for very high volumes and elevated temperatures. It is therefore important to consider the smoke control system as part of an overall fire safety strategy, not just as an isolated system.

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[*] An 'intermediate floor' is defined in the Annex to the Building Code Approved Documents as an upper floor within a firecell which is not smoke-separated from the floor(s) below. In this context it usually covers an atrium within a building.

[**] Such as an office, as defined by NZS4541:1996 "Automatic Fire Sprinkler Systems"

3.3 Leakage Paths

Knowledge of the air leakage paths that exist in any building is vital to the proper design of smoke management systems.

To a casual observer, modern buildings appear to be relatively air-tight and to some degree they are. However, glazing systems contain drainage tracks, wall construction includes building tolerances, exterior doors require operating clearances and all component assemblies contain allowances for differential thermal expansion of the various constituent parts. These otherwise insignificant gaps all allow air to pass through and can add up to substantial areas over the total building surface area.

Within the building, the possible paths for air flow are much more numerous. Lift shafts, stairways and service risers all provide direct vertical flow paths, each having one or more doorways (complete with clearance cracks) allowing access at each level. Buildings also usually have HVAC ducts running horizontally on each floor as well as vertically between floors. Floors are penetrated to allow electrical cables or plumbing to pass through.

All these gaps and cracks provide leakage paths, allowing air to pass through the building envelope or between spaces within the building. The direction of air flow will depend on the relative pressures either side of the path. The magnitude of the flow depends on both the size of the leakage path and the magnitude of the pressure differential.

The availability of air flow paths, both through the building exterior and within the building, will allow air to move around the building under the influences of the HVAC system, stack effect or wind. Similarly, smoke can move from area to area under these influences or due to the natural buoyancy of the hot gases. Conversely, smoke can be kept out by selectively forcing air into adjacent zones and utilising the leakage paths to pressurise the zones.

Little research appears to have been carried out on the amount of leakage area that is found in a typical construction. Klote [1995] quotes values for leakage areas that were measured in a relatively small number of tests carried out by the National Research Council of Canada in the 1960s and 70s, and notes that leakage areas are primarily dependent on workmanship rather than construction type.

Construction Element	Wall tightness	Area Ratio A/A_W
Exterior building walls (includes construction cracks, cracks around windows and doors)	Tight	0.70×10^{-4}
	Average	0.21×10^{-3}
	Loose	0.42×10^{-3}
	Very Loose	0.13×10^{-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}
Lift 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 areas around penetrations)	Tight	0.66×10^{-5}
	Average	0.52×10^{-4}
	Loose	0.17×10^{-3}

A = leakage area, A_W = wall area, A_F = floor area

Evaluated at 75Pa for walls and 25Pa for floors

Figure 3.2 – typical leakage areas for walls and floors of commercial buildings[*]

ASHRAE [1989] also gives data on leakage areas through particular building components.

Brundrett [1997] outlines a testing program in progress in the UK which is measuring leakage rates in a range of buildings with a view to ultimately minimising energy wastage due to infiltration. The tests are establishing leakage in terms of cubic metres per hour, per square metre of façade area at a particular pressure difference. This data could be related back to leakage areas (averaged over the whole building)

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[*] Data from Klote [1995]

but does not isolate particular components. Values reported to date are 5 to 27 $m^3/h/m^2$ at 50Pa, which equates to leakage areas of 0.24×10^{-3} to 0.13×10^{-2} m^2/m^2, falling into the 'average' to 'very loose' categories in the table above.

There does not appear to be any equivalent data available on New Zealand construction techniques.

3.4 Fires in Air Conditioning Equipment

Statistics on New Zealand fire events are kept by the NZ Fire Service for all incidents that they attend. Their publication "Emergency Incident Statistics 1993-1997" [NZFS, 1998], which covers data from their July-June reporting years, lists 48 incidents where air conditioning units were described as the source of ignition and a further 21 where the ignition source was a hot air duct or heat transfer system, out of a total of 17,292 structure fire incidents*. These combined represent only 0.4% of the total structure fires attended.

Data was obtained directly from the Fire Service on these incidents and also on others which occurred over a longer period (1991 to mid-1998). This enabled some additional analysis to be carried out, including the isolation of 14 incidents where the source of the fire was the air conditioning equipment and some smoke or flame travel had occurred via the air ducts.

Of particular note about these 14 incidents were the following statistics:

1. In no incident did the damage extend beyond the equipment that was the fire source. In 6 of these incidents the damage was described as nil.
2. In 4 incidents the fire had self-extinguished and in a further 6 the fire was extinguished by isolating the power to the equipment.

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[*] The statistics are drawn from the 241,042 incidents of all types to which the Fire Service turned out over the period, including false alarms, vehicle accidents, structure fires and non-structure fires (eg vegitation).

3. In 3 incidents the fire was described as having past the smouldering stage into a flaming fire. In one of these the fire had self-extinguished before the Fire Service arrived.
4. The causes of the fires were evenly divided between electrical short circuits, mechanical (friction) and other miscellaneous faults.

The conclusion reached from all this data is that fires due to air conditioning equipment failure are very unlikely, and those that do occur are of a relatively minor nature.

4. TYPES OF HVAC SYSTEMS

HVAC systems are intended to move high volumes of air from one part of a building to another and can therefore also move large quantities of smoke, either intentionally (to prevent it causing a hazard to the building occupants) or unintentionally (thereby creating a hazard). The flows and pressures generated by the HVAC equipment can be utilised to enhance the safety of the building by either removing smoke from the fire zone or by preventing smoke from entering the spaces where people are present.

Using the HVAC system has a major advantage over dedicated smoke management equipment in that it is operated every day and any malfunction will be noticed and rectified quickly. Plant that is tested relatively infrequently (and often in isolation and only for short periods) could have faults go unnoticed or unremedied for a considerable time. The danger with using the air conditioning equipment is that any maintenance or modifications that are carried out must fully recognise the dual role and not inadvertently bypass or defeat the emergency features.

For the purposes of this report, air conditioning and ventilation systems can be divided into two basic categories in relation to the amount of fresh (outside) air delivered to the occupied space.

(1) those that provide only the minimum fresh air to the space with the remainder being recirculated within the space, and
(2) those that provide for all the air delivered to come from outside the space.

The former category includes such systems as fan coil units, induction units, hydronic* units and split systems. They are all characterised by their recirculation of a high proportion of the air that they deliver, taking it from the occupied space and passing it through a local heating and/or cooling unit and returning it to the space, with only a minimum of fresh air added to maintain habitable conditions for the occupants. Normally, each unit serves only a single space or a small group of spaces. These systems are typical of those found in a wide range of office accommodation,

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* Sometimes known as water source heat pump (WSHP) systems

particularly in smaller buildings. The fresh air delivery is often from a separate air handling unit (perhaps just a simple fan) located remote from the occupied space and serving many or all of the units in the building. The important feature which distinguishes these systems from the second category is the minimal amount of air which is introduced from outside the space, and this volume is not usually able to be varied during normal operation.

The second category includes systems with larger air handling units which deliver all the air to the space. Systems such as variable air volume (VAV), constant volume and dual duct systems are included, which comprise large air handlers remote from the occupied spaces and a ductwork reticulation system of risers, main and runout ducts (the 'supply air' system) to distribute the air to many spaces simultaneously. The air delivered to the space is later returned to the air handler via another network of ducts (the 'return air' system). Frequently these systems are capable of delivering a mixture of fresh and recirculated air, or all fresh air to the occupied spaces.

It is not unusual for a building to contain more than one type of system, with different systems serving different parts of the building. There may be (for example) a VAV system serving the inner zones of the typical office floors, with induction units around the perimeter of the floors and fan coil units in a ground floor retail area.

Both categories are discussed in more detail below under the headings of Unitary and Central Plant systems, respectively.

The systems covered are the main categories of HVAC equipment found in New Zealand multistorey buildings. The descriptions that follow concentrate on the air handling abilities and features of the various systems, as these are the most relevant to the capabilities for smoke control. Other features are noted in general terms only, for the information of the reader.

It is worth noting that typically both categories of system operate with an excess of air supplied into the occupied space over that which is extracted. The balance migrates out of the building via minor extract systems including toilet and kitchen exhausts and also by a variety of leakage paths such as cracks around doors and windows, construction cracks and so on. This excess of supply is done deliberately to slightly pressurise the building with respect to the outside, to prevent the infiltration of unconditioned outside air.

4.1 Air delivery rates

The 'energy crisis' of the early 1970's forced air conditioning designers to consider methods to reduce the energy requirements of HVAC systems. One means was to retain the maximum conditioned air possible within the space by recirculating as much air as possible and reducing the amount of fresh air introduced. Fresh air rates were typically decreased to 5l/s per person, or 0.5l/s per square metre (floor area) or less, depending on the occupancy rate (persons per square metre)

Since then, minimum fresh air rates have been increased due to concerns such as 'sick buildings' so that they are now typically a minimum of 10l/s per person, or around 1l/s/m^2 for typical office accommodation.

The quantity of conditioned air that is supplied to a space is matched to the heating or cooling load of the equipment and people that occupy it. The air quantity that is required for this duty is normally significantly greater than the fresh air rate alone. In a normal office occupancy, air volumes of 6 to 10l/s/m^2 would be needed to match the heating/cooling load, ie 6 to 10 times more than the fresh air volume alone. Depending on the type of HVAC system, the difference could be made up from air recirculated within the space, air recirculated and diluted by a remote air handler or new air introduced from outside.

In temperate climates such as New Zealand's, one energy saving method does have a positive side effect which is useful to the fire engineer. Buildings usually have a large (in relation to the total floor plate area) central zone which contains people and equipment, all producing heat, with nowhere for this heat to be dissipated. This means that even during winter conditions the principal HVAC objective is to provide cooling. A method often utilised in central plant installations is to introduce high proportions of cold outside air as 'free cooling', with the used air being expelled from the building via the return air system. Supply of 100% fresh air is often used. The consequence in many buildings is that fans and air flow control systems are already in place which are ideally suited to the purposes of smoke control as they can move large quantities of air (or smoke) from any potential fire site.

As noted in section 3, smoke volumes produced in a sprinklered building will easily be of the order of 8000 to 10,000l/s. It follows that an air conditioning plant designed to ventilate occupied areas of at least 800 to 1000m^2 at a rate of 10l/s/m^2 may be capable of handling the volumes of smoke that could be produced. Smaller plant will likely be overwhelmed by the volumes of smoke to be handled.

4.2 Unitary Systems

4.2.1 Description of Unitary Systems

Unitary systems comprise a number of small air handlers, each located close to the area being conditioned - typically in the ceiling space above. These air handlers are fed fresh air by an external system, either passively or via a fan system, and are also supplied with their heating and/or cooling medium from outside the space. They are usually only capable of recycling the air from within the occupied space with a minimum make-up of fresh air, the balance being reconditioned within the unit before being returned to the space.

They normally contain a single fan which both supplies the air to the occupied zone and also provides the suction to return the recycled air back to the unit. The quantity of air which is not recycled is usually allowed to find its own path out of the building, via leakage around windows and doors as well as via miscellaneous extract systems such as toilet or kitchen extracts. All unitary systems operate on similar principals, with only the heating/cooling medium changing.

Most (but not all) unitary systems have electrically driven equipment contained within the unit. These can be a source of ignition if electrical faults occur.

Fan Coil Units (FCUs)

Fan coil units (fig 4.1) are probably the most common form of unitary HVAC equipment found in multistorey buildings, most frequently in smaller buildings and hotels but sometimes also found in lesser quality high-rises. They consist of a simple electrically driven fan and a heat exchanger coil, similar to a car radiator. Air is forced over the coil by the fan, while hot or cold water is circulated through the coil to heat or cool the air. Usually some form of air filtration is included.

Induction Units

These are similar to fan coil units but are of even simpler construction (fig 4.2). Instead of a fan inside the unit to circulate the air, these units are provided with a relatively high pressure air supply from a remote air handler which is ejected from nozzles within the unit. This high velocity air induces a circulation of external air through the unit which is passed over a coil in the process. These systems are now relatively uncommon in new buildings as they have a (somewhat undeserved) reputation of being noisy and expensive to operate.

It is worth noting that induction units have no electrically driven components within the unit. All the powered equipment is located in the remote air handler.

Hydronic (WSHP) Units

Hydronic units are also sometimes known as Water Source Heat Pump (WSHP) units. They are similar to fan coil units except in the manner in which they produce the heating or cooling for the air. These units contain their own refrigeration equipment which operate to provide cooling or heating directly into the coil. They require only an external source of electricity and cooling water to operate.

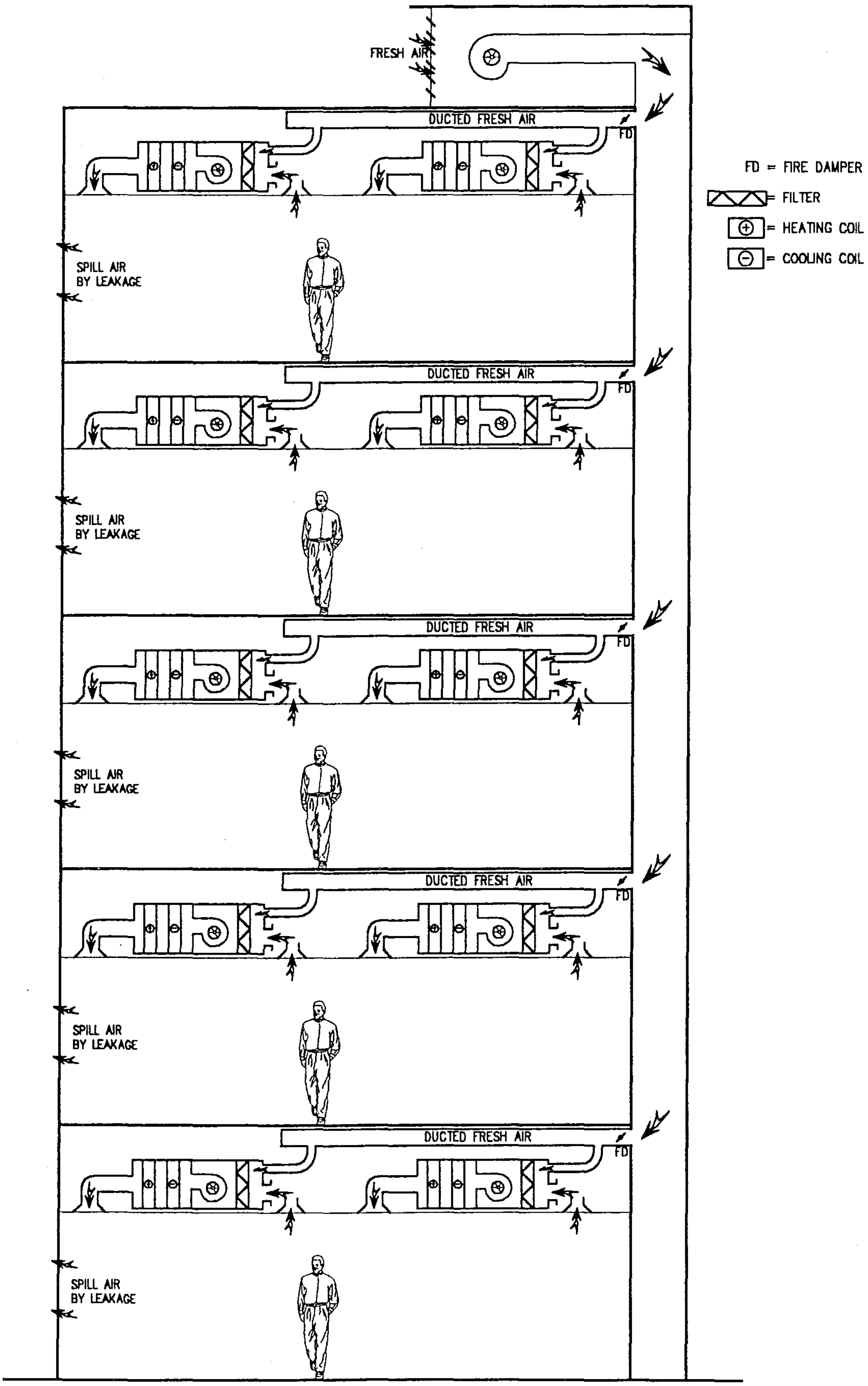

fig 4.1 Airflows for a Fan Coil Unit system
(Hydronic and Split systems similar, except for cooling source)

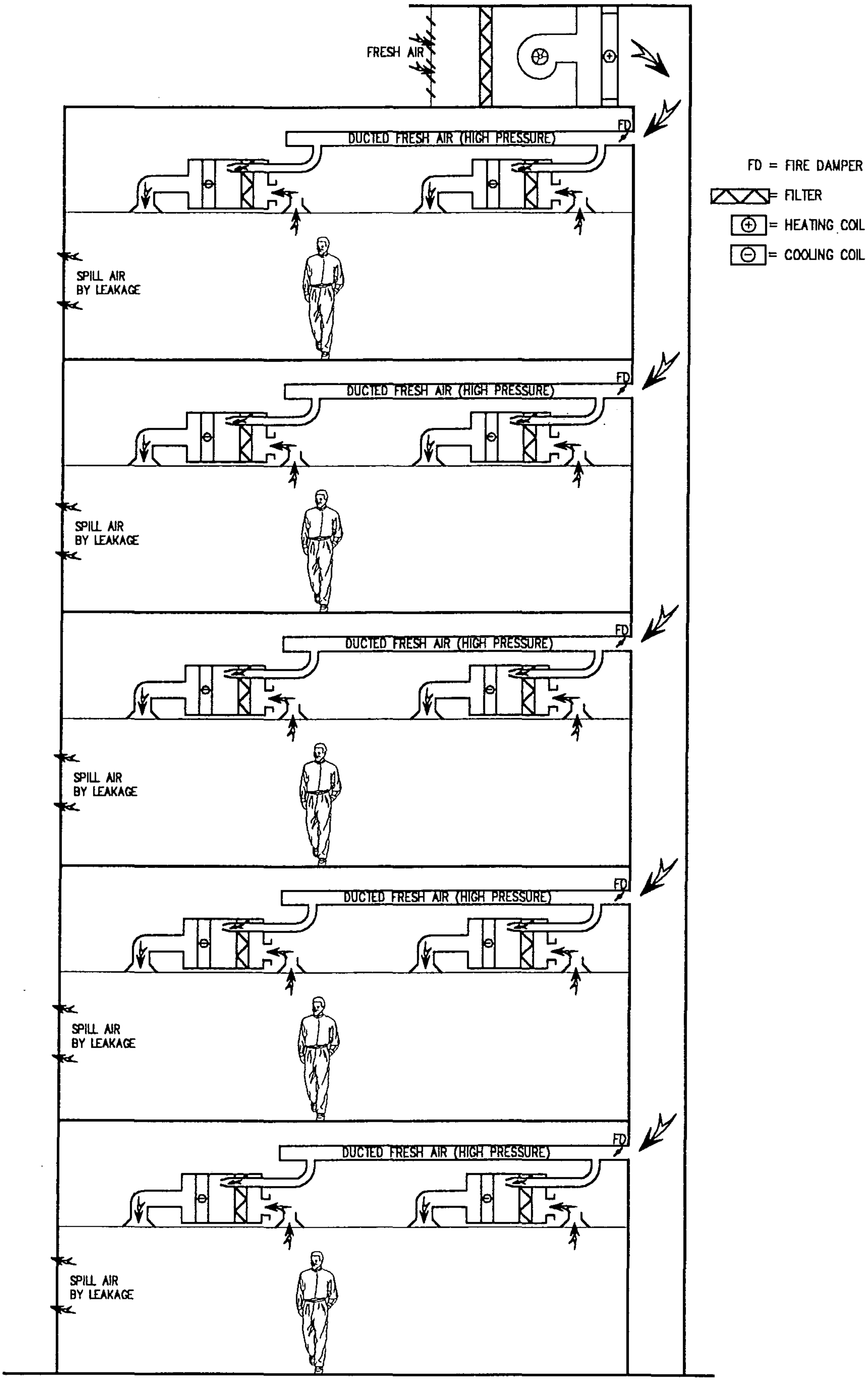

fig 4.2 – airflows for Induction Unit systems

Split Systems

Split systems comprise two separate components for each unit – an indoor air handling unit and an outdoor condensing unit, connected by a circuit of pipework containing refrigerant. The indoor unit is essentially a fan coil unit with refrigerant rather than water flowing through the coil. The outdoor unit contains the refrigeration equipment that is required to produce the cooling effect. Indoor units can be mounted in concealed spaces such as ceiling voids, or can be wall or floor mounted within the space. The units only require an external electrical supply to operate.

Through-wall or window units have the indoor and outdoor sections closely coupled into a single cabinet and usually have a fresh air supply feature built in to the unit.

An extension of the split system is the multi-unit system where several indoor units are connected to a single outdoor unit, often incorporating some control on the amount of refrigerant flowing around the system and hence called variable refrigerant volume systems (VRV).

4.2.2 Suitability of Unitary Systems for Smoke Control

Because unitary systems are designed to recirculate most of the air that they handle, their ability to either remove smoke or provide pressurisation is very limited. As noted previously, they have only a small amount of fresh air provided and usually do not have any separate 'used air' removal facility included.

Smoke removal

Unitary systems therefore cannot be used to remove smoke from an affected area without an additional air/smoke removal fan and duct being provided. These require space which reduces the lettable area in the building. The drive to gain maximum usable floor area puts pressure on architects and designers to eliminate unnecessary riser space and to use alternative means of achieving fire safety, such as stair pressurisation.

The author is not aware of any building in New Zealand that has unitary air conditioning with a separate, dedicated smoke extract facility included as part of the design.

Pressurisation

The relatively small volumes of outside air introduced to the occupied spaces means that the ability of the system to provide a significant pressure differential is minimal. As discussed in section 5 of this report, what ability the fresh air system does have to provide pressurising may be contrary to the smoke management objectives in the building. The introduction of outside air during a fire condition may in fact force the smoke into the stairs and riser shafts and aid its spread to other parts of the building.

Smoke Production

By design, the unitary air conditioners draw air from the occupied space, treat it and then reintroduce it to the space with as much mixing as can reasonably be achieved without causing discomfort to the occupants. The air is usually delivered at ceiling level via air diffusers. As this is also the level at which any smoke will accumulate it is apparent that the mixing will also mix air and smoke, if it is present, thereby creating more smoke. This obviously has the potential to aggravate a fire situation.

Summary

The conclusion traditionally drawn from the factors above is that the safest course of action is to stop unitary systems and their associated fresh air systems on the activation of a fire alarm.

4.3 Central Plant Systems

4.3.1 Description of Central Plant Systems

Central plant air conditioning systems consist of large air handlers that provide conditioned air to the occupied spaces via a distribution system of ductwork, including risers, main and run-out ducts. They are characterised by supplying all or most of the air from the central air handlers, and then returning it all back to the air handler for recycling or spilling to outside. These air handlers may be located in plant rooms on only one or two floors of the building, or may by constructed every floor (known as floor-by-floor air conditioning).

It is usual for these systems to have separate supply air handlers and return fans, with the return systems sized to return about 80% of the supply air quantity back to the central plant for either recycling or spilling (or some of both).

In central plant systems the electrically driven equipment is usually located in the main air handlers.

Variable Air Volume (VAV)

VAV systems (fig 4.3) supply only the airflow to a particular space that is required to match the heating or cooling needs of the space or zone at the particular time. They have to be capable of supplying a high volume of air at times of peak loading so the air handlers are typically large capacity units, able to supply many spaces simultaneously. Each zone has some form of terminal unit to vary the local air flow to match the demand.

VAV system controls are often relatively complex, as they must adjust the volume of air delivered by the air handler in response to multiple demands from the various spaces.

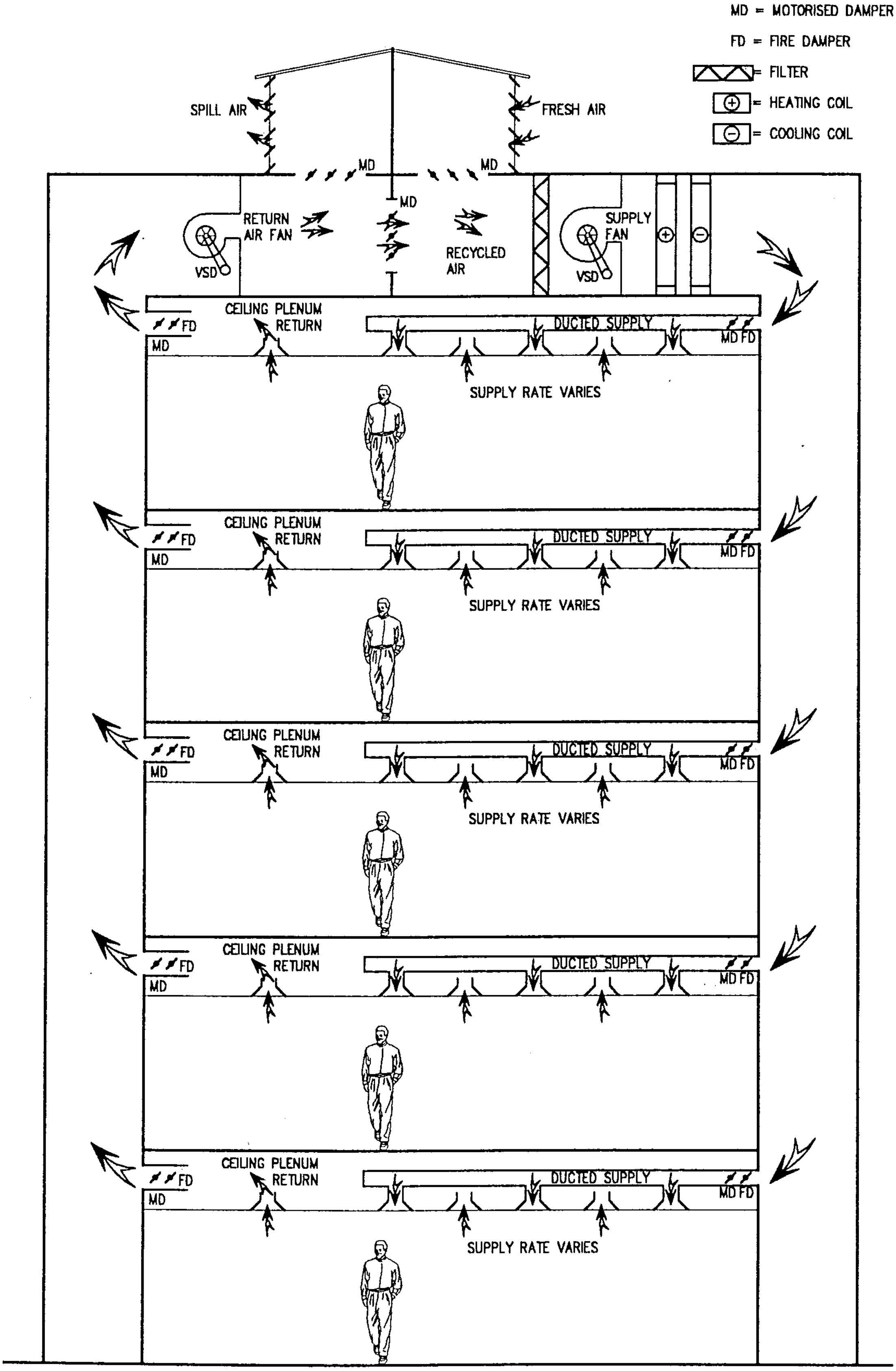

fig 4.3 – airflows for a Variable Air Volume system

Depending on the control system fitted, the terminal units may be able to supply or shut off air to particular spaces on receipt of a fire signal. This feature has the capability to be used to provide zone control of smoke, but the designer and the maintenance staff must be aware of the importance of all parts of the system operating as intended, if it is to be used reliably as part of the building's safety system.

A variant on the standard VAV system is to use some fan assistance in the terminal units to aid the circulation of air during times of low air conditioning demand, to avoid stagnation or stratification of the air within the space.

Constant Volume (CV)

(Fig 4.4) These systems are not commonly installed nowadays due to their relatively inefficient use of energy. As the name suggests, they provide a constant amount of conditioned air to the space which is then usually given some additional heating or cooling to match the requirements of the space. The consequence is that the air from the central air handler is usually over-conditioned to cater for the highest demand and then re-conditioned locally for the other spaces – a wasteful exercise. On the plus side, these systems are simple and reliable, and can often be adapted to provide some zone control by the addition of relatively few control dampers (where these are not already fitted).

Dual Duct

Similar to constant volume systems, these deliver a constant amount of air to the occupied spaces, but it is through two independent duct systems (fig 4.5). After the air handler, the air path splits into two and the air is heated in one and cooled in the other. At the occupied space the two ducts again meet at a mixing box where the hot and cold air is combined in the appropriate ratio to match the space's requirements at the time. Dual duct systems are not common in new buildings.

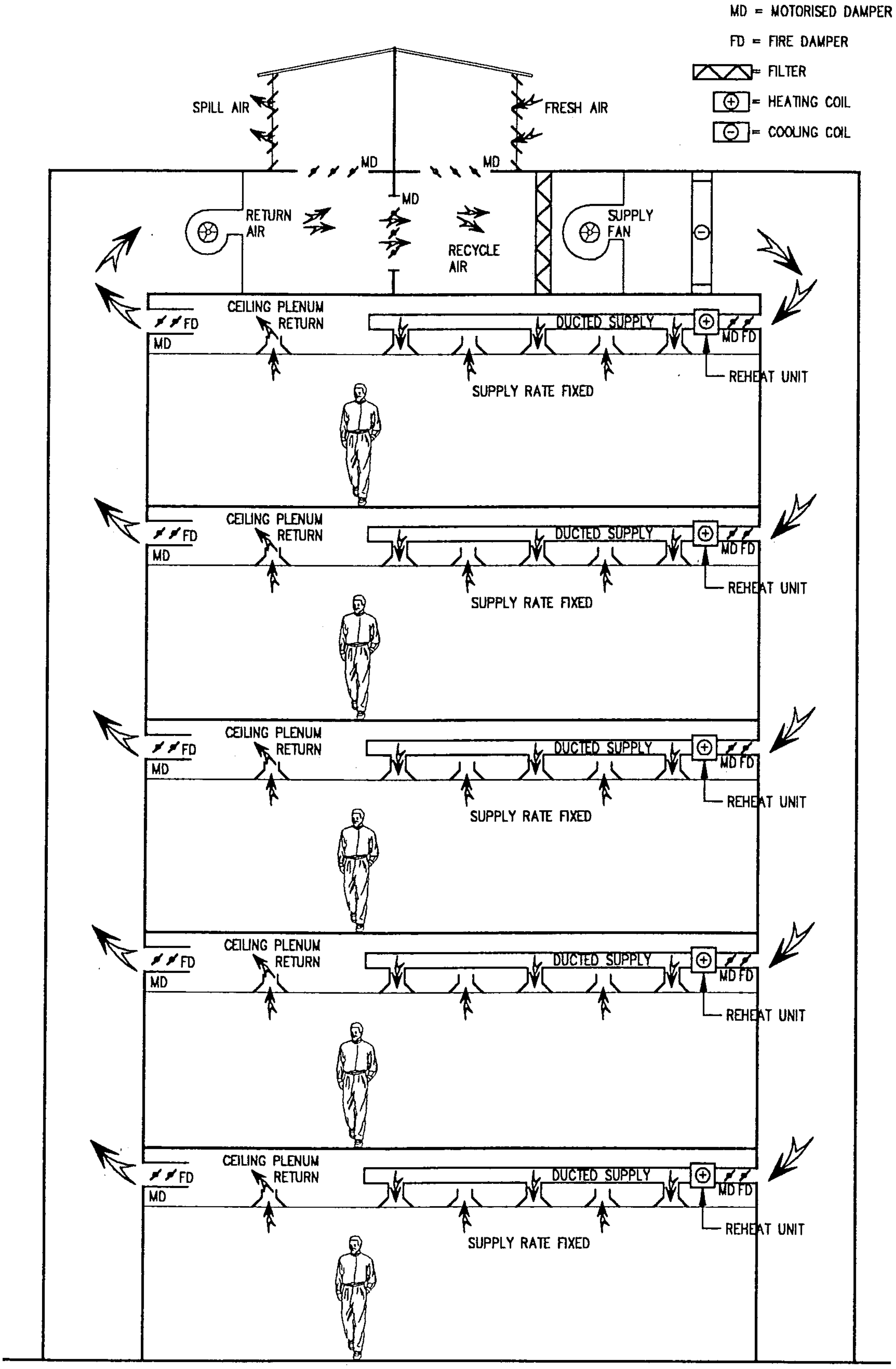

fig 4.4 – airflows for a Constant Volume system

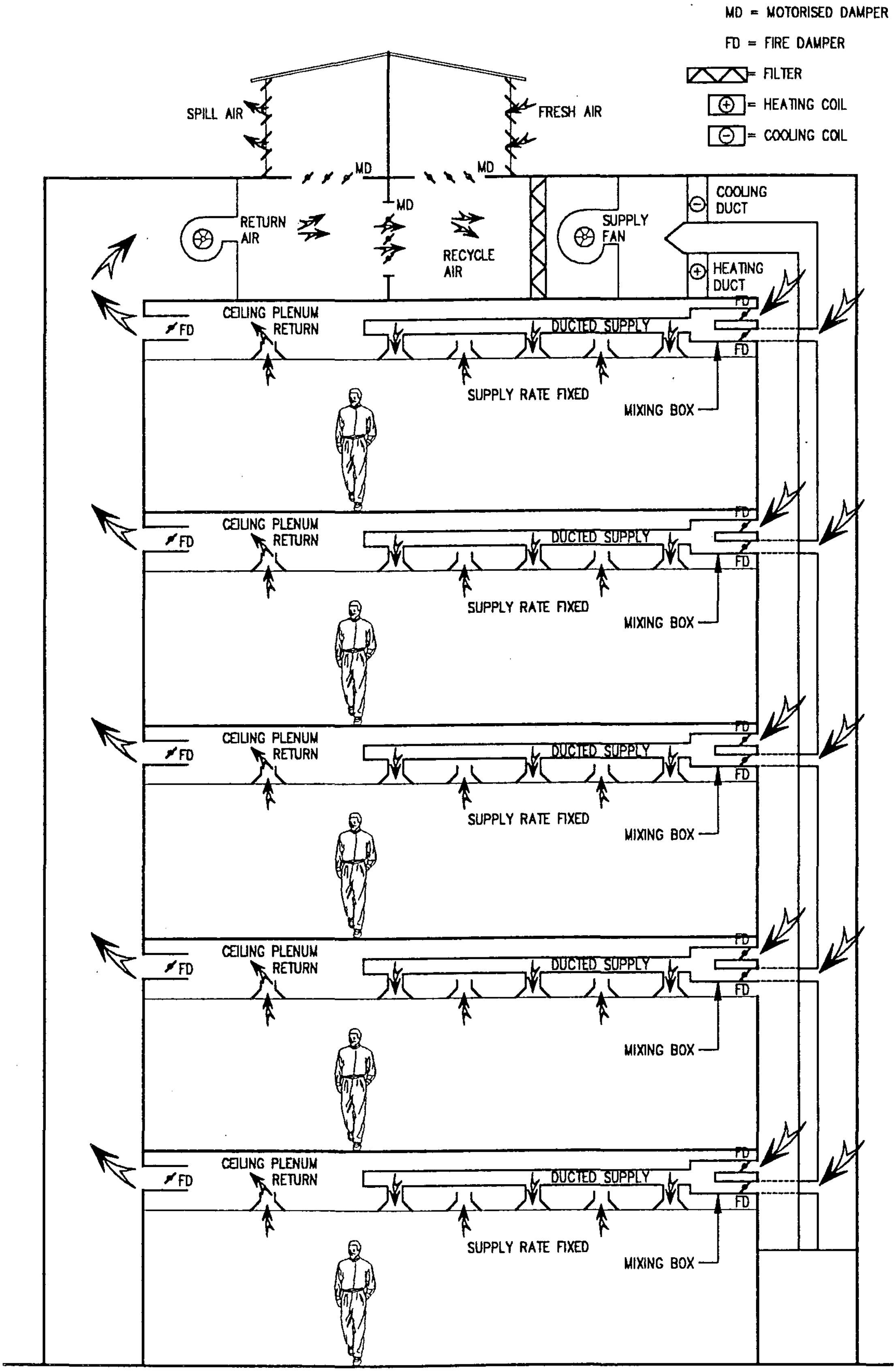

fig 4.5 – airflows for a Dual Duct system

4.3.2 Suitability of Central Plant Systems for Smoke Control

Central plant systems are designed to return all or most of the air that they handle back to the air handlers in remote plant rooms. Therefore, they are usually well suited to either remove smoke or provide pressurisation by selective airflows. They frequently have the ability to draw in all fresh air and to spill large quantities of exhausted air and smoke products. The ability to pressurise zones within the building has the potential to significantly enhance the safety of the occupants.

Smoke removal and pressurisation

The return air fans are usually of sufficient capacity to exhaust quantities of smoke comparable to those produced by a sprinkler controlled fire and can be specified to be suitable to operate at the expected smoke temperatures. Control systems are frequently already in place or can be modified to achieve selected air supply and exhaust to achieve zone pressurisation. Care must be exercised, however, to ensure that if the control systems and devices fail they will do so into a safe condition if they are to be relied upon as a safety system.

Smoke Production

Similar to the unitary systems, central plant systems also usually supply air at ceiling level which will be above any smoke layer produced by a fire. This obviously has the potential to aggravate the situation by causing mixing which creates more smoke.

Summary

On balance, in the author's opinion the advantages of having an active smoke control system outweigh the disadvantage of possibly increasing the smoke volume being produced and any central plant system that can be operated in a smoke control mode should be given serious consideration as an active smoke management system.

4.4 Other Systems

Displacement Systems

Displacement systems utilise large volumes of air introduced at very low velocity at floor level in the occupied space, allowing the air to move by natural convection as it heats up, to finally be extracted at ceiling level. The air handling units could be of either unitary or central plant type. The very low velocities used equate to low pressures within the equipment and it is unlikely that the air handlers can be used to control smoke movement. Also, as the air is supplied at floor level, particular care would be required to ensure that smoke is not inadvertently drawn in with the supply air and delivered directly into the space where people are present.

Floor by Floor units

Floor by floor units are the half-way stage between unitary and central plant systems. In multi-storey buildings the designer sometimes prefers to have a small amount of equipment in a plantroom on each floor rather than concentrating all the equipment into a large plantroom occupying a whole floor, or conversely having the units located in the ceiling of the occupied space. These systems can have all the characteristics of central plant systems but on a smaller scale. They can usually operate in full fresh air mode in the same way, and can therefore be considered for smoke control purposes.

5. COMPUTER MODELLING

To enable some conclusions to be drawn on the relative abilities and risks of HVAC systems under fire conditions, several 'typical' buildings were modelled (using CONTAM96 [Walton 1993]) to determine likely airflow directions and pressures for a variety of situations under the influence of stack effect and it's interaction with mechanical systems.

Under conditions of normal stack effect (internal temperature higher than external), the density difference between the warm air inside the building and the cool air outside causes the air flow in the building to be generally upwards, utilising flow paths such as lift shafts, service risers and stairways. Air will flow into the building at low levels and out at higher levels. At approximately the building mid-height there is a point where the flow is neither in nor out which is known as the neutral plane. Therefore the worst case under these conditions is a fire on the lowest floor, as the smoke will be transported into and within the building rather than being expelled to the outside.

5.1 Buildings Modelled

The buildings modelled are defined below. They are intended to represent typical multistorey office buildings in New Zealand and are derived from the author's observations of many buildings throughout the country.

1. A three storey building with a single lift.
2. A seven storey building with two lifts in a common shaft.
3. A ten storey building with three lifts in a common shaft.
4. A twenty storey building with two lift banks – a low rise group of four lifts with a machine room at the 13th level and a high rise group of four lifts with a roof machine room. Low rise lifts have entrances on all levels 1 to 11 and high rise lift have entrances on levels 1 and 11 to 20.

Features which were kept common to all of the buildings were:

- Floor plate size – each floor was kept at 800m^2 with a perimeter of 120m (ie a 30m square building with a 100m^2 core).
- Floor to floor height of 3.5m, giving building heights (ground to highest occupied floor level) of 7, 21, 31.5 and 66.5m.
- Stairwell – each building had a stair core of 16m^2 and a perimeter of 16m, with the ground level stair doors opening to outside.
- Lift core – each lift shaft was taken as occupying a 3x3m space (ie a three lift group took up 27m^2 and had a perimeter of 24m).
- Roof – at the roof level of each building was a lift machine room (LMR) and the top of the stairwell. The LMR floor area was four times the size of the lift shaft below. Each lift had a 0.09m^2 rope penetration to the shaft below and the LMR was linked to the stairwell by a single door. The stairwell also had a single door directly to the outside.
- On the ground floor, two doors went to the outside and also the stairwell was linked to the outside by two doors.
- The building fabric was taken as being of 'average' construction tightness as defined by Klote [1995], except for roof LMR construction which was taken as being 'loose'.
- Stair doors were taken as having a 3mm crack all round, with lift doors and ground floor entry doors having a 6mm gap all round.
- Interior temperatures were set at 21°C (as is normal for office environments) with external temperatures of -4°C*.

The building internal layout was assumed to be simple with the lifts and stairs opening directly onto the occupied space. No attempt was made to model any internal fitouts or lobbies that may be installed, as these would only restrict smoke movement. The open plan layout is therefore the worst case with the most free smoke migration.

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* This temperature is the 1% winter design temperature for Dunedin, being the coldest winter design temperature for the main centres, as published by the National Institute for Water and Atmospheric Research (source: IHRACE Journal, July 1996).

5.2 Conditions Modelled

For each building four situations were modelled –

1. stack effect alone,
2. stack effect plus a 0.5l/s/m^2 outside air supply into the occupied space (to model a fresh air supply as would be included with an HVAC system, but allowing for some minor extract systems such as kitchen and toilet extracts)
3. stack effect plus a supply into the stairway (to model a simple stair pressurisation system)
4. stack effect plus HVAC fresh air, plus stair pressurisation.

As well as the 'typical' buildings under normal stack effect which were modelled, the ten storey building was also modelled under reverse stack effect (with an external temperature of 29°C) and under normal stack effect (external temperature of -4°C) but with 'tight' wall construction. All other parameters were unchanged.

The particular data of interest is the air flow from the worst case fire floor into the service shafts (such as stair and lift shafts) and then identifying:

(1) the magnitude of the pressure differential forcing air flow into the service shafts, and
(2) on which upper floors the air flow is from the risers or lift shaft onto the floor.

This air flow could carry smoke into the occupied areas and possibly endanger the occupants.

Under conditions of normal stack effect, the worst case position for a fire is on the ground floor (level 1, in the results presented) as this is the level that has the highest driving forces into the service shafts. For reverse stack effect, the worst case is for a fire on the top floor.

During the modelling, it is implicitly assumed that the buildings are sprinklered and hence the smoke temperatures remote from the fire are approximately the same as the building internal temperature and the same density as air. Additional buoyancy effects from hot smoke are therefore not modelled.

The pressure differential driving the flow into the stair also gives an indication of how difficult the flow would be to stop. This can be used to determine whether simple smoke seals on doors would be sufficient, or the magnitude of stair pressurisation that would be required to keep the stairway clear of smoke.

In addition to the discussion that follows, for each situation the results of the modelling are presented in the Appendix as graphs of air flow and pressure difference against building height (measured from level 1, up). The sign conventions used are that positive flows are from the shaft into the occupied space (negative values indicate flows into the shaft) and positive pressure differences are the shaft at a higher pressure than the space. In all cases the ground floor is level 1.

5.3 Observations

The observations made of the flows and driving pressures are:

Stack effect alone

- As expected, the air flows from slightly above building mid-height are from the vertical shafts into the occupied spaces, with flows into the shafts below mid height. This follows the expected effect of smoke from a fire low in the building being carried onto the upper occupied levels.
- For the 20 storey case, the flows into/out of the low-rise lift shaft are as though the building were only 12 storeys (the height of the shaft), with flows below shaft mid-height into the shaft and above mid-height from the lift shaft into the occupied space. The effect of the low-rise lift machine room is significant on this and the adjacent floors, as the shaft and the machine room above are acting as a direct channel for airflow from the lower floors.
- Under the influence of stack effect alone the driving pressures on air flow are less than 12Pa, even for buildings of 20 storeys at an external temperature of –4°C. For the 3 storey building the driving pressures are less that 5Pa.

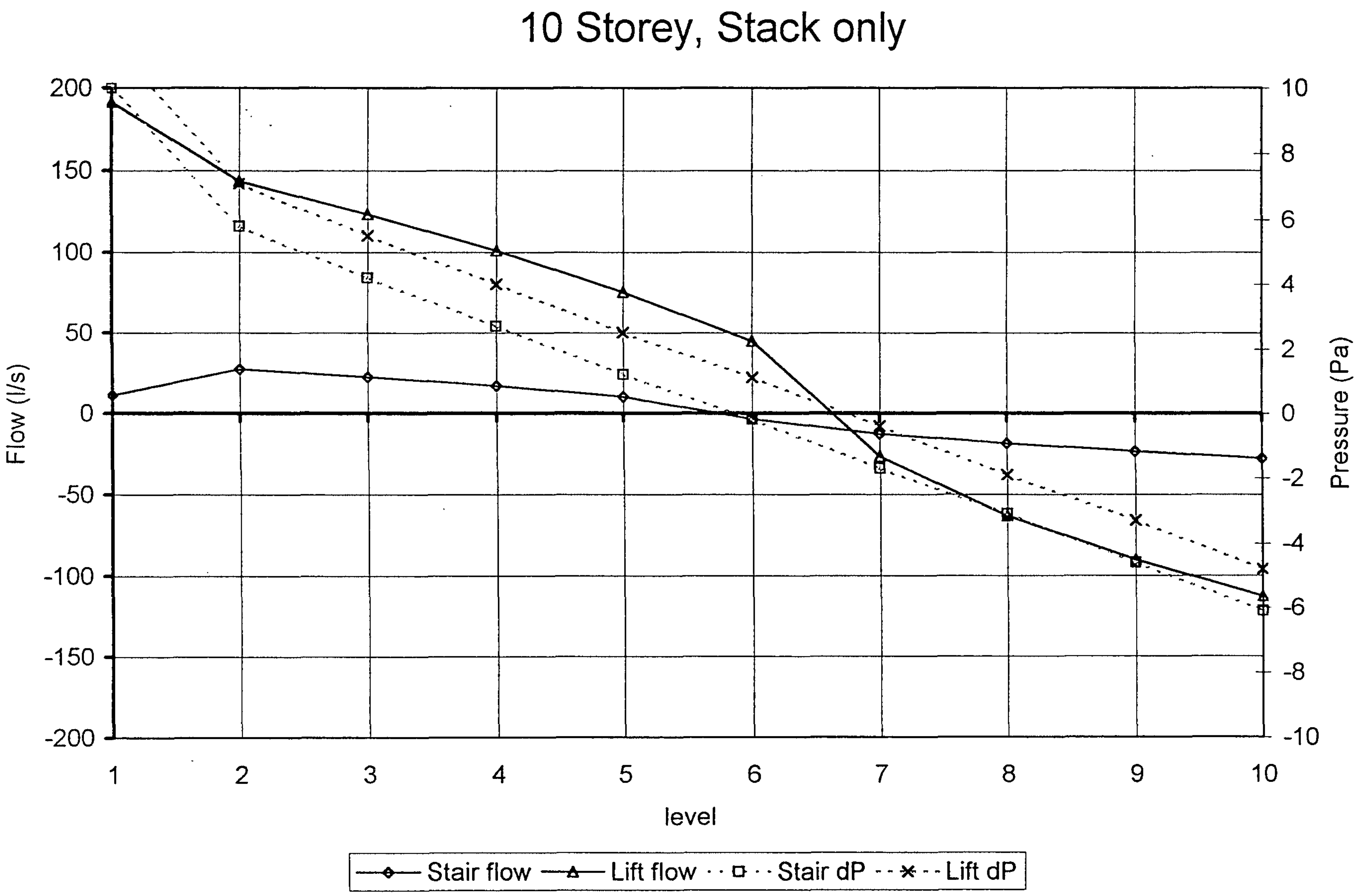

fig 5.1 – Airflows for a 10 storey building with stack effect alone

The airflows for the ten storey case are shown in graphical form in fig 5.1, The graph shows the magnitude and direction of the airflow and driving pressure, plotted against the height of the building (ie levels 1 to 10). For this case, both the lift shaft and stairway have flows into them below the seventh level, and out of the shafts above this point. Therefore the consequences of a fire below level 7 would be that smoke is transported to all floors above level 7 via these shafts. Just as important in this example is that the stair shaft would experience smoke ingress, being driven into the stairway by up to 10Pa, if the fire was on level 1.

Fresh air system operating

- When the fresh air system is operating, the air flow is from the occupied space into the shafts on all levels up to about 9 floors (30m high, approximately). This air flow is for both the stair shaft and the lift shaft and so smoke would be forced into the stairways which is not a desirable situation.
- The pressure differences driving the air flow into the stairways is less than 8Pa, except for the three storey case, where it is up to 12Pa.

Again using the ten storey case as an example (fig 5.2), the fresh air system will prevent flows from entering the occupied spaces from the riser shafts up to level 8. However, in doing so it is also forcing the flow to be into the stairway on all levels below this. This could obviously lead to an unacceptable situation of smoke in the escape stair.

Stair pressurisation

- The simple stair pressurisation system alone keeps the stair flows in the desired direction but has little if any affect on the flows into/from the lift shafts.

Examining the plot of the ten storey case (fig 5.3) shows that although there is no flow into the stair, the lift shaft flows are almost identical to the case above of the stack effect alone. Flows on the lower floors are into the lift shaft and on the upper floors they are out of the shaft, so smoke from a fire on a lower floor will be transported to the upper floors.

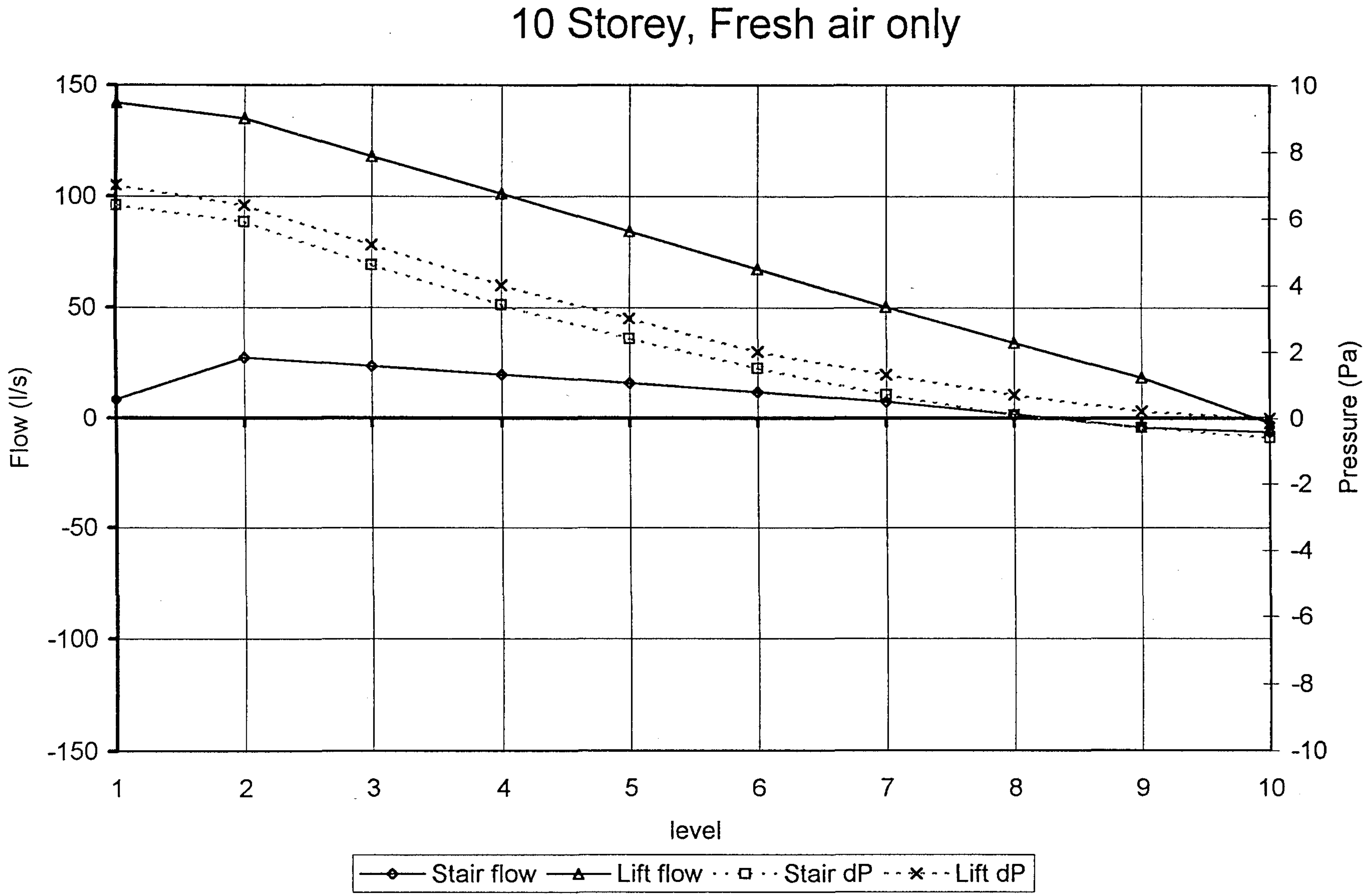

fig 5.2 – Airflows for a 10 storey building with stack effect and fresh air

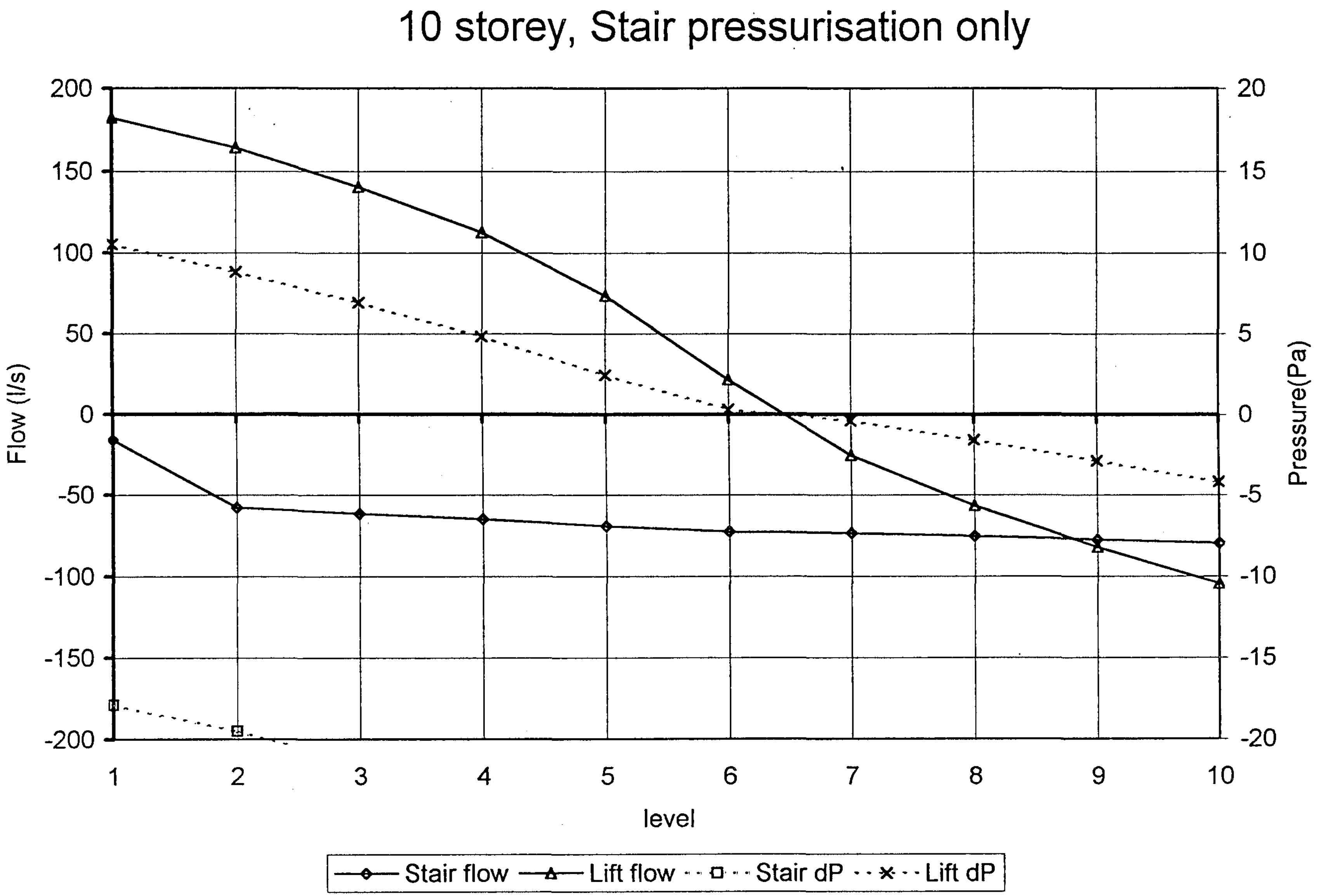

fig 5.3 – Airflows for a 10 storey building with stack effect and stair pressurisation

Fresh air plus stair pressurisation

- The combination of stair pressurising and the fresh air system is sufficient to stop flow from the lift shaft into the occupied space up to about 10 storeys (say 35m high).

As shown in fig 5.4, the air flow is prevented from exiting the lift shaft up to level 10. Consequently, a combination of stairway pressurisation and leaving the HVAC operating could be used (in the test building) to keep the occupied floors clear of smoke.

However, to illustrate the complications that can be introduced, inspection of the flows for a 20 storey building (fig 5.5) under the influence of stack effect only shows how confused the flows can be, even for this relatively simple case. The high-rise lift shaft and the stairway both have flows into the shafts below mid-height and out of the shafts above this level (as expected). Pressures driving the flows are at maximum at the extreme floors (1 and 20) and vary in approximately a linear fashion between. However, the flows in the low-rise lift shaft behave as though the building were only 13 storeys tall, with a neutral plane at level 7. The consequences of a fire on level 1 would be that smoke would be transported to floors above level 7 via the low-rise lift shaft, and to all floors above 12 via the high-rise lifts and the stairs. Adding lobbies around lifts or subdividing floors will further complicate the flows.

Outside temperature 29°C

- The reverse stack effect is as expected, with flows above building mid-height into the riser shafts and below mid-height into the occupied spaces (see fig 5.6).
- As for the normal stack case, the fresh air system alone is sufficient to prevent air flows onto the occupied levels except for the extreme floor (the ground floor, in this case) and stair pressurisation alone does not have a significant influence on the lift shaft flows.
- The fresh air plus stair pressurisation will contain the flows in the lift shaft for all levels except the ground.
- As expected, the driving pressures are significantly less than those calculated for the normal stack cases. This is due to the magnitude of the temperature

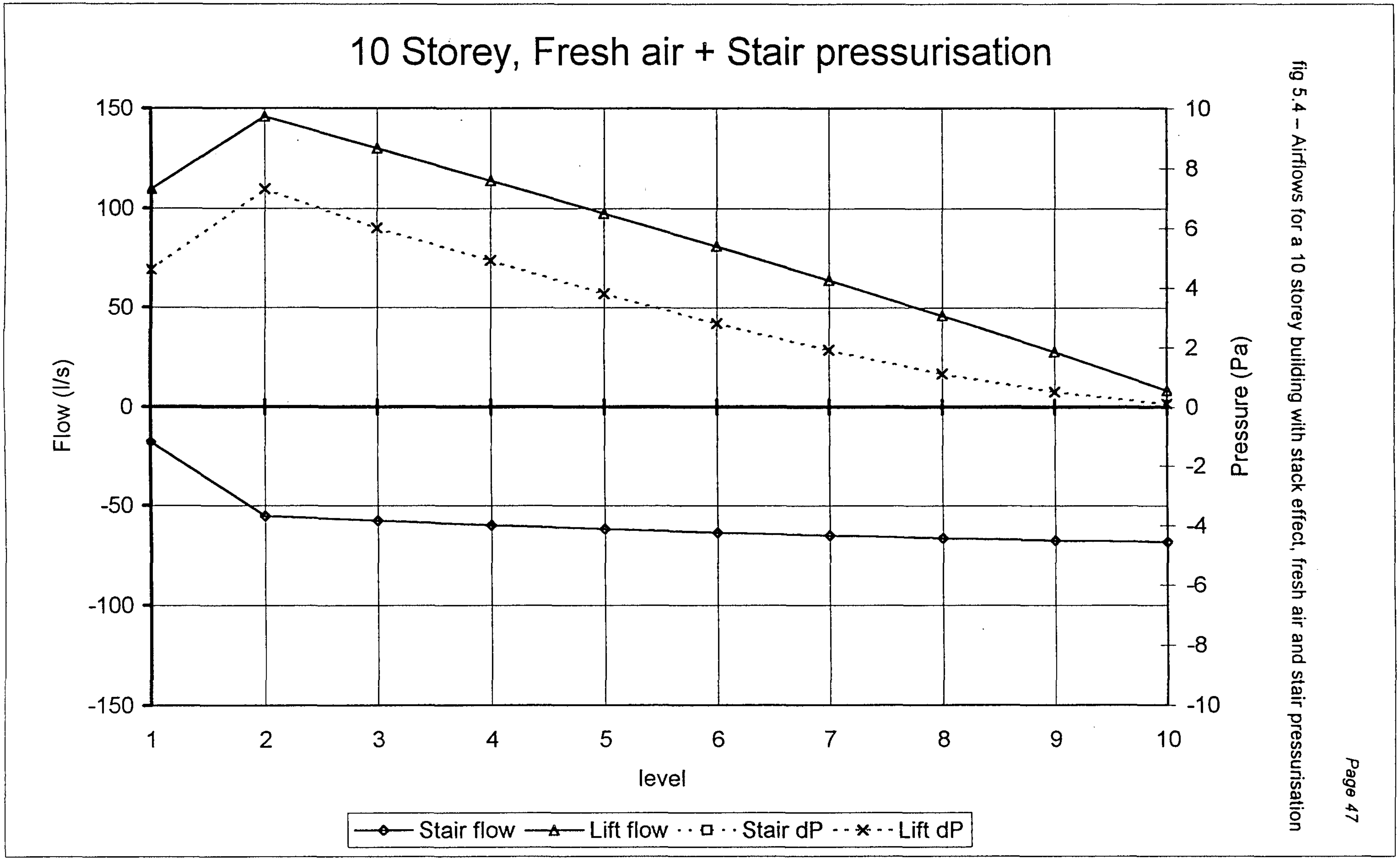

fig 5.4 – Airflows for a 10 storey building with stack effect, fresh air and stair pressurisation

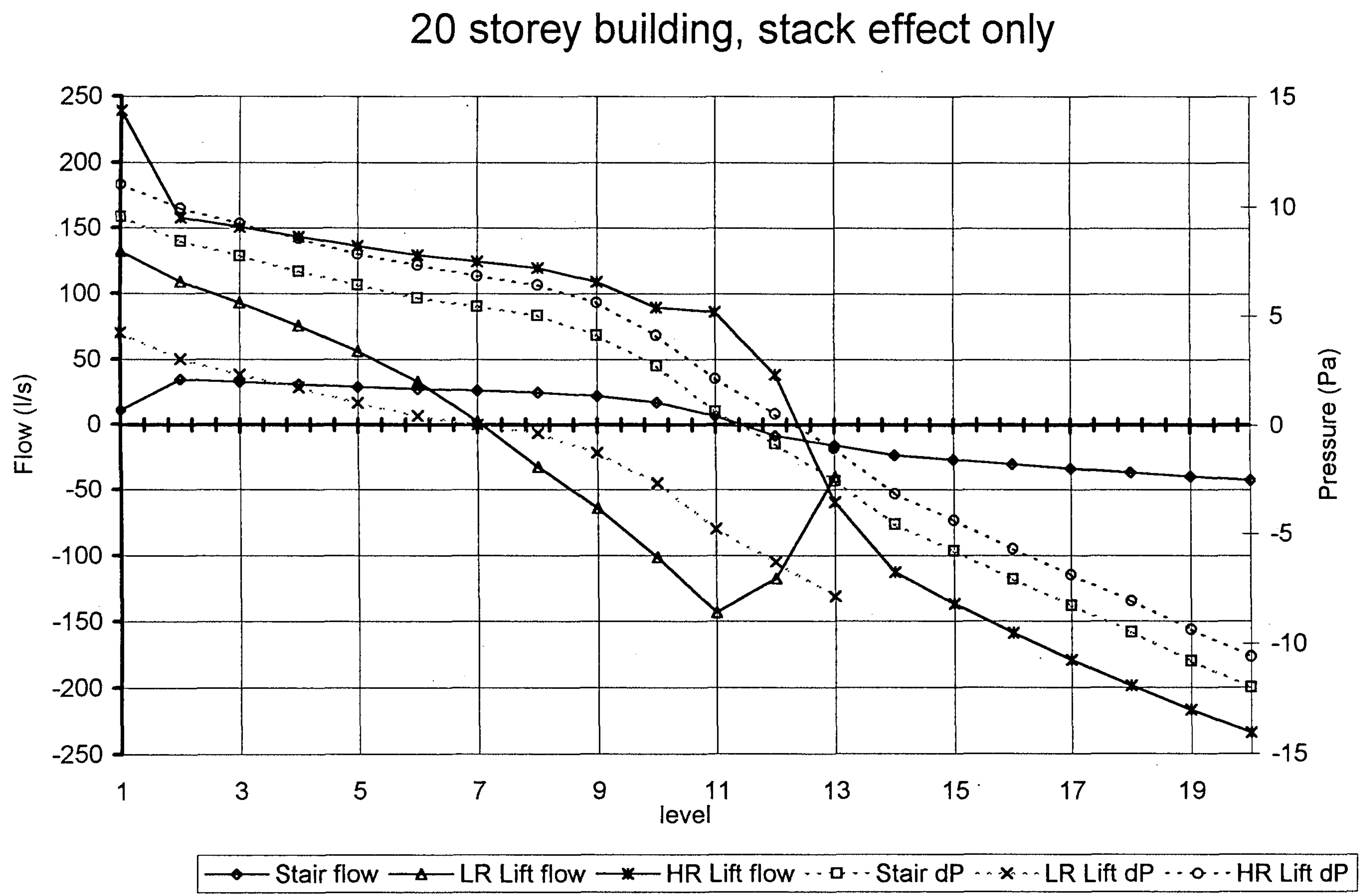

fig 5.5 – Airflows for a 20 storey building with stack effect alone

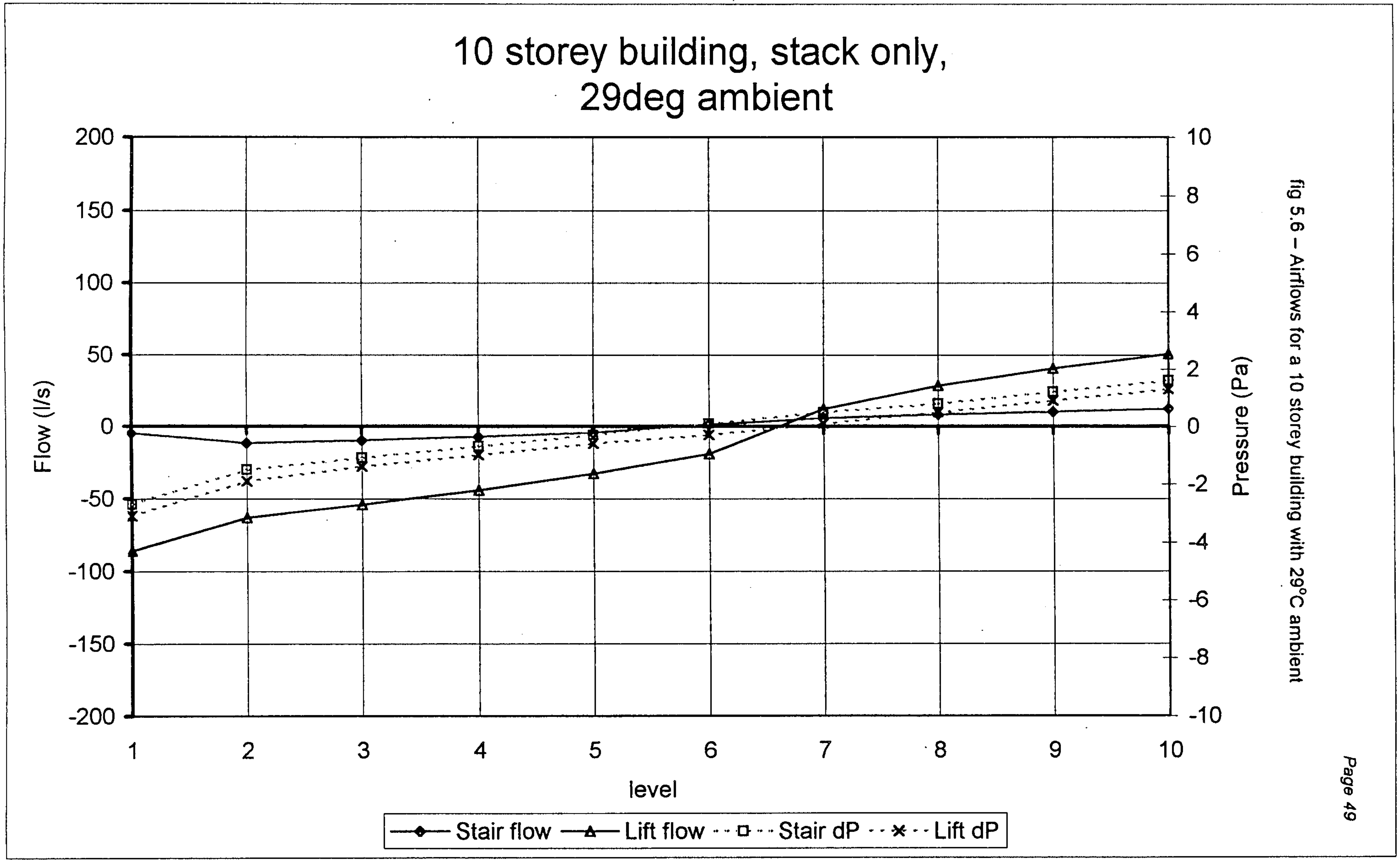

fig 5.6 – Airflows for a 10 storey building with 29°C ambient

difference between the interior and the exterior being less in the summer case than in the winter (29–21=8 degree difference, vs 21-(-4)=25 degree difference).

<u>'Tight' building construction</u> (fig 5.7)

- These cases have increased pressure differences and decreased flows compared to the 'average' construction cases.
- The greater contrast between the tight building exterior and the loose lift machine room walls moved the neutral plane height significantly towards the top of the building.
- With the fresh air system alone the maximum air flow into the shafts is similar to the 'average' case, but the flow is almost constant on all levels rather than decreasing towards the building top. This is presumably because the leakage around the doors dominates over the other construction cracks whereas in the 'average' case the total leakage areas are similar.
- Unlike the 'average' case, the stair pressurisation alone is sufficient to influence the flow into the lift shaft.

The building construction obviously has a strong influence on the airflows, which makes leakage area data vital if accurate calculations are to be undertaken.

5.4 Conclusions drawn from modelling

The conclusions that have been drawn from this modelling are:

1. For average construction buildings, the heights for which active smoke control is invoked by the Acceptable Solutions are reasonable. Above heights of around 7 to 10 storeys (25 to 35m) driving pressures are significant and active control will be required to prevent smoke from migrating into occupied areas. The building heights called by the Acceptable Solutions of 25m and 16m appear to be somewhat conservative, but not overly so in the author's opinion. The purpose groups for which 16m is the cut-in point are the relatively high risk groups, either due to high fire load or the occupancy characteristics. The 25m limit is only used for the lower risk groups.

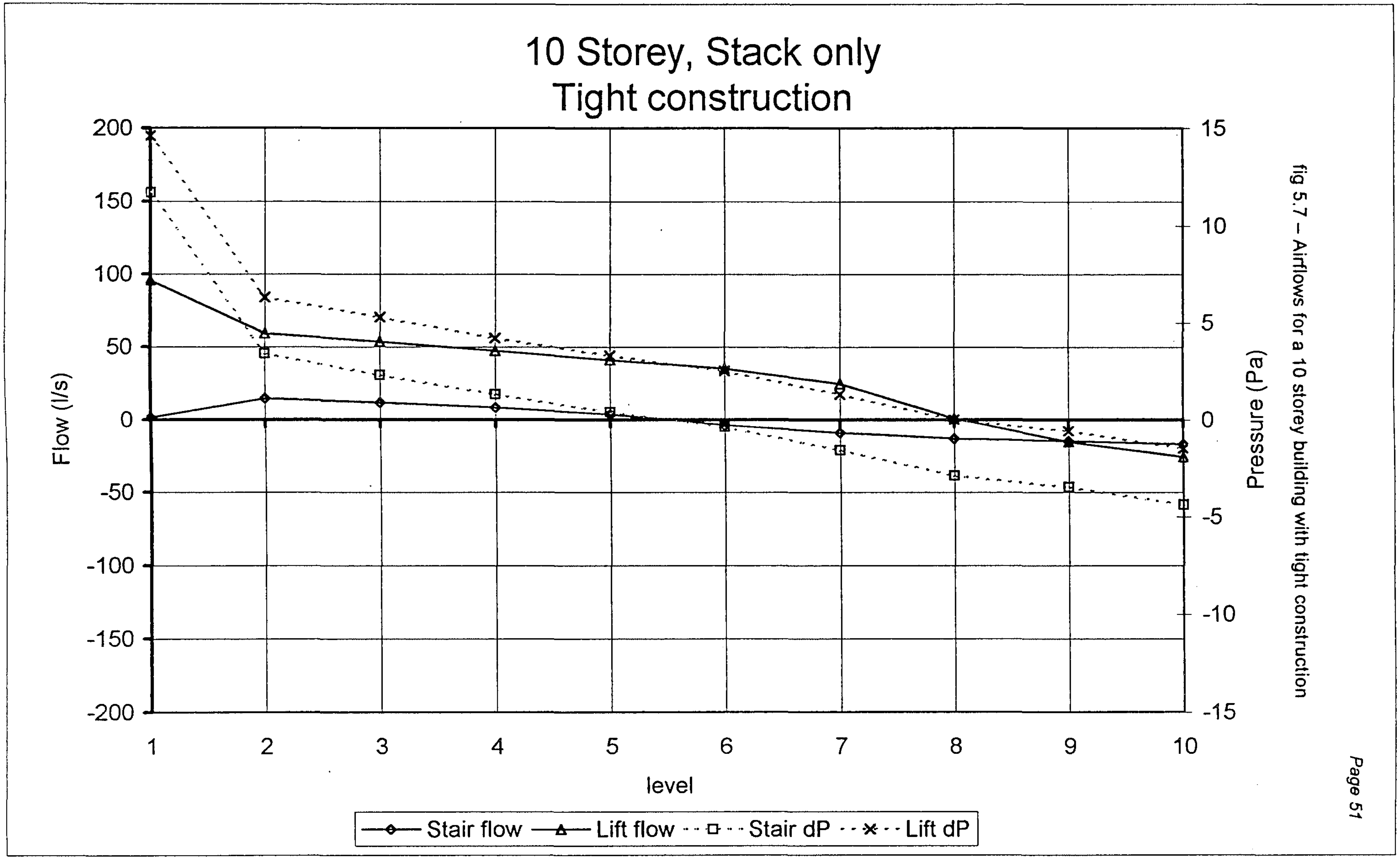

fig 5.7 – Airflows for a 10 storey building with tight construction

2. Below these heights, where precaution 9 is not invoked, the driving pressures are small (<5Pa) and smoke could be reasonably contained by passive means such as door seals. However, it is apparent that any air system which pressurises the fire floor must be shut off to prevent it forcing smoke into the shafts, unless stair shaft pressurisation is also provided. If stair pressurisation is present, there may be some merit in utilising the HVAC to enhance the building safety. This will depend on the exact physical characteristics of the building and so should be examined case by case.
3. The building construction has a significant impact on the air flows and pressures. There are significant differences between the airflow patterns of average and tight constructions. There is unfortunately little data available on leakage areas and none (as far as the author is aware) relating to New Zealand construction techniques. This is an area of future research which would be extremely beneficial to refining the design of smoke control systems.
4. Systems for actively managing smoke in lift shafts are not addressed by the Acceptable Solutions but are worthy of some consideration. The lift shafts are obvious routes for transport of smoke and design philosophies to control this are required. The current Acceptable Solutions make no allowance for this and only attempt to contain the smoke (with lift lobbies, much to the ire of many architects) or detect the presence of smoke if it should come out of the shaft into an occupied floor. Lift shaft pressurisation could be considered as a viable alternative to these measures.
5. In buildings with stair pressurisation systems, it is possibly beneficial to keep the HVAC (or at least it's fresh air system) operating, to assist in preventing smoke from exiting the lift shafts into the occupied spaces. This is another area which would benefit from further research and testing.

6. THE NZ BUILDING CODE AND THE APPROVED DOCUMENTS

6.1 The Document Structure

The legal requirements surrounding the construction and operation of buildings are covered by the NZ Building Act 1991, which creates the Building Regulations and the schedule entitled the NZ Building Code.

In the area of fire safety, the Building Code includes clauses C1, C2, C3 and C4. These clauses lay out the objectives, functional requirements and performance requirements to achieve the desired level of safety and protection for building occupants, firefighters and neighbouring property. These (and all clauses in the Building Code) are expressed in performance terms - they describe what is to be done, not how to do it.

The Building Code clauses that are of interest in the area of fire safety are:

C1 - Outbreak of Fire
C2 - Means of Escape
C3 - Spread of Fire
C4 - Structural Stability During Fire

Associated with each clause of the Building Code are the 'Approved Documents', which contain 'Verification Methods' and 'Acceptable Solutions'. The Acceptable Solutions provide a prescriptive, 'deemed to comply' method of satisfying the requirements of the respective Building Code clause. Verification Methods describe test methods which can be used to ascertain compliance with particular aspects of the Building Code. There are currently no verification methods associated with C2, C3 or C4. In the area of fire safety, the Acceptable Solutions C2/AS1, C3/AS1 and C4/AS1 are the principal focus of Territorial Authorities and designers for the majority of commercial building situations.

Alternative designs that are outside the framework of the Acceptable Solutions are able to be used providing they can be shown to satisfy the Building Code objectives and requirements.

In addition to the Building Code clauses and Acceptable Solutions there is also the Fire Safety Annex, which contains the appendices to C2, C3 and C4. The Annex contains (among other things) the basic design data for any particular building use and configuration and is therefore the starting point for any analysis.

Clauses C1 and C4 do not contain requirements for HVAC systems. Clause C1 is principally aimed at the installation of fuel-burning appliances (such as furnaces and fireplaces) to minimise the likelihood of a fire occurring, and clause C4 covers structural aspects of buildings under fire conditions.

With respect to the aspects of ventilation in multistorey buildings as they apply to fire safety, it is only particular provisions of clauses C2 and C3 which are relevant to this discussion, although the analysis must inevitably include aspects from the Fire Safety Annex.

6.2 Ventilation and Smoke Control Objectives and Requirements

The objectives, functional requirements and performance requirements that relate to ventilation and smoke control in clauses C2 and C3 are:

C2: *Objective C2.1 - The objective of this provision is to:*

(a) Safeguard people from injury or illness from a fire while escaping to a safe place, and

(b) Facilitate fire rescue operations.

Functional Requirement C2.2 - Buildings shall be provided with escape routes which:

(a) Give people adequate time to reach a safe place without being overcome by the effects of fire, and

(b) Give fire service personnel adequate time to undertake rescue operations.

C3: *Objective C3.1 - The objective of this provision is to:*

(a) Safeguard people from injury or illness when evacuating a building during fire.

(b) Provide protection to fire service personnel during fire fighting operations.

Functional Requirement C3.2 - Buildings shall be provided with safeguards against fire spread so that:

(a) Occupants have time to escape to a safe place without being overcome by the effects of fire,

(b) Firefighters may undertake rescue operations and protect property

Performance C3.3.7 - Air conditioning and mechanical ventilation systems shall be constructed to avoid circulation of smoke and fire between firecells

Performance C3.3.8 - Where an automatic smoke control system is installed, it shall be constructed to:

(a) Avoid the spread of fire and smoke between firecells, and

(b) Protect escape routes from smoke until the occupants have reached a safe place.

6.3 The Requirements of the 'Acceptable Solutions' for HVAC Systems

The Acceptable Solutions C2/AS1 and C3/AS1 and the Fire Safety Annex contain the requirements for smoke management by natural and mechanical ventilation wnich are deemed to be required under certain circumstances. Parts of these requirements are somewhat convoluted which makes them not particularly clear about their scope of application, or how the requirements should be achieved when they are applied.

In particular, the areas that are dealt with in the Acceptable Solutions are:

Exitway pressurisation
Exitway natural ventilation
Atria and intermediate floors
Air handling systems

It is this last item which is applicable to HVAC systems in typical multistorey buildings and is the principal subject of this discussion. Some comments are also made in relation to natural ventilation of exitways.

The Acceptable Solution requirements for how an air handling system should behave if a fire is detected, or even to which air handling systems the requirements apply, are not clearly described. There is also one section that, if strictly applied, has some wide implications on the type of alarm system installed.

The sections of the Acceptable Solutions that are relevant to ventilation are summarised below:

The Fire Safety Annex

Table B1 in the Annex calls up the required firecell F rating, the associated alarm type and the other precautions which are deemed to be appropriate to the firecell purpose group, number of occupants and building height.

The requirements for ventilation systems (by natural or mechanical means) under fire conditions appear in the following precautions from table B1:

Precaution 9	Smoke control in air handling systems
Precaution 10	Natural draught ventilation
Precaution 11	Mechanical smoke control
Precaution 13	Pressurisation of safe paths

These precautions are summarised below:

Precaution 9

HVAC systems shall comply with the requirements for smoke control in C2/AS1 and C3/AS1. Activation may be initiated by either a self-contained detection system or the main building alarm system.

Precaution 10

Natural draught smoke extraction, where a firecell is provided with a smoke reservoir and with outlet vents and fresh air inlets to allow smoke movement by natural draught (as described in C3/AS1, section 9.2). This precaution applies only to common spaces in buildings with intermediate floors, (ie. Atria).

Precaution 11

As for precaution 10, but with mechanical ventilation instead of relying on the natural buoyancy of the smoke (as described in C3/AS1, section 9.3). This precaution also applies only to common spaces in buildings with intermediate floors, (ie. Atria).

Precaution 13

Exitway pressurisation is to comply with AS1668.1, section 6 (sic)*.

Each of these precautions (and the others included in the Annex) are invoked for buildings containing various combinations of purpose group, occupant numbers and height.

It is Precaution 9, 'Smoke Control in Air Handling Systems', that is of interest here, which is invoked by table B1 for the following occupancies and building heights:

---

* Presumably the reference in the document should be to AS1668.1, section 8 (not 6), as it is section 8 which covers stair pressurisation.

CS/CL Crowd occupancies	• 2 or 3 storey buildings with over 100 occupants • Buildings over 16m in height*
CM Retail occupancies	• Single level with more than 250 occupants • 2 storey with more than 100 occupants • 3 storey with more than 50 occupants • All buildings over 3 storeys
WL/WM Offices and factories	• 3 storey with more than 250 occupants • All buildings over 25m high
WD Industrial occupancies (high fire risk)	• 3 storey with more than 100 occupants • All buildings over 16m high
SC/SD Sleeping occupancies (occupants are restrained or require assistance to evacuate)	• All buildings over 16m high
SA Transient accommodation (eg hotels)	• All buildings over 25m high
SR Attached dwellings	• (never required)

fig 6.1 – Buildings/occupancies for which Precaution 9 is invoked

In addition, the parts of the Acceptable Solutions C2/AS1 and C3/AS1 that include requirements for ventilation are:

---

* Building height is measured from the floor level of highest occupied floor to the final exit level.

C2/AS1 - Means of Escape

8 Smoke control

8.1 gives the general objectives, and refers to C3/AS1, paragraph 9.2 for firecells with intermediate floors.

8.2 gives ventilation area requirements for natural ventilation of exitways for sleeping purpose groups, where mechanical ventilation is not provided. (Note that the alternative requirements for mechanical ventilation are not defined, however).

8.3 puts a smoke separation at mid height of stairways greater than 25m in height (if not pressurised nor sprinklered).

C3/AS1 - Spread of Fire

7 Concealed spaces

7.1.1 and fig.14 have requirements for concealed spaces where these act as air handling plenums.

9 Smoke Control

9.1 Exitways

9.1.1 states that the acceptable solution for natural ventilation of IE purpose group exitways is given in C2/AS1 (presumably this refers to C2/AS1 para 8.2, as mentioned above).

9.1.2 requires that where exitway pressurisation is required, it shall comply with AS1668.1 section 8.

9.2 Firecells with intermediate floors

9.2.1 requires that firecells with intermediate floors include provisions for the control smoke spread (refers to NFPA92B – Smoke management systems in malls, atria and large spaces for guidance).

9.2.2 covers horizontal smoke spread in large areas - refers to Morgan & Gardner [1990] as an acceptable method of compliance.

9.2.3 for CM occupancies of more than 500 people, the smoke control system is to be independent of other systems.

9.2.4-9.2.11 cover requirements for smoke reservoirs and smoke baffles.

9.2.12 covers natural ventilation requirements.

9.3 Mechanical smoke control where intermediate floors are present (ie relates to precaution 11 from the Fire Safety Annex)

9.3.1 gives the basic requirements.

9.3.2 – 9.3.8 gives design parameters such as fire size, design velocities and pressure differences.

9.4 Discusses sprinkler systems in relation to smoke baffles and tall spaces.

9.5 Mechanical smoke extraction in buildings with intermediate floors is to be activated by smoke detectors, with requirements for detector locations.

9.6 When smoke detection is activated, it shall start smoke control systems and shut down other HVAC plant. (This paragraph appears to be out of place – this is discussed further, below).

9.7 Covers air handling systems in buildings without intermediate floors, and states that AS1668.1 is acceptable to prevent smoke recirculation to other firecells via the air handling system.

9.8 Emergency power requirements (where required by table B1).

9.9 Requirements for theatre stages.

6.4 Discussion of HVAC Aspects

Of all the sections noted above, the only ones which are apparently directly relevant to HVAC systems in multi-storey buildings (ie a building without an atrium) are C3/AS1 sections 7.1.1, 9.6 and 9.7.

The particular aspects discussed here are:

- Are the requirements of section 9.6 sensible?
- Are there other options suitable to comply with section 9.7?
- Should C3/AS1 sections 9.6 and 9.7 apply to all HVAC systems, or only when invoked by table B1?
- What are the implications of section 7.1.1 and are they sensible?

Some comments are also made concerning the provision of mechanical ventilation to satisfy C2/AS1 section 8.2.

It needs to be noted at this point that each of the sub-sections of paragraph 9 apply to a particular set of circumstances or conditions and effectively can be read in isolation from the others.

6.4.1 C3 Paragraph 9.6 "Automatic activation of services plant"

This paragraph states:

> *The smoke detection equipment when activated shall:*
>
> *a) Open all vents which are part of the smoke extraction and air supply systems*
> *b) Start smoke extraction and air supply systems, and exitway pressurisation where installed*
> *c) Turn off air-conditioning and mechanical ventilation plant which is not required or designed for fire safety, and*
> *d) Start the emergency power supply system used for fire protection systems.*

This paragraph appears to presuppose that these various features are fitted to the HVAC systems. This raises questions about the intentions of the paragraph - whether it intends to require these features to be fitted or if it only applies should they happen to be already present.

As noted above, each of the sub-sections of paragraph 9 apply to a particular set of circumstances or conditions and effectively can be read in isolation from the others.

However, I believe that this paragraph is not intended to stand alone, but applies wholly to the previous paragraph, (9.5 – Smoke detectors in mechanical extraction systems), which concerns the types of smoke detection systems used to activate extraction systems in buildings with intermediate floors. All the other main paragraph headings of section 9 are able to read in isolation whereas para 9.6 is meaningless when applied this way. It is, however, sensible when read in conjunction with 9.5.

I believe it should be renumbered to become 9.5.2, which will remove the confusion surrounding its application.

6.4.2 C3 Paragraph 9.7 "Air-handling Systems"

This paragraph states:

> *9.7.1 Compliance with AS1668:Part 1 is an acceptable method of preventing the recirculation of smoke through an air-handling system to other firecells in buildings without intermediate floors.*

This is the principal section of the Acceptable Solutions which applies to HVAC systems in multistorey buildings, but it gives only the advice that AS1668.1 [SAA, 1991] is <u>an</u> acceptable method of compliance. What other methods are acceptable? Is AS1668 applicable in all situations? Does this paragraph apply to all air handling systems, or only when precaution 9 (smoke control in air handling systems) has been invoked?

To attempt to address these questions it is relevant to first look at the provisions of AS1668.

<u>AS1668 "The Use of Mechanical Ventilation and Air-conditioning in Buildings", Part 1 Fire and Smoke Control</u>

AS1668.1 is a prescriptive document that covers smoke control in central plant and individual air handlers that supply over 1000l/s to a given firecell, including any group of small air handlers that collectively exceed this volume, where it is invoked by the local (Australian) building regulations. It therefore applies equally to central plant and unitary systems. It also notes, however, that central plant air handlers in buildings with separate fire stairs are to comply, regardless of whether the local regulations require smoke control to be fitted.

This standard includes two methods of smoke control which may be applied:

1. Purging smoke control
2. Zone smoke control

Purging

The purging method is only applicable with central plant systems and requires that the air handler(s) serving the zone containing the fire floor are run to achieve an extract rate of 6 air changes per hour from all floors in the zone, with the air supply set to 50-85% of the extract rate. The extracted air (and smoke) is exhausted to outside the building. No attempt is made to treat the fire floor differently from any other floor.

Zone Smoke Control

Zone smoke control applies to either central plant or individual air handlers (floor by floor units, in this context). The standard requires that the firecell is kept at 20Pa below the surrounding areas and the exhaust rate achieved from the fire zone is at least 6 air changes per hour. This is achieved by selectively operating air control dampers on the various floors - on the fire floor the return air damper is opened and the supply air damper is closed. On non-fire floors, the opposite is done with the supply air dampers opened and the return air restricted. This ensures that the pressure of the fire zone is below that of the surrounding spaces.

The problem with using AS1668.1 as the means of compliance is that the methods of purging and zone control are only possible with central plant or floor by floor systems. The unitary systems (described in section 4 of this report) are incapable of the type of operation required to achieve either zone or purging control, as they do not move air into or out of the firecell but (mainly) recycle the air within it. As discussed in section

4, the only air introduced from outside is via the fresh air system, which is insufficient for the control regimes required by the standard.

It is also noted in the Literature Review section of this report that a purging system alone is not regarded as satisfactory for fire safety. The commentary to AS1668.1 acknowledges that purging is less effective than zone control, but the method is still included as it has the advantage of simplicity, which therefore also increases the reliability.

What alternative means of compliance are available?

NFPA 90A and 92A

In the USA, the documents NFPA 90A, "Standard for the Installation of Air Conditioning and Ventilating Systems" and NFPA 92A "Recommended Practice for Smoke Control Systems" [NFPA 1993] provide good general discussion of many HVAC system types, with sensible installation standards and describe pressure control methods similar to the zone control of AS1668, but in more general, performance based terms. The action recommended for unitary systems is to shut the system down.

The principal hindrance to the utilisation of the NFPA documents in New Zealand is that they cross-refer to NFPA or other US standards in many instances. They could however provide a base for formulating an alternative solution.

Shutting off

As an alternative to AS1668, the compliance method most often employed is simply to shut off the HVAC system when a fire alarm occurs, as was the normal practice since the 1930's. This is employed for all types of HVAC system – central plant and unitary.

In smaller buildings this is probably acceptable, but for tall buildings there is the possibility that shutting off the air conditioning will allow the natural air flows (due to stack effect) to assist smoke to travel to occupied areas remote from the fire, more than if the HVAC was not shut down. This was discussed further in Section 5

Recommendations

For tall buildings with suitable systems there is no doubt that active smoke management by zone control methods is the best solution, but for other (unitary) systems, the modelling discussed in Section 5 suggests that shutting off the HVAC may not be the best solution in all circumstances. In tall buildings with stair pressurisation systems, also keeping the outside (fresh) air system operating may assist in preventing smoke from entering remote floors via lift shafts and other vertical smoke paths.

The modelling discussed in Section 5 was not exhaustive and some of the basic design data necessary for an in-depth study is not available for New Zealand conditions. This is an area which could be the subject of more analysis.

The modelling also suggests that natural smoke movement around a low level multistorey building is due to driving forces which are small enough to be overcome by passive means (eg smoke seals on doors) whereas for taller buildings an active smoke management system is required. This leads to the conclusion that the Acceptable Solutions invoke Precaution 9 at levels which are generally reasonable, and that active smoke control using the HVAC system is probably unnecessary in lower buildings.

The author's recommendation is therefore that active smoke control measures should be put in place whenever Precaution 9 is invoked, but in other situations the shutting down of the HVAC is sufficient. Buildings with unitary systems that require active smoke control may need to have additional dedicated equipment to achieve this.

6.4.3 C3 Paragraph 7.1.1 "Cavity within firecells"

This paragraph states:

> *An upper cavity space acting as an air handling plenum (see Figure 14) may extend over more than a single lower space if all the following requirements are satisfied:*
>
> a) *The upper cavity space shall not extend into another firecell except as permitted in Para 7.1.2* {which requires fire-rated closures},
>
> *b) An automatic fire detection and alarm system is fitted throughout the firecell, with detectors in the cavity and in all return ducts,*
>
> *c) Detector activation automatically causes the ventilation system to switch from circulation to extract, as required by Para 9.6.1,*
>
> *d) The ceiling and its supports and surfaces within the cavity are non-combustible,*
>
> *e) Electrical wiring is laid in metal trays, and*
>
> *f) The SFI and SDI of any pipe insulation or acoustic insulation comply with the requirements of Table 4.*

The sketch accompanying this paragraph, (Figure 14, shown below as fig 6.2), is intended to clarify the requirements. Note that it specifically mentions <u>smoke</u> detectors, rather than the <u>fire</u> detectors included in the text, and also depicts a plenum supply, ducted return configuration which is very unusual. The result is that the figure confuses more than it clarifys.

Two possible objectives can be surmised for this paragraph –

(1) to prevent smoke from a fire in one occupied space being transported into another occupied space via the ceiling void and air handler, or

(2) to prevent smoke from a fire located in the cavity from being transported into the occupied spaces below.

The apparent principal objective of this paragraph can be deduced from the requirement that it applies only to cavities which extend over more than one lower space. The objective would therefore appear to be to prevent smoke spread from one room to another. However, the other requirements of non-combustible ceiling construction, pipe insulation SFI and SDI limits and electrical cable trays imply that a fire originating within the ceiling void is the danger.

For the purposes of this discussion, both possible objectives are examined.

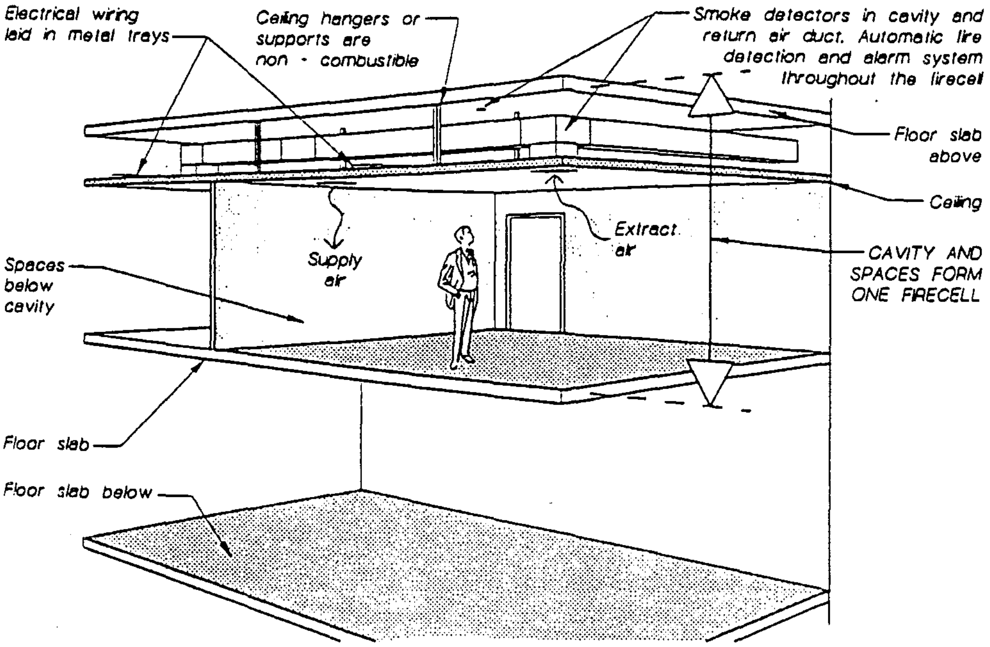

fig 6.2 - Figure 14 from Paragraph 7.1.1 of C3/AS1

(Note that this paragraph exceeds the performance requirements of clause C3, which requires that smoke spread between firecells is prevented. However, this paragraph seeks to prevent smoke spread between spaces within the firecell.)

What are the implications of this paragraph?

Ceiling plenums are commonly used as air return paths in both unitary and central plant systems. Strictly applying this paragraph requires that whenever the ceiling void is used in this manner and it covers more than one room below, then in-ceiling fire detection must be fitted (smoke detection, if fig 14 is strictly applied) even if the fire alarm standard NZS4512 does not require it. (Indeed, it is possible that the building did not previously have a requirement for an alarm system to be installed at all!)

Also, there is an implied requirement that the air system is to be capable of operating in an extract mode.

As it is more likely than not that an air system will include more than one room, it is very likely that the requirements of this paragraph will be invoked.

It also needs to be noted that the installation of smoke detection within a ceiling void is contrary to the recommendations of most alarm equipment suppliers, due to the frequency of false alarms caused by dust in these areas.

How can the requirement be complied with?

Apart from the installation of all the items listed in b) to f), the simplest method employed to comply with this requirement is to avoid using the ceiling plenum as an air return path and installing ductwork to carry the air back to the air handler. This can be a severe limitation on the HVAC system designer and has an obvious cost penalty in the additional ducting required (though possibly less so than items b to f) as well as significantly reducing the flexibility of the system to cater for altering uses of the spaces below.

It also does nothing to prevent the transport of smoke from one room to another via the air handler which was one of the deduced objectives of the paragraph.

It could also be argued that this will exacerbate the situation if a fire should start within the ceiling void, as detection will be delayed as there is possibly no detection system fitted and no way of the early fire effects being noticed by the occupants (eg a smell of smoke)

Are the objectives of the paragraph sensible?

In the author's opinion, the deduced objectives are sensible, but the method of execution is not.

Preventing the transport of smoke from one room to another via the air system is not achieved by this paragraph. As mentioned above, strict compliance is achieved by utilising a fully ducted system, but this does nothing to prevent the transmission of smoke. In fact it could be argued that it will exacerbate the situation by reducing the amount of dilution that would be achieved by the air passing through the much bigger ceiling void.

The danger of smoke from a fire originating within the ceiling void is real and would be diminished by the measures invoked. However, the danger is just as real whether the ceiling void covers more than one space or not. Also, as discussed in section 3.4, fires resulting from air conditioning equipment are very rare.

The question of provision of detectors within the ceiling void is, I believe, already adequately covered by NZS4512 (the fire alarm system standard) and NZS4541 (the sprinkler standard), but the requirements for non-combustible ceiling construction is sensible, as are the SFI and SDI requirements for materials used within the cavity.

The requirement for electrical wiring to be laid in metal cable trays is somewhat unnecessary and it should be sufficient that the wiring is adequately supported clear of the ceiling members and other equipment (eg on catenary wire) as is good trade practice anyway.

How could it be improved?

I believe the paragraph should clearly indicate the requirements for allowing the use of the ceiling void as an air path, regardless of whether it covers more than one lower space, but leave the provision of in-ceiling detection to the alarm or sprinkler standards, as appropriate.

My recommendation is to extend the scope to apply to all uses of the ceiling cavity as air handling paths, but to make the requirements reasonable. The wording of this paragraph should be amended to read:

> *An upper cavity space may be used as an air handling plenum if all the following requirements are satisfied:*
>
> a) *The upper cavity space shall not extend into another firecell except as permitted in Para 7.1.2,*
> b) *The ceiling and its supports and surfaces within the cavity are non-combustible,*
> c) *Electrical wiring is adequately supported clear of the ceiling members and other equipment, and*
> d) *The SFI and SDI of any materials used such as pipe insulation or acoustic insulation comply with the requirements of Table 4.*

6.4.4 C2 Paragraph 8.2 "Ventilation in enclosed exitways for purpose groups SC, SD, SR and SA"

This paragraph gives the requirements for opening areas for natural ventilation in exitways that serve more than one household suite, where *"pressurisation or mechanical ventilation is not provided"*. The requirements for pressurisation are well defined elsewhere in the Acceptable Solutions, but the difficulty that is introduced by this section is that it does not define the extent of mechanical ventilation which is adequate to substitute for natural ventilation.

Building Code clause G4 covers ventilation, and refers to NZS4303 "Ventilation for Acceptable Indoor Air Quality". This gives the minimum air flows which are to be delivered into a space to maintain reasonable conditions of freshness. For an internal corridor space such as an exitway this minimum is $0.25 l/s/m^2$, which equates to an air change rate of about 0.35 – 0.4 air changes per hour (based on a normal ceiling height of 2.4m). For comparison, continuously occupied spaces require fresh air rates of around 1.5 air changes per hour.

How does this compare with the ventilation that would be expected from the opening areas required by para 8.2?

The areas for natural ventilation which are called up by this section are:

Stairways – $1.5m^2$at both top and bottom, or 2.5% of plan floor area at each level

Horizontal paths – $1.5m^2$ or 5% of floor area, arranged so that approximately two thirds of the area is at the top.

To make some estimate of the natural air flow rates that would be achieved by these areas, a variety of stair heights, floor areas and internal/external temperature differences were modelled using CONTAM96 [Walton, 1993]. The resulting air flows are summarised in table 6.2, below. Air flows are given in both litres per second and air changes per hour.

The modelling indicates that the air change rates that would be expected due to the areas defined by section 8.2 significantly exceed the minimum requirements of NZS4303. Large temperature differences are probably unusual in most New Zealand locations, but even differences of 2 or 5 degrees are sufficient to induce air change rates of 4 to 10 changes per hour, if not more.

The conclusion reached is therefore that to attain equivalence with natural ventilation, any mechanical ventilation must achieve air change rates matching these. A rate of 4 changes per hour would seem to be a reasonable minimum, and the clause should be amended to include this.

	Temperature difference (internal to external)							
	21°C		11°C		5°C		2°C	
	l/s	Ac/h	l/s	Ac/h	l/s	Ac/h	l/s	Ac/h
2 level stair, 2x1.5m² vents	1300	48.8	920	34.5	610	22.9	380	14.3
3 level stair, 2x1.5m² vents	1700	42.5	1200	30.0	820	20.5	510	12.8
5 level stair, 2x1.5m² vents	2300	34.5	1600	24.0	1100	16.5	670	10.1
2 level stair, 2x2.5% vents	360	13.5	260	9.8	170	6.4	110	4.1
3 level stair, 3x2.5% vents	520	13.0	370	9.3	240	6.0	150	3.8
5 level stair, 5x2.5% vents	1200	18.0	860	12.9	570	8.6	350	5.3
Horizontal, 1.5m²	500	24.0	350	16.8	230	11.0	140	6.7
Horizontal, 5%	800	23.0	560	16.1	370	10.7	230	6.6

Fig 6.3, Corridor/stairway air flows due to natural ventilation

7. CONCLUSIONS

In many fires, the fatalities that occur are often due to the effects of smoke rather than from direct contact with the fire. HVAC systems in multistorey buildings can be used to actively manage the smoke produced by a fire, but they can equally be instrumental in transporting smoke to areas which endanger the occupants, if the HVAC controls respond inappropriately to the alarm. An understanding of both the nature and volumes of smoke produced and the characteristics of various HVAC systems is vital for the Fire and HVAC Engineers to work together to build safe systems.

This report has described some simple equations to enable the HVAC Engineer to appreciate the large volumes of smoke that can be produced by even relatively small fires.

For the benefit of the Fire Engineer, the various types of HVAC systems that are commonly found in New Zealand multistorey buildings have been described, with an emphasis on how the systems may be appropriate in a smoke control situation. The systems have been generally categorised as 'Unitary' or 'Central Plant', depending on their ability to deliver air from outside the occupied space or firecell.

Particular aspects of the Building Code Acceptable Solutions that are relevant to HVAC systems in multistorey buildings have been discussed, concentrating on aspects which are not particularly clear in their application or objectives. Specific recommendations for amendments to the current Acceptable Solutions are:

C3/AS1 clause 9.6

This clause is confusing because (at first glance) it is intended to stand alone, as do the other clauses in section 9 of C2/AS1. However, on examination it does not make sense unless it is read as a continuation of the previous clause. The recommendation is that the text is made to be clearly part of the preceding clause by a simple renumbering.

C3/AS1 clause 9.7

As the main clause covering the fire behaviour of HVAC systems in multistorey buildings, this clause only states that AS1668.1 may be used as a means of compliance. It does not make compliance with AS1668.1 mandatory, nor are other options given, and it is not even clear whether the clause applies to all HVAC systems or only when precaution 9 has been invoked by the Fire Safety Annex. A frequently used option is to simply shut the HVAC down on a fire alarm.

Computer modelling of air flows in typical buildings suggests that active smoke control is necessary in buildings for which precaution 9 is required (generally tall buildings), but for smaller buildings the shutting off of the HVAC is probably sufficient. Active control could be compliance with AS1668.1 or NFPA90A and 92A. For tall buildings fitted with unitary type systems some form of separate smoke control equipment will probably be required, as the HVAC plant is likely to be incapable of providing the air flows necessary.

The modelling also suggests that for buildings fitted with stair pressurisation systems there may be some merit in not shutting off the HVAC, to assist in preventing smoke from using lift shafts and other risers to enter floors remote from the fire. This is an area where further data and analysis is required before definitive conclusions can be reached.

C3/AS1 clause 7.1.1

Clause 7.1.1 contains requirements for concealed (ceiling) spaces that extend over more than one lower space if they are to be used as air handling plenums. The objective of the clause is not clear and the requirements are (in the author's opinion) excessive. The recommendation is that the clause is re-written to give a clear objective and to provide reasonable requirements. A suggested revision to the text is given.

C2/AS1 clause 8.2

This clause contains a requirement that natural ventilation to exitways should

> be provided when no pressurisation or mechanical ventilation exists. The criteria for pressurisation are well defined but equivalent rates of mechanical ventilation are not defined anywhere. Computer modelling was carried out to assess the air change rate that the specified natural ventilation areas would achieve under a variety of ambient conditions.
>
> The modelling indicates that an air change rate of at least four changes per hour would be achieved by natural ventilation. The clause should be amended to require natural ventilation if neither pressurisation nor mechanical ventilation <u>of this air change rate</u> is provided.

The results of some computer modelling of air flows around typical multistorey buildings are presented in Section 5. The modelling indicates that the normal HVAC airflows may be suitable to influence smoke flows under some conditions, but it is dependent on accurate data on building element leakage rates. The data that is available on building elements is sparse, and none of it applies specifically to New Zealand conditions and building techniques. This is an area of further research that would be very useful to pursue.

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APPENDIX A – LIST OF FIGURES

APPENDIX B – MODELLING RESULTS

The graphs that follow give the air flows and pressures calculated for the various building configurations and conditions discussed in Section 5. The air flows are in litres per second and the pressure differentials are in Pascals. The modelling was carried out using "CONTAM96" [Walton, 1993]

In all cases the sign conventions used are positive air flows are from the occupied space into the riser shafts and positive pressure differences result in positive air flows. Level 1 is the ground floor.

A complete discussion of the modelling carried out is in Section 5, but in summary, the features which were kept common to all of the buildings were:

- Floor plate size – each floor was kept at 800m^2 with a perimeter of 120m (ie a 30m square building with a 100m^2 core).
- Floor to floor height of 3.5m.
- Stairwell – each building had a stair core of 16m^2 and a perimeter of 16m, with the ground level stair doors opening to outside.
- Lift core – each lift car was taken as occupying a 3x3m space (ie a three lift group took up 27m^2 and had a perimeter of 24m).
- Roof – at the roof level of each building was a lift machine room (LMR) and the top of the stairwell. The LMR floor area was four times the size of the lift shaft below. Each lift had a 0.09m^2 rope penetration to the shaft below and the LMR was linked to the stairwell by a single door. The stairwell also had a single door to the outside.
- On the ground floor, two doors went to the outside and also the stairwell was linked to the outside by two doors.
- The building fabric was taken as being of 'average' construction tightness as defined by Klote [1995], except for roof LMR construction which was taken as being 'loose'. A limited series of calculations were also performed for 'tight' construction.
- Stair doors were taken as having a 3mm crack all round, with lift doors and ground floor entry doors having a 6mm gap all round.

Interior temperatures were set at 21°C (normal for office environments) with external temperatures of -4°C except for one set of calculations with a 29°C external temperature.

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9. 3 storey building, stair pressurisation only
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12. 20 storey building, stair pressurisation only
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17. 10 storey building, stack effect only, tight construction
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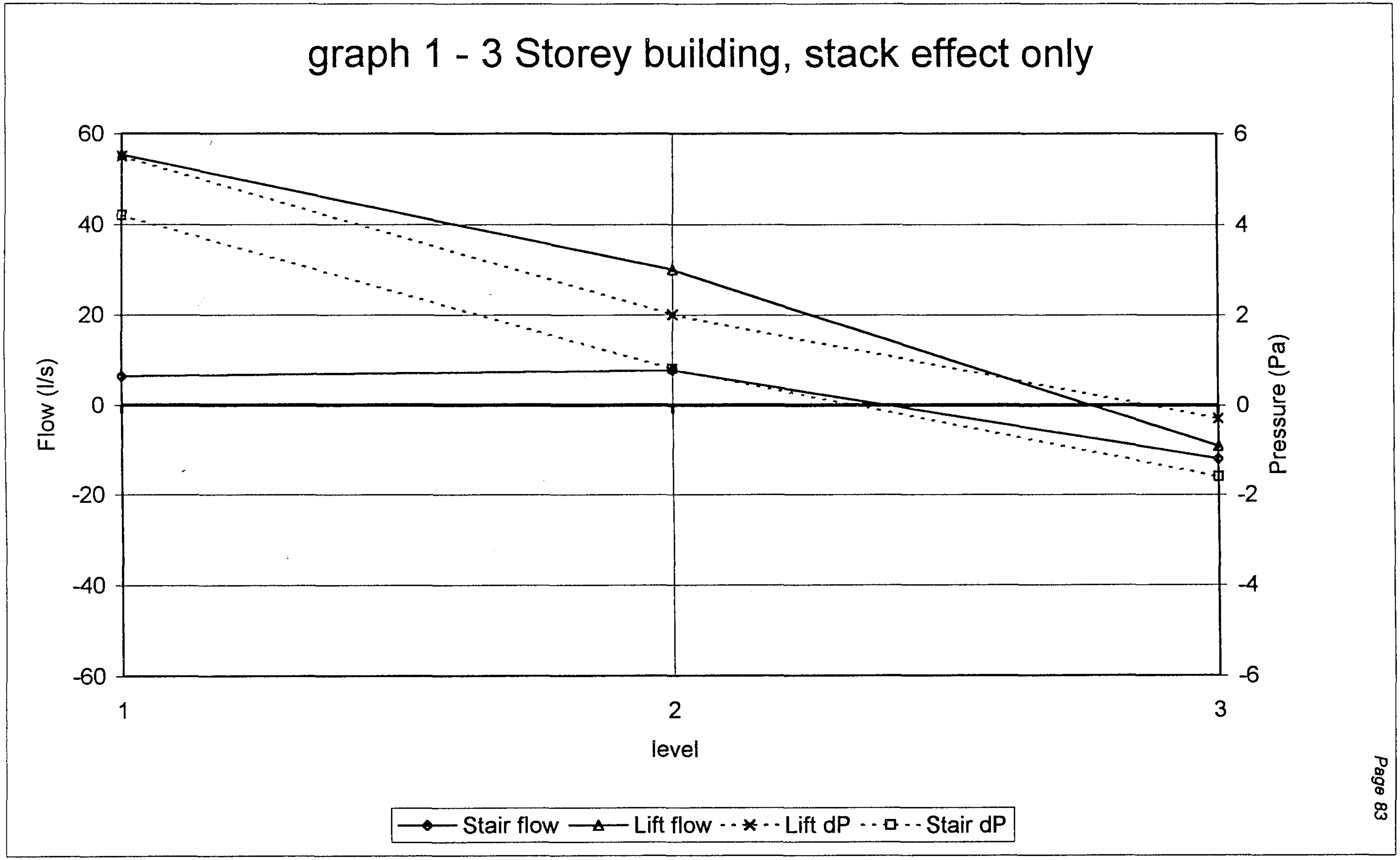
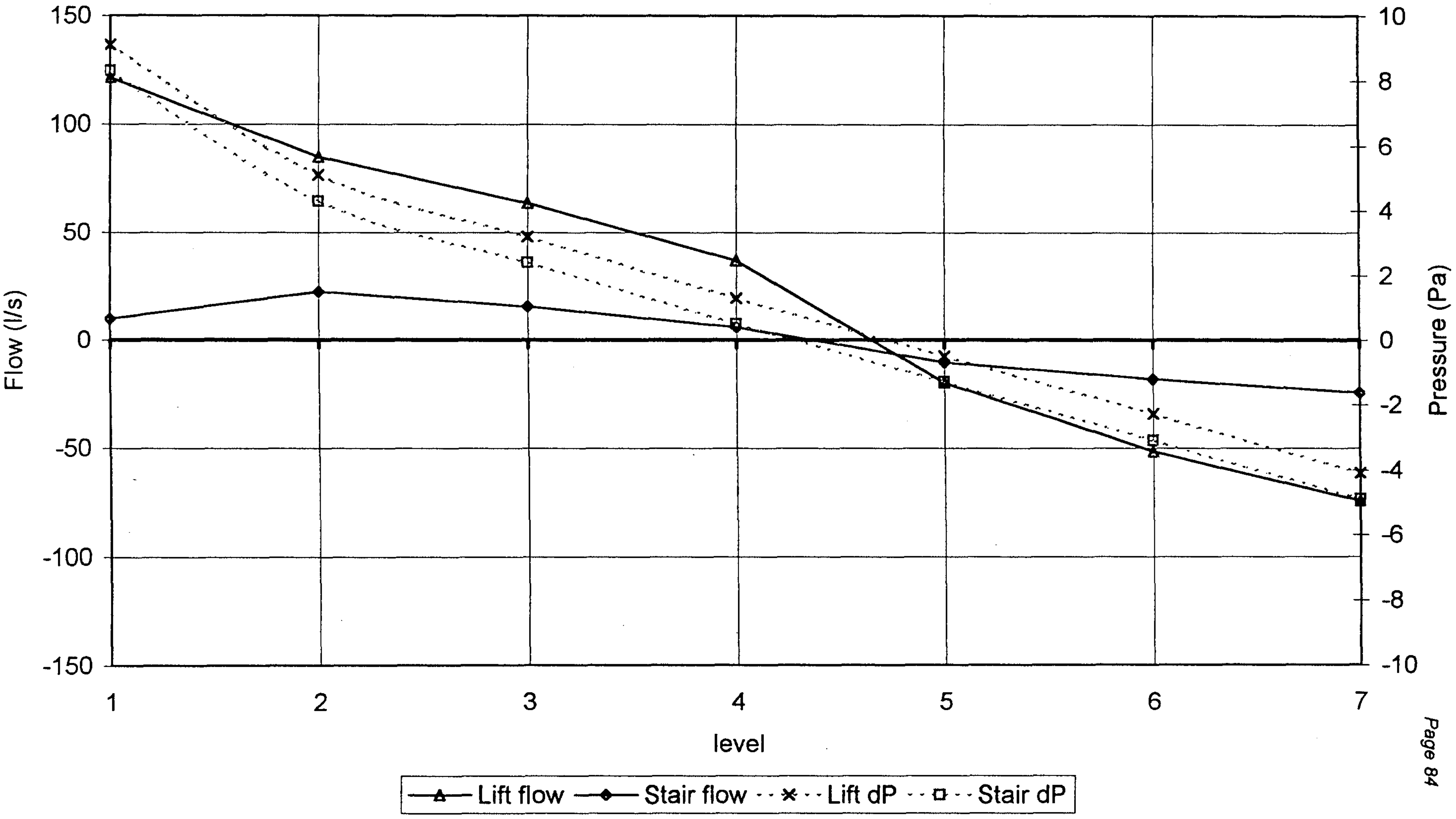
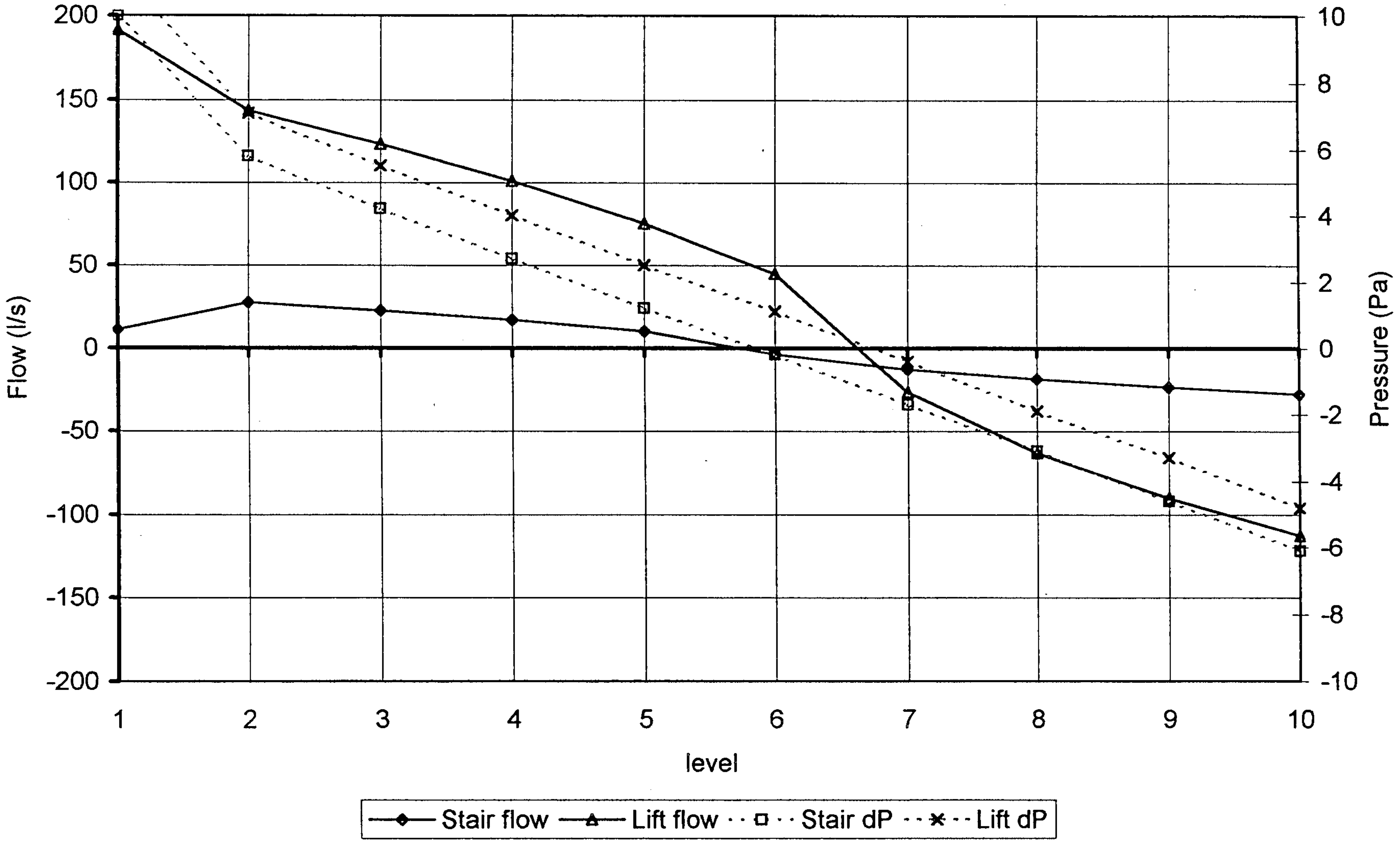
21. 10 storey building, stack effect only, 29 degree outside ambient
22. 10 storey building, fresh air only, 29 degree outside ambient
23. 10 storey building, stair pressurisation only, 29 degree outside ambient
24. 10 storey building, fresh air and stair pressurisation, 29 degree outside ambient



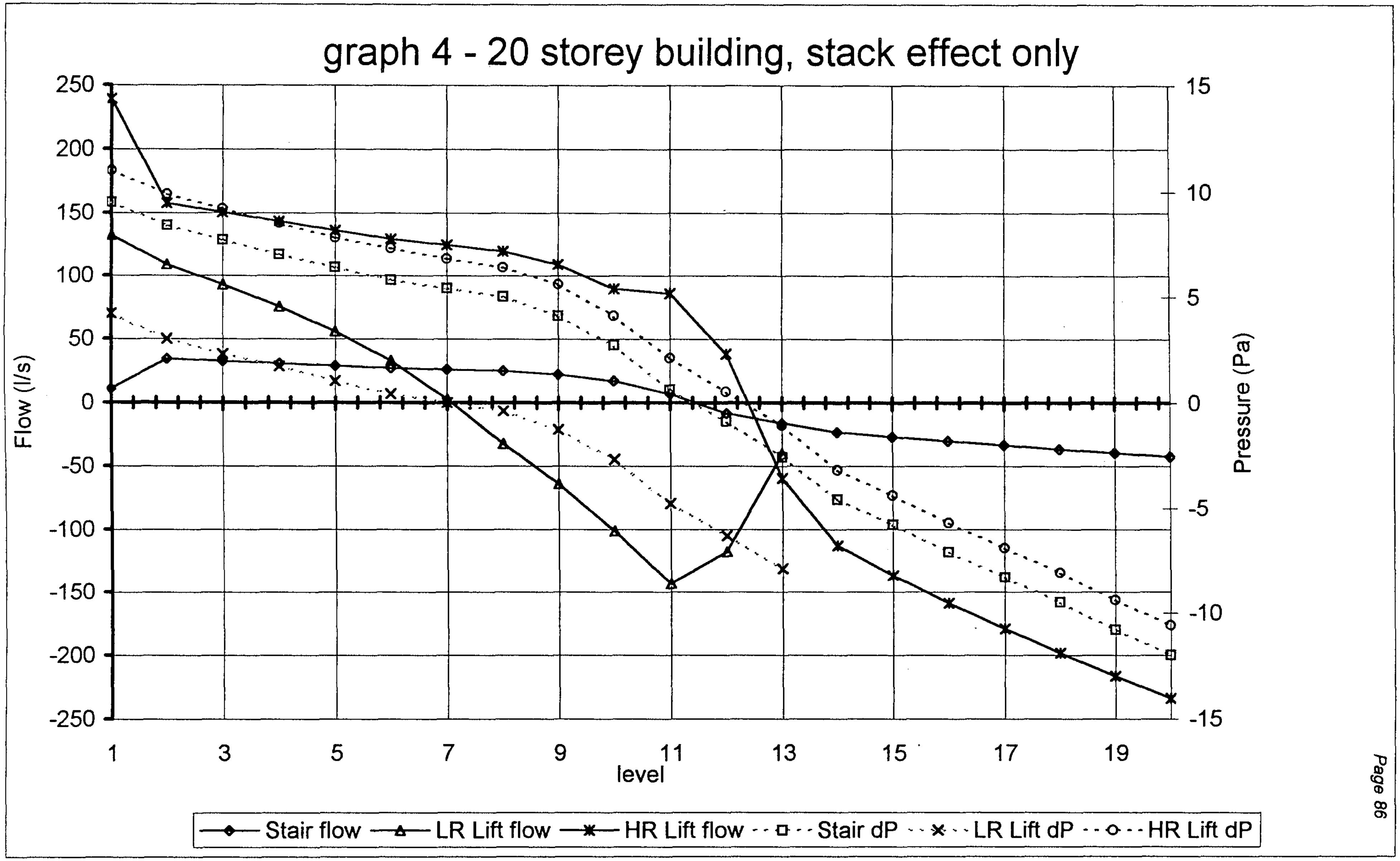
graph 1 - 3 Storey building, stack effect only

graph 2 - 7 storey building, stack effect only

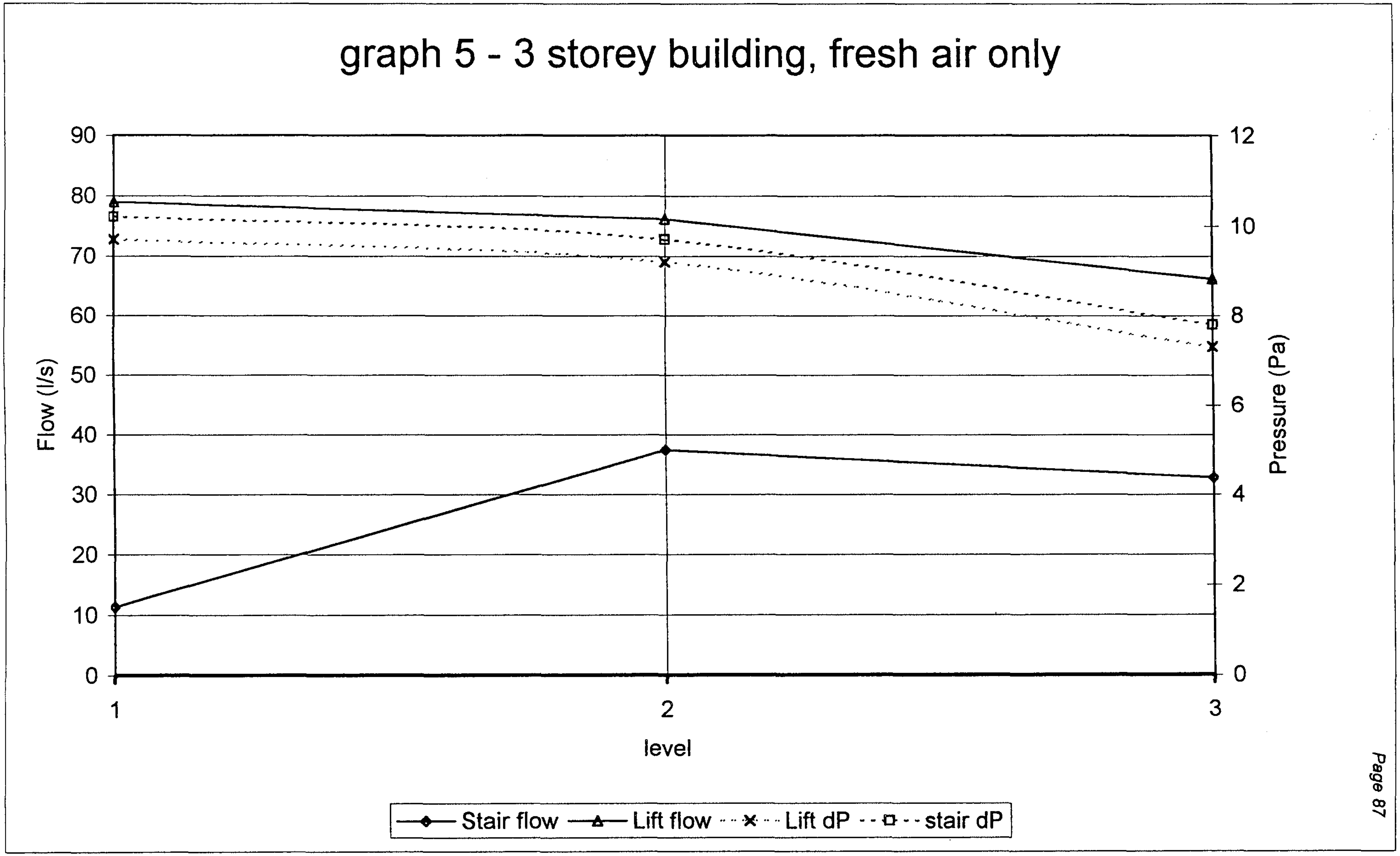


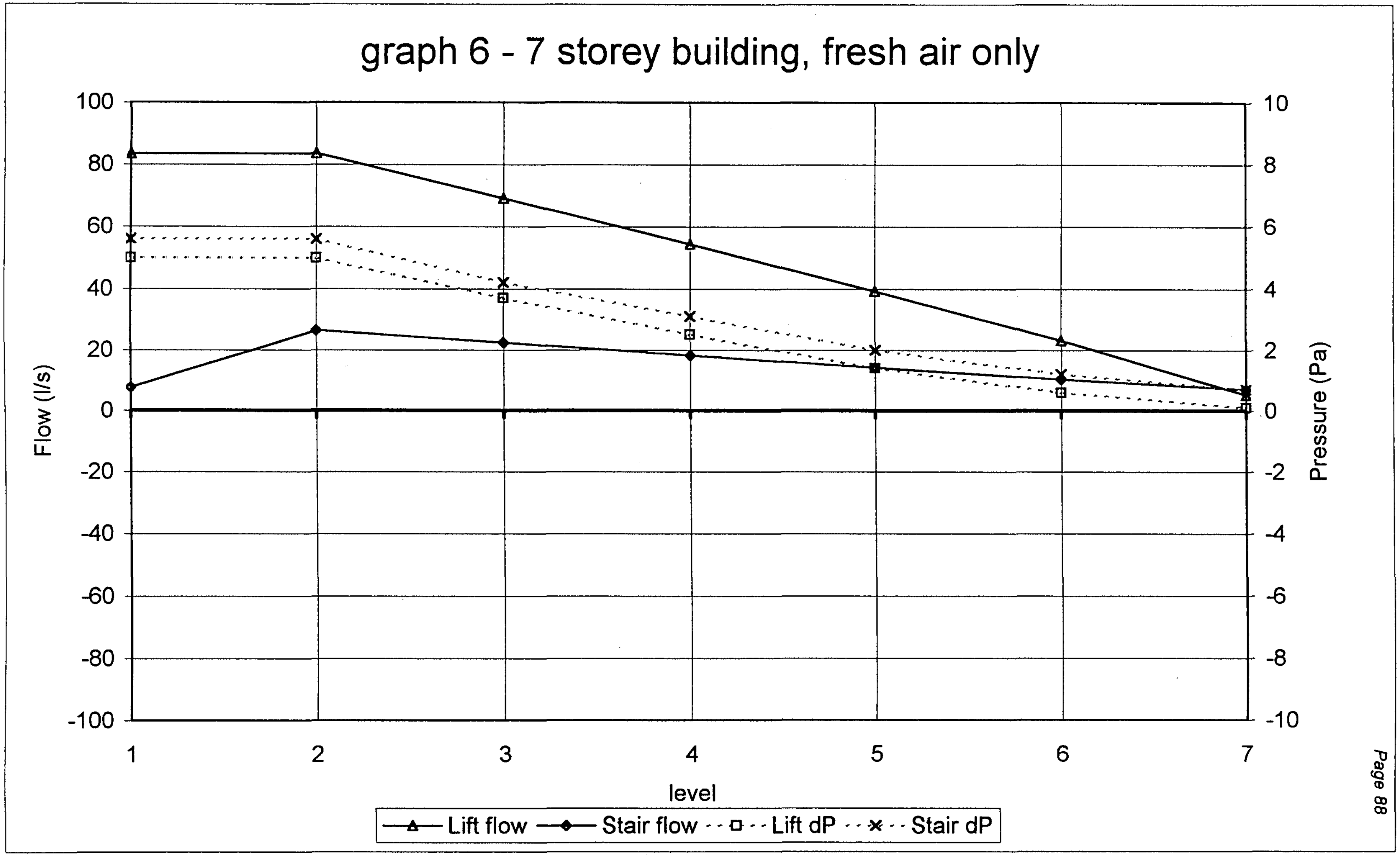


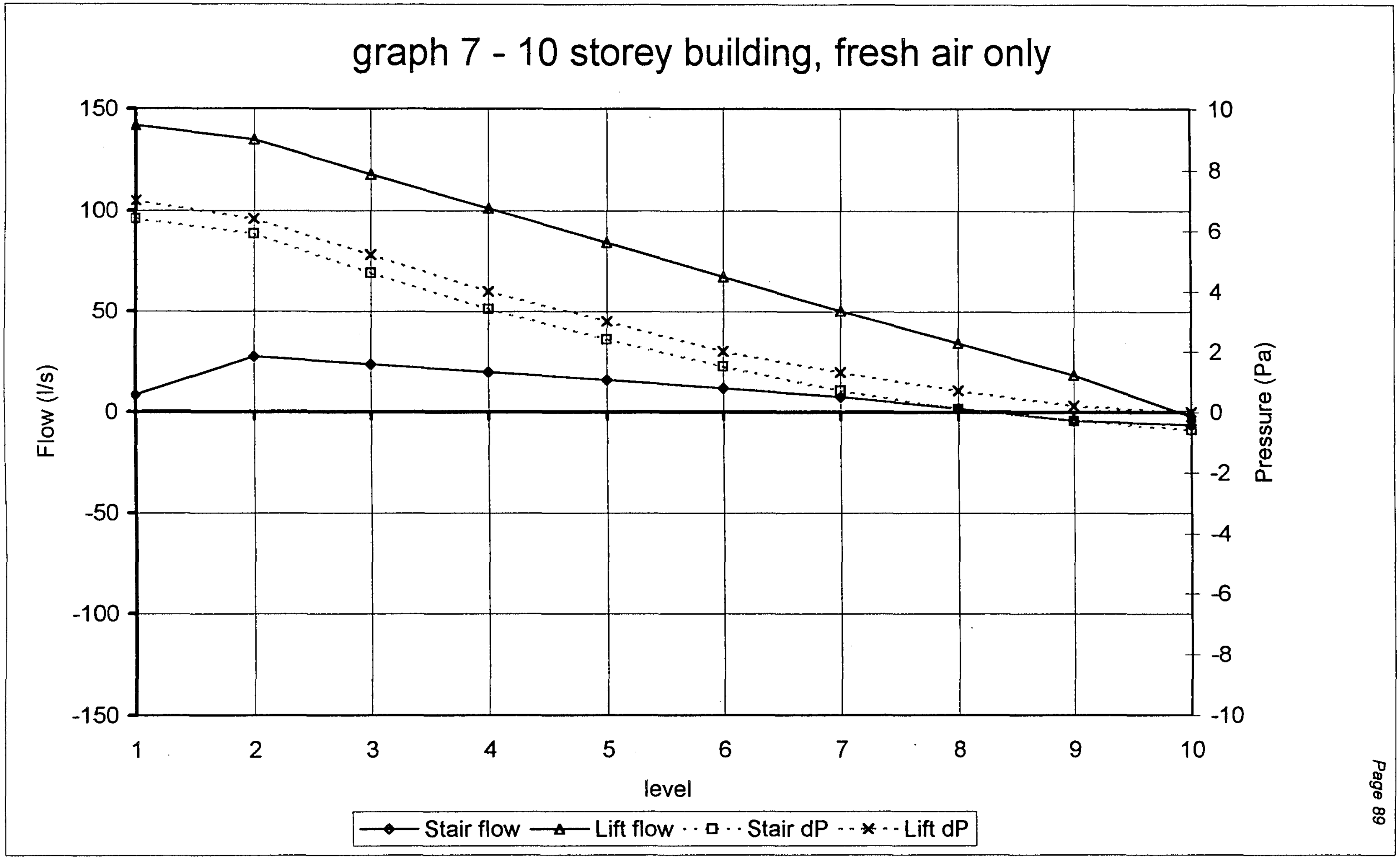
graph 3 - 10 storey building, stack effect only



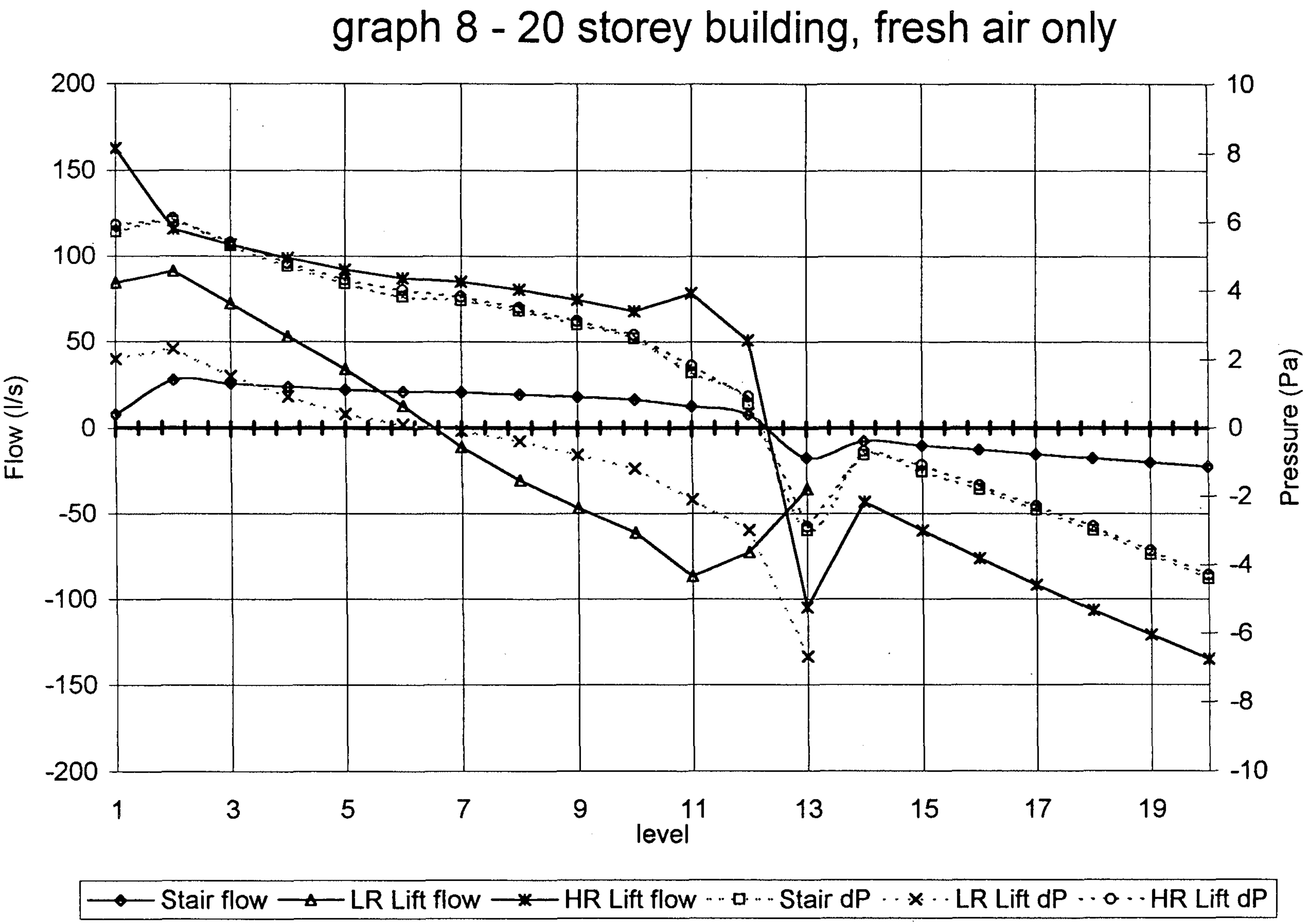
graph 4 - 20 storey building, stack effect only


graph 5 - 3 storey building, fresh air only

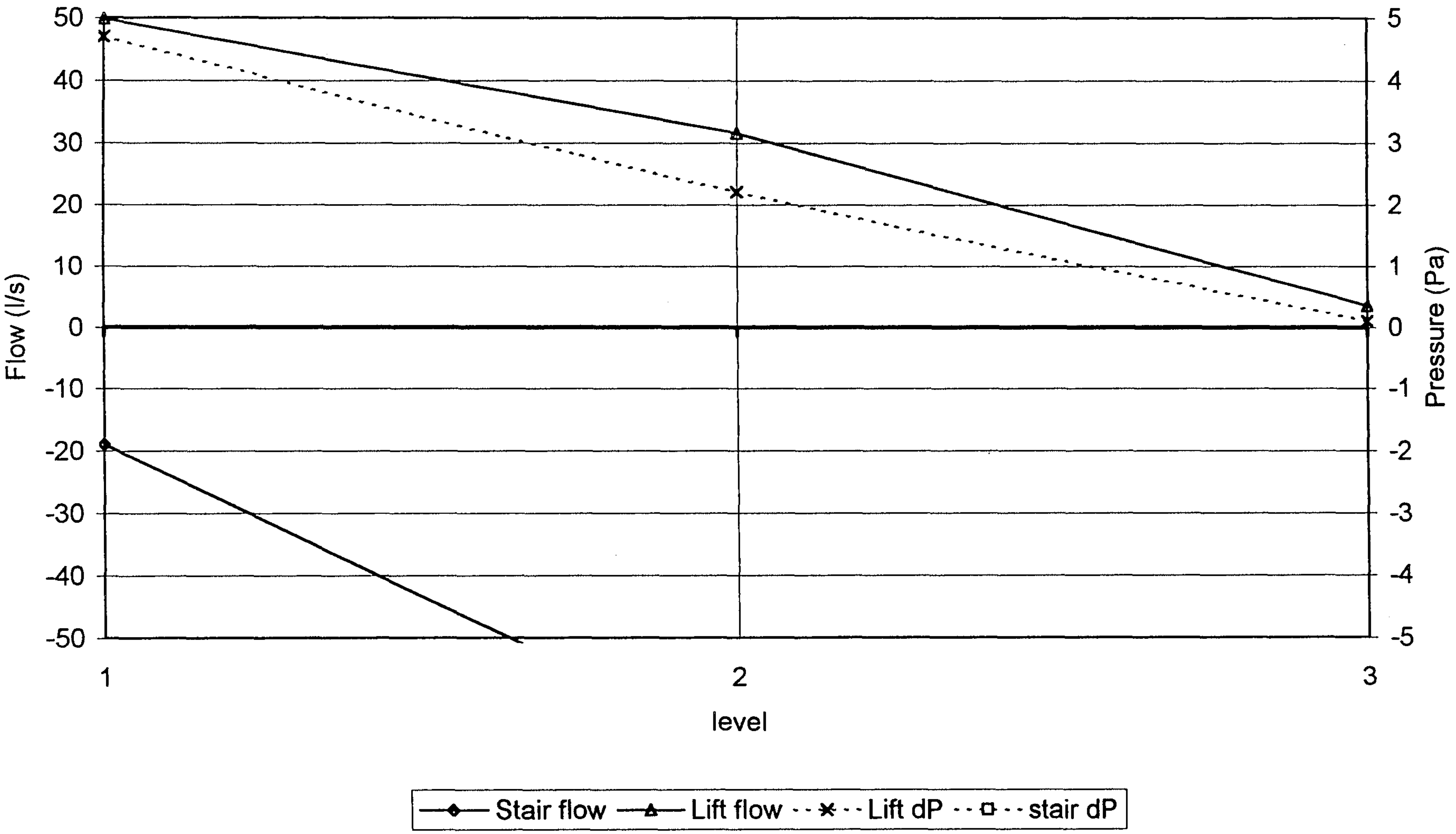

graph 6 - 7 storey building, fresh air only

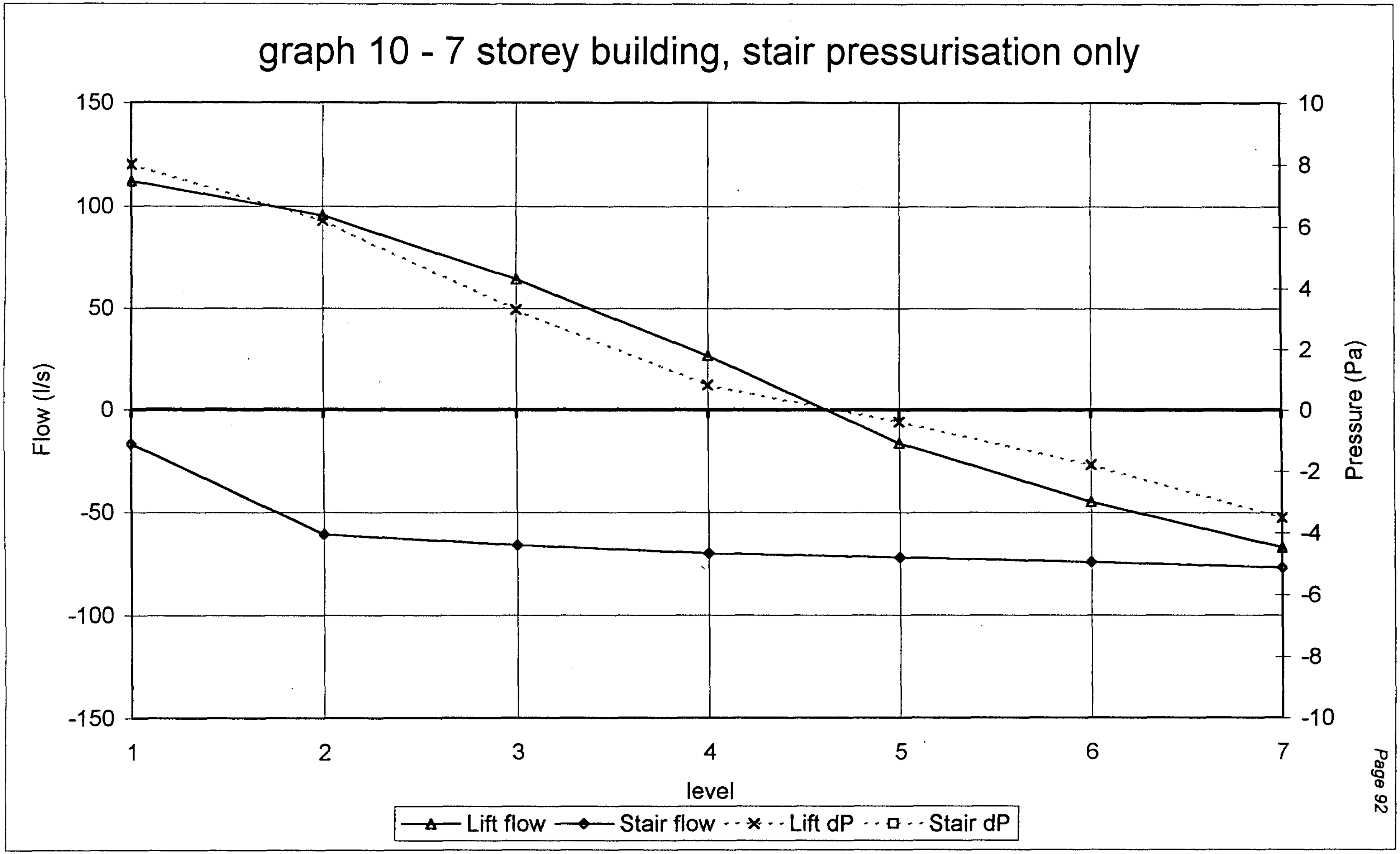


graph 7 - 10 storey building, fresh air only


graph 8 - 20 storey building, fresh air only
Flow (l/s)
200
150
100
50
0
-50
-100
-150
-200
Pressure (Pa)
10
8
6
4
2
0
-2
-4
-6
-8
-10
1
3
5
7
9
11
13
15
17
19
level
Stair flow
LR Lift flow
HR Lift flow
Stair dP
LR Lift dP
HR Lift dP

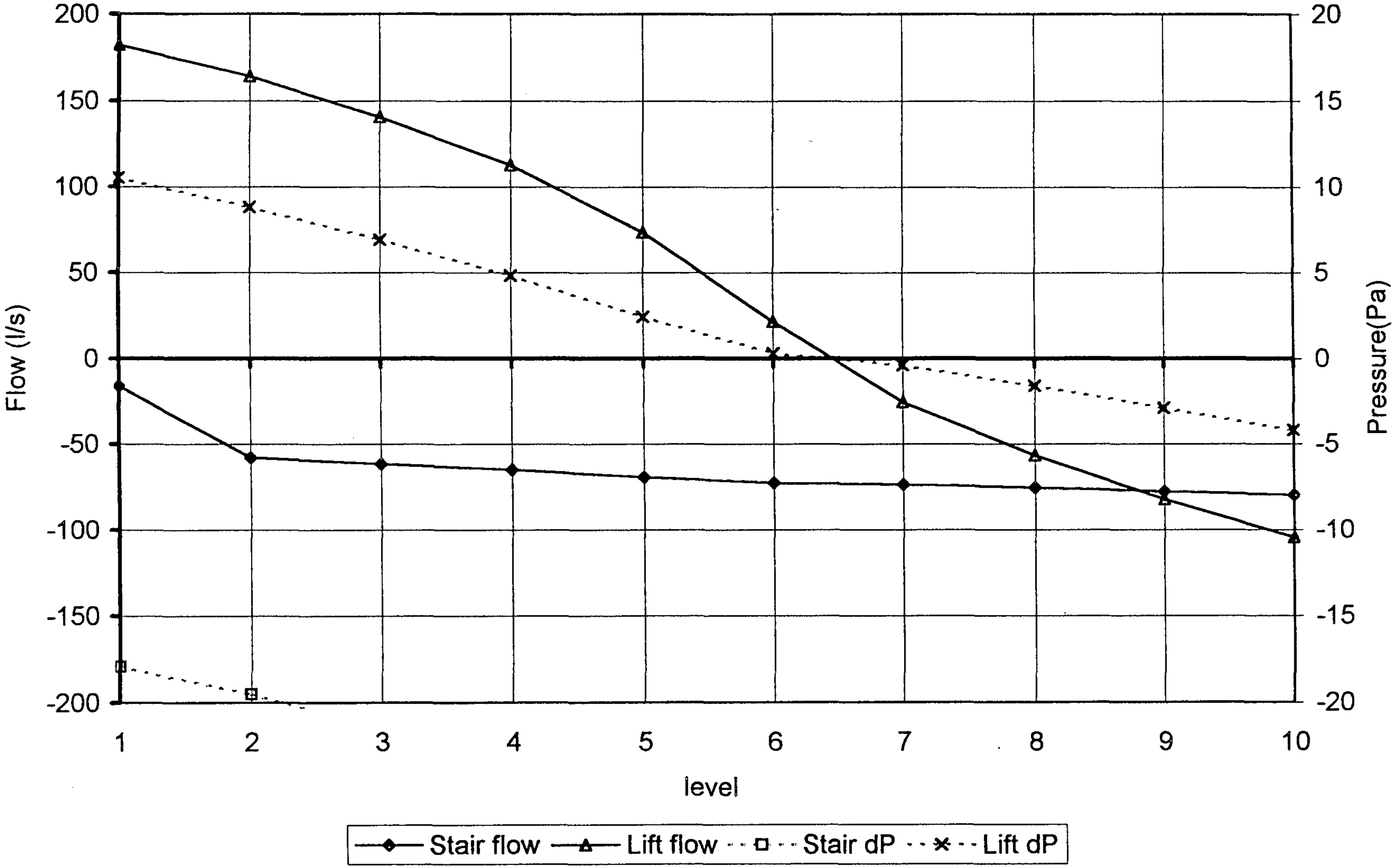
graph 9 - 3 storey building, stair pressurisation only



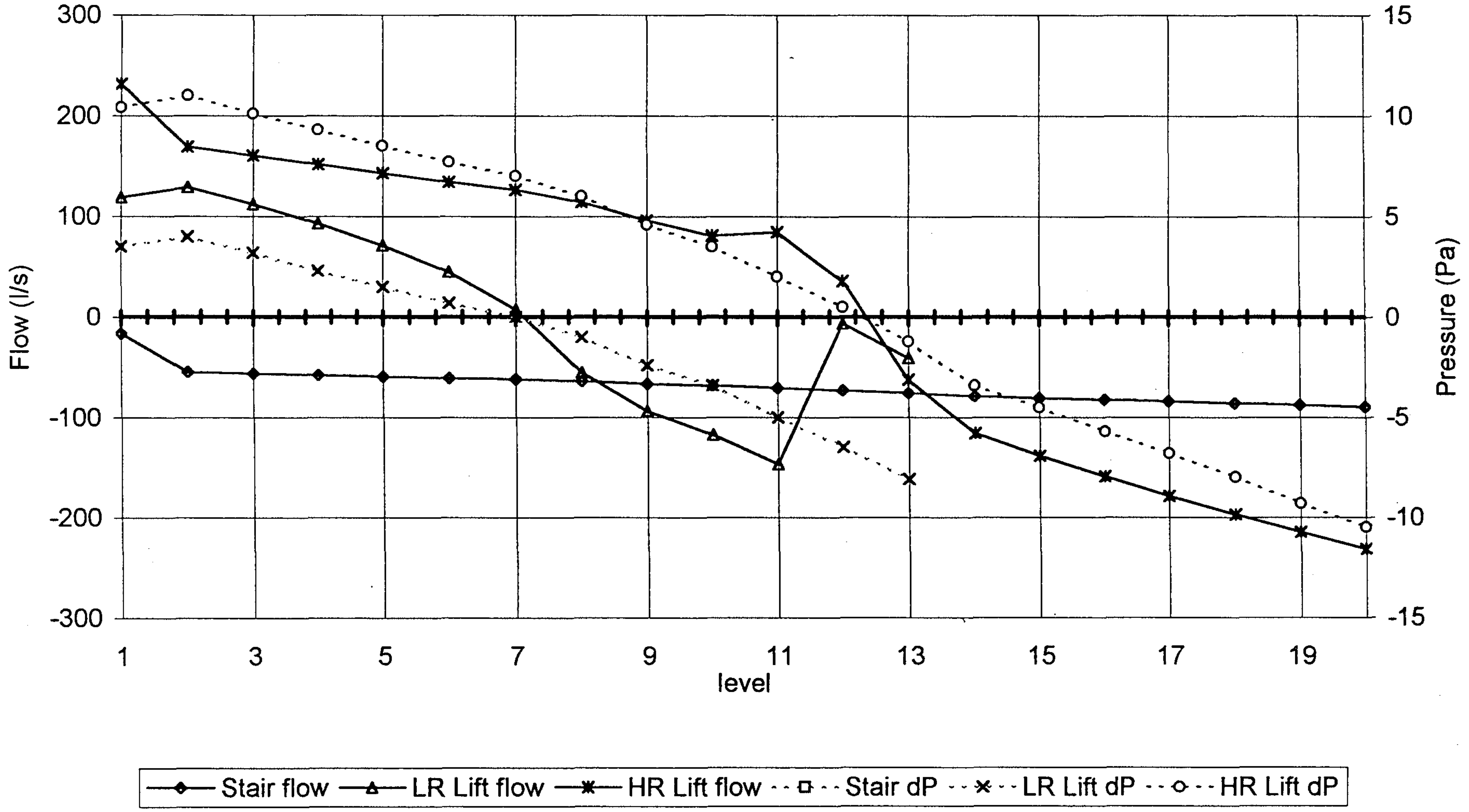


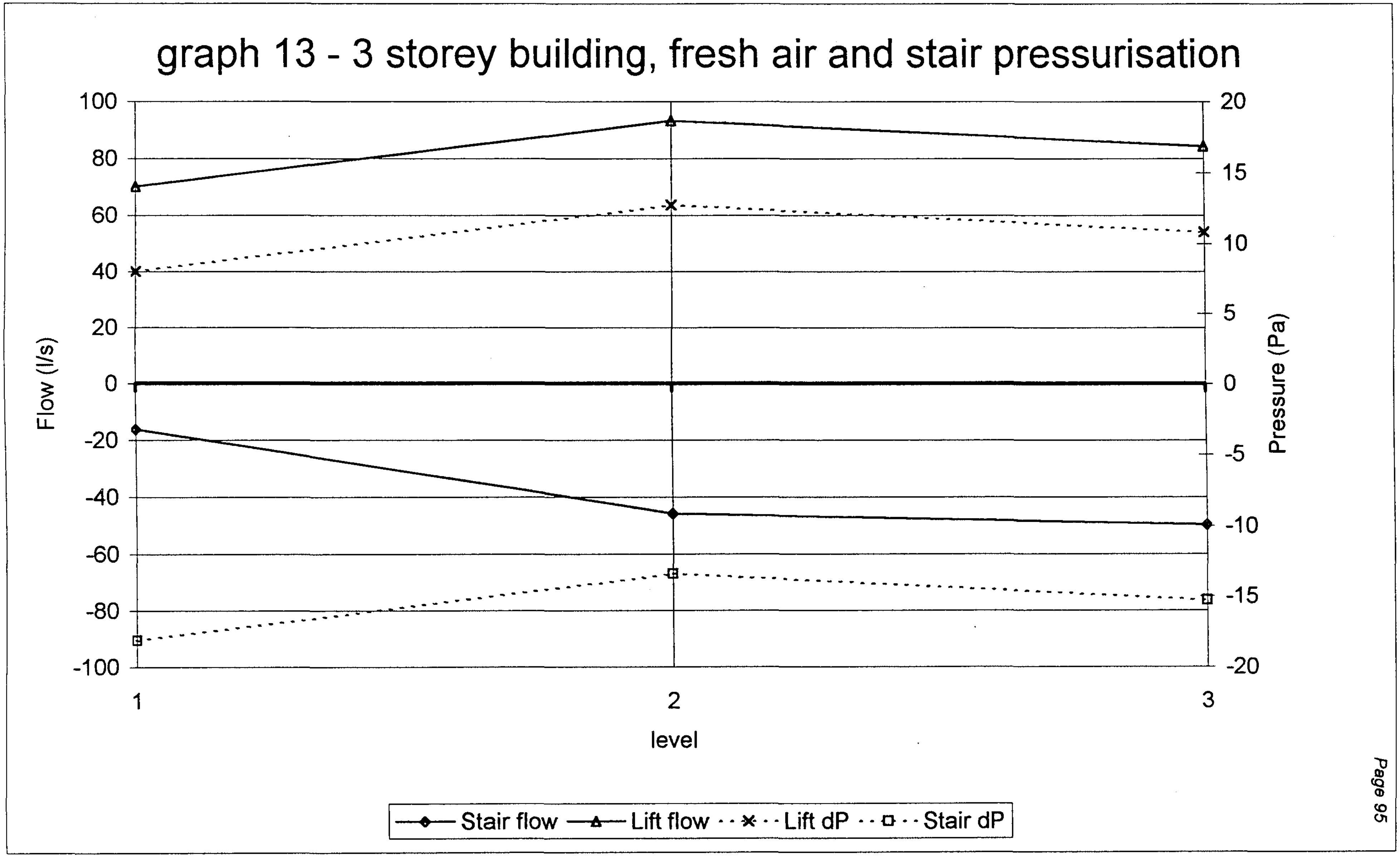
graph 10 - 7 storey building, stair pressurisation only

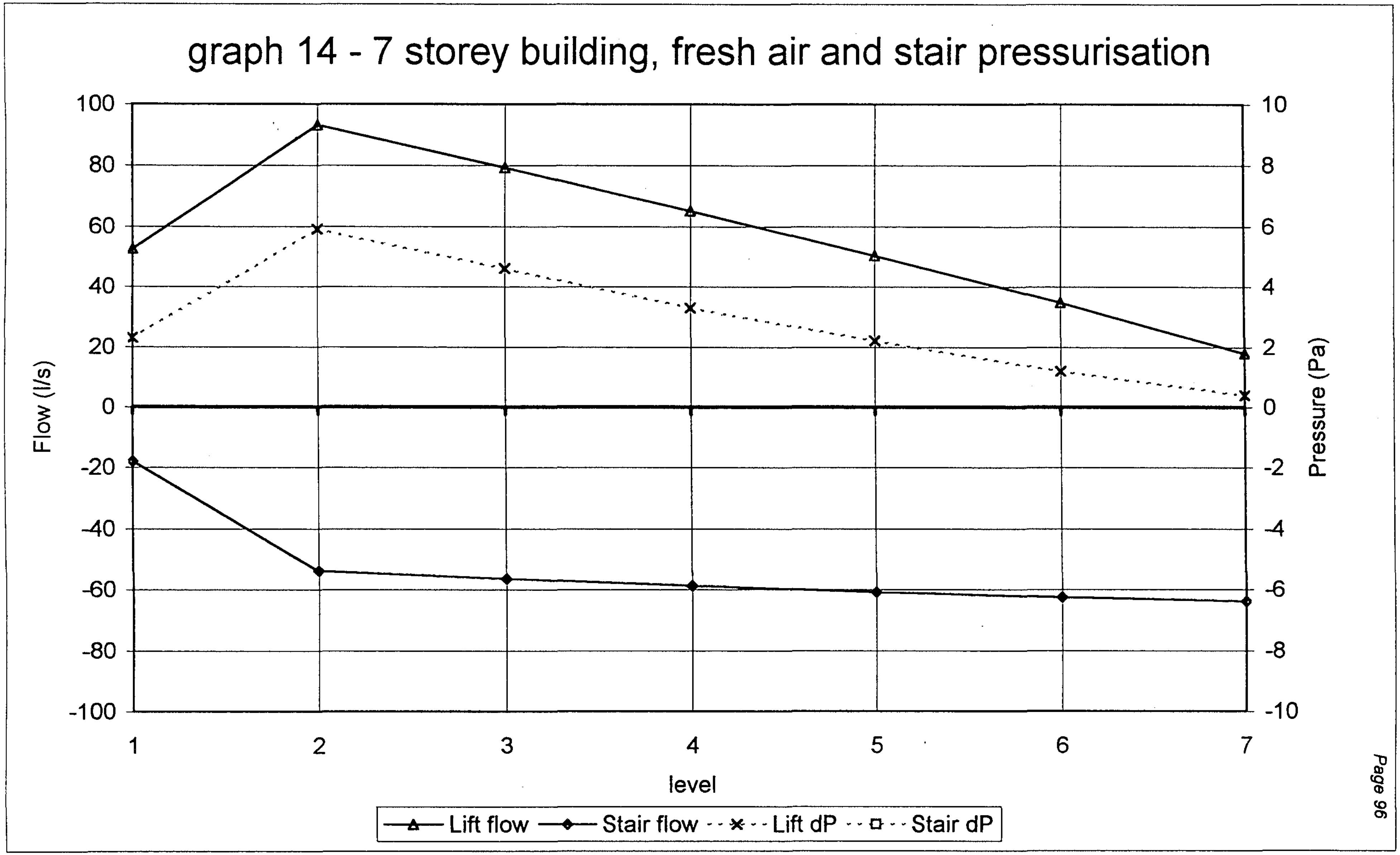
graph 11 - 10 storey building, stair pressurisation only



graph 12 - 20 storey building, stair pressurisation only

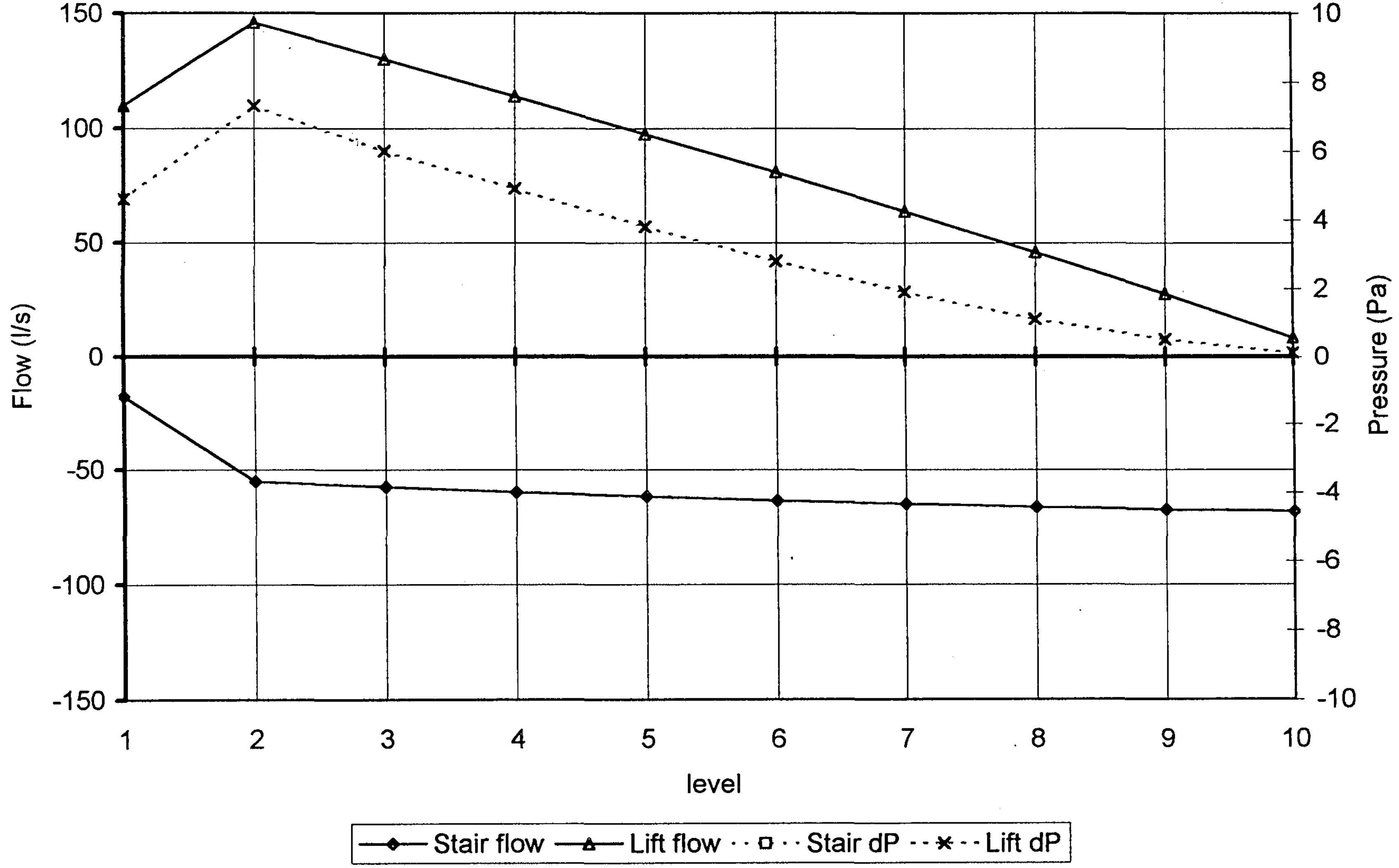


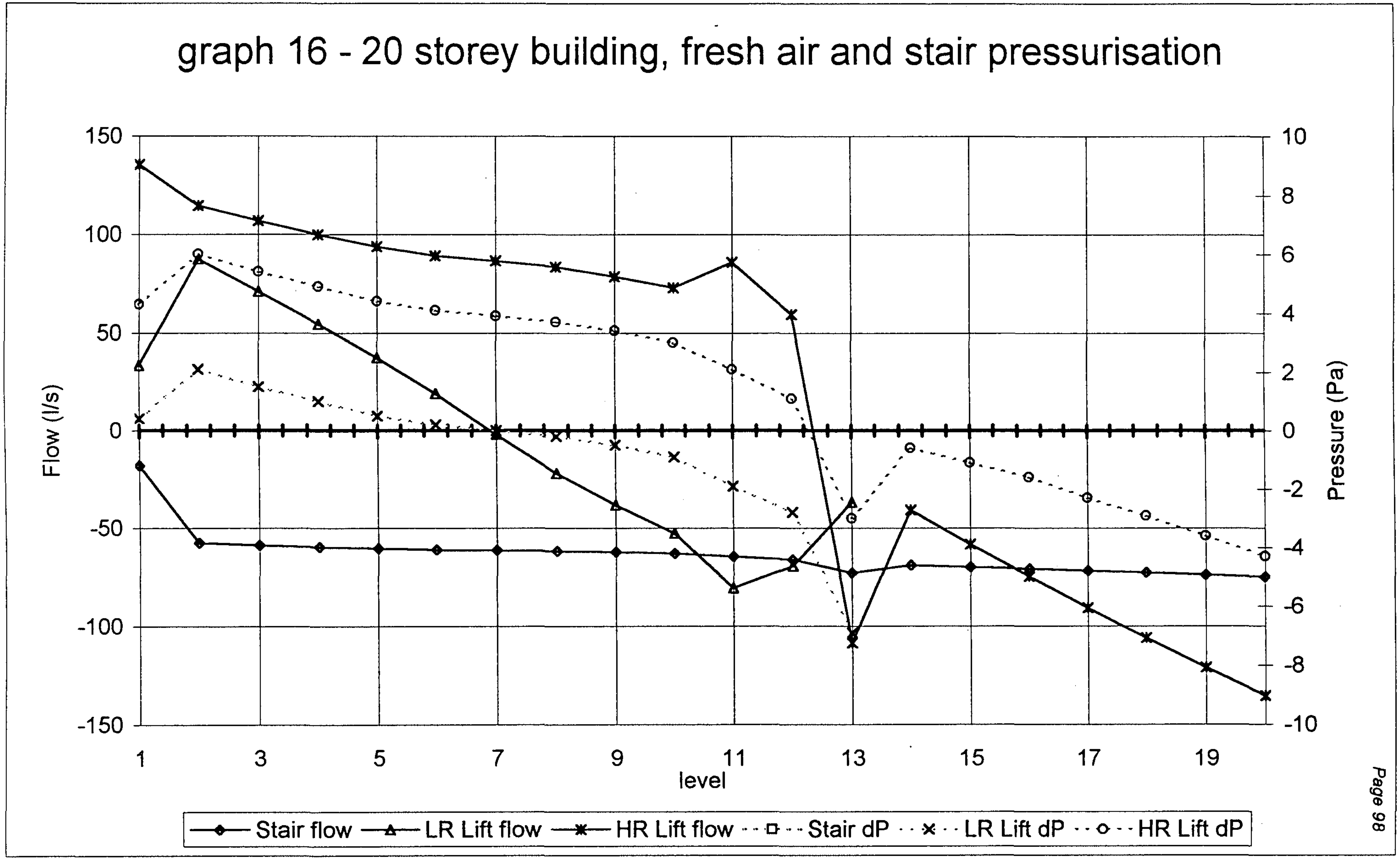

graph 13 - 3 storey building, fresh air and stair pressurisation



graph 14 - 7 storey building, fresh air and stair pressurisation

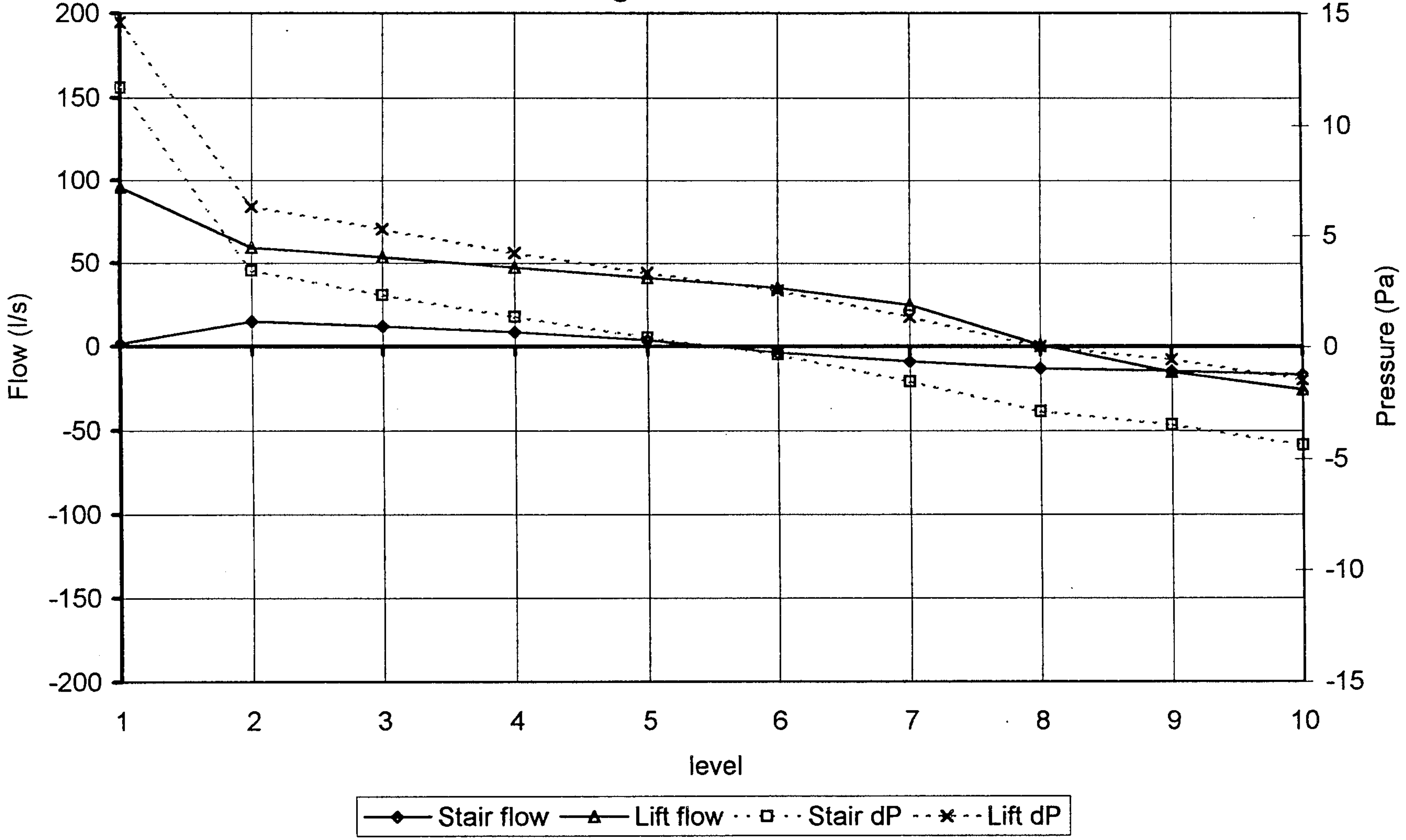
graph 15 - 10 storey building, fresh air and stair pressurisation



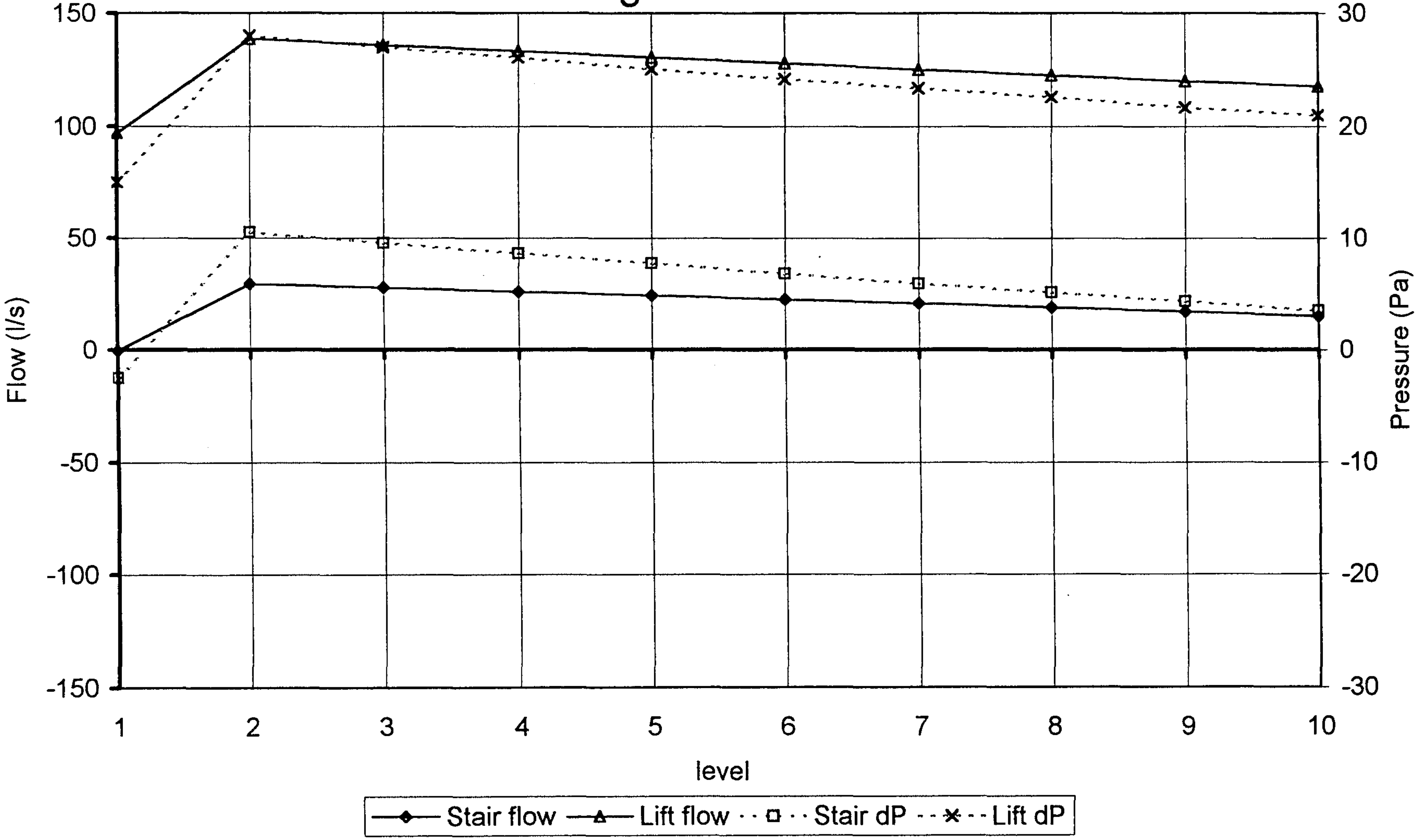


graph 16 - 20 storey building, fresh air and stair pressurisation

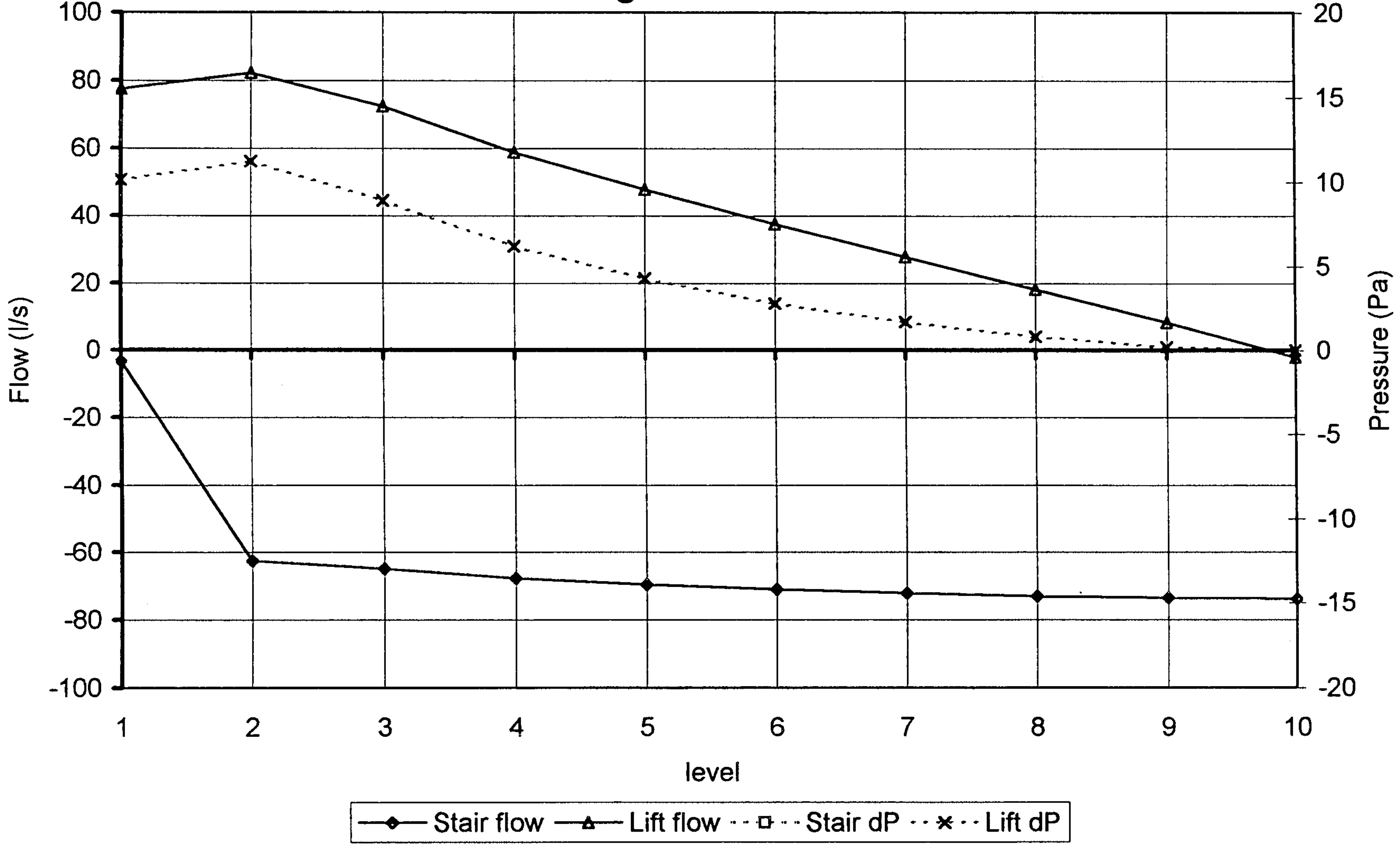
graph 17 - 10 storey building, stack effect only, tight construction



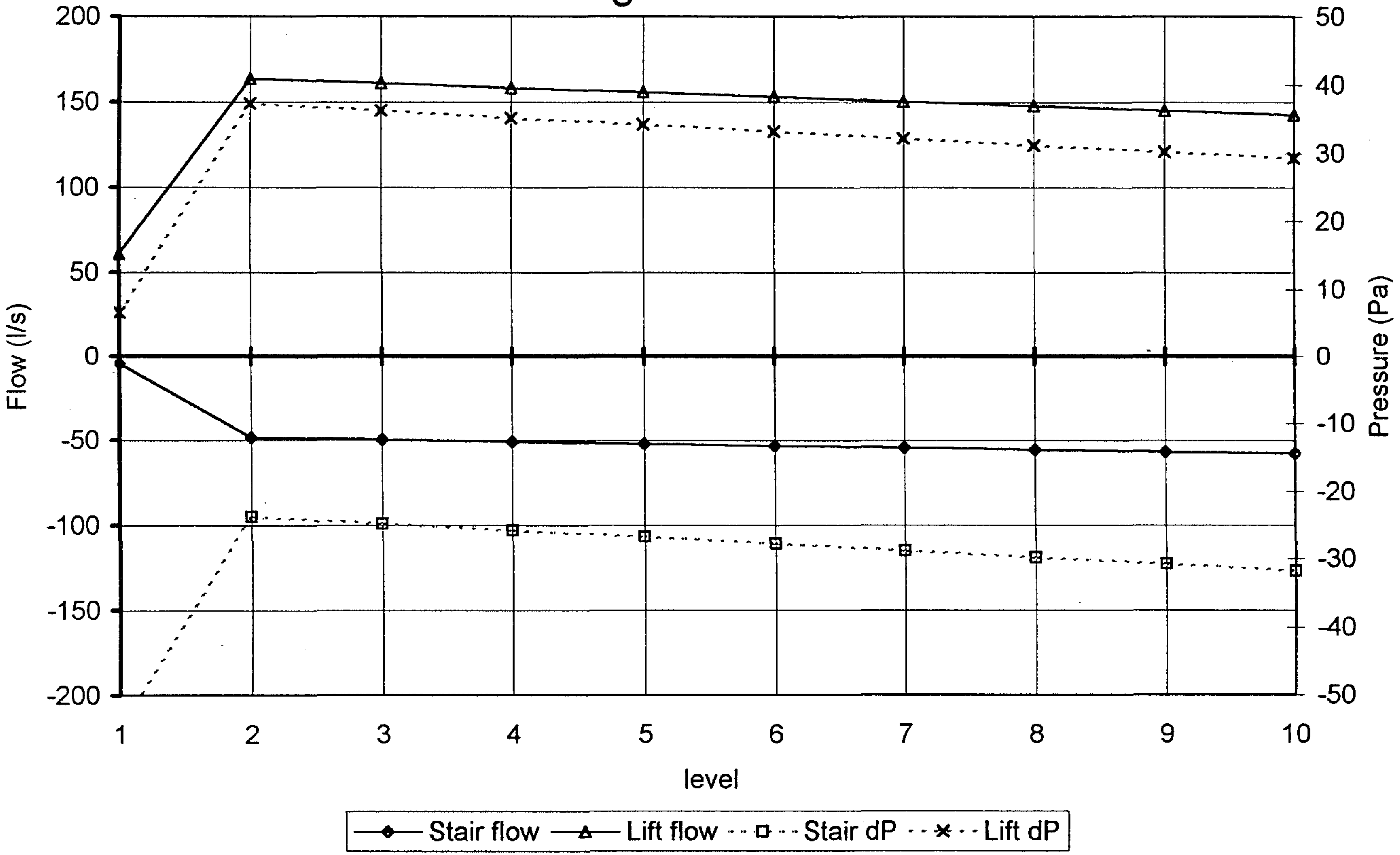
graph 18 - 10 storey building, fresh air only, tight construction



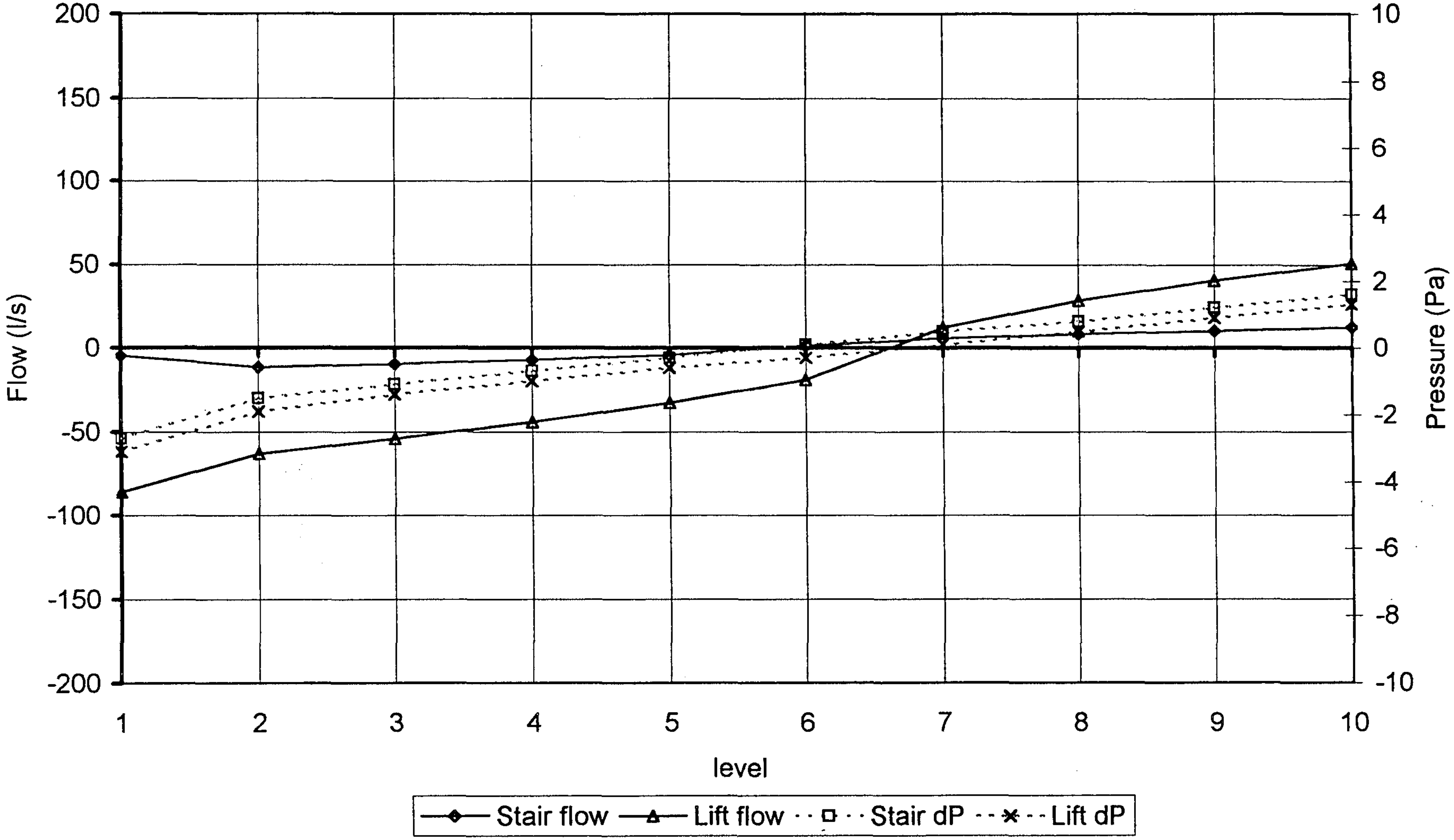
graph 19 - 10 storey building, stair pressurisation only, tight construction

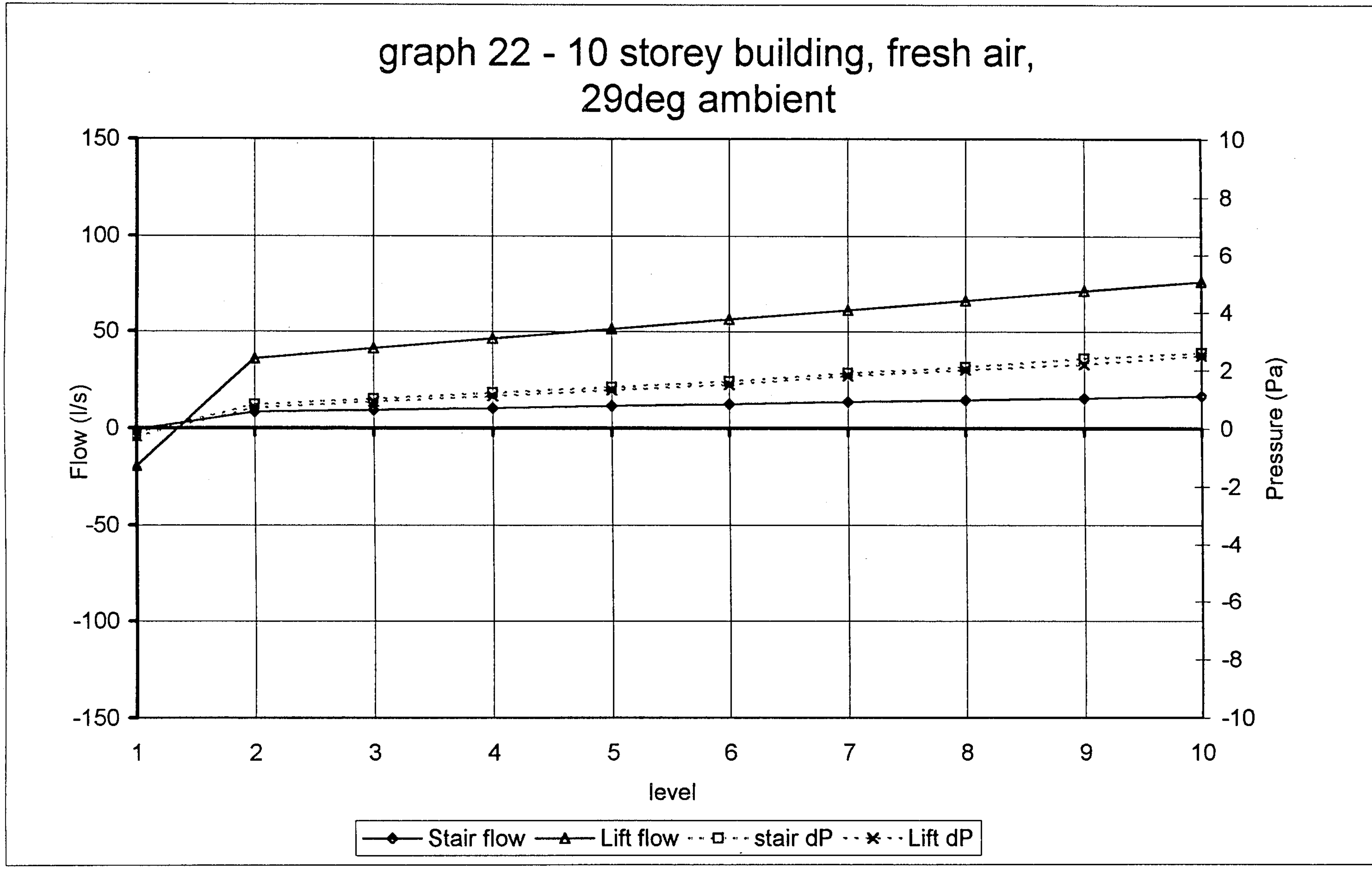


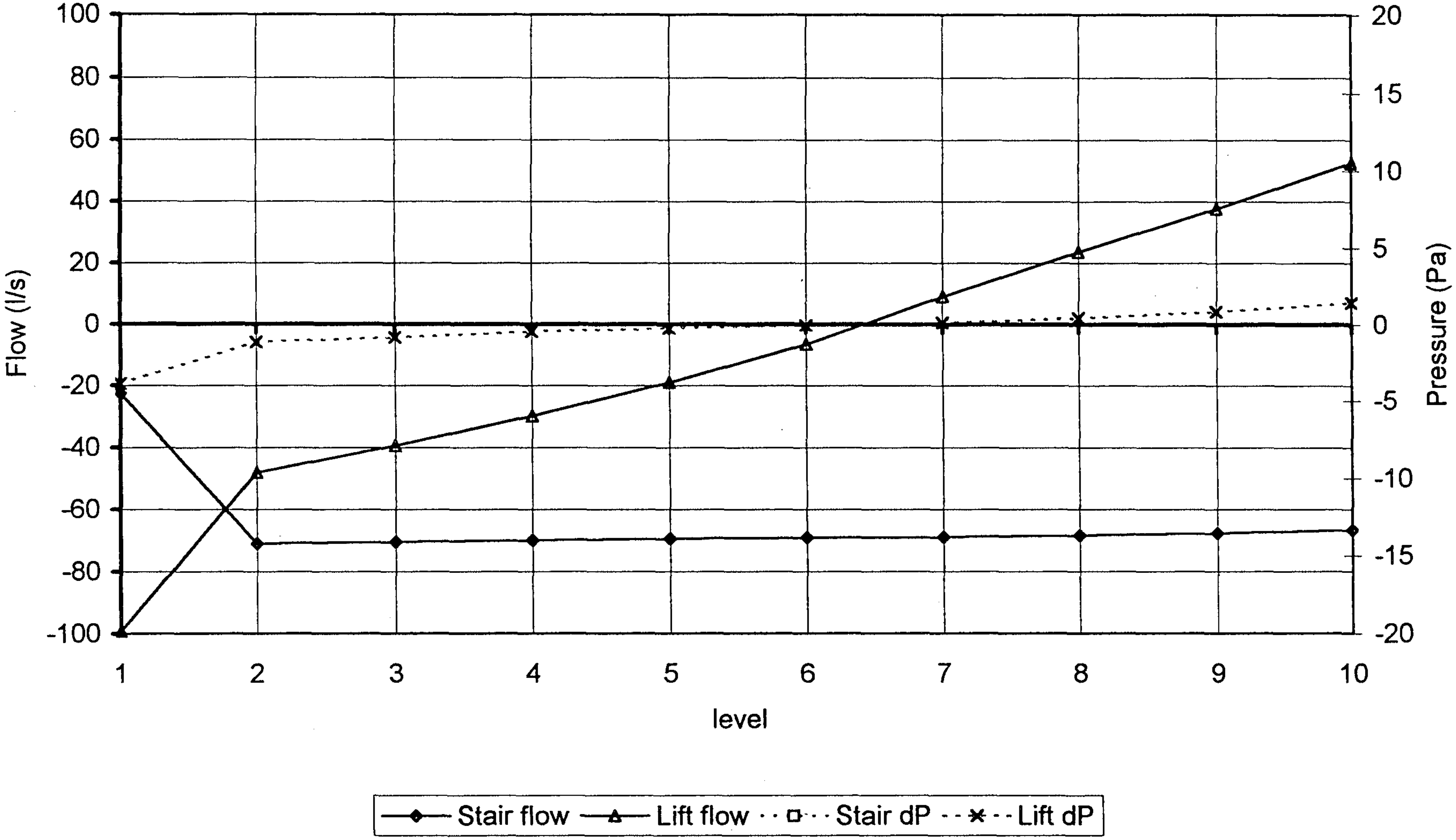
graph 20 - 10 storey building, fresh air + stair pressurisation, tight construction



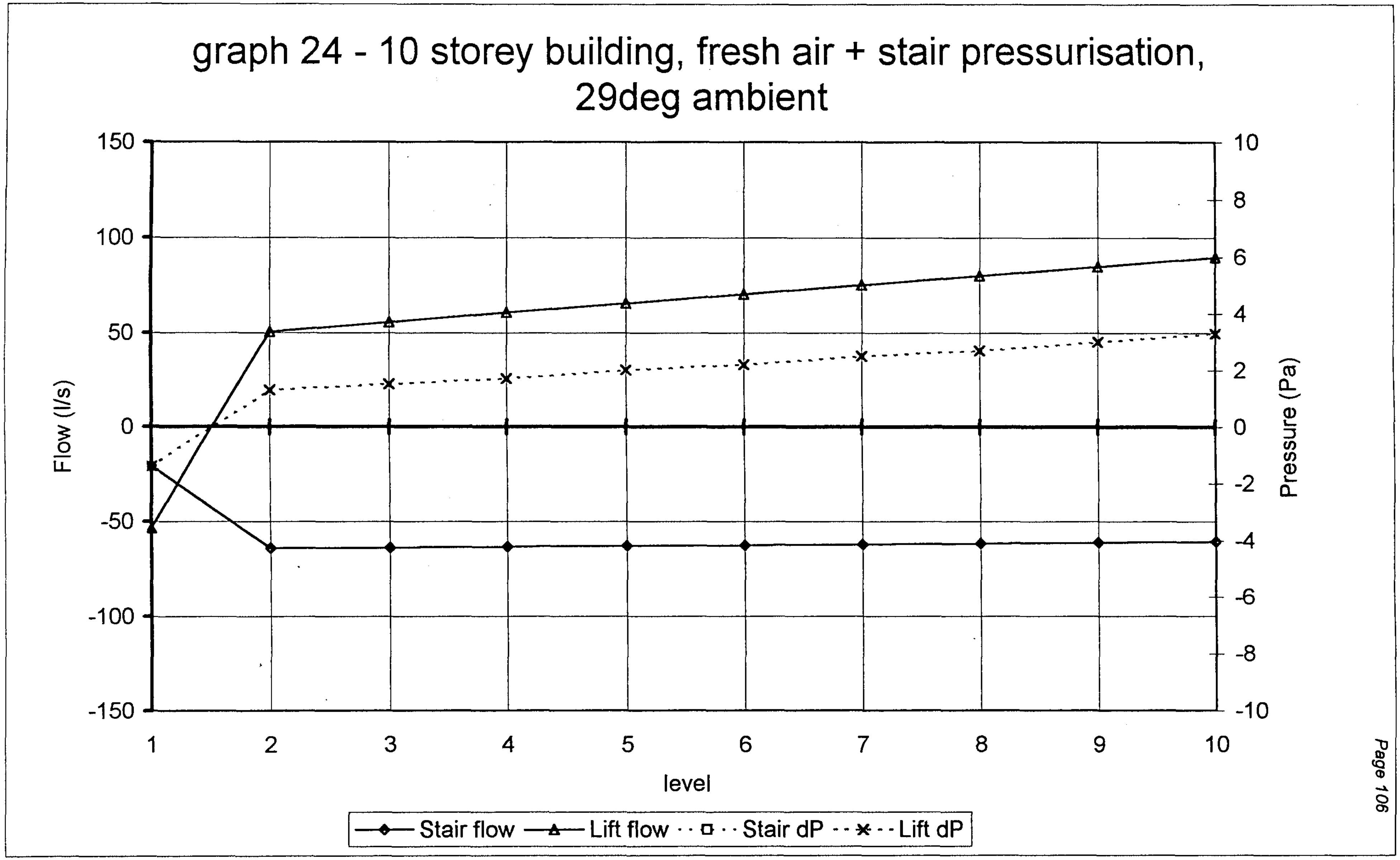
graph 21 - 10 storey building, stack only, 29deg ambient




graph 22 - 10 storey building, fresh air,
29deg ambient
Flow (l/s)
150
100
50
0
-50
-100
-150
Pressure (Pa)
10
8
6
4
2
0
-2
-4
-6
-8
-10
1
2
3
4
5
6
7
8
9
10
level
Stair flow
Lift flow
stair dP
Lift dP



graph 23 - 10 storey building, stair pressurisation only, 29deg ambient


graph 24 - 10 storey building, fresh air + stair pressurisation, 29deg ambient

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