Leaky Buildings: Experiences from full-scale measurements; methods of description

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Abstract

This paper considers some effects of wind on leaky buildings and details experiences and measurements from several of them It discusses two useful concepts; of Interconnected leaky tubes and of Pressure line representations of the pressure gradient in the building. The buildings were judged to have insufficient make up air to balance outflows.

Background

Leaky Buildings carry pressure gradients and airflows through the various interconnected cavities within themselves. Symptoms observed include undue noise, lifts that will not operate, doors that slam… Residential buildings in Australian cities are being built taller, and at the edges of the existing built up areas. Their wind exposure is causing differential pressures across their various openings and flows within their various systems and volumes. This paper considers resulting symptoms at three buildings.

Vipac had previously carried out some ground level wind tunnel testing of the two buildings numbers 1 &2. Those tests were limited to overall wind speed controls (from a town planning perspective) and specific controls aimed at control of winds and gusts at pedestrian access locations. Those tests gave us an insight into the flows around the buildings and the specific flows that may have been occurring at the various openings to the building systems; when the buildings exhibited noise and operational symptoms we were invited to investigate further.

Common Characteristics

The buildings are moderately tall (70m) compared with their surroundings (typically 1 to 3m nearby), and rise abruptly from a relatively flat approach terrain. Approach terrain is cat 2 to 2 ½. The subject buildings are upwind of other city building blocks, and are grouped to some extent with others similar. The podiums are relatively small compared with their towers, being around 2 to 4 times their area. The tower location is for flat faces of the towers to extend upwards from one or two edges of the podium.

Typically there is an entry to the ground level foyer from at least one of those podium faces, connecting to the (vertical) line of the lift shaft within. Also within the podiums are several car park levels with lift foyers. Mechanical plant is located on the roof level; with toilet exhaust; kitchen exhaust; stair pressurisation; lobby (floor-by-floor) smoke exhaust, lift motor room ventilation; garbage chute ventilation and lobby make-up air supply.

Site Experience No1& No2

Towards the end of the fit out and the commissioning period, complaints were registered concerning wind noise at the lifts and on some occasions the lift doors failing to fully close, trapping the lifts when at least one took itself to "out of service" status. Complaints were seen to peak when the wind was strongest.

Measurements were made of pressures and flows between adjacent spaces and in the accessible systems. For some of the time builder's staff was preparing the towers for handover, and many floors were open to external and internal air. The mechanical services were only partly operating. Measurements were taken on some closed floors, enabling a preliminary assessment. On other days the wind was quite strong and, being rostered days off, there was little activity in the buildings. On these days the buildings were substantially closed.

Measurements of either velocity or pressure of air were recorded relative to the foyer or to the apartment from which the measurement was made. The measurements were dynamically varying with time during the measurement period. The extremes quoted here cover the range observed over 1 or 3 minutes, with a 1 sec averaging time. It was estimated that the expected one year return maximum wind pressures would likely be 2 times those measured on the highest wind speed test day. Data was discussed with the client in terms of the measured data (on the day) and the likely one-year event.

Recommendations to fix the symptoms were made and implemented. These included a range of changes to the flow paths for the air, and to the resistances to the flow of air between spaces…some opening, some closing off.

Ground Floor Lobbies

The ground level doors faced the predominant wind direction. They were relatively well sealed, for glass sliding doors. On the days of testing, there was high pressure outside the foyers. The front doors and smaller service doors returned pressures above those of the foyers. The internal service doors, the lifts and the stairwell returned pressures below the foyer pressure. Problems were that the lift doors "stalled" and wind noise was generated.

Depending on the days and times, the pressures were found to be

Outside to lobby	30 to 50 Pa, up to 90 to 110 Pa; indicating 1 year data of	~200 Pa or,
Lobby to lift shaft	20 to 50 Pa, up to 100 to 140 Pa; indicating	~240 Pa.

We describe the pressures as either or because of the transfer of the main location of resistance to the pressure upon the action of opening the door in question. One of the more easily implemented solutions was the installation of lobby doors to the (otherwise open) car park lift lobbies, and to one of the entry lobbies.

Car Park lobbies

At levels 2, 3, 4 the lifts opened directly to the car park volumes. These car parks were themselves substantially (>50%) vented to the outside faces of the podiums.

Pressures measured between the lift shaft and the car parks were found to be of a similar magnitude to those at the ground floor; 15 to 40 Pa, up to 90 to 115 Pa. Lift "jamming" and door noise was experienced here too.

Lift Shafts

The lift doors were found to stall when the differential pressures across them (inside the car to outside in the foyer) exceeded 50-60 Pa. The doors would come very close but fail to meet, and would back off and try again. Three fails or a timing-out would trigger the "car out of service" mode.

When substantially closed or fully closed the gaps between the doors would whistle. Noise was mostly at the closed lobby lift doors, upon or after the lift car departure. Sound levels from whistles were estimated as

Low sound	3 m/s velocity	8 Pa pressure	200 l/s through each lift door when closed
Moderate	5		300
Loud	9	65	600 l/s

These pressures are seen to be substantially below the anticipated yearly occurrence.

It was initially assumed that the lift shafts were acting as chimneys, and that flow out through the lift motor room vents would be the dominant mechanism. This was not correct for these buildings. At the roof, the net ventilation through the lift motor room was found to be nil. While the openings from the shaft to the room were fairly small (~0.01m2), the openings to the outside (above roof) were substantial (~1m2). When the mechanical services fans were not operating the net pressure in the lift shaft closely matched (+/-10 Pa) that outside on the roof. When the fans were switched on, the pressures in the lift shaft were measured to depress by 5 to 10 Pa at the ground level and 15 to 20 Pa at the roof. The net effect of the ventilation services to the occupied spaces was to decrease the pressure in the (not mechanically serviced) lift shaft.

Apartment Levels

Measurement of the relative pressures between the lift shaft and floor-by-floor apartment lobbies showed the lobbies to be generally negative (being +1 to -6 Pa wrt lift shaft), and the apartments themselves to be more negative again. Typical outflows from the apartments of 20 to 50 l/s were observed at each of 3 to 5 exhaust points (at a sample of 10% of the apartments); with overall ("toilet" and "kitchen" exhaust) flows estimated at between 8 and 15 m3/s.

The apartment pressures were generally negative wrt the foyers. Upwind apartments (2 per floor) were at +5 to +60 Pa (typically +30 Pa); down wind and cross wind ones (6 or 7 per floor) were at –6 to –60 Pa (-30 Pa); and ones under the roof, or venting to it (14 apartments) were at –14 to –40 Pa (again typically -30 Pa). Air infiltration through the facades was generally close to the limit of the façade curtain-wall test standard (AS4284), estimated at 5 to 10 m3/s through 6,000m2 (~ 1 to 2 l/sm2 at -60 Pa differential). Inspection of the ceiling voids above the uppermost apartments revealed significant air paths and interconnections between those apartments and the pressure fields above the building, leading us to anticipate significant negative pressures in those apartments on high wind days, even when all the façade (operable windows and doors) was closed.

At the apartment front doors, the performance of the drop seals was particularly important. At the start of our testing, there were many that were not yet adjusted. For these, typical airflows at the apartment (negative) pressures were 20 to 60 l/s. Upon adjustment, this fell to around 10 l/s per door, doubling during the windier times. During the life of the building it may be fair to assume a proportion of poorly adjusted seals (say 20 l/s per door), and a proportion of open doors, (say 100 l/s per door). An allowance of 3 or 4 m3/s seemed reasonable over each 100-door block.

Mechanical Systems and Other Interconnections

Toilet/kitchen out flows were judged fairly constant on the test days. Pressure measurements across the rooftop fans showed, on the test days, small variations (+/- 10%) with time, implying smaller time variations in the flows.

There was an amount of make up (fresh) air delivered from the roof to the floor lobbies, through a small supply air fan and duct. The mechanical system-balancing contractor reported its flow as 2.2 m3/s, which on the face of it may have been sufficient on still days. On the windy test days, our sampling of half of the grilles led us to estimate only 1.4m3 supply. More air volume than this quantity was estimated to leave the foyers through the apartment doors.

To each floor was a smoke relief vent. The damper at each grill was designed as normally closed, with an opening time of around 3 to 5 seconds, should a fire or smoke call be registered by the BAS. The duct behind was connected to a rooftop fan and an open roof discharge. It was found very useful to open the damper at the ground level foyer. On the windier days, the stack effect of this duct allowed the removal of some 1 to 3 m3/s from the foyer, doubling upon the opening of the foyer outer door (apartment block front door). The reduction in the foyer pressures was a very useful 20 to 30 Pa.

Other floor-by-floor connections included the stairs (only one, centrally located, for the tower section). These had a stair pressurisation fan, normally off and also with an open discharge to roof. When there were a number of doors open at upper floors, the stairwell was at a steady negative pressure. Later in commissioning, the pressures were seen to vary with time corresponding with door operation. At several locations there were cupboards, with access from the residential lobbies, which registered pressures different from the lobby. These were reported as inadvertent leaks and subsequently repaired. Each floor had a garbage chute in a garbage room off the residential lobby. Typically the rooms were slightly positive (0 to 8 Pa) wrt the lobbies, and the chute itself was strongly (~50 Pa) positive. On many floors the de-odoriser being introduced at the garbage room could be smelled. The interconnection between the upwind faces at the ground floor and the openings to the "carousel room" was believed to have contributed to pressures in those rooms being strongly positive (close to outside upwind pressure).

Overall the effect of the wind pressures at the openings of the mech systems seems to have decreased the supply of air to the building, but to have not increased its extraction. Depending upon the system considered, then, there was less than the anticipated interaction between the wind and the services, and this may usefully be the subject of further work.

Mass Balance

An air balance was attempted for various sub systems and for the building as a whole. Apartment out-flows seemed governed by the toilet/kitchen exhausts, and the flows out through the façade. Upon the blocking off of the exhausts one by one, the apartment vs foyer pressures fell, with apartment vs out door pressures also falling. Mechanical exhausts dominated. The mass balance, over a 5% of apartments sample, varied from +/- 5% to +/- 80%. At the identified inleaks, velocities were up to 3 to 5 m/s, close to those needed for whistling. For other buildings where the facades were tighter, one may expect a larger depression of pressure upon the closing of the windows and doors, and operation of the exhausts. For those the pressures over the front door could become a problem.

For the lift shaft, the inflows at the ground and car park levels were ~> 1 m3/sec long term (6 to 8 doors each at 200 l/s). As wind speeds increased, up to 4 m3/sec (6 to 8 doors at 600 l/s) was estimated. Since out flows through the lift motor room were low (<1 m3/s), it was assumed that the flows to the apartment floors induced all of the remainder.

Site Experience No3

This building had substantial complaints of whistling noises during windy days and of lifts stalling on the stronger wind days. Wind noises included those from the upwind apartment balcony doors, and service doors from the various lobbies. Most whistles were high pitched (2kHz).

Lifts

Typical differential pressures at the ground floor doors were 60 to 140 Pa. Estimates under lobby-door closed and open tests showed airflows into the lift shafts of 2 to 6 m3/s. Outflows from the lift motor room were substantial, at around one quarter of the inflows at lower levels. As in the previous examples, a large volume of air was removed from the upper levels of the lift shaft, to the apartment lobbies. One novel solution at the ground floor was to increase the separation between the lift door surface and its frame surrounds. This had the effect of lowering the velocities in the gaps and reducing the noise. Alternatively a separate vent between the lobby ceiling and the lift shaft was recommended.

Lobbies

There were multiple connections between the lobbies and out doors, and to the apartments. At the ground level, the main entry door faced the dominant wind direction and was, as in the other cases, not amenable to exterior attenuation. Here it was feasible to install an intermediated door system that acted to divide the lobby and separate the front from the lift doors.

Towards the top of the building there were many interconnections between those lift lobbies and the exterior. These included services ducts that needed sealing, roof system coverings and the apartment doors themselves.

Apartments

The outer walls of this building were substantially more leaky than those of the first example, estimated at 2 to 4 l/sm2; at least 2x the façade standard (AS4284). This was mainly due to air leakage through operable sliding doors. Whistles at apartment – lobby doors were common.

Discussion

Buildings as Leaky Tubes

A useful concept to describe the building was to think of it as a series of interconnected cavities, each with some air leakage, and some pressure resistance. Overall the building consists of a group of vertical tubes, each leakily connected to the others. For example, the lift shafts are one set of such leaky vertical tubes being exposed at many locations to different local air pressures. See figure 1.

The Pressure Line Method

A second useful concept for consideration is the description of the overall pressures and pressure differences along an airflow path. This was used to illustrate the shifting of a potential problem from one location to another upon implementing some sort of action. See figure 2.

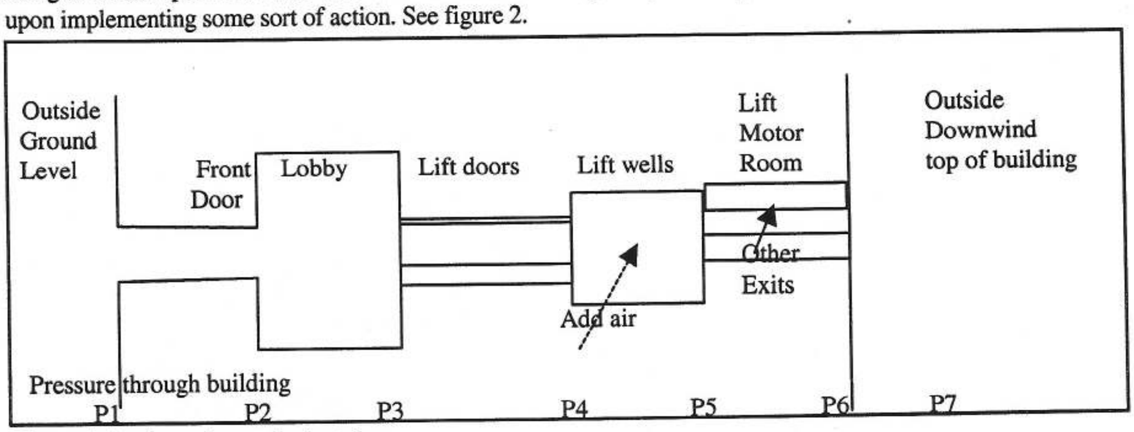

Figure 1: Leaky volumes, leaky tubes

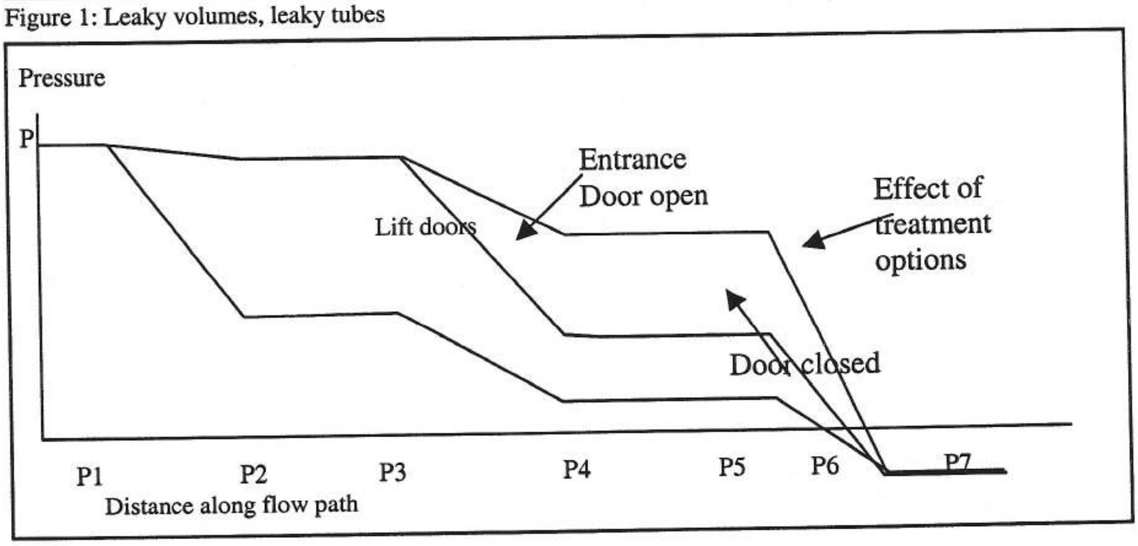

Figure 2: Relative Pressure Line description