

# Duct leakage and leakage testing

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## ABSTRACT

Although air leakage from ducts has previously been treated as insignificant and leakage testing as not cost effective, this paper demonstrates that even minor leakage can have a significant effect on plant energy consumption and greenhouse gas emissions. Recognising this, the recently published AS 4254.2:2012 reverses past practice and now mandates leakage testing of systems over 3000 L/s. Not only will reducing leakage reduce energy use and greenhouse gas emissions producing a better outcome for the building owner and community, but attention to issues raised in this paper will benefit the contractor by reducing or eliminating the need for costly rectification of leaks revealed by leakage testing. The paper examines the implications of the Standard's testing requirements and suggests extension of its scope.

## 1. INTRODUCTION

In the past, the effects of duct leakage have received little attention in Australia. The last time AIRAH published a paper on the subject was 1978 [1], and in 2002 AS 4254 [2] followed earlier editions in recommending against duct leakage testing on the grounds that "leakage tests are an added expense in system installation [and] generally not cost effective". With the publication of AS 4254.2:2012 [3] that view has changed and leakage testing is now required for each duct system over 3000 L/s. As the standard has been incorporated into the 2013 National Construction Code, leakage testing will be a legal requirement for all such systems after 1 May 2013. It is therefore an appropriate time to look at duct leakage, duct sealing and leakage testing in the light of the new standard.

## 2. WHY WORRY ABOUT LEAKS?

### 2.1 Effect of leakage on energy and greenhouse gas emissions

Despite the view expressed in AS 4254:2002, a few simple calculations suggest that there is reason for concern about the impact of duct leakage.

Consider a typical air conditioning system in which the designer follows AIRAH DA09 [4] and assumes a supply duct leakage rate of 5%. To deliver the design air quantities to the spaces served, the fan must handle 1/0.95 times the sum of the room air quantities or 105.3% of the nominal air flow. Applying fan laws gives an increase in fan power of 117%, so the widely accepted leakage rate of 5% has added 17% to supply fan energy, for every hour the plant operates. At 10% leakage the extra fan energy is 37%.

This is not the end of the story because leakage also affects cooling and heating plant energy consumption. The size of the effect depends on where the duct is located. If the duct is in the conditioned space and the leakage percentage low, one might argue that nothing need be done, that is, that the fan can safely supply 100%, not 105.3% of design because the leaked air produces useful cooling or heating effect. This is not the case if the duct is in a ceiling return air plenum, as the leaked air will travel around the system producing minimal useful cooling and heating effect while increasing fan power and reducing return air temperature slightly.

If the supply duct is outside the conditioned space, such as in a ventilated roof space, the assumed leakage is simply lost and the 17% increase in fan power is compounded by 5% waste in cooling and heating effect and corresponding increase in greenhouse gas emissions.

The analysis for return air ducts also depends on where the return air duct is located. If the duct is in the conditioned space, leakage has little or no effect since the air leaking into the duct is the air that would have been returned anyway. If the return air duct is outside the conditioned space, the effect is more serious. Assume that under normal (non-economy cycle) operation the plant handles 15% outside air, in which case return air will be 85% of design supply air. Leakage at the rate of 5% into the return air duct will thus be 5% of 85% or 4.3% of the design supply air. If the air that leaks in is from outside the building, it adds to the outside air load, the outside air percentage becoming  $15\% + 4.3\% = 19.3\%$  of the supply air. Since the outside air load is pro rata, the outside air load increases by  $4.3\% / 15\% = 28\%$ . For a typical comfort cooling plant in Sydney, 15% outside air would be about 18% of the peak cooling capacity so the leaked outside air will add  $28\% * 18\% = 5\%$  to the peak cooling load.

In summary, a 5% leakage rate implies 17% increase in fan power and fan energy on the supply side plus 5% additional cooling and heating energy if the leakage is to outside the conditioned space plus another 5% waste in heating and cooling energy on the return side if it increases the outside air percentage. The combined effects of these will depend on the detail of the system. It will have less effect on a VAV system with an economy cycle but more on a constant volume system with a lower percentage of outside air. For the example discussed, it is not unreasonable that a modest 5% leakage rate could add 10 or 15% to operating energy and greenhouse gas emissions.

We do not have published data for the effect of duct leakage in Australian systems but there have been a number of overseas studies dealing with the issue. One [5] estimated the heating energy wasted by duct leakage in Belgium at 15 GW.h (0.054 PJ) per annum and 0.75 TW.h ((2.7 PJ) per annum for the rest of Europe (excluding the former Soviet Union). Another study of VAV systems in large commercial buildings in California [6] calculated that, compared to "tight" duct systems (2.5% leakage), systems with 10% leakage had annual HVAC system operating costs 9 to 18% higher, while those with 5% leakage used 2 to 5% more energy.

Duct Pressure Class	Static pressure limit		Maximum air velocity	Air leakage limit C in equation (2)
	Positive	Negative		
	Pa	Pa	m/s	L/s/m <sup>2</sup> duct surface area
Low pressure – Class A	500	500	10	$0.027 \cdot \Delta p^{0.65}$
Medium pressure – Class B	1000	750	20	$0.009 \cdot \Delta p^{0.65}$
High pressure – Class C	2000	750	40	$0.003 \cdot \Delta p^{0.65}$

Figure 1: Shows equation (2) plotted for the pressure ranges above.

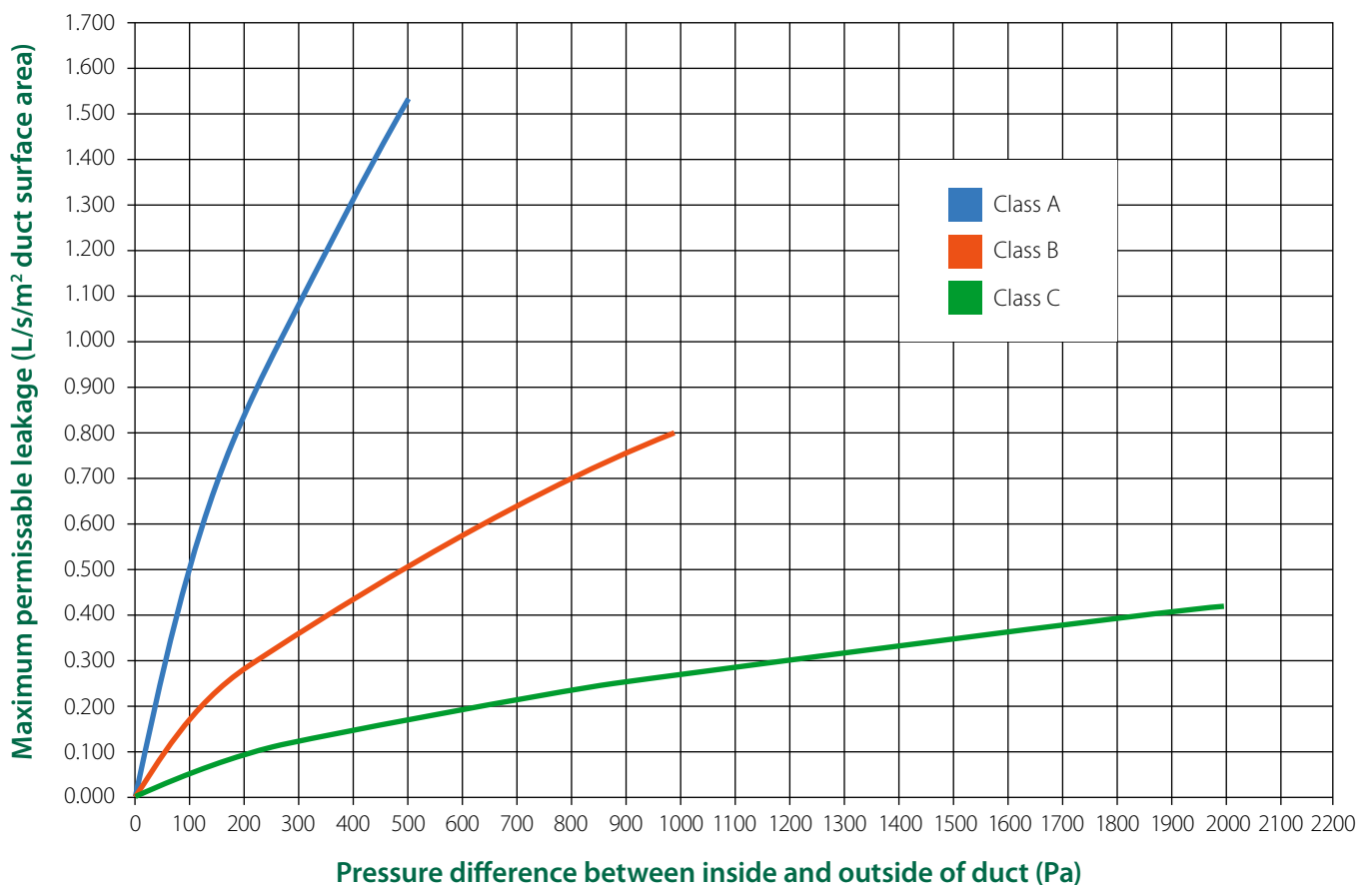


Figure 2: Permissible duct leakage as a function of Class and pressure.

If duct leakage has such significant effects we might ask why it has not been seen as a problem in the past. One answer is that conventional plant design techniques assume leakage is minimal so the fan is selected to handle the sum of the outlet air quantities. In practice leakage does not show itself as a problem because is compensated for by increasing fan speed or pitch angle, a much cheaper solution for the contractor (but not the building owner) than making the duct more airtight.

## 2.2 Duct leakage, tightness, surface area and pressure

Leakage is dependent on three factors: the “tightness” of the construction and installation; the duct surface area, and the pressure differential across the duct wall. This can be characterised by a power relationship (for a discussion of the derivation of this, see [7]):

$$Q_{leak} = C \cdot A_s \cdot \Delta p^n \quad (1)$$

Where  $Q_{leak}$  is the quantity of leaked air, C is a constant related to the duct tightness (which relates to the details of manufacture, installation and sealing),  $A_s$  is the duct surface area,  $\Delta p$  is the pressure difference between the inside and outside of the duct and n is an exponent related to the geometry of the holes through which the air leaks. For leaks through round holes, n is 0.5, while for long openings such as longitudinal seams, it is 0.6 or higher. Eurovent [8] and most other sources use a value of 0.65 for n. Substituting this into equation (1) gives:

$$Q_{leak} = C \cdot A_s \cdot \Delta p^{0.65} \quad (2)$$

For  $Q_{leak}$  in L/s,  $A_s$  in m<sup>2</sup> and  $\Delta p$  in Pa, HVCA [9 Table 1] sets the limits shown in figure 1. The values in the right hand column are the same as for the same Leakage Class (A, B or C) in Eurovent [8].

### 3. LEAKAGE TESTING

Test methods such as HVCA DW/143 [9] and SMACNA [10] require a section of duct to be temporarily sealed by covering the inlet end, incomplete branches, spigots and the like, to make it air tight (Figure 2). The test apparatus consists of a relatively low volume fan or blower fitted either with an inlet damper or variable speed drive to permit the flow to be varied. This is temporarily connected to the duct system via a flow measuring device such as an orifice plate or anemometer. The blower speed or damper is then adjusted to achieve the nominated static test pressure in the duct, the air volume supplied by the blower being the leakage from the duct at that pressure. If it is less than the permitted leakage, the system passes. If not, the leaks must be found, sealed and the system retested. Leak detection can employ a variety of methods including visual inspection, listening for leaks, feeling for air movement, application of soap and water or use of tracers such as a smoke pellet in the duct or tracer gas introduced at the blower. When leaks are detected, the source should be recorded and, since AS 4254.2:2012 requires only a type-test, the information used to rectify leaks in the parts of the system not tested.

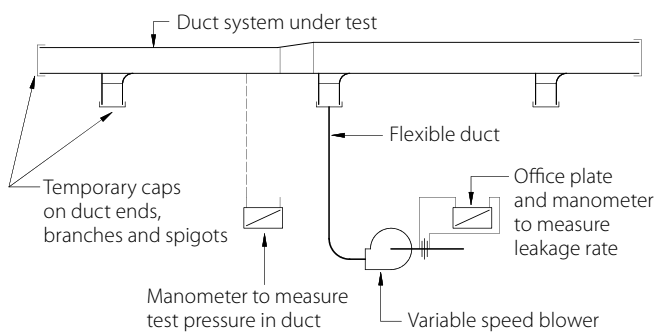


Figure 2: Typical leakage testing set up.

While leakage is clearly a cause for concern, leakage testing has its own issues. Apart from the time involved, cost and complication of temporarily closing up the duct, testing disrupts efficient work flow on site. It is also essentially a contractual hold point but may be difficult to program because the whole of the section to be tested must be complete but not yet externally insulated or enclosed in ceilings or risers. The contractor will need to weigh up the cost of careful sealing of ducts at the factory and as they are erected against the potentially greater cost and complication of identifying and rectifying leaks found when the system fails under leakage testing.

The demise in the 1970s of high-pressure, high-velocity duct systems that were routinely leak tested has meant that few duct manufacturers and installers have had their normal duct construction and sealing methods tested. Except in extreme cases where leakage is so great that system air quantities cannot be achieved during commissioning, we simply do not know how little, or how much, ductwork constructed to current industry practice leaks. Some traditional approaches (Figure 3) are clearly not leak tight. American research [11] measuring duct leakage in existing buildings found rates between 0% to 30%, with most between 10% and 20%. Since these American systems would most likely have been constructed to SMACNA standards which are very similar to the AS 4254 series, similar results are likely in Australia.

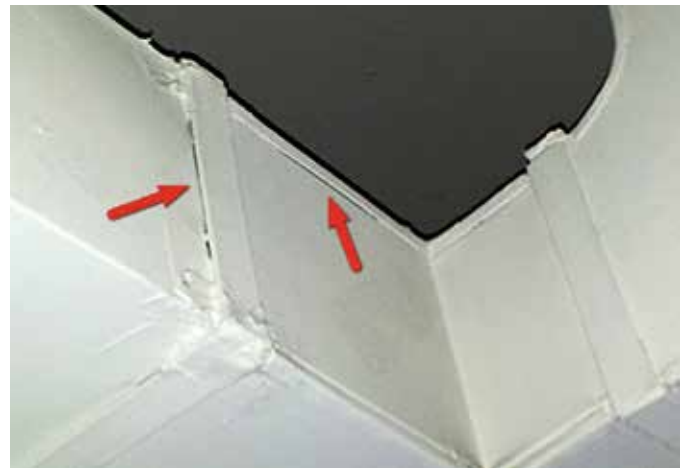


Figure 3: Despite having been painted, this duct still shows potential leakage points (arrowed).

#### 3.1 AS 4254.2:2012 Ductwork for air-handling systems in buildings – Rigid duct

As noted previously, previous editions of the AS 4254 series recommended against leakage testing but AS 4254.2:2012 now requires testing (Clause 2.2.4). In summary, the standard requires that each duct system of 3000 L/s or more be tested to at least 1.25 times its operating pressure, and not leak more than 5% of the design air quantity of the duct system. It is notable that the standard does not require the whole of the system to be tested. Instead it calls for type-testing of at least 10% of the system, including longitudinal seams, circumferential joints, floor distribution, riser and plant room duct, and each type of seam, joint and sealing construction. The standard does not indicate whether the 10% relates to total duct length, surface area or length to seams but overseas standards use duct surface area. Designers and contractors should agree as to which sections are to be tested having regard to design intent and practicability on site.

Several points should be noted about these requirements.

Firstly, testing is done under static, rather than operating, conditions and, as the test pressure is higher than the operating pressure, the leakage rate in operation will be less. As the actual leakage in operation cannot be calculated from the static leakage, the approach recommended in [1] and [8] is to use the arithmetic average of the pressure at the start and end of the duct system. For example, consider a rigid supply duct system with 250 Pa at the fan end and 40 Pa at the spigot to the last flexible duct. For this system, the arithmetic average pressure is 145 Pa. The test pressure to AS 4254.2:2012 for such a system is 312 Pa (1.25 times 250 Pa). In this case, the ratio of leakage rates, from equation (2) will be  $(145/312)^{0.65}$  or about 61%. That is, if the system passes the leak test with less than 5% leakage, in operation leakage can be expected to be less than 3%. This is an improvement on the design norm of 5% discussed above. It is also a significant improvement on leakage rates reported in overseas research [5] [6] and comparable with the value of 2.5% assumed for a “tight” system in [6].

Secondly, type-testing of 10% of each system rather than whole system should simplify the task and reduce the impact of leakage testing on construction cost and site programming.

This however raises a third issue: how much of the system should be tested. Eurovent [8] uses a staged strategy in which the first stage of testing uses 10% of the total surface area for round ducts or 20% for rectangular. If the air leakage rate on test is greater than the permitted rate, the test is repeated with double the duct area. If it still fails, Eurovent requires that the whole of the system be tested. This staged strategy compels the contractor to fix most leaks, not just those in the test section. AS 4254.2:2012 does not include such a strategy and, since in Australia most duct systems are rectangular, requires only half the amount to be tested (10%) compared to Eurovent.

The fourth issue is that the permissible leakage in AS 4254.2:2012 is expressed as a percentage of the design flow. This criterion has the merits of being simple and directly related to the effect the standard wants to achieve, reducing the impact of total leakage on the system. However, it differs from the practice in Europe and the US where permissible leakage is expressed as a function of system pressure and duct surface area. In 1985, SMACNA [12] concluded that "this approach is far superior to the arbitrary assignment of a percentage of fan flow rate as a leakage criteria". The single percentage used in AS 4254.2:2012 produces anomalous results as can be illustrated by reference to equation (2). Consider two systems each handling 3000 L/s. One has a duct surface area of 50 m<sup>2</sup> and operates at 200 Pa, the other has a surface area of 150 m<sup>2</sup> and operates at 500 Pa. For each system the permissible leakage is 5% of 3000 L/s or 150 L/s. Substituting these values into equation (2) gives

values for the constant, C (representing duct "tightness") of 0.096 for the first system and 0.018 for the second. That is, the second system must be over five times "tighter" than the first to meet the same leakage criteria. This is likely to create uncertainty for contractors since they will be unable to confidently predict (and hence price) what needs to be done to meet the AS 4254.2:2012 leakage requirements. They could perhaps mitigate this by using the surface area of the system to determine the required leakage class and sealing using overseas standards.

Finally, there is the question of what will and will not be tested. Since AS 4254.2:2012 covers only rigid mild and stainless steel sheet metal ducts, its testing requirements do not apply to:

- Rigid ducts constructed from aluminium, PVC u and other materials not covered by AS 4254.2:2012.
- Flexible ducts, which are covered by AS 4254.1:2012.
- Air handling units.
- Non-duct components installed in the duct system such as VAV boxes, active chilled beams, diffusers and grilles.
- Builder's work items such as ceiling plenums and risers. Experience has shown that these can be very leaky, in part because of the division of responsibility on site.

Although the standard does not include these, designers and specifiers should consider including them in the parts to be tested, having regard to the project's performance and energy requirements.

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## 4. CONCLUSION AND RECOMMENDATIONS

Duct leakage can have a significant effect on HVAC system performance, energy consumption and greenhouse gas emissions in the form of CO<sub>2</sub> from power stations. The leakage testing requirements of AS 4254.2:2012 are an important step towards addressing this problem and can be expected to improve the quality of duct construction and installation in Australia. This is an important first step but there is potential for expanding the content of the standard:

1. At present leakage test criteria are divorced from the design process. Ideally, the designer should determine the permissible leakage rate (or Leakage Class, for simplicity), and take this into account in selecting plant and include it in the contract specification.
2. Research is required to correlate duct sealing methods to achievable leakage rates. Interrelating these would give the contractor some certainty that if the prescriptive sealing methods are followed, the duct system would be likely to pass the leakage test.
3. The present single value percentage leakage rate is not related to duct pressure class, duct construction or duct surface area. It would be preferable if the standard followed overseas practice and adopted leakage criteria based on equation (2). Pending a change to the standard, the designer could specify leakage class and sealing based on overseas practice. This would also increase designer and contractor certainty.
4. As presently written, AS 4254.2:2012 covers only testing of rigid duct only but there are many other potential leak sources including air handling plant, builder's work items, flexible ducts and terminal equipment. Leakage testing could be extended to cover these. Despite the desirability of reducing the leakage in builders work items, there are significant practical problems in extending AS 4254.2:2012 to cover their sealing.

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### About the author

Ian Wills is currently Engineering Services Editor for NATSPEC, the National Building Specification. He has worked in the HVAC industry in Australia for over 40 years and was a director of D Rudd and Partners (Australia) Pty Limited where he was responsible for design and construction of building services in a wide range of commercial, health, education, defence and other projects.



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