Study Report

SR455 [2020]

Airtightness of selected apartments in New Zealand

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Funded from the
Building Research Levy

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ISSN: 1179-6197

Acknowledgements

BRANZ would like to thank all those involved in allowing us to test in their buildings.

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Reference

Overton, G. & McNeil, S. (2020). *Airtightness of selected apartments in New Zealand*. BRANZ Study Report SR455. Judgeford, New Zealand: BRANZ Ltd.

Abstract

This study sought to measure the airtightness of a number of apartment buildings with the aim of getting some indicative sense of the level of airtightness being provided by the wider stock of apartments in New Zealand. While a limited amount of data exists for stand-alone low-rise residential buildings, very little was known about the airtightness level being provided by apartments.

The airtightness of a building is a key aspect of a building's performance – affecting the energy efficiency, thermal comfort and indoor air quality provided by the building. However, airtightness is only mentioned indirectly in the New Zealand Building Code, and there is no requirement to meet a particular level of airtightness.

Although the basic forces that drive airflow through apartment buildings (wind pressure, stack pressure and ventilation system pressure) are the same as stand-alone dwellings, the magnitude of the forces will be different. There are also further consequences arising from uncontrolled airflow such as adverse effects on the air quality of neighbouring apartments (via pollutants, sound and smoke) and having inconsistent ventilation across units.

The testing investigated the basic level of airtightness of individual apartments using ISO 9972:2015. Further, the magnitude of inter-apartment leakage was investigated doing additional guarded testing. In total, nine apartment buildings were investigated comprising 148 individual (non-guarded) airtightness tests.

In general, the apartments were of a similar level of airtightness to what could be expected from a typical new-build stand-alone dwelling – approximately 5 ach @ 50 Pa. However, the results suggest a strong dependence on construction style. For example, for an apartment building comprising a number of concrete cells, the average result was 3.5 ach @ 50 Pa. Inter-apartment leakage appeared to be insignificant in this style of apartment but did occur in some instances, most clearly when timber partition walls were used to separate dual-key apartments.

The report also contains a general discussion around possible airtightness targets and the rationale for their potential inclusion in the Building Code. This culminates in BRANZ recommending that an airtightness level of under 3 ach @ 50 Pa becomes a

target for all residential typologies in conjunction with whole-house mechanical ventilation as standard. Mandatory blower-door testing is not recommended initially, but it is signalled as being desirable in the medium-term future.

Keywords

Airtightness, ventilation, medium-density housing.

Contents

Figures

Tables

Executive summary

This study sought to measure the airtightness of a number of apartment buildings with the aim of getting some indicative sense of the level of airtightness being provided by the wider stock of apartments in New Zealand. The airtightness of a building is a key aspect of a building's performance – affecting the energy efficiency, thermal comfort and indoor air quality provided by the building

Whilst data exists for the airtightness of low-rise, stand-alone dwellings in New Zealand, little is known about apartments, which represent a significant and growing percentage of new building consents. Stand-alone dwellings appear to be built more airtight than previously. This has been driven by new materials and construction methods as opposed to any prescriptive requirements for airtightness.

In this study, nine apartment buildings were tested for airtightness following the method of ISO 9972:2015 *Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method*. A measurement in accordance with ISO 9972:2015 yields a measure of the airtightness of an individual apartment. Further to that basic measurement, guarded testing was also performed to understand the level of inter-apartment leakage.

In general, the apartments were of a similar level of airtightness to what could be expected from a typical new-build stand-alone dwelling – approximately 5 ach @ 50 Pa, However the results suggest a strong dependence on construction style. For example, for an apartment building comprising a number of concrete cells, the average result was 3.5 ach @ 50 Pa. Inter-apartment leakage appeared to be insignificant in this style of apartment but did occur in some instances, most clearly when timber partition walls were used to separate dual-key apartments.

In terms of variation across the whole sample, the most airtight unit measured 1.9 ach @ 50 Pa, and the least airtight unit measured 12.6 ach @ 50 Pa. This considerable range of airtightness is understandable, given that airtightness is often not a key consideration when constructing buildings in New Zealand.

The report concludes with a discussion around possible airtightness targets and the rationale for their potential inclusion in the Building Code.

These are the key recommendations:

- Aiming for an airtightness target – the primary reason for doing so in the context of the current Building Code is to facilitate effective whole-house mechanical ventilation. Previous BRANZ research suggests a significant proportion of our housing stock is being underventilated. Mechanical ventilation systems reduce the chance of this occurring. Energy savings are also achieved by building more airtight. However, the reduction in energy loss becomes less pronounced as the airtightness improves. Once mechanical ventilation is introduced, the energy consequence of ventilation is predictable, and can therefore be factored into design.
- We recommend a target of 3 ach @ 50 Pa across all typologies. Given the airtightness of the buildings we have measured, this is an achievable target for industry with minimal additional cost. At this level, the heat loss associated with infiltration is less significant than losses through many other building elements.

- The only way to truly ascertain whether such a target has been met is to test the construction, and we expect airtightness testing to become more common in the future. However, given that many buildings are already in the vicinity of this target, simple changes to some common construction details would likely mean the vast majority of buildings would meet the target if tested. Adoption of such details would reduce the need for an immediate testing regime, easing the regulatory impact.
- If the thermal envelope is being upgraded to levels significantly above Code, the heat loss associated with ventilation becomes proportionally more significant. In this scenario, the case for a ventilation system with heat recovery becomes stronger. For a thermal envelope that is around the Code specifications, investment in recovering heat from the outgoing ventilation air would be better spent on reducing heat losses from other parts of the thermal envelope, in particular, glazing.
- If a non-mechanical ventilation option is desired, it should be validated for efficacy by modelling or calculation.

1. Introduction

1.1 What is airtightness?

The airtightness of a building is a measure of how much air can flow between indoors and outdoors through the structure itself. More specifically, it is a measure of the collective size of any holes in the fabric of the building. The airtightness of a building is a key aspect of a building's performance affecting the energy efficiency, thermal comfort and indoor air quality provided by the building.

Airtightness is generally measured by establishing a pressure difference between inside and outside using a fan. The flow rate through the fan corresponds to the airflow through the structure at that particular pressure difference. Data is collected over a range of pressure differences to generate a characteristic curve, but the result is usually expressed in relation to a single pressure difference, often 50 pascals, and the volume of the house – air changes per hour at 50 pascals (ach @ 50 Pa). There are other metrics used to express airtightness. These may express the results at different test pressures or express the results with respect to the surface area of the building as opposed to the volume. In addition to the above, different countries can require measurement to be performed with different units – i.e. metric versus imperial.

1.2 Airtightness in New Zealand

Airtightness is only mentioned indirectly in the Building Code, and there is no requirement to meet a particular level of airtightness. Building Code clause H1 *Energy efficiency* states that buildings must be constructed to achieve an adequate degree of energy efficiency by, amongst other things, limiting uncontrollable airflow and taking the airtightness of the building envelope into account.

One means of demonstrating compliance of housing with clause H1 is to ensure the building performance index (BPI) does not exceed 1.55. The BPI can be calculated using the BRANZ Annual Loss Factor (ALF)[1] tool, but ALF is not intended for multi-unit dwellings. The building airtightness is part of the input to the BPI but the capacity to add particular airtightness levels is limited – the user is only permitted to select broad categories relating to the date of construction and general complexity of the building envelope. In general, however, the idea is to have an airtight building to help lessen thermal losses whilst also ensuring that the ventilation needs are being met.

In New Zealand, houses are being built more airtight than they used to be, despite the lack of any Building Code requirements to so do. Figure 1 shows BRANZ data on the airtightness of stand-alone dwellings, which was collected in several surveys, and the trend to more airtight construction can clearly be seen. A significant contributor to envelope airtightness around 1960 was the shift from suspended tongue and groove flooring to sheet floor construction and slab-on-ground floors. Another change at a similar time was the shift from timber joinery to aluminium-framed doors and windows. Newer construction practices have continued to influence the airtightness of houses. Relatively recent examples of changes are the widespread use of bonded plaster cornices or a square stopped interior plaster finish, the adoption of air seals around window and door assemblies to control rain penetration and the increased use of rigid sheathing.

[1] https://alf.branz.co.nz/

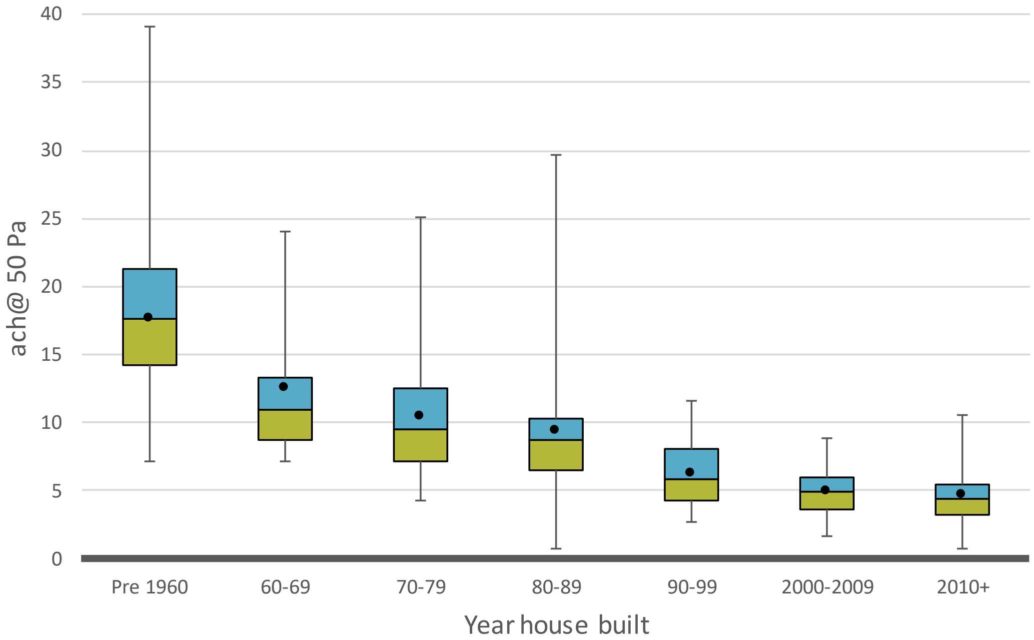

Figure 1. Airtightness of New Zealand houses by date of construction.

For houses built since 2000, the mean airtightness level was just below 5 ach @ 50 Pa. Incidentally, the floor area of the newer houses was also larger than in the previous surveys, increasing from 115 m^2 to 155 m^2. The recent airtightness results also generally fell in a tighter range, suggesting more consistency in construction, but there are evidently new homes where the airtightness exceeds 10 ach @ 50 Pa. Cases where this occurred tended to deviate from simple construction and contained a wider variety of interior finishes other than the paper-faced gypsum board typically used (Overton, Bassett & McNeil, 2013; McNeil, 2018).

1.3 How does airtightness in New Zealand compare with overseas?

As mentioned above, BRANZ data suggests new houses built in New Zealand will commonly have an airtightness of approximately 4–5 ach @ 50 Pa. Table 1 provides a compilation of airtightness requirements and recommendations from around the globe (Limb, 2001; Erhorn-Kluttig, Erhorn, Lahmidi & Anderson, 2009; NRC, 2010; Retrotec, 2014; ASHRAE, 2016).

In Table 1, the normalised values assume the following building parameters:

- Volume = 288 m^3
- Surface area (walls + ceiling + floor) = 345 m^2
- Floor area = 120 m^2.

To convert requirements that are at pressures other than 50 Pa, the following relationship is assumed.

$$Q = C\Delta P^{0.66} \quad (1)$$

where Q is the flow rate and the ΔP is the pressure difference. This equation is used to calculate a value for the flow coefficient C, which in turn is used to calculate the adjusted flow rate at 50 Pa.

Table 1. Selected airtightness requirements.

Programme	Standard	Region	Comments		Requirement		Normalised ach 50
North America							
		Canada	Recommendation in code		0.05 to 0.2 L/s.m² @ 75 Pa (for opaque wall specimens, not whole buildings) – value depends on ability of wall to dry to the outside)		1.6–6.5
R-2000	CGSB 149.10	Canada	Voluntary		1.5	ach 50	1.5
Vancouver	CGSB 149.10	Canada	Code		3.5	ach 50	3.5
LEED for Homes 2012 Certified 1 pt		USA, Canada	Climate Zones 3–4		3.5	ach 50	3.5
			Climate Zones 5–7		2.75	ach 50	2.75
LEED for Homes 2012 Certified 2 pts		USA, Canada	Climate Zones 3–4		2.5	ach 50	2.5
			Climate Zones 5–7		2	ach 50	2
ASHRAE 62.2		USA	Compliance for minimising leakage from adjacent spaces		0.3	cfm 50/sq ft	6.7
EEBA		USA	Guidelines		0.25	cfm 50/sq ft	5.6
ENERGY STAR V 2.0	ASTM E779	USA	Climate Zones 3–4		6	ach 50	6
			Climate Zones 5–7		5	ach 50	5
ENERGY STAR V 3.0	ASTM E779	USA	Climate Zones 3–4		5	ach 50	5
			Climate Zones 5–7		4	ach 50	4
LEED		USA	Air quality standard used for apartments, all 6 surfaces enclosing an apartment, same as 1.25 sq in EfLA at 4 Pa.		0.23	cfm 50/sq ft	5.1
					1.17	(L/s 50)/m²	5.0
ICC (2012)		USA	Climate Zones 1–2		5	ach 50	5
			Climate Zones 3–8		3	ach 50	3.5
Europe							
	Passive House	Europe (and elsewhere)			0.6	ach 50	0.6
		Austria	Naturally ventilated		3	ach 50	3.5
			Mechanically ventilated		1.5	ach 50	1.5
		Belgium (ventilation standard)	Mechanically ventilated		3	ach 50	3
			Mechanically ventilated with heat recovery		1	ach 50	1
		Bulgaria	Apartments	H	<2	ach 50	<2.0
				M	2–5	ach 50	2.0–5.0
				L	>5	ach 50	>5.0
			Single family houses	H	<4	ach 50	<4.0
				M	4–10	ach 50	4.0–10.0
				L	>10	ach 50	>10.0
	TNI 730329	Czech Republic	Low Energy House		1.5	ach 50	1.5

Programme	Standard	Region	Comments		Requirement		Normalised ach 50
	TNI 730330	Czech Republic	Natural		4.5	ach 50	4.5
			Forced		1.5	ach 50	1.5
			Forced + heat recovery		1	ach 50	1
			Forced + heat recovery passive house		0.6	ach 50	0.6
		Denmark	Residential		0.5	(L/s @ 50 Pa)/m^2 floor area	0.7
		Estonia	Small buildings, new		6	(m^3/h @ 50 Pa)/m^2	7.1
			Small buildings, existing		9	(m^3/h)/m^2	10.6
		Finland	Building heat loss reference		2	ach 50	2
			Energy Performance Certificate (EPC)		4	ach 50	4
			New apartments		0.5	ach 50	0.5
		France	Single family houses		0.8	(m^3/h @ 4 Pa)/m^2	5.0
			Other residential buildings		1.2	(m^3/h @ 4 Pa)/m^2	7.4
		Germany	Mechanically ventilated		1.5	ach 50	1.5
			Naturally ventilated		3	ach 50	3.5
		Lithuania	Mechanically ventilated		1.5	ach 50	1.5
			Naturally ventilated		3	ach 50	3.5
		Latvia	Dwellings		3	ach 50	3.5
			Ventilated buildings		3	ach 50	3.5
		Netherlands	Mechanically ventilated		2–3	ach 50	2–3
			Naturally ventilated		4–6	ach 50	4–6
		Norway			3	ach 50	3.5
		Portugal			0.6	ach 50	0.6
		Slovenia	Mechanically ventilated		2	ach 50	2
			Naturally ventilated		3	ach 50	3.5
		Slovakia	Single family house with high-quality windows		4	ach 50	4
			All other buildings		2	ach 50	2
	TS 825	Turkey (levels of air impermeability when calculating heat loss in mechanically ventilated buildings)	Heat multiple dwellings per floor	H	2	ach 50	2
				M	2–5	ach 50	2–5
				L	>5	ach 50	>5
			Single dwelling per floor	H	<4	ach 50	4
				M	4–10	ach 50	4–10
				L	>10	ach 50	>10
	ATTMA TSL1 (2016)	UK	Best practice	Naturally ventilated	4	(m^3/h @ 50 Pa)/m^2	4.8
				Mechanically ventilated	3	(m^3/h @ 50 Pa)/m^2	3.6
				Mechanical with heat recovery	1.5	(m^3/h @ 50 Pa)/m^2	1.8
		UK	Dwelling regulation		10	(m^3/h @ 50 Pa)/m^2	12.0
Oceania							
		Australia	Dwelling regulation		10	(m^3/h @ 50 Pa)/m^2	12.0

For the Canadian case, it has been assumed that the leakage of a whole building is an order of magnitude greater than the leakage through an opaque wall specimen. This assumption is based on the different ASTM requirements for the airtightness of materials, air barrier assemblies and whole buildings respectively (Anis, 2016). Because of the assumptions made, the normalised comparison should be treated as an approximation.

Although New Zealand does not have an airtightness requirement for residential buildings, they have progressively been built more airtight. As such, the airtightness that might be expected of a new build house is quite close to many international targets. Contrast this with Australia, where a study of 125 modern homes found an average airtightness of 15.5 ach @ 50 Pa (Ambrose & Syme, 2017). In 2019, the Australian Building Codes Board introduced a requirement of 10 $m^3/hr.m^2$ @ 50 Pa (with optional verification) – something that would likely be achieved by the majority of new residential construction in New Zealand.

Table 1 highlights several things:

International requirements cover a large range of airtightness values and testing is not always mandatory

Many of the entries in Table 1 go hand in hand with some kind of energy rating scheme, with the motivation to build more airtight being a higher energy rating. The UK is an interesting example because it is often anecdotally compared with New Zealand. With respect to the building regulations, the airtightness requirement in the UK is not that stringent and only has to be demonstrated for a proportion of houses in any one development. However, airtightness testing is often performed to support an energy assessment, often in the form of the standard assessment procedure (BRE, 2014), so testing is more common than the regulations imply. Further, data from the UK Air Tightness Testing & Measurement Association (ATTMA, personal communication, 2019) shows the average tested result for dwellings in the UK is 4.73 $m^3.h^{-1}.m^{-2}$ @ 50 Pa (approximately 5.7 ach) compared with an average target of 5.32 $m^3.h^{-1}.m^{-2}$ @ 50 Pa (approximately 6.4 ach).

Split requirements for different ventilation strategies are quite common

Several entries in Table 1 have differing airtightness requirements depending on whether the buildings are naturally ventilated (typically 3–5 ach @ 50 Pa) or mechanically ventilated (typically 1–3 ach @ 50 Pa). The most stringent requirements correspond to the Passive House (and similar) standards, which in turn correspond to buildings that also use a mechanical ventilation system with heat recovery. It is desirable to have an airtight building with a whole-house mechanical ventilation system because it allows the systems to be designed and operated more efficiently – the maximum amount of heat can be recovered from the exhaust air for a given ventilation rate. For naturally ventilated buildings, a very airtight structure could lead to underventilation. Interestingly, data from ATTMA suggests that builders are not yet changing their construction methods when different ventilation systems are used, with the average result being very similar for all types of ventilation system. Also of note in the UK are proposed changes to the building regulations (MHCLG, 2019) that would limit the incentives in the standard assessment procedure that encourage very airtight naturally ventilated dwellings by encouraging a level of infiltration. ASHRAE 62.2 allows an infiltration credit where specifying ventilation, although anecdotally the use of this is not widespread.

1.4 Airtightness of apartments

In New Zealand, we have some data on the airtightness of stand-alone dwellings but very little is known about the airtightness offered by the stock of apartment buildings. Apartment consents have increased as a proportion of all residential building consents by over 60% (to 12.6% of all consents) between 2014 and 2019 (Stats NZ, 2019). Townhouses, flats and units have increased by 98% (to 21.3% of all consents) in the same period, whilst houses have fallen to just under 60% of all consents. Although the basic forces that drive airflow through apartment buildings (wind pressure, stack pressure and ventilation system pressure) are the same as stand-alone dwellings, the magnitude of the forces will be different. There are also further consequences arising from uncontrolled airflow in apartments such as adverse effects on the air quality of neighbouring units (via pollutants, sound and smoke) and having inconsistent ventilation across units. The lack of data in New Zealand is unsurprising given the lack of any airtightness target in the Building Code, but there is a body of research from overseas that can be used as a comparison for our buildings.

Ricketts, Finch and Bombino (2013) produced a report for the Canadian Mortgage and Housing Corporation (CMHC) to help inform potential requirements for multi-unit residential buildings (MURBS). Airtightness testing is more common in Canada than New Zealand, but at the time, there was still a relatively small amount of data relating to MURBS. As well as a thorough description of airflow mechanisms and general approaches to air sealing, that work collected existing test data together into a database of 43 MURBS with construction dates ranging from 1956 to 2011 and surveyed industry on their preparedness to control air leakage. The data showed that new buildings (and air barriers) were more airtight than older ones and that taller buildings were slightly more airtight than shorter buildings. An average airtightness of 4.6 ach @ 75 Pa is reported (corresponding to approximately 3.5 ach @ 50 Pa). The report also describes approaches for performing guarded tests where multiple fans are used to pressurise neighbouring units so that air leakage for individual faces can be isolated.

Further work for the CMHC (Red River College, 2015) looked at field testing a new protocol for airtightness tests on MURBS, in particular looking at the challenges of performing whole-building tests (as opposed to individual units) of occupied buildings.

Ueno and Lstiburek (2015) conducted a detailed case study of five vertical townhouse units. The middle unit was air sealed to represent current practice, and the other four units had 'improved' details or extra taping applied to walls. Testing was then conducted on a per-unit basis and as guarded tests to theoretically eliminate unit-to-unit leakage. Despite obvious attention to the air barrier system for these townhouses, none met the 3 ach @ 50 Pa requirements of the 2012 International Energy Conservation Code (ICC, 2012). The report discusses the merits of volume based or surface area-based airtightness targets, noting that 3 ach @ 50 Pa can lead to more stringent area-based targets for buildings, such as the studied townhouses.

Kaschuba-Holtgrave, Rohr, Rolfsmeier and Solcher (2020) have an ongoing study on individual and guard-zone airtightness of apartment buildings in Germany. At the time of writing, three different developments had been measured. Germany has reasonably stringent regulations on airtightness, as shown in Table 1. The measured apartments were within those regulations, i.e. less than 1.5 ach @ 50 Pa. Guarded tests and assumptions about material permeabilities and flow resistance for individual components such as window seals were used to estimate the leakage due to permeability and leaks for both the interior and exterior envelope. Top-floor apartments were found to be less airtight than the lower floors, with about 25% of the air leakage to neighbouring units.

1.5 How can airtightness be achieved?

The airtightness measurements in Figure 1 show that we are building tighter despite the lack of either carrots or sticks in our building regulations. This represents an argument against imposing extra regulation and the associated costs on the New Zealand building sector to ensure houses are built to be below an airtightness target. However, the BRANZ data is unlikely to encompass the full range of airtightness being offered by our new homes, and the evidence from overseas suggests that regulation changes and testing and education schemes are the most effective way of changing the airtightness offered by the building stock (Arsenault, 2016; Carrié, Kapsalaki & Wouters, 2017).

Useful resources for helping people who want to achieve an airtight construction for stand-alone dwellings exist, such as the US Department of Energy's air leakage guide (Building Energy Codes, 2011) and the US Environmental Protection Agency's thermal bypass checklist for ENERGY STAR qualified homes (EPA, 2008). The air leakage guide is to help meet the requirements of the 2012 International Energy Conservation Code (ICC, 2012) and contains information on where to pay particular attention to air sealing and case studies. There is also guidance to support the Passive House standard (Price, Baines & Jennings, 2020). For apartments or MURBS, CMHC (2017) and Higgins Haaland and Ricketts (2017) both provide useful information for the design, construction and testing of buildings. Common guidance is that effective air control does not happen by accident, and checklists for each stage of construction, including having a designated responsibility for each aspect of the air barrier system, are encouraged.

Recent BRANZ research in this area has highlighted a number of leakage paths that can be addressed with simple measures able to be achieved by the industry with current skill levels (McNeil, 2018). This mirrors the guides above and essentially recognises that the current methods of lining with square stopping or bonded cornices deal with these leakage opportunities relatively well. The major leakage pathways remaining are:

- bottom plate/floor/plasterboard junctions
- window and door edge sealing details
- plumbing penetrations
- electrical penetrations
- lack of detailing behind bathtubs and fireplaces
- downlights.

2. Project objective

Given the increasing prevalence of apartments, the objective of this project was to improve the knowledge and understanding of how apartment buildings perform in terms of airtightness in New Zealand. Although the results are not intended to be statistically representative of the entire stock, the data will provide some sense of the range of airtightness being provided by multi-unit residential buildings, particularly apartments. A better understanding of the dominant leakage paths in multi-unit residential buildings would enable industry to flag and address ventilation and moisture control issues.

The results of the work can also be used to facilitate conversations about the feasibility of introducing more widespread or mandatory airtightness testing in New Zealand.

3. Methodology

3.1 Apartment selection

The apartments for this study were volunteered for measurement by parties involved with their construction, be it architect, developer or builder. Parties were made aware of the project via some of BRANZ's communication channels, such as seminars and *Build* magazine. Although this selection process is biased, opportunities to have several days' access to a building for testing are quite uncommon, so it was felt to be the most effective approach.

3.2 Test methods

In general, the procedure described in ISO 9972:2015 was followed to obtain airtightness data for individual apartments. ISO 9972:2015 has three methods with different requirements for sealing or closing openings. For the most part in our tests, every opening was sealed using tape, with particular attention being paid to sinks and toilets when no water was connected. In some instances, outlets and inlets for mechanical ventilation systems were simply closed, but where they wouldn't fully close, tape was used to seal them. The blower door fan was mounted in the main doorway in each apartment, which represents a difference to the in-use situation of the building – the airtightness of the blower door will be different to the airtightness of the real door.

The equipment used was Retrotec Blower Doors (5000 and 6000 series) in conjunction with DM32 fan controllers.

3.2.1 Guarded testing

Guarded testing allows the calculation of the airtightness of individual faces of an apartment building. The opportunities to perform guarded testing were not consistent across the visited apartments. Some apartments were still under construction, and therefore we could not have access to all neighbouring units.

The general procedure used for guarded testing was as follows:

- Perform an airtightness test on the main unit under test. This produces a relationship between pressure and flow that corresponds to all of the leakage paths from the unit.

$$Q_1 = C_1 \Delta P^{n_1}$$

- Perform another airtightness test, this time also pressurising one (or more) neighbouring apartment(s) to the same level as the main unit under test. This produces another relationship between pressure and flow that corresponds to all of the leakage paths, less those linking the main unit under test with the other pressurised units.

$$Q_2 = C_2 \Delta P^{n_2}$$

- To obtain the pressure-flow relationship for the shared face, the two equations can be used to calculate flows at similar pressures for the two cases. The difference in flow for the two cases can then be used to calculate a third relationship

$$Q_{shared} = C_{shared} \Delta P^{n_{shared}}$$

- In several of the buildings under test, it was quickly established that no connecting flows were present by pressurising the main unit under test to a high level (100 Pa) whilst monitoring the pressures in the neighbouring units. If the pressure in the neighbouring units remained unchanged, it was assumed that no significant leakage was occurring between units.

4. Results

4.1 Apartments #1

Apartments #1 was in the Stonefields development in Auckland (Figure 2). This 5-storey building was constructed in 2017 and tested in October 2017 prior to occupancy over 3 days. The units are mechanically ventilated, although the ventilation system wasn't operational at the time of testing. Additional rangehood exhausts were also present. Each unit was separated from its neighbours by a concrete fire separation wall, and guarded testing showed no significant flow occurred between units. BRANZ tested units across the lower three floors at the western end of the building. Floor areas for these units ranged from 60 m^2 to 105 m^2.

Figure 2. Apartments #1, Auckland.

- Building status: Complete but unoccupied.
- Average airtightness for apartments = 2.7 ach @ 50 Pa.

Table 2. Summary results for Apartments #1.

Unit	Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
G12	90	493	25.50	0.76	2.3
G13	96	660	37.79	0.73	2.9
G14	90	568	44.64	0.65	2.6
G15	82	700	51.65	0.67	3.6
G16	60	719	50.34	0.68	5.0
112	90	417	20.17	0.77	1.9
113	105	774	47.28	0.71	3.1
114	90	525	36.42	0.68	2.4
115	82	393	20.01	0.76	2.0
116	60	427	27.07	0.71	2.9
212	90	400	12.23	0.89	1.9
213	105	534	51.41	0.60	2.1
214	90	581	8.34	1.08	2.7
215	82	571	7.70	1.10	2.9

Discussion

The average result for Apartments #1 of 2.7 ach @ 50 Pa is more airtight than the average modern stand-alone house from the earlier BRANZ data. The results between apartments are fairly consistent, but one apartment appeared slightly leakier at 5.0 ach @ 50 Pa. There was no time to investigate this further whilst on site.

The apartments were well compartmentalised with no significant flow observed between them. The apartments have whole-house mechanical ventilation, so overall, the airtightness is well matched to the ventilation strategy.

4.2 Apartments #2

Apartments #2 were student accommodation in Dunedin and were tested in January 2018 (Figure 3). The units tested were in a 4-storey block.

Construction was still active so that the buildings could be completed in time for the academic year to start. This meant that testing could only be done when no tradespeople were working in a particular unit and meant no guarded testing could be completed. There were also numerous areas where holes had to be sealed prior to testing due to faceplates or other fixtures not being installed at the time of testing.

The units were a mixture of apartments (four bedrooms and a shared living area) or studios (simple one-bed units). Both types of unit were naturally ventilated. BRANZ was able to test over the course of 2 days.

Figure 3. Apartments #2, Dunedin.

- Building status: Incomplete – airtightness could have improved post testing.
- Average airtightness for apartments = 5.1 ach @ 50 Pa.
- Average airtightness for studios = 6.9 ach @ 50 Pa.

Table 3. Summary results for Apartments #2.

Unit	Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
a201	73	663	43.93	0.69	3.8
a202	73	1186	99.19	0.63	6.8
a203	73	736	49.19	0.69	4.2
a405	73	970	73.39	0.66	5.5
a406	73	947	65.91	0.68	5.4
s401	26	456	28.22	0.71	7.4
s405	21	471	32.36	0.68	9.3
s203	21	316	30.99	0.59	6.3
s301	26	367	23.84	0.70	6.0
s303	21	244	26.84	0.56	4.8
s403	21	291	22.86	0.65	5.8
s405	21	435	45.89	0.57	8.6

Discussion

The average result for Apartments #2 was somewhat higher (worse) than expected. Although there was no airtightness target for the project, the construction reportedly had air barriers on both the interior and exterior of the framing and so it was assumed that the units themselves would be relatively airtight, especially given their reasonably simple form. The fact that no guarded testing could be performed means it is not known if the leakage was mainly to outside or to neighbouring apartments.

4.3 Apartments #3

Apartments #3 were located in Miramar, Wellington, and were tested in December 2018 (Figure 4). Because of the small number of units, it was possible to get the consent of the tenants and coordinate the testing around their activities. The apartments were naturally ventilated with spot exhaust ventilation for bathrooms, rangehoods and tumble dryers.

Figure 4. Apartments #3, Wellington.

- Building status: Complete, occupied.
- Average airtightness for apartments = 5.3 ach @ 50 Pa.

Table 4. Summary results for Apartments #3.

Unit	Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
1	40	578	41.63	0.67	6
2	52	618	35.88	0.73	5
3	40	788	41.31	0.75	5.6
4	52	740	40.88	0.74	4.7
1 with 3 also pressurised	40	586	66.03	0.56	6.1
2 with 4 also pressurised	52	601	42.06	0.68	4.8

Discussion

The average result for Apartments #3 was similar to the airtightness of a typical new-build house. The upper units (3 and 4) had higher ceilings than the ones below but similar results in terms of air changes per hour. It was not possible to determine whether the higher flows for units 3 and 4 were simply due to the increased wall area or whether the leakage was into the roof space. The apartments are naturally ventilated so the airtightness level is broadly in line with this strategy.

Guarded testing was performed between units 1 and 3 and between units 2 and 4. In both cases, leakage through the floor/ceiling was being eliminated, but the testing showed no significant difference in the airtightness result, suggesting there was insignificant flow between the units.

Note the apparent decrease in airtightness of apartment 1 when the ceiling was sealed. This is thought to be attributable to the fact the fitted coefficients and exponents do not perfectly describe the measured data over the entire pressure range. In both cases, the change in flow as a percentage of the unguarded results was small, hence the leakage through the floor/ceiling was concluded to be minimal.

4.4 Apartments #4

Apartments #4 were 2-storey penthouse apartments in central Wellington and were tested in January 2019 whilst being renovated (Figure 5). Because construction work was ongoing, only three of the five units could be tested. The apartments were naturally ventilated with spot exhaust ventilation for bathrooms, rangehoods and tumble dryers.

Figure 5. Apartments #4, Wellington.

- Building status at time of testing: Construction active – airtightness unlikely to be affected by the remaining work.
- Average airtightness for apartments = 7.1 ach @ 50 Pa.

Table 5. Summary results for Apartments #4.

Unit	Volume (m^3)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
C	250	1803	149.74	0.64	7.2
D	224	1437	94.90	0.69	6.4
E	242	1866	139.14	0.66	7.7
D with C also pressurised	224	1354	95.26	0.68	6.0
D with E also pressurised	224	1324	80.08	0.72	5.9

Discussion

The average result for Apartments #4 was higher than a typical new-build house. Guarded testing showed there were some airflow paths connecting the units. The shared party wall area was approximately 45 m² between unit D and E and about 20 m² between unit D and C. The increase in airtightness of unit D does not exactly follow the ratio of the shared wall areas, but it does suggest a reasonably uniform leakage associated with the party walls.

4.5 Apartments #5

Apartments #5 were located in Auckland CBD (Figure 6). A total of 23 units were tested in February 2019. Whilst the overall building was nearing completion, all the units tested were in a finished state, so the airtightness was unlikely to change post testing. The units were generally separated from each other by concrete fire separation walls and so there was no significant leakage between these units. However, some of the units were dual-key apartments divided using a timber-framed partition wall, and the leakage across the partition was quantified. The apartments here had whole-house mechanical ventilation in addition to extracts at the rangehood.

Figure 6. Apartments #5, Auckland.

- Building status at time of testing: Construction active – airtightness unlikely to be affected by the remaining work.
- Average airtightness for non-dual-key apartments including 'home' configuration = 3.8 ach @ 50 Pa.
- Average airtightness for dual-key apartments = 6.0 ach @ 50 Pa.

Table 6. Summary results for Apartments #5.

Unit	Flow @ 50 Pa (m^3/hr)	Area (m^2)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa	ach @ 50 Pa (guarded)	Effective hole diameter in party wall @ 4 Pa (mm)
304	422	50	26.25	0.71	3.4		
303	278	31	24.98	0.62	3.6		
302b	443	30	22.31	0.76	5.9		
302a	428	30	23.43	0.74	5.7	3.8	48
301b	591	35	40.78	0.66	6.3		
301a	550	35	21.15	0.85	6.8	4.3	50
301 'home'	738	74	46.65	0.71	4.0		
404	395	50	18.11	0.79	3.2		
403	276	31	34.06	0.54	3.6		
402b	460	30	23.47	0.76	6.1		
402a	448	30	26.82	0.72	6.0	3.6	48
401b	627	35	47.59	0.63	6.3		
401a	553	35	64.23	0.58	7.2	4.7	113
401 'home'	779	74	57.11	0.67	4.2		
504	315	50	16.08	0.76	2.5		

Unit	Flow @ 50 Pa (m^3/hr)	Area (m^2)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa	ach @ 50 Pa (guarded)	Effective hole diameter in party wall @ 4 Pa (mm)
503	325	31	25.16	0.66	4.2		
502b	524	30	39.92	0.66	7.0		
502a	545	30	38.83	0.68	7.3	5.5	56
501b	511	35	39.09	0.66	5.8		
501a	534	35	45.66	0.63	6.1	4.5	69
501 'home'	738	74	40.38	0.74	4.0		
604	407	50	31.56	0.65	3.3		
603	325	31	27.03	0.64	4.3		
602b	490	30	24.95	0.76	6.5		
602a	462	30	28.87	0.71	6.2	3.9	56

Discussion

Data from floors 3 to 6 is shown in Table 6. Each tested storey had an identical floor plan, with units X02 and X01 being dual-key apartments (a and b). The dual-key apartments were tested as stand-alone units and then with the neighbouring unit pressurised to the same level to enable the effective leakage through the party wall to be measured. For the X01 units, an additional configuration was measured to mimic the 'home' configuration on the upper floors, i.e. one larger apartment. In this case, the fan was mounted in the main door off the breezeway with the doors for each of the dual-key apartments left open, effectively making one large apartment.

The average result of 3.8 ach @ 50 Pa for the stand-alone apartments represents reasonably airtight construction. The airtightness was reasonably consistent across the similar units, which could be expected given the common features between them. There was no significant leakage across the concrete walls and floors. The only air leakage in the single units was through the front and back faces. Fog testing was performed with one unit depressurised, and leakage was through the ranch slider at both the sliding door and the internal corner (Figure 7).

Figure 7. Air leakage paths through ranch slider joinery shown by passage of smoke.

The dual key apartments had an average result of 6.0 ach @ 50 Pa from unguarded testing. The higher leakage arose from airflow paths between units. This leakage was primarily due to the IT cupboards (fog tested again) on the interior dividing wall and was roughly equivalent to a 60 mm diameter hole in the wall.

To estimate the airtightness results of the dual key apartments when treated as a single unit, the results from the 'home' configuration for the X01 units is probably a good estimate.

In reality, the degree of cross-flow between the dual key apartments would depend on the pressure difference across the wall. For example, cross-flow may be higher in the X01 units than the X02 units because X01a and X01b were on different sides of the building, whereas X02a and X02b were on the same face.

4.6 Apartments #6

Apartments #6 were a hotel in Queenstown and were tested in May 2019 prior to being renovated (Figure 8). Some areas of the walls and ceilings had been opened up for inspection. These areas were taped as much as possible. Some of the hotel rooms were essentially bedsits. In these cases, the adjoining door to the larger neighbouring units was opened so that the combined space was more like a real apartment.

Figure 8. Apartments #6, Queenstown.

- Building status at time of testing: Some defects due to inspection openings but considered unlikely to have a large effect on the measurements.
- Average airtightness for apartments = 8.98 ach @ 50 Pa.

Table 7. Summary results for Apartments #6.

Unit	Area (m^2)	Flow @ 50 Pa (m^3/hr)	C (m^3/hr/Pa^n)	n	ach @ 50 Pa
504b	90	2500	128.34	0.76	7.9
503b	90	2105	112.80	0.75	6.7
502b	90	2342	120.72	0.76	7.4
501b	90	2163	118.90	0.74	6.9
504	110	2821	194.18	0.68	10.7
503	115	2709	186.60	0.68	9.8
502	115	3144	194.50	0.71	11.4
501	110	3336	225.89	0.69	12.6
404	110	2397	170.39	0.68	9.1
403	90	1598	89.62	0.74	7.4
403a	25	623	25.04	0.82	10.4
402	115	2677	188.02	0.68	9.7
401	110	2284	179.52	0.65	8.7
304	110	2739	194.73	0.68	10.4
303	115	2232	138.69	0.71	8.1
302	115	2925	198.52	0.69	10.6
301	110	2069	152.47	0.67	7.8
204	110	2296	153.42	0.69	8.7
203	115	2370	143.30	0.72	8.6
202	115	2575	135.01	0.75	9.3
201	110	2199	124.59	0.73	8.3
104	110	2071	78.04	0.84	7.8
103	115	2633	201.43	0.66	9.5
102	115	2457	163.60	0.69	8.9
101	110	2058	140.80	0.69	7.8

Discussion

The average result of 8.98 ach @ 50 Pa is not particularly airtight and represented the least airtight apartments seen over the course of the project.

There was no significant leakage to the neighbouring units on the same floor. In terms of leakage to the units above and below, in a spot check at 50 Pa, about 10% of the airflow went through each of the ceiling and floor, so the majority of the leakage appeared to be to the outside through joinery and the non-concrete external walls.

Overall, Apartments #6 represents a building with a high amount of uncontrolled air leakage to outside. It would be interesting to see how the remediation affects this. If higher levels of airtightness are desired, the key areas to look at would be the joinery and the perimeter of the wall (bottom plates), which smoke testing showed to be significant airflow paths.

4.7 Apartments #7

Apartments #7 were in Te Atatū, Auckland, and were tested in June 2019 prior to being renovated (Figure 9). The apartments were naturally ventilated with spot exhaust ventilation for bathrooms, rangehoods and tumble dryers.

Figure 9. Apartments #7, Auckland.

- Building status at time of testing: Apartments complete and unoccupied.
- Average airtightness for all apartments = 4.33 ach @ 50 Pa.
- Average airtightness for top-floor apartments = 7.66 ach @ 50 Pa.
- Average airtightness excluding top-floor apartments = 3.68 ach @ 50 Pa.

Table 8. Summary results for Apartments #7.

Unit		Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
Floor 1	A	81	623	38.25	0.71	3.2
	B	75	681	42.03	0.71	3.8
	C	72	467	27.75	0.72	2.7
	D	72	846	71.87	0.63	4.9
	E	72	505	33.29	0.70	2.9
	F	71	755	43.35	0.73	4.4
	G	71	530	29.21	0.74	3.1
	H	85	712	52.31	0.67	3.5
Floor 2	A	81	573	30.23	0.75	2.9
	B	75	750	43.80	0.73	4.2
	C	72	444	19.52	0.80	2.6
	D	72	692	49.38	0.67	4.0
	E	72	544	27.18	0.77	3.1
	F	71	647	40.78	0.71	3.8
	G	71	479	30.90	0.70	2.8
	H	77	666	45.17	0.69	3.6
Floor 3	A	81	796	51.86	0.70	4.1
	B	75	843	47.83	0.73	4.7
	C	72	581	38.25	0.70	3.4
	D	72	1068	90.82	0.63	6.2
	E	72	573	33.83	0.72	3.3
	F	71	639	35.43	0.74	3.8
	G	71	605	39.99	0.69	3.6
	H	77	722	45.32	0.71	3.9

Unit		Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C (m^3/hr/Pa^n)	n	ach @ 50 Pa
Floor 4	A	81	526	38.35	0.67	2.7
	B	75	802	60.54	0.66	4.5
	C	72	614	31.83	0.76	3.6
	D	102	942	68.76	0.67	3.8
	E	72	620	39.44	0.70	3.6
	F	93	916	54.89	0.72	4.1
	G	77	630	29.74	0.78	3.4
Floor 5	A	81	1636	88.40	0.75	8.4
	B	75	1705	124.54	0.67	9.5
	C	72	1326	89.33	0.69	7.7
	D	110	1778	105.64	0.72	6.0
	E	102	1542	87.78	0.73	5.6
	F	74	1562	76.14	0.77	8.8

Discussion

Apartments #7 was among the more airtight apartments measured in this study and considerably more airtight than the other properties that had undergone or were about to undergo renovation work. All the units were well compartmentalised. The only real point of note was the reduction in airtightness of the top-floor units, due to being connected with the roofspace above rather than a concrete floor.

4.8 Apartments #8

Apartments #8 were a newly built social housing development in Wellington (Figure 10). They were tested in their completed state in July 2019. The units are a mixture of single-storey units and 2-storey units and are naturally ventilated with spot exhaust ventilation for bathrooms and rangehoods.

Figure 10 Apartments #8, Wellington

- Building status at time of testing: Complete and unoccupied.
- Average airtightness for apartments = 4.7 ach @ 50 Pa.

Table 9. Summary results for Apartments #8.

Unit	Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
1	40.5	554	38.50	0.68	5.7
2	40.5	587	42.85	0.67	6.0
3	81	715	31.92	0.79	3.7
4	40	445	16.31	0.84	4.6
5	35	401	20.32	0.76	4.8
6	31	437	37.79	0.63	5.9
7	67	755	42.47	0.74	4.7
8	32.5	435	12.03	0.92	5.6
9	71.5	786	42.01	0.75	4.6
10	72	825	58.55	0.68	4.8
11	91	673	21.70	0.88	3.1
13	91	789	26.79	0.86	3.6
14	69	626	46.64	0.66	3.8

Discussion

One difficulty we faced at Apartments #8 was due to the nature of the doorframes. The hinges made it quite difficult to install the fans on a number of apartments, meaning the seal between the blower door and the frame was not always ideal.

The average test result was 4.7 ach @ 50 Pa. This is in line with what would be expected for a new-build house. In terms of a ventilation strategy, Apartments #8 had local extract ventilation at the rangehood and in the bathrooms but otherwise was naturally ventilated.

A limited amount of smoke-testing was performed to identify areas of air leakage. Figure 11 shows leakage at the bottom plate of an external wall.

Figure 11. Smoke coming through the bottom plate of an external wall under depressurisation of the apartment.

The leakage shown in Figure 11 is commonly seen and is not being flagged as a defect with the apartments. If there was a desire to increase the airtightness of the structure, the bottom plate detail is an area that should be targeted. Note that this wall was specified as having a fire resistance rating of 60/60/60. The fire resistance rating does not correspond to smoke control requirements, and there is no evidence to suggest the smoke leakage observed under depressurisation corresponds to a reduction in the fire resistance level.

4.9 Apartments #9

Apartments #9 was a retirement village in Upper Hutt and was tested in December 2019, just as construction was finishing (Figure 12). Some units required a few areas to be taped up prior to fixtures being installed. The apartments were mechanically ventilated using a centralised system with spot exhaust for rangehood and dryers. Testing was performed on the western wing across all three floors.

Figure 12. Apartments #9, Upper Hutt.

- Building status at time of testing: Construction ongoing but tested units were in a near-complete state.
- Average airtightness for all apartments = 4.2 ach @ 50 Pa.
- Average airtightness for top-floor apartments (excluding 304) = 6.3 ach @ 50 Pa.
- Average airtightness excluding top-floor apartments = 3.4 ach @ 50 Pa.

Table 10. Summary results for Apartments #9.

Unit	Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
101	66	471	47.50	0.59	3.0
102	66	448	20.48	0.79	2.8
103	66	674	29.05	0.80	4.3
104	75	596	22.02	0.84	3.3
201	66	465	31.98	0.68	2.9
202	66	526	44.95	0.63	3.3

Unit	Floor area (m^2)	Flow @ 50 Pa (m^3/hr)	C ($m^3/hr/Pa^n$)	n	ach @ 50 Pa
203	66	481	43.52	0.61	3.0
204	63	616	38.18	0.71	4.1
205	63	706	28.30	0.82	4.7
206	75	524	35.49	0.69	2.9
301	66	860	57.69	0.69	5.4
302	66	1035	77.41	0.66	6.5
303	66	1009	65.24	0.70	6.4
304*	63	1112	102.20	0.61	7.4
305	63	1022	81.64	0.65	6.8

* Unit 304 had a dryer vent left unsealed by mistake. There was no opportunity to retest, and the 304 result has been removed from the averages below.

Discussion

Apartments #9 a showed no significant flow to neighbouring units and so appeared to be well compartmentalised.

Overall, the data in Table 10 shows reasonably consistent airtightness across units. The apartments on the first two levels had an average airtightness of 3.4 ach @ 50 Pa. The top-floor apartments were less airtight with an average of 6.3 ach @ 50 Pa if we exclude unit 304. The explanation for the higher air leakage on the top floor is because the roof space is above it, which in turn is open to the outside. The lower apartments are separated by concrete floors, which are more airtight than the roof space.

5. Discussion

The results collected in the study represent an initial look at what level of airtightness is being provided by the stock of apartments in New Zealand and how prevalent inter-unit air leakage may be. It is important to restate that there is no quantified target for airtightness in the New Zealand building regulations – i.e. none of the measurements here represent passes or failures.

Figure 13 shows the results of the 148 individual (non-guarded) airtightness tests completed in this study added to Figure 1, noting that the apartments cover a range of ages (although all were post 2000). Viewing the data this way suggests that, overall, the airtightness level offered by apartments is slightly less than typical new-build stand-alone housing.

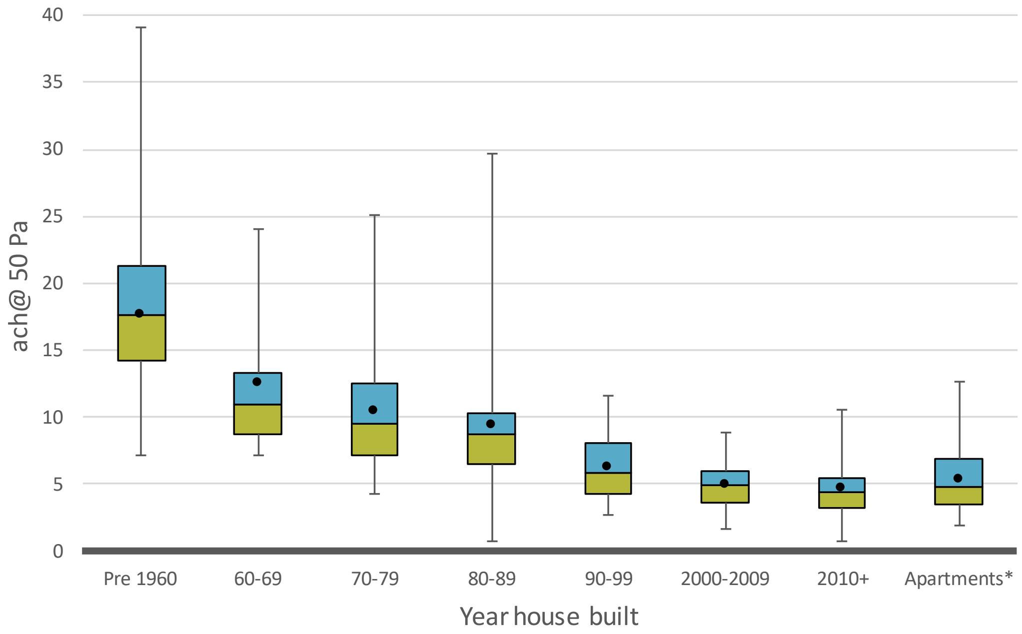

Figure 13. Airtightness of New Zealand houses by date of construction including apartment data.

Viewing the data as in Figure 13 does not show the full picture. The airtightness of the apartments measured here was strongly dependent on the construction methods used. In buildings where the units were effectively concrete cells, there was very little leakage to other units, and in general, the individual units were also quite airtight. The average result for Apartments #1, #5, #7 and #9, for example, was 3.5 ach @ 50 Pa if top-floor and dual-key apartments were excluded. That represents reasonably airtight construction, although it would still not meet the requirements of many jurisdictions as shown in Table 1. In addition, although the overall result is a reasonably airtight apartment, the leakage is predominantly through those faces adjacent to the exterior. Therefore, those faces are reasonably air permeable.

The data also highlights the variability of airtightness in the stock both across the sample and across individual developments. This is unsurprising but worth highlighting. For example, top-floor apartments, as measured in Apartments #3, #7, and #9, were significantly less airtight than the lower floor apartments. This is probably because, above the ceiling of the top-floor units, the roof space is effectively vented to outside, whereas above the ceiling of the lower units is a well-sealed floor. In terms of variation across the whole sample, the most airtight unit measured 1.9 ach @ 50 Pa and was at Apartments #1, and the least airtight unit measured 12.6 ach and was at Apartments #6. That is clearly a considerable range of airtightness, which again is understandable given that airtightness is often not a key consideration when constructing buildings in New Zealand.

5.1 Potential targets for New Zealand

There is often debate in New Zealand about what is an appropriate level of airtightness for our buildings and whether there should be a target. In this section, some of the arguments for and against a target are presented, with the discussion not being limited to apartments.

The ideal performance case is one where ventilation is controlled, the heat loss associated with that airflow is minimised and infiltration is also minimised. These principles are essentially embodied as part of the Passive House standard. There is minimal infiltration because of the 0.6 ach @ 50 Pa airtightness target. The buildings have whole-house mechanical ventilation systems so ventilation is controlled, and the systems employ heat recovery so that the outgoing air is not carrying useful heat away.

If instead we look at a typical Code-complaint New Zealand house built today, we might expect it to have an airtightness of about 5 ach @ 50 Pa, have some spot-exhaust ventilation and have openable windows for ventilation. Considerably more infiltration will occur than in the Passive House case. Although this infiltration can contribute to the air needed for ventilation, it is dependent on wind pressures, the locations of the leakage points and temperature difference between inside and outside. There is also normally no attempt to recover heat from outgoing air other than any inadvertent heat exchange as the air moves through the building fabric.

New Zealand houses have historically somewhat relied on infiltration to supplement deliberate ventilation, but we know a significant number of newer houses are likely to be underventilated (Overton et al., 2013). Forcing buildings to be more airtight without addressing ventilation at the same time would therefore increase the proportion of underventilated dwellings. Therefore, any initiatives to do so should also incorporate more comprehensive ventilation requirements, ideally with verified flow rates, whilst addressing other weak points in the thermal envelope that are more significant than airtightness. Naturally ventilated buildings can evidently work. However, for the purposes of this discussion, we will consider mechanical ventilation only since it is more straightforward to consider a fixed amount of ventilation.

Figure 14 is reproduced from McNeil, Plagmann, McDowall & Basset (2015). It shows the estimated infiltration for a particular single-storey house in Christchurch. Often a rule of thumb such as dividing the airtightness result by 20 is used to estimate infiltration. However, the data in Figure 14 is based on using tracer gases to measure infiltration at the BRANZ site and then estimated for Christchurch based on a typical meteorological year. For the case where the airtightness is 3 or less, the infiltration level is low and provides a good base for providing mechanical ventilation. The reduction in infiltration associated with going from 3 ach @ 50 Pa to 1 ach @ 50 Pa is not that significant in this case.

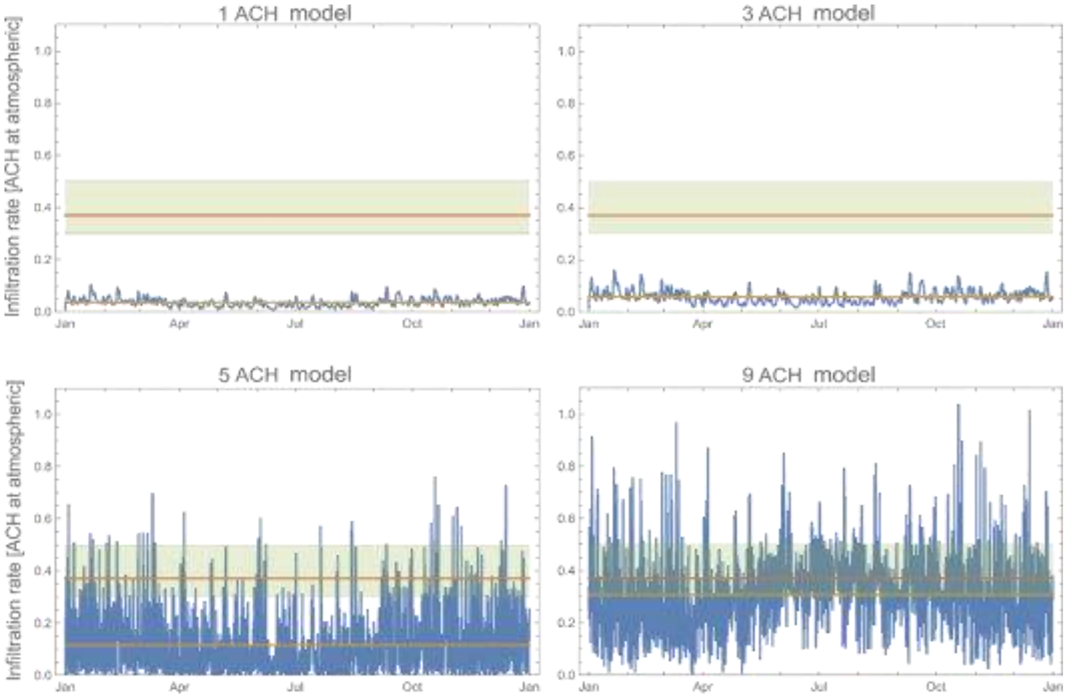

Figure 14. Estimated infiltration rates associated with different levels of airtightness for a BRANZ test house if it were located in Christchurch.

As a basis for providing a controlled amount of infiltration, airtightness of 3 ach @ 50 Pa would appear to be a pragmatic possible target for New Zealand, given the airtightness typically associated with new stock. Further, Figure 14 shows why we are likely to see underventilated houses in the current stock. At an airtightness level of 5 ach @ 50 Pa, the average ventilation rate is around 0.1 ach, and the buildings are therefore reliant on opening windows for ventilation. For 9 ach @ 50 Pa, the average infiltration is close to what is needed for ventilation (shown by the green region), but it is clearly not a consistent level of infiltration with some periods being close to zero flow and other periods where it is in excess of the ventilation requirement.

In terms of the heat losses associated with ventilation and infiltration, Figure 15 shows the approximate heat losses for our hypothetical Christchurch case using ALF at two airtightness levels: 3 ach @ 50 Pa and 5 ach @ 50 Pa. Mechanical ventilation at 0.4 ach is shown, both with and without heat recovery (70% overall efficiency). Two levels of insulation have also been used: the schedule method of NZS 4218:2009 *Thermal insulation – Housing and small buildings* and the Homestar V4 schedule method (NZGBC, 2017) for 7 Homestar, which was chosen arbitrarily as something higher than the minimum Code requirements.

Several things can be inferred from Figure 15. The first is that, given the airtightness typically associated with new houses built today, the energy argument for introducing airtightness targets (in isolation) is not that strong. The infiltration heat loss is of course reduced, but this is small compared to the rest of the heat losses. Ventilation still has to be provided, and there is a heat loss cost associated with this. The ventilation heat loss can be reduced using a heat recovery system, but again the value of that should be compared with where other savings can be made. Note also that our 70% overall system efficiency is considered to be representative of a case where the ducting is within the thermal envelope. This would drop considerably if this were not the case. For the 7 Homestar case, the ventilation heat losses are a bigger proportion of the total heat loss, and heat recovery therefore has a proportionately bigger effect.

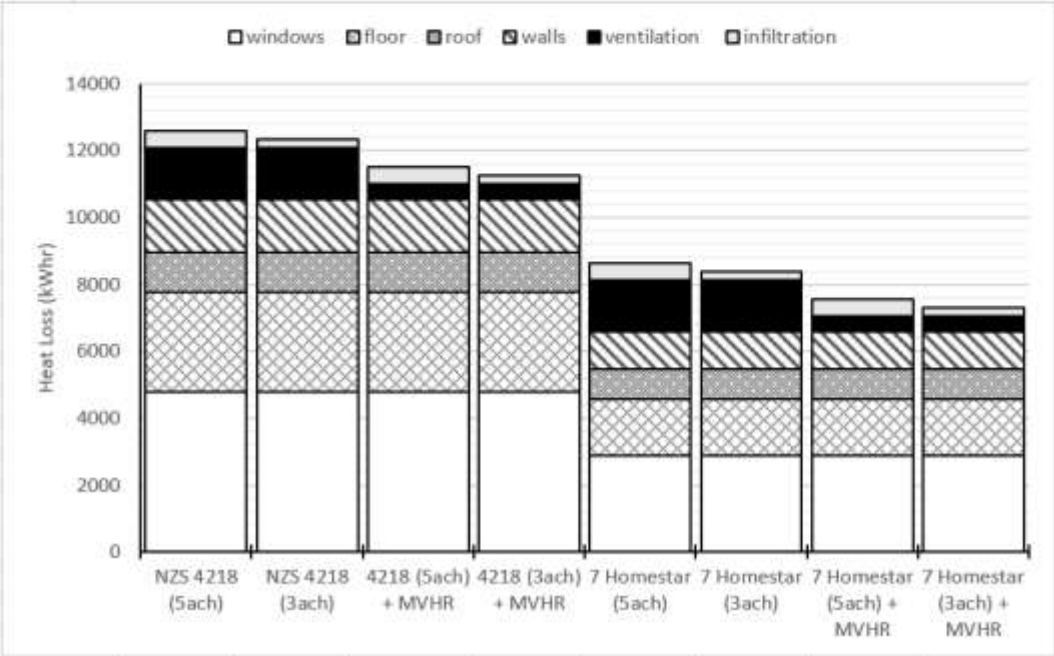

Figure 15. Heat loss components for an illustrative case in Christchurch with mechanical ventilation.

Other indirect savings (such as health costs) can be realised by helping provide a 'better' indoor environment, which airtightness can contribute to, and New Zealand clearly appears to be lagging behind many in the international community with respect to airtightness targets. As discussed in section 1, these targets often stem from energy regulations, which may be the most appropriate lens through which to look at the problem. As the R-values of building components (walls, ceilings and windows) are increased, the relative importance of infiltration and ventilation heat losses becomes more important. Therefore, airtightness control becomes necessary so as not to undermine the other thermal upgrades. If upgrades to the Building Code or voluntary standards are made to support New Zealand's obligations under the Paris Accord, for example, it would be logical to do this holistically – i.e. increase required R-values at the same time as introducing airtightness requirements and requirements for controlled ventilation.

5.2 Achieving a target

It is clear that very airtight buildings are achievable on a wide scale – the evidence from Germany supports this. This is likely a result of a continued effort by Germany over the course of several decades to focus on airtightness in tandem with the vast majority of building being of massive construction. In New Zealand, any target would represent a step change from the status quo. Given the typical airtightness of new buildings, a pragmatic approach may be to introduce new Acceptable Solutions to help seal the most prevalent leakage pathways (bottom plates, pipe penetrations) in conjunction with an optional 3 ach @ 50 Pa target for a measured building airtightness. A set of easy-to-inspect details to reduce leakage where it is most prevalent would tighten the distribution of measured leakage in new stock, and the optional target should begin to transition airtightness testing to be the norm. As mentioned in section 1, evidence from overseas suggests that regulation changes, testing and education schemes are the most effective way of changing the airtightness offered by the building stock.

With specific reference to future tests on apartments, it is suggested that, if possible, the test be performed in a manner akin ASHRAE 62.2, which concerns acceptable ventilation and indoor air quality of residential buildings (including apartments) and states that air transfer from other dwelling units should be minimised. Compliance can be shown by testing a unit as if it were exposed on all sides to outside air by opening windows and doors of adjacent units. In ASHRAE 62.2, the airtightness should be a maximum of 1.5 L/s.m² (approximately 6.7 ach @ 50 Pa using the normalising method in section 1). This method was not employed in this study, but it would be surprising if it significantly affected the results reported here, where many units were tighter than 6.7 ach @ 50 Pa with little sign of inter-apartment leakage. However, in the opinion of the authors, future testing in this manner (with a target of 3 ach @ 50 Pa), would give a fairer representation of the airtightness of each unit and provide confidence that inter-apartment leakage was not severe, without the need to do guarded testing.

The suggestions here represent a possible transition to the point where airtightness is commonly being measured in New Zealand. Over time, as the industry becomes comfortable with airtightness being a key consideration, there remains the opportunity to revise the target accordingly to support further improvements to the overall performance of our buildings.

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