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NZTA Ventilation Specification Review

Review of current literature and District Plan rules

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1.0 INTRODUCTION

Acoustic Engineering Services (AES) has been engaged by the New Zealand Transport Agency (NZTA) to undertake a review of ventilation specifications.

The scope of the review can be broadly split into two main components; a literature review of current guidance and research relating to the use of mechanical ventilation systems, and a review of District Plan rules with ventilation requirements throughout the different regions of New Zealand. AES was also engaged to concurrently review District Plan rules relating to reverse sensitivity provisions, however that is outside of the scope of this report and was delivered separately.

The first section of this report outlines our findings after reviewing international standards and guides on the topic of ventilation requirements in residential units. These standards and guides have been informed by decades of scientific and industry led research, and provide definitions of core concepts and standard specifications.

The next section provides our findings of current scientific literature relating to the thermal comfort provided by ventilation systems, and the human factors involved in the use of ventilation systems. This section also details current trends in research, and provides insight into opportunities for further studies.

Following this, there is a section outlining our findings when examining the application of ventilation specifications in New Zealand as shown through Resource Consent hearings, Ministry of Business, Innovation and Employment determinations, and changes to District Plan rules.

Finally, this report provides a summary of District Plan rules relating to ventilation and shares general trends identified. We have provided a table which summarises these rules as Appendix B. The full Excel spreadsheet will be provided to NZTA alongside this report.

2.0 REVIEW OF INTERNATIONAL STANDARDS AND GUIDES

We have reviewed international standards and guides relating to mechanical ventilation in residential units. Below is a summary of our findings including commonalities, key differences, gaps in the information available, and recommendations for further investigation.

2.1 Indoor Air Quality

Indoor air quality (IAQ) is a concept which relates to the standard of air inside buildings and can include contaminant densities, air flow rates, humidity, and other metrics. The guides we reviewed identified that there is no singular accepted definition of IAQ, nor an agreed upon singular metric to determine the overall quality.

Approved Document F [1] of the English Building Regulations notes that the inherent assumption of any discussion regarding IAQ is that the outdoor air is of sufficient quality to be used for ventilation. Based on the overall scope of this project, we have assumed that our interest in IAQ is limited to prescribed air flow rates and exhaust rates, and that a review of removal of contaminants or any other factors of IAQ is not required.

Across the available standards and guides there was a large disparity in the recommended air flow rates, and whether these were mandatory regulations or only recommendations.

There were several ways of viewing air flow and exhaust rates that occurred frequently in the standards and guides:

- A prescriptive rate for the whole house
- A rate for different spaces based on the floor area and use case of each space
- A rate for different spaces based on the number of occupants and use case of each space
- A combination of the above methods

The given values were typically presented as litres per second (L/s), metres cubed per hour (m^3/h), or air changes per hour (ACH).

Typical air flow rates for residential units ranged from 0.35 ACH in ASHRAE Standard 55 [2] to upwards of 5 ACH in the International Mechanical Code [3], noting that the required rates are even higher for different use cases. For example, the NZ Ministry of Education document Designing Quality Learning Spaces [4] recommends an ideal air flow rate of between 4 and 10 ACH for teaching spaces.

The more robust methods of calculating the required air flow rates such as those found in the ASHRAE Standard S62.2 [5] and British Standard EN 15251 [6] require some knowledge of the actual spaces and use cases in order to determine the required flow rate.

An AIVC study in 2004 [7] compared the minimum ventilation rates of residential buildings in 15 countries across Europe, Asia and North America, as required by their respective regulations. For a model house with 151 m^2 floor area occupied by a family of four, the minimum air flow rates ranged from 0.36 ACH to upwards of 0.80 ACH, with a mean of 0.58 ACH. This study showed that with the exception of Switzerland and USA (ASHRAE) the various provisions typically resulted in at least 0.5 ACH for the house.

Only CIBSE Guide B2 [8] makes an allowance for airflow rates based on the target Indoor Air Quality performance level. Four levels are defined, ranging from 5 L/s per person at the lowest performance level to 20 L/s at the highest.

The exhaust rates given in the standards and guides were similarly varied, and there was little consistency as to whether there was a single rate provided, or if it varied based on room size or number of appliances/fixtures present.

Typical continuous exhaust rates for residential dwellings ranged from 8-20 L/s for bathrooms, and 15-60 L/s for kitchens. A 50 L/s intermittent rate for rangehoods and 25 L/s intermittent rate for bathrooms was reasonably common. The exhaust rate for laundries is specified in Australian Standard AS 1668-2:2012 [9] for situations where there is no dryer, where there is a condensing dryer present, and where there is a non-condensing dryer present (20 L/s, 20 L/s, and 40 L/s respectively). Other guidance did not specify the exhaust rate for laundries based on what appliances were present, with continuous exhaust rates ranging from 8 L/s to 40 L/s. Of all the guidance reviewed, only British Standard EN15251 [6] had a recommended unoccupied ventilation rate of 0.05-0.1 L/s per m^2, while AS 1668-2:2012 [9] makes an allowance for periods where occupancy is below design levels, when the ventilation rate can be reduced to a minimum of 0.35 L/s per m^2.

Only AS 1668-2:2012 [9] gives a requirement for situations where both supply and exhaust air provisions are present in a space, stating that the exhaust rate must be at least 10% higher than the supply air rate.

The United States Department of the Interior Design Guide [10] has a prescribed air speed, requiring residential ventilation systems to have an air speed between 50 feet/minute and 75 feet/minute (0.25 to 0.38 m/s). In CIBSE TM59 [11], it is noted that air speed should be nominally 0.1 m/s. No other guidance provided a rate for this feature.

Australian Standard AS 1668-4:2012 provides guidance on natural ventilation requirements, in the form of minimum open areas in the wall or ceiling based on a percentage of gross floor area. There are two methods to determine the required open area [12]. The simple method considers only the building class, with 5% of the floor area required in residential dwellings and 10% of the floor area required in other buildings. The complex method uses a combination of the average metabolic rate per person and the net floor area per occupant to determine the required open areas, ranging from 2.5% up to 15%, and noting that the rate should be multiplied by 1.25 in classrooms.

CIBSE Guide B2 [8] provides ventilation data for windows open for natural ventilation when subjected to a 100 Pa blower door test. The ventilation rates ranged from 3-50 m^3/h per m^2, with horizontal centre pivot windows providing the highest airflow rates, and top hung windows providing the lowest.

The applicable standard in New Zealand, NZS 4303 [13], has not been updated since 1990, and is based on earlier versions of the ASHRAE standards. The minimum airflow rate for occupied areas is 0.35 ACH but not less than 7.5 L/s per person. The exhaust rate for kitchens is minimum 12 L/s continuous extraction or minimum 50 L/s intermittent extraction, while bathrooms and toilets are minimum 10 L/s for continuous extraction or 25 L/s for intermittent extraction.

2.2 Infiltration

Infiltration is defined in the ABCB Handbook on IAQ [14] as the uncontrolled entrance of outdoor air through cracks in the building envelope (i.e. gaps around doors and windows, wall and floor joints, etc). This is a factor in determining the required ventilation in a space, and also impacts greatly on the thermal performance of the building.

The ABCB Handbook [14] recommends that modelling or measurements of the infiltration are performed as part of the assessment of compliance for any ventilation system.

Approved Document F [1] recognises two general categories of houses; those with an envelope with no air permeability and an infiltration rate of 0 ACH, and those with an envelope that allows leakage of air and have an assumed infiltration rate of 0.15 ACH. In the second instance, it is recommended that the provided ventilation system has a lower air flow rate to allow for the contribution of infiltration.

The International Mechanical Code [3] requires mechanical ventilation to be installed if the infiltration rate is less than 5 ACH.

2.3 Thermal comfort

Thermal comfort is a measure of the level to which an end user will be content with the thermal environment, and can include consideration of metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and other metrics.

One commonality between most of the standards and guides was the idea that IAQ and thermal comfort are strongly interlinked, and that user comfort is dependent on both needs being fulfilled adequately.

ASHRAE Standard S55 [2] provides a method for assessing thermal comfort based on the following 6 key factors:

- Metabolic rate
- Clothing insulation
- Air temperature
- Radiant temperature
- Air speed
- Humidity

Of these factors, five can be related to the selected ventilation strategy within a space, with only metabolic rate being fully independent. The Standard notes that users who have a means of control over one or more of the factors are likely to have higher thermal comfort.

In the International Standard ISO 7730 [15], an alternative method for assessing thermal comfort is provided, based on the percentage of users likely to be dissatisfied. The NHBC Foundation guide Overheating In New Homes [16] notes that this Standard gives consistent results regardless of climatic conditions; however, the standard does not take into account the building type or its surroundings.

With regard to temperature, there are similarities in the range of acceptable indoor temperatures provided in different standards and guides. The majority of guidance provides a range of temperatures spanning 6-8 °C between the acceptable minimum and maximum indoor temperatures.

The WHO recommends an indoor temperature band of 18-24°C for residential use [17, 18]. Approved Document F states that there should be a maximum of 4°C departure from the comfort temperature, noting that a maximum temperature of 27°C must not be exceeded [1]. EN 15251 provides three temperature ranges for living spaces including bedrooms for each of summer and winter periods based on metabolic rates, with a minimum internal temperature of 18°C in winter and a maximum internal temperature of 27°C in summer [6].

The fourth edition of the AIRAH Technical Handbook (2007) notes that a temperature difference of 2°C or less throughout a day is not typically noticed by occupants [19].

British Standard EN 15251 contains a concept of adapted and un-adapted users, where an adapted user is someone who is already experiencing adequate thermal comfort in a space, and an un-adapted user is someone who has recently arrived to a space and is not experiencing thermal comfort [6]. This Standard requires higher ventilation capacity than other guidance, to account for the need to rapidly adjust the internal temperature to improve thermal comfort for an un-adapted user.

CIBSE Guide B2 recommends that thermal comfort of feet and legs is controlled such that a combination of near-floor temperatures below 22°C and air velocities greater than 0.15 m/s does not occur [8].

2.4 Overheating

In the context of the ventilation of residential units, overheating is defined as occurring when the indoor temperature:

- Exceeds a specified maximum temperature at any time; or,
- Exceeds the external temperature by a specified amount; or,
- Exceeds a specified threshold temperature for more than the permitted number of annual hours

The CIBSE technical memo TM59 (2017) notes that there is no recognised international definition for the point at which overheating occurs, as there is no recognised research in the area [11]. British Standard EN15251 suggests that there is a maximum allowable difference from comfort temperature, in the case of the UK this would be 3-4°C [6].

From our research it appears that very few countries have an allowance for overheating in their building codes, and while some international guides touch on the topic of overheating, we could not find a standard which provides a definition of the point at which overheating occurs, or the required ventilation rate to minimise the effects of overheating.

A common inference was that adequate management of overheating is provided by satisfying the purge requirements of the relevant building code. This is typically performed by opening windows, or with a high extract setting on a mechanical ventilation system.

However, CIBSE TM59 comments that in practice it is not feasible for this be relied upon, as often occupants are unable to open windows for safety reasons, or in the case of a heat wave opening windows for ventilation could result in higher internal temperatures [11].

Approved Document F requires a minimum of 4 ACH in each habitable room to mitigate overheating, also stating that upwards of 10 ACH would not be unreasonable [1]. Other guidance did not provide a specific figure, only noting that allowances for overheating should be incorporated into the ventilation system design.

CIBSE TM59 gives separate overeating criteria for naturally ventilated spaces and mechanically ventilated spaces [11]. Where natural ventilation is used, overheating is deemed to occur when the inside temperature is 1°K or more above the operative comfort temperature during more than 3% of summer occupied hours for living rooms and bedrooms, or when the inside temperature of bedrooms is above 26°C for more than 1% of annual night-time hours. For mechanical ventilation systems, overheating is deemed to occur when the internal temperature in any occupied room exceeds 26°C for more than 3% of occupied hours.

CIBSE Environmental Design Guide A (as referenced in [11]) outlines that temperatures above 24°C in bedrooms may compromise sleep, and that temperatures should never exceed 26°C in bedrooms at any point.

In AS 1668-2:2012, an allowance is made for situations where the internal temperature is expected to exceed 27°C under normal operation, requiring the airflow rate to be increased to a minimum of 15 L/s per person in order to provide appropriate filtration of body odour caused by the elevated temperatures [9].

One unexpected finding was that the English Building Regulations base the design of ventilation systems on the winter period, with a note saying some additional allowances may need to be made for the warmer months [20].

The AVO Guide references a study in London where 85% of planning applications requiring both noise and overheating assessments for consenting purposes relied on having windows closed for acoustic purposes while also needing windows to be openable to prevent overheating [20]. This is a common trade-off noted in the guidance where occupants must choose thermal comfort or acoustic comfort.

2.5 Noise

Noise was discussed in the guidance in two main contexts; internal noise generated by a mechanical ventilation system, or external noise break-in through the building envelope.

There was some disparity in the total internal noise levels (including ambient noise break-in and noise from ventilation systems) that were considered acceptable by different standards and guides. Approved Document F provides a limit of 30 dB L_{Aeq} for noise sensitive spaces such as bedrooms and living rooms, and a limit of 35 dB L_{Aeq} for less noise sensitive spaces [1]. British Standard EN 15251 recommends a design limit of 32 dBA for living rooms and 26 dBA for bedrooms [6]. BS 8233:2014 recommends an internal noise level of 35 dB L_{Aeq} for living rooms, 40 dB L_{Aeq} for dining rooms, and 35 dB L_{Aeq} for bedrooms during daytime and 30 dB L_{Aeq} during night-time [21]. The Passivhaus Standard requires noise in all habitable rooms to be less than 35 dBA [22]. AIRAH Handbook 4th edition recommends 40 dBA for living areas and 35 dBA for bedrooms in detached houses, with an additional 5 dB allowed for apartments [19]. CIBSE Guide B2 recommends that noise from building services does not exceed NR25 in bedrooms [8]. CIBSE Guide B4 recommends an internal noise limit of 40 dB L_{Aeq} in living rooms, but did not specify noise limits for any other rooms in dwellings [23].

Approved Document F notes that noise from mechanical ventilation systems is not currently regulated in the UK [1].

The AVO guide notes that there is research indicating that noise levels above 26 dB L_{Aeq} will result in occupants having increased difficulty falling asleep [20].

BPIE Overheating In New Homes notes that to create the ventilation rates required in some standards, large fans and additional ducting are necessary, making it difficult for them to achieve the required internal noise levels [16].

The ABCB Handbook notes that noise will impact on an occupant's perception of issues with ventilation and indoor temperatures [14].

The British Domestic Ventilation Compliance Guide requires that mechanical ventilation systems are designed to minimise noise generation, and outlines a process to check for abnormal noises during the commissioning process [24].

The UK ProPG defines the point at which adverse noise effects are observed as the Lowest Observed Adverse Effect Level (LOAEL), where noise is audible and small changes in occupant behaviour are noted in response [25]. It suggests that this is the point at which mitigation begins to be required, with increases in the severity of the adverse effects requiring additional mitigation measures.

British Standard EN 15251 states that ventilation should not rely on opening of windows in areas with high outdoor noise [6]. CIBSE Guide B4 provides methods for calculating internal noise levels where natural ventilation systems are used, and recommends that noise from mechanical ventilation systems uses the dB L_{Aeq} descriptor [23].

BPIE Overheating In New Homes notes that where high external noise levels are present, occupants are less likely to open their windows to provide additional ventilation [16].

In situations where high levels of energy efficiency are required in conjunction with a need for noise protection, DIN 1946-6 mandates the need for mechanical ventilation [26].

ISO 17772-1 notes that noise levels 5-10 dB higher may be acceptable when rapid changes to heating or cooling are required to improve the thermal comfort of the occupant [27].

2.6 Review of the effectiveness of ventilation provisions

In 2015 the UK Ministry of Housing, Communities and Local Government commissioned AECOM to undertake a study on new homes which had been built since the introduction of Approved Document F of the Building Regulations [28]. The aim of the study was to validate the ventilation provisions of Approved Document F by examining the air quality of houses which had been constructed in accordance with the criteria.

Walk through inspections were conducted on 80 new homes across several developments in the UK, with the occupants being interviewed. Of these homes, 55 were naturally ventilated (with trickle ventilation and intermittent extracts for key areas), and 25 were ventilated using a decentralised mechanical ventilation system. Following this, limited monitoring was conducted in 54 of the homes, with subsequent long-term detailed monitoring conducted in 10 of the homes.

The study was compromised because it found that only two of the naturally ventilated homes and one of the homes with decentralised mechanical ventilation were able to fully meet the requirements of Approved Document F with regard to extract fan flow rates and minimum trickle ventilator area.

The study notes that reasons for the homes not meeting the minimum ventilation provisions include incorrect fan selections or poor installation of exhaust fans such as the wrong speed, or duct resistance settings. Aside from one development in Leeds, 50% or fewer homes met the requirements for trickle ventilation areas. Trickle ventilators were also installed in wet rooms, short circuiting the mechanical ventilation, in two of the three developments sampled and around one quarter of doors had undersized door undercuts.

In close to half of the survey cases, bathroom and WC fans, or continuous fans associated with the decentralised mechanical ventilation system had been turned off by the occupants due to noise concerns or misunderstandings about the intended purpose. The report refers to similar findings from a site verification study undertaken by Zero Carbon Hub [29] where occupants had turned off ventilation systems because they were too noisy. Reducing external noise ingress (i.e. from a main road) was also described as a reason for closing trickle ventilation in one survey case.

Although 86% of occupants were aware of the presence of trickle ventilators and had a basic understanding of their use, in 29% of the homes the trickle vents were closed during the initial visit to the property. Additionally, due to the layout of rooms, many of the trickle vents were located behind curtains, and the study raises concerns about their effectiveness during the night-time period.

2.7 Summary of standards and guides

A wide range of ventilation provisions appeared in the international standards and guides which were reviewed. While there do not appear to be singular accepted performance standards for airflow rates, infiltration rates, thermal comfort, overheating, or noise, we have summarised some general observations below.

- Often the minimum ventilation rates cannot be directly compared because of the different parameters used. Some are based on a number of air changes for the whole house or specific spaces and others are based on a rate per m^2, or a rate per person. The 2004 AIVC survey [7] is helpful in this regard, as it compares the provisions in 15 countries based on a model house with 151 m^2 floor area occupied by a family of four. This study showed that with the exception of Switzerland and USA (ASHRAE) the various provisions at this time typically resulted in 0.5 ACH or higher for the model house.

- The exhaust rates given in the standards and guides were similarly varied, although a 50 L/s intermittent rate for rangehoods / kitchens and 25 L/s intermittent rate for bathrooms was common.

Continuous rates were an order of magnitude lower, typically less than half. Extract rates for laundries were also provided in a number of cases.

- Infiltration rates were not commonly discussed, however the International Mechanical Code requires mechanical ventilation to be provided when the infiltration rate is less than 5 ACH. There was also very little reference to pressure difference or relief air provisions.

- IAQ and thermal comfort are strongly interlinked, and user comfort is dependent on both needs being fulfilled adequately.

- The majority of guidance provides a range of acceptable temperatures spanning 6-8°C between the acceptable minimum and maximum indoor temperatures. The minimum internal temperature was typically 18°C or higher for living spaces and the most common threshold for overheating was 26°C. Overheating provisions often included an allowance for a small percentage of annual occupied hours (1-10%) to exceed the threshold value.

- There was no consensus on appropriate internal noise levels, with limits ranging from 26 to 40 dBA in bedrooms and 30 to 45 dBA in other habitable spaces. Minimal guidance was presented on appropriate noise levels from mechanical ventilation systems.

- A post occupation study of relatively new homes in the UK found that the ventilation performance standards were not met in most cases, with reasons including incorrect fan selections or installation, undersized trickle ventilators, or trickle ventilators installed in wet rooms. In close to half of the survey cases, bathroom and WC fans, or continuous fans associated with a decentralised mechanical ventilation system had been turned off by the occupants due to noise concerns or misunderstandings about the intended purpose.

A summary of key ventilation parameters found in the reviewed standards and guides is also appended to this document as Appendix A.

2.8 Further standards

There are two further standards that may be useful to source and review in more depth as part of a future study. These are:

- German Standard DIN 1946-6 E (2019) *Ventilation and air conditioning – Part 6: Ventilation for residential buildings – General requirements, requirements for design, construction, commissioning and handover as well as maintenance*

- International Standard ISO 16814 (2008) *Building environment design — Indoor air quality — Methods of expressing the quality of indoor air for human occupancy*

3.0 REVIEW OF SCIENTIFIC LITERATURE

We have reviewed published literature to identify studies relating to thermal comfort and human factors affecting the use of mechanical systems. A summary of our findings is outlined below.

Our search has been primarily completed using the ScienceDirect and Google Scholar databases. We have generally excluded studies relating solely to modelling or simulations. As our initial search for 'thermal comfort' gave a very large number of results, we refined our search to focus on studies which also involved buildings and noise, and for the most part excluded any studies that did not relate to residential activity. We have not concentrated on conference papers as these are often part of ongoing research, which is eventually published in a peer reviewed journal paper. Where possible, we have focussed on studies which relate to real buildings and people's subjective reactions to them.

We could not locate any research relating specifically to appropriate mechanical ventilation / thermal comfort design in situations where people cannot open their windows due to high external noise levels. We were also not able to find relevant research on how people interact with mechanical ventilation systems differently if there are high external noise levels.

3.1 The thermal environment

There are numerous studies on thermal comfort in the built environment, and it is often considered alongside energy consumption. Much of the credible research forms the basis for the Standards and Guides discussed in the previous section and we have therefore concentrated on reporting research which covers different areas or provides new information.

There are also some other literature reviews available which cover much of this background research comprehensively. For example a comprehensive review and summary of studies between 2005 and 2015 was undertaken by Rupp et al [30]. That review describes the two basic approaches that are often encountered for managing thermal comfort:

- The first is the *Fangers* model which predicts the percentage of people who will be dissatisfied with the thermal environment calculated via six variables: metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity. As above, this method was the basis for ISO 7730 and ASHRAE 55.

- A second approach is the adaptive model which is based on the principle that users are active and not passive in their relationship to the thermal environment, and will open windows, close blinds and otherwise react in ways that will restore their comfort. This approach is based on field studies in naturally ventilated buildings. The adaptive model provides an acceptable range of temperatures according to outdoor climate and was included in ASHRAE 55:2004 for evaluating naturally ventilated buildings. It appears that the recent increased focus on the adaptive model means that there is less literature available for windows closed situations.

Another literature review published in 2016 with a focus on the environmental quality of commercial and office buildings discusses thermal comfort, sick building syndrome and indoor air quality in this context [31].

Some of the key factors and relevant additional research relating to the thermal environment are discussed in the following sections.

3.1.1 Temperature

For air-conditioned buildings, BS EN 15251 suggests that the maximum operating temperature in the summer season for categories II (normal expectation, used for new buildings/renovations) and III (moderate expectation, used for existing buildings), is 26 and 27°C respectively [6]. This corresponds to a running mean outdoor temperature of approximately 13°C for a building without mechanical cooling [32]. However, as a building type changes from older 'generally leaky' buildings to newer 'air-tight' buildings additional ventilation is needed to maintain this relationship.

The drivers of heat gain in buildings are well understood, including the fact that the means of rejecting heat are typically limited. Ventilation is effective for moderating temperatures but the required volumes of air to remove even a small heat load are significant. The use of thermal mass has been demonstrated to be highly effective in reducing the diurnal variation of internal air temperatures; however, unless linked with very effective night-time ventilation with cooler night air, it can result in overheating being exacerbated as heat is retained within a dwelling as outdoor temperatures fall [32]. Buildings where a thermal balance is only able to be achieved through mechanical means, i.e. comfort cooling or full air conditioning, are generally viewed as inferior due to growing concern about energy consumption.

Some studies have investigated the detail around the variation in optimal internal temperature with time of day and location within a dwelling. Liddament [33] found that improved temperature conditions were experienced if windows were opened at night, and during the day before overheating occurred. Similarly reducing ventilation before the outdoor air temperature exceeded the indoor temperature assisted with maintaining a desirable indoor temperature.

Modern 'sustainable' buildings have generally not led to improvements in temperature regulation. For example, Jones et al [34] measured the temperature in two sustainable houses (with improved thermal insulation) compared with an identical house built to minimum building standards but with the same ventilation systems. The sustainable houses had a mean temperatures at least 4 °C above the conventional dwelling and showed temperatures exceeding the recommended summertime temperatures 50-60 % of the time exceeding 25 °C in living rooms in the daytime and 72-98 % of the time over 24 °C in bedrooms between 2300 and 0700 hours.

With regard to optimal internal temperatures, there are some studies which show that optimal thermal conditions for a good night's sleep are different to ASHRAE, (Leung et al 2012 and Lan et al 2013, as cited in [30]). M. Berge and H. Mathisen [35] concluded that there was a clear need for temperature zoning throughout dwellings, and a desire for lower bedroom temperatures was observed.

3.1.2 Air movement

3.1.2.1 Issues with lower air velocities

Zhang et al. (as cited in [30]) analysed air movement preference using the CBE database (data from office buildings in North America and Finland) and found higher dissatisfaction among users in lower air velocities, which called into question the low air velocity limits set by ASHRAE 55 and ISO 7730. Yang et al. [36] investigated air movement preference during the different seasons in naturally ventilated buildings in humid subtropical China, including offices, residences and classrooms and also found user's preference for higher air movement, mainly in warm conditions.

3.1.2.2 Preference for higher air velocities

Tablada et al 2009 (as cited in [30]) proposed a comfort zone for the summer in residential buildings located in Old Havana, Cuba. In the questionnaires residents identified a preference for higher air velocities. This is similar to the findings of R. Daghigh [37] who established that with good air movement, occupants can be more comfortable at higher temperatures and humidity levels than would be possible in still air conditions.

3.1.3 Adaptation and acclimatisation

Field studies across the board show that people have considerable capacity to adapt to their surroundings provided they have sufficient adaptive opportunities. This observation holds good for both air-conditioned as well as free running buildings. Mishra and Ramgopal [38] undertook a review of thermal comfort studies by climate zone and found that in all climates the most popular means of adaption are modifying air movement and clothing. The studies also show that individuals are likely to perceive the same thermal environment differently when they have no control over it. A wider range of temperature, humidity and air movements is therefore acceptable for naturally ventilated buildings than air-conditioned ones.

Overall thermal comfort and the assessment of indoor environmental quality do not depend solely on physical parameters. The human body's physiological and psychological responses to the environment are dynamic and integrate various physical phenomena that interact with the space (light, noise, vibrations, temperature, humidity etc. (Parsons K, 2000, as cited in [30]).

There are also numerous studies confirming the validity of acclimatisation theory – for example Kim et al. (as cited in [30]) demonstrated that people who are exposed to a narrow range of temperatures (due to air conditioning) then have a very low tolerance for hot indoor climates. Similarly, R. Daghigh et al [39] found strong evidence of acclimatisation when he studied thermal comfort in an air-conditioned office in Malaysia. Malaysia is a hot and humid tropical country that has a yearly mean temperature of between 26ºC and 27ºC including high daytime temperatures of 29°C to 34°C and relative humidity of 70 to 90% throughout the year. The office was considered too cool by all occupants when windows were closed suggesting the occupants were acclimatised to much higher environmental temperatures than those recommended by ASHRAE.

3.1.4 Indoor Air Quality in bedrooms

Several conference papers have been identified covering IAQ in bedrooms. A review of the literature in 2015 [40] discusses the available information relating to the effects of ambient room temperature and IAQ on sleep quality. Both elevated and reduced temperatures were shown to decrease deep sleep and REM phases, with increased wakefulness events – although different clothing and covering scenarios made direct comparisons difficult. None of the studies found in this review were able to conclusively link objective measures of sleep quality with indoor air quality.

The limited number of field studies relating sleep and IAQ is also noted in another paper [41]. The authors of this paper undertook an experimental study which compared sleep quality with "window open" and "window closed" scenarios in dormitory rooms where the temperature varied only by a minor amount. This study showed positive effects of an open window on the actigraph-measured sleep latency and on the subjects' assessment of the freshness of the air and ability to fall asleep. A later study by the same authors [42] compared the sleep quality when occupants of dormitory rooms were exposed to low and high levels of ventilation for a week each, again where the internal temperature varied only by a minor amount. Higher levels of ventilation had a positive effect on the perceived freshness of air, and subjectively assessed mental state and feeling of being rested. There was also a tendency for the subjects to sleep better, feel less sleepy and perform better on a logical reasoning task. Mouth dryness and skin dryness were however increased with the higher ventilation rate. A similar field study suggests that low ventilation rates cause the subject to be more passive during sleep and sleep more superficially [43].

Another paper [44] discusses the importance of having separate IAQ assessments in bedrooms and living areas and reports findings that up to 70% of time spent by the average western human in their house is in the bedroom. Based on a modelled house, the relative exposure to unacceptable perceived air quality (measured by exposure to excess CO_2 concentrations) was shown to be up to 16 times higher in the bedroom then the rest of the dwelling.

3.1.5 Other findings

Studies have shown that women are more sensitive to heat and less sensitive to humidity than men and that older people prefer higher temperature [30]. Older people are also less sensitive to ambient conditions and physiologically less able to regulate their body temperatures, which can be exacerbated by medication that further reduces physiological tolerance. Care is also required as respiratory illness or cardiovascular disease can mean that the effects of high temperatures are much more serious [45]. None of these factors are considered in the documents discussed in section 2.0.

3.2 Human factors

We have identified numerous studies relating to how people interact with dwellings and mechanical systems from researchers in China, Malaysia, Switzerland, U.K, Canada and Holland. The studies provide information about behaviour including the use of windows, and alternative ventilation systems ranging from trickle vents to whole house ventilation with heat recovery.

The studies relating to human factors influencing use of alternative ventilation are commonly intertwined with investigation of people's window opening behaviour – and so we have discussed both below.

3.2.1 Opening windows even when an alternative system is provided

Studies have conclusively demonstrated that occupants often open windows for airing even when there is whole house alternative ventilation.

J. Hou et al, [46] carried out a field study in order to identify window opening patterns during heating season and its related factors in residential buildings in Tianjin, China during winter. 10 Residences were monitored, seven with mechanical ventilation and three with natural ventilation. Hou found that during winter occupants in bedrooms opened their windows almost as much for mechanically ventilated dwellings as for naturally ventilated dwellings. Average daily opening times were 65 minutes for mechanically ventilated houses and 66 minutes for naturally ventilated houses. Residents typically open windows when there is no haze outdoors or it is 'stuffy' indoors. In winter they close them for bad weather and in summer they close windows for noise.

C.Dubrul, [47] found that the presence of an alternative ventilation system only had an effect on window opening behaviour when its use was properly understood. This led to windows in centrally heated dwellings being less likely to be opened for long periods than those in non-centrally heated dwellings. This difference was most pronounced in bedrooms. Dubrul also found that people opened the windows less in dwellings with warm-air central heating, compared to dwellings with radiator systems.

D. Lai et al, [48] monitored the usage of natural and mechanical ventilation in 46 Chinese apartments in a number of climate zones for a year. Lai found that on average, for dwellings equipped with mechanical ventilation the system operated for 7 hours per day, while windows were also open for 11 hours per day. As the climate became warmer, natural ventilation increased and mechanical ventilation decreased. This is a much longer duration of both open windows and mechanical ventilation operation than those found by Hou et al. but represents the average of a whole year and many different climate zones rather than one location in winter.

Magdalena Baborska-Narozny and Fionn Stevenson [49] conducted a one year-long in-depth building performance evaluation of 40 households in two UK developments. One had mechanical ventilation with heat recovery (Case A) and the other had mechanical extract ventilation (Case B). They found that the availability of cross-ventilation combined with environmentally driven urges to switch off all energy consuming appliances prompted the majority of inhabitants to develop hybrid ventilation practices. Figure 3.1 below shows the declared behaviour of occupants of two buildings – Case A with mechanical ventilation with heat recovery and Case B with mechanical extract ventilation.

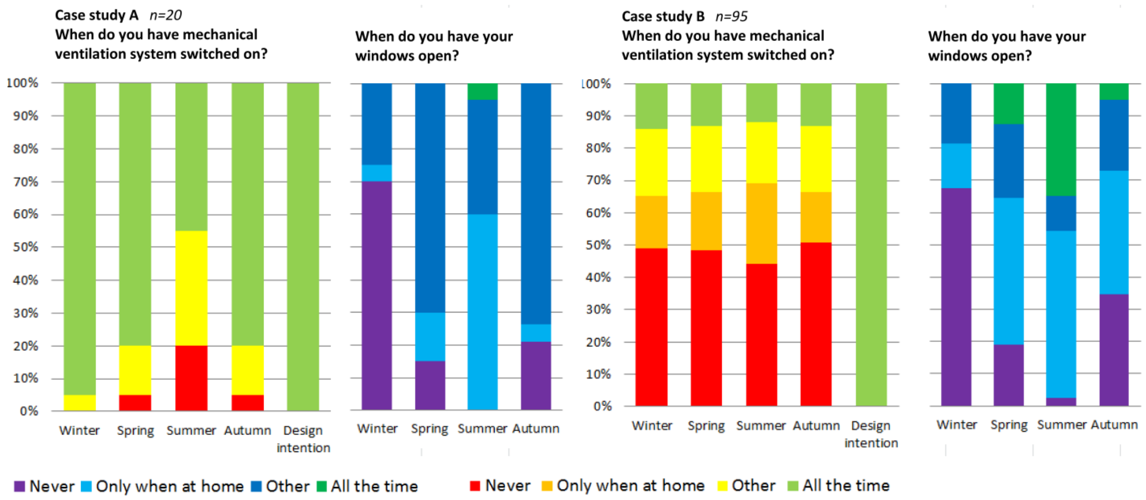

Figure 3.1 – Seasonal variation in declared ventilation behaviour (from Magdalena Baborska-Narozny and Fionn Stevenson [49])

This research demonstrates that many people have their windows open even when mechanical ventilation is operating. The reasons for this are discussed further in section 3.2.3 below.

J.E.F van Dongen (TNO), [50] analysed different types of ventilation ranging from 1-3 L/s (trickle vents) to 100 L/s (windows wide open) during a moderate Dutch winter. Dongen demonstrated that ventilation behaviour is only partly related to the type of ventilation system. In 25% of main bedrooms a window is always open for ventilation, mostly in addition to ventilation. At 19 °C apartment occupants aired living rooms for an average of 13 hours by opening the doors. This reduced to seven hours when the temperature was 14 °C and two hours when the temperature was 5 °C (Dongen, 1990a: and Cornelissen 2002 as cited in [50]). The number of hours that people ventilate increases as the temperature increases, however people still open their windows down to -5 °C.

Overall, the literature suggests that even if provided with a well performing mechanical ventilation system, people will still open their windows. External environmental conditions such as noise, air quality and weather will affect the duration of opening but even in adverse conditions windows are opened for short periods.

3.2.2 Air-change rates

It has also been found that the rate of successful interaction with mechanical ventilation in dwellings can be significantly increased if the learning process is better supported and user's varied expectations are met in terms of control over the system. In the 1980s (Dongen 1990b as cited in [50]) found that there seems to be a relatively constant 'subjective preferred' amount of total ventilation from mechanical devices and behaviour combined of 175 m^3/hour (24 hour average) in living rooms which is more than 2 ACH for a 30 m^2 living area.

However, studies have also shown that the performance of ventilation systems across Europe is in practice often poor, resulting in reduced ventilation rates (lower than 0.5 ACH) [51]. However, Dubrul [47] found that 8 Danish dwellings with mechanical ventilation systems when monitored for a week had an average ACH of 0.97, of which the mechanical component was 0.63 ACH and natural ventilation 0.34 ACH. In the same study of naturally ventilated dwellings an average ACH of 0.51 was measured.

P. Price and M. Sherman, [52] sent questionnaires to 4,972 single-family detached homes in California built in 2003, and 1448 responded. 67 of these responses that had mechanical ventilation systems were interviewed. They found that 50 – 90% of houses have below 0.35 ACH (which Price and Sherman state is recommended) and up to 30% of households rarely or never use their bathroom fan. C. Hoffmann et al. [18], found that when eight dwellings with trickle ventilation and mechanical extract fans were assessed, five of them did not meet the demand for fresh air required by the SIA 328/1 *Swiss Society of Engineers and Architects – Ventilation and air conditioning systems – General basics and required performance,* instead providing only between 35 – 80 % of demand.

These air change rate findings confirm that mechanical ventilation systems need to be well-designed and occupants well informed to replace opening windows. Many current systems provide a low air-change rate.

3.2.3 Priorities and satisfaction with ventilation

Lai et al. [48] found that residents prioritised their thermal comfort needs over healthy indoor air quality. However, when the temperature was acceptable, they were willing to spend money on mechanical ventilation to improve air quality. Dubrul [47] found that while personal comfort was very important, low-middle income groups were more likely to change behaviour to save money.

Another study performed in low to middle income housing in South Australia demonstrated that, due to the cost of using air-conditioning, people primarily tried to cool themselves through less expensive methods: by turning on fans, operating openings and curtains and by changing their clothes (Soebarto and Bennetts 2014 as cited in [30]).

Dubrul also demonstrated that the older people are, the less they ventilate. Conversely, educated, elderly and renters conversely complain about ‘less ventilation than preferred’ [47]. Occupants who smoke use more ventilation in living rooms. Households with respiratory diseases ventilate and air more than average and complain more about too warm conditions [50]. There is no evidence that health issues motivate ventilation behaviour, except in households which contain asthmatics [52].

C. Hoffmann et al. [53], studied trickle ventilation in everyday use. They found that the overall satisfaction with the trickle ventilation was very high in three of the surveyed buildings. Almost half of the participants (47%) said they would move into an apartment with trickle ventilation and an exhaust fan again.

Berge [35] found that the indoor environmental quality was perceived to be higher in homes with mechanical ventilation with heat recovery when compared with other ventilation types when considering air quality, perceived dryness of air, noise and control options.

With regard to the outcomes reported by Baborska-Narozny and Stevenson and demonstrated in figure 3.1 above, Case A was a community led project where occupants were involved in the building design and were concerned about energy use mainly for environmental reasons [49]. Anxiety about mechanical ventilation with heat recovery related energy consumption was deepened by the inability to check it and manuals did not prove to be helpful even for technically advanced inhabitants. All but two households opened their windows for ventilation as a result. Case B was a building managed by a large company. Occupants are concerned about energy bills. From a building use studies survey, out of 95 questionnaires returned, 19 inhabitants stated they did not have mechanical ventilation installed or did not know what it was. A further eight respondents left all ventilation related questions blank which may also suggest lack of awareness of the subject. Up to 30% of inhabitants lacked basic awareness of having the mechanical ventilation system.

When C. Brown and M. Gorgolewski, [54] conducted post occupancy questionnaires for four high rise buildings in Canada, over half the resondants did not use their heat recovery ventilators due to acoustic dissatifaction, difficulty accessing filters, and lack of engagement with training materials.

The above findings illustrate that human response to ventilation is a complex issue and that humans have a wide variety of requirements. Nevertheless, the studies identified various commonly perceived shortcomings with mechanical ventilation systems. Shortcomings identified by Dubrul, Baborska-Narozny and Stevenson, C. Brown and M. Gorgolewski and Balvers [47] [49] [54] include:

- No instructions to inhabitants and a resulting lack of understanding of the system (e.g. thermal bypass switch, boost control)

- No user control
- High noise particularly when going to sleep
- Severe draught
- High extra energy
- Insufficient ventilation rates
- Odour transfer (e.g. kitchen/bathroom to living
- Not installed properly
- Insufficient maintenance, unclean, poor access (e.g. filters)

Conversely, factors that appear to contribute to acceptance of and a positive attitude towards a mechanical ventilation system are:

- Quality and directions
- Good performance
- Fulfilling expectations
- User-friendliness
- Integration with usual behaviour
- Increased sense of comfort, health and safety promoting
- Ease of installation, repair, maintenance and cleaning
- Aesthetics

Other findings were that any ventilation system installed should be able to cover a wide range of comfort levels and should be user controlled. To achieve thermal comfort often both the heating and ventilation system performance as well as the user knowledge and awareness need to be improved.

Good education includes ensuring that inhabitants know why a system is installed. Even better outcomes can be achieved when inhabitants are involved in design, as occupants' ventilation practices can be influenced during the process. A low setting is important to allow for a diurnal quiet period to aid sleeping and avoid noise 'nuisance' whilst maintaining indoor air quality [49]. The device needs to function as expected, 'growing pains' are decisive for whether people will ultimately use or not use the system [50].

3.3 Existing house review

A review of the condition of houses across New Zealand was conducted by BRANZ in 2015. The report highlights the difference between the condition of owner occupied and tenanted dwellings, and common defects [55]. In total 560 houses were surveyed, with 411 being owner occupied and 149 being a tenancy.

It is not stated whether the homes had natural or mechanical ventilation, however only a small proportion (15% of owned homes and 8% of rented homes) were constructed post 2000. Approximately 50% of homes had visible signs of mould, and subjectively 11% of owner occupied homes and 31% of tenanted homes were considered to be damp by the occupants.

Mould is noted as a key indicator of indoor air quality so the presence of mould could mean that a significant number of the surveyed homes are inadequately ventilated, whether due to design flaws, occupant activity, or deterioration of building elements.

3.4 Summary of literature review

The scientific knowledge base in the area of thermal comfort and user perception of ventilation systems is relatively large. We therefore focussed our review on residential activity, and people's interactions with real buildings where possible. We were not able to find any research relating specifically to the design of mechanical ventilation in situations where people cannot open their windows due to high external noise levels, or how people interact with ventilation systems in this scenario.

Some key observations from this review are as follows:

- While ventilation is effective for moderating temperatures, high volumes of air are required to remove even a small heat load [32].

- Temperature zoning in dwellings, with lower temperatures in bedrooms may be desirable [35]. We note that some of the guidance from the standards and guides summarised in Appendix A outlines higher temperatures for living rooms compared to bedrooms, in cases where separate criteria are provided.

- There are some studies that show that higher air movement is preferable in warm conditions and enables occupants to be comfortable at higher temperatures than would otherwise be possible [36] [37].

- A range of surveys have been undertaken in existing buildings examining occupant behaviour with regard to window opening [46], [47], [48], [49], [50]. Overall, the literature suggests that even if provided with a well performing mechanical ventilation system, people will still open their windows. External environmental conditions (such as cold temperatures) will affect the duration of opening but even in adverse conditions windows are opened for short periods. Locations with high external noise levels were not the focus of these studies.

- There is good evidence that opportunities for control of the environment is an important factor in how people perceive it (for both airconditioned and naturally ventilated buildings). This suggests that ventilation systems with an increased level of occupant control are preferable.

- There is also good evidence that clear instructions on the use of a ventilation system and why it is installed would be beneficial and increase the likelihood of effective use.

- For lower income households, cheaper ventilation methods (such as fans, windows or changes in clothing) were used primarily [47]. In some surveys concerns about energy consumption and noise from the system were also identified as reasons why systems were not used [49], [54].

- A lower night-time setting and noise level to aid sleeping was noted as an important factor in one study [49].

- Studies in Europe and California have shown that the performance of installed ventilation systems is often inadequate [47], [52]. Some studies show that measured air change rates in homes in Europe were typically below 0.5 ACH [51].

4.0 REVIEW OF RELEVANT RESOURCE CONSENTS

We have also reviewed evidence produced at RMA hearings in support of different ventilation specifications. This is limited in scope as the majority of Councils do not have a search function within their past hearings and Consent decisions libraries, and so without knowing the application number of a specific application, or approaching individual Councils, it is not possible to find information that way.

We were able to find a small selection of relevant hearings and decisions by using the Environment Court decisions search, Environment Canterbury search function, Ministry of Business Innovation and Employment determinations, and a general keyword search.

The majority of information we were able to find was in relation to proposed Plan Changes or Proposed District Plan Chapters, and while this is not necessarily envisioned within the scope of this section of the review, we believe that it provides useful insight and so have included it in our discussion below.

4.1 Updates and changes to Plans

In 2018 the Environment Court reviewed an appeal to the Proposed Invercargill City Council District Plan relating to Appendix VI – Noise Sensitive Insulation Requirements [56]. Invercargill Airport Limited appealed the proposed conditions of the Appendix relating to properties located within the noise boundaries for the airport on the grounds that the requirements were inappropriate for the local context. The following issues with the proposed wording of the Appendix were noted:

- The required range of airflow rates cannot be achieved by a single fan
- Separate systems would be required for bedrooms and other habitable areas
- The heating requirement is for 18°C above outdoor air temperatures which may not provide an adequate level of thermal comfort during winter
- The high airflow requirement in other habitable areas may result in large noisy fans and large ductwork being required
- Supply air only with no balanced exhaust may pressurise the house
- To meet the requirements a bespoke system is required for each house, increasing cost and complexity
- 15 ACH in living areas is unnecessary in the local climate

The engineering evidence outlines how the requirements in the Appendix are appropriate for warmer climatic regions, but do not provide adequate amenity for the Invercargill region. The planning evidence suggests that the proposed Appendix contains an unduly onerous set of specifications with little clarity around compliance pathways. The Court determined that the changes proposed in the appeal were appropriate and ordered their inclusion in the Proposed Plan. After the completion of the review process, an amended version of the rule was introduced to Appendix 15 of the now Operative Plan, with the following specification for ventilation systems in habitable rooms:

- Low air flow setting between 0.35 and 0.5 ACH with a noise level less than 30 dB $L_{Aeq\,(30s)}$ at 2 metres from any grille or diffuser
- High air flow setting of at least 5 ACH with a noise level less than 35 dB $L_{Aeq\,(30s)}$ at 2 metres from any grille or diffuser

- Cooling that is controllable by the occupant and able to maintain the temperature of the room at 25 degrees Celsius or less

- Heating that is controllable by the occupant and able to maintain the temperature of the room at 18 degrees Celsius or greater

- A relief air path must be provided to ensure the pressure difference between the internal and external environments is never greater than 30 Pa

In 2014 Nelson City Council was reviewing the proposed Plan Change 16, which deals with Inner City Noise [57]. The S42A Council Officer report outlines the proposed Plan Change and response to submissions. While the Plan already had provisions in place for ventilation of dwellings in the Port Noise Control Area with two types of system allowed, the proposed Plan Change would provide flexibility for developers and owners to use a combination of either ventilation strategy at their discretion on a space by space basis.

Additionally, a new section of Appendix 19 was drafted specifically relating to bedrooms in the Inner City Zone, taking into account the received submissions. The rule states that where the indoor design noise level cannot be met with ventilating windows open, alternate ventilation must be provided. The minimum specifications are as follows:

- Mechanical ventilation option
    - 5 ACH in bedrooms
    - Control of airflow capacity down to 0.5 +/- 0.1 ACH
    - Internal pressure less than 30 Pa above ambient air pressure
    - Each system must be able to be individually turned on and off by occupants
    - Noise emissions of less than 30 dB $L_{Aeq\ (15m)}$ in bedrooms at one metre from any diffuser
- Air conditioning plus mechanical ventilation option
    - Internal temperatures not greater than 25 degrees Celsius at 5% ambient design conditions
    - 0.5 +/- 0.1 ACH in bedrooms
    - Each system must be able to be individually turned on and off by occupants
    - Noise emissions of less than 30 dB $L_{Aeq\ (15m)}$ in bedrooms at one metre from any diffuser

No specific evidence was provided in the Council Officers report as to why these ventilation specifications were chosen.

In 2016 proposed Plan Change 41 of the Whanganui District Plan was reviewed by the Statutory Management Committee [58]. The proposed Plan Change would update the noise requirements to be in line with current guidance and standard practice, including reverse sensitivity provisions for buildings in close proximity to State Highways.

The notified version of chapter 17.5.2 included a requirement for a mechanical ventilation system capable of complying with G4 where the internal noise limits could not be achieved with openable windows. It also had a requirement for noise from the system to not exceed 30 dB $L_{Aeq\ (30s)}$ at 1 metre from any grille or diffuser. After reading the submissions, it was decided to change the noise limit to 35 dB $L_{Aeq\ (30s)}$ at 1 metre from any grille or diffuser, and to include a rule requiring user control of the ventilation rate in increments up to a high flow setting providing at least 6 ACH.

Several submissions requested the inclusion of a requirement for a cooling system to be provided, however this was rejected on the grounds that the ventilation system would already provide a means of regulating internal temperature during warm weather and so a secondary system for this purpose would likely be redundant and result in additional cost.

In 2018 as part of the review of the Proposed Queenstown Lakes District Plan, QLDC prepared a S42A report on an amendment to the Proposed Chapter 24 [59]. A large number of submissions commented on the inadequacy of the ventilation provisions in the chapter, and it was found upon review that there had been a transcription error from the ventilation study conducted for Auckland Airport in 2000 which had provided the basis for the rule.

The Council Officer states that the aim of the ventilation system is to provide sufficient thermal comfort for occupants, to enable them having the choice of leaving windows closed to reduce aircraft noise. Their recommendation was to change the ventilation requirements to be in line with the systems outlined in the 2014 BECA study conducted for NZTA.

In 2017 Auckland International Airport Limited undertook a review of the acoustic mitigation packages being offered to dwellings that are affected by high and moderate levels of aircraft noise [60]. As part of the process of developing the Auckland Unitary Plan, the existing designations were renewed, and a new Noise Mitigation Programme was required, which was prepared with input provided by AECOM and Marshall Day Acoustics.

The original mitigation package required a mechanical ventilation system which meets the requirements of G4 to be provided, along with a higher ventilation volume in summer to increase summer comfort. This commonly resulted in an HRV type system installed to meet the G4 requirements, with additional larger fans serving living areas and bedrooms. Drawbacks included high capital and running costs, and the review also states this system did not provide a level of comfort equivalent to natural ventilation.

In 2016 an interim package was proposed with the following specification. This was still recommended in the 2017 report:

- Positive pressure ventilation system comprising ventilation fans (one or more depending on room size) servicing principal living areas and other habitable areas
- System mounted within the roof space with ductwork and diffusers to each room
- 0.5 ACH to principal living areas on low setting, 1 ACH on high setting
- 0.5 ACH to other habitable rooms including bedrooms on low setting, 3 ACH on high setting
- Inverter driven domestic high-wall heat pump in the living room providing heating and cooling
- Automatic ventilation control with control panel mounted in the common corridor
- Automatic heat pump control and wall-mounted control panel located in the room the heat pump serves
- Mechanical kitchen extract fan and cooker hood directly ducted to outside

It is worth noting that the relevant condition proposed under the AUP at the time required 15 ACH in principal living areas and 5 ACH in other habitable spaces. The review proceeds to summarise the acoustic mitigation packages of other national and international airports, noting that there was a large variance in the following factors:

- If mechanical ventilation was required
- External noise levels at which mitigation requirements were triggered
- Internal noise levels at which mitigation requirements were triggered
- Air flow rates of different spaces
- If relief air was specified
- If air conditioning was considered

In the process of reviewing the interim mitigation packages, the proposed packages were compared with relevant ventilation and thermal comfort criteria.

Regarding ventilation, it was found that the proposed system would be typically expected to provide 0.5 ACH, which meets the G4 requirement of 0.35 ACH. Additionally, the system is expected to meet the extract ventilation requirements of G4 where a kitchen hood extract of greater than 50 L/s is provided.

The review notes that as there are no statutory requirements for controlling overheating in dwellings, the methodology for achieving thermal comfort in summer is reliant on planning interpretations. The report proposes that elevated ventilation rates in the range of 3-15 ACH would be adequate for controlling internal temperature in summer months, which is deemed to be equivalent to opening windows for ventilation. Similarly, it was observed that there is no Code requirement for minimum temperatures in residential dwellings, so the Airport was under no obligation to provide heating as part of the package. However, the high-wall heat pumps that are included as part of the proposed mitigation package were expected to provide adequate heating in the principal living area, noting that bedrooms would require separate discrete heating.

4.2 RMA Hearings

In 2016 a hearing was held in the Environment Court appealing a Resource Consent decision made by Auckland Council [61]. The consent was for a Council run sports reserve that was to be formed close to residential properties. As a result of the hearing it was decided that it was appropriate for mechanical ventilation and upgraded glazing to be offered to residents where it was shown by modelling that noise levels of 58 dB L_{A10} or higher were expected on the façade. The following specifications were given:

- Mechanical ventilation systems shall satisfy both the requirements of Clause G4 of the New Zealand Building Code and provide adequate thermal comfort
- In living and rumpus rooms the system shall be able to deliver 0.5 +/- 0.1 ACH on low setting, 15 ACH on high setting, and generate no more than 40 dB $L_{Aeq\ (1m)}$ at 1 metre from grilles
- In bedrooms the system shall provide 0.5 +/- 0.1 ACH on low setting, 6 ACH on high setting, and generate no more than 35 dB $L_{Aeq\ (1m)}$ at 1 metre from grilles
- Internal air pressure must be no more than 10 Pa above ambient external air pressure
- Controls will allow for three settings between low and high
- The system must incorporate temperature control to avoid situations where users open windows to mitigate heat

No explanation was provided for the rationale behind the specification for the mechanical ventilation system. This may have been included in the original Resource Consent Application; however, we were unable to source the Application and so could not confirm whether this was the case.

In 2015 an Environment Court hearing was held for an appeal of a denied retrospective Resource Consent Application relating to the conversion of commercial spaces to create 14 residential units [62]. The Court was concerned about the provision of fresh air for the units as most bedrooms did not have operable windows and there was no mechanical ventilation system present. Some of the units had a skylight in the bedrooms which was supposedly able to be opened, however no evidence was provided in support of this claim. The Environment Court dismissed the appeal for a number of reasons, including a lack of evidence for compliance with the ventilation provisions of the Building Code and concerns for the health of residents.

It is worth noting that an acoustic assessment was undertaken which confirmed that compliance with the relevant District Plan internal noise limits could be achieved with the implementation of façade upgrades and the installation of mechanical ventilation, both of which measures were subsequently volunteered by the Applicant. This was acknowledged by the Court, but was not deemed satisfactory to ensure that residential amenity was provided for, in light of other concerns regarding the development.

In April 2016 a hearing was held before Canterbury Regional Council and Waimate District Council relating to 8 Resource Consent applications by Fonterra relating to a proposed expansion of facilities and activities at their Studholme milk processing operation [63]. One of the concerns raised by the Council and submitters was the potential for reverse sensitivity effects at nearby residential dwellings due to the increase of noise emissions. Noise emissions were modelled by Marshall Day Acoustics and based on this modelling a noise control boundary approach to managing noise was chosen, with appropriate daytime and night-time limits offered. As a result of the hearing, Condition of Consent 38 was drafted which requires Fonterra to offer noise insulation or mechanical ventilation to the residents of any dwellings within the noise control boundary where internal noise levels exceed 35 dB $L_{Aeq\ (15m)}$. However, the specifications of the mechanical ventilation were not defined.

4.3 MBIE Determinations

In MBIE Determination 2001-01 a Building Consent was appealed on the grounds that a block of apartments had been consented as three bedroom units, but delivered as two bedroom units with studies/store rooms [64]. The appellant pursued the appeal on the grounds that adequate ventilation had not been provided if the space was to be used as a bedroom. Initially the room had natural ventilation provided by a skylight, however this was shown to be inadequate and a mechanical ventilation system was installed with a Producer Statement confirming compliance with G4/AS1. The Determination dismissed the appeal on the basis of there being no technical evidence to show non-compliance with G4.

In MBIE Determination 2002-12 a Building Consent had been denied due to the extract ventilation of the laundry not complying with the requirements of G4 [65]. The Applicant appealed the dismissal on the basis that a condensing clothes dryer was being used in the space, and as this was the main source of moisture generation that an external extraction system would not be required. Additionally, the Applicant intended to bolt the dryer to the ground so that it could be classed as a sanitary fixture. The Determination dismissed the appeal on the grounds that the space would need to be appropriately ventilated regardless of whatever appliances future inhabitants chose to use, and that bolting the dryer to the ground would not impact on the lack of appropriate ventilation.

In MBIE Determination 2013-032 a Building Consent for a prefabricated building design was refused on a number of grounds, including lack of evidence to support compliance with G4 [66]. The building has no external windows, and MBIE stated that it does not consider external doors to be an appropriate source of natural ventilation. The drawings showed a mechanical heat recovery system was to be installed which would provide mechanical ventilation to the habitable spaces of the building. The consensus from MBIE was that while this type of system is likely to be able to provide compliance with G4, in lieu of details regarding installation methodology and minimum air changes the Consent Authority was correct in its decision.

In MBIE Determination 2015-040 the Consent Authority had refused a code compliance certificate for a dwelling, and one of the reasons was that the master bedroom did not meet the requirements of G4 [67]. The bedroom had external doors, but no ventilating windows and no mechanical ventilation system. The

Determination stated that remedial work is needed to provide adequate ventilation, but did not specify what type of ventilation was required.

MBIE Determination 2016-025 examines the design of a proposed pool house on a residential site after the Consent Authority denied Building Consent due to lack of moisture control [68]. The building design includes a proprietary water vapour barrier, however it is reliant on users opening the doors and windows to provide ventilation to the space. The decision of MBIE was that natural ventilation of the space is unlikely to achieve the required ventilation required to remove internal moisture, and strongly recommends the use of a mechanical ventilation system. It is worth noting that in that instance mechanical ventilation is not mandated, but strongly recommended.

4.4 Summary of resource consent review

Our review in this case was limited to information we could source through the Environment Court decisions search, Environment Canterbury search function, Ministry of Business Innovation and Employment determinations, and a general keyword search. It is possible that more information on RMA hearings could be sourced by approaching individual Councils, although this was outside the scope of this report.

Since the sample size was limited, we have not drawn any conclusions about general trends. However there are some useful practical observations that can be drawn from two of the cases reviewed, as follows:

- Ventilation provisions with a high air change rate may not be necessary to regulate thermal comfort in certain areas of New Zealand. Revised ventilation provisions were accepted by the Environment Court in the vicinity of Invercargill Airport to account for the local climate. A high airflow rate of 15 ACH was initially proposed and this was reduced to 5 ACH. The supporting evidence stated that large, noisy fans and bespoke systems would be required to achieve the requirement, and that such a high rate was not required for temperature control in the local climate. The condition requiring an 18°C increase above outside temperature was amended to a condition which required a minimum temperature of 18°C inside, and a relief air provision was included.

- High capital and running costs were also identified as an issue with systems installed to meet both G4 and high airflow rate provisions (15 ACH) at Auckland Airport. An HRV type system to meet G4, and additional fans to meet the high airflow provision was the commonly installed solution. The revised proposal, recommended in the 2017 report was for a positive pressure system which provided lower airflow rates (0.5 ACH on low and 1-3 ACH on high) in combination with a high wall heat pump in the living room to provide heating and cooling.

5.0 SUMMARY OF DISTRICT PLAN REQUIREMENTS

Our review of the operative and proposed District Plan standards relating to ventilation identified 121 relevant rules. The largest subset of rules related to noise sensitive activities establishing in noise generating zones containing business, industrial and commercial activity. In the order of 40 of the rules appeared in this context. Aircraft and traffic noise provisions were also common (25 and 28 rules respectively). Rules relating to noise sensitive activities establishing near rail corridors, ports and specific industrial facilities such as dairy processing plants and electricity generation made up the balance of the rules.

A summary of the rules in table format is attached as Appendix B to this report. The full Excel spreadsheet will be provided to NZTA alongside this report and includes additional columns which have been hidden in Appendix B for clarity.

5.1 Noise levels from the system

Less than half of the ventilation rules (51 rules) provided criteria for noise emitted by the system. These have only been identified where the rules specify noise levels for the system or clearly state they are from the system and break-in noise at the same time.

For those rules, the most common requirement was between 30 and 35 dB L_{Aeq} in bedrooms and 40 and 45 dB L_{Aeq} in other habitable spaces. There were a handful of rules which had an NC 30 requirement instead (8 rules). Where a time base was included for the L_{Aeq} parameter, this was typically 30 seconds, although 15 minute, 1 hour and 24 hour time bases were also used for some rules.

For variable speed systems, different noise criterion for low and high speed operation are common. For example, the Proposed Kapiti Coast District Plan outlines noise criteria of 30 dB $L_{Aeq(30s)}$ on low and 35 dB $L_{Aeq(30s)}$ on high received in habitable spaces from the ventilation system.

Figure 5.1 below summarises the various noise levels referenced by the District Plan rules and how frequently they appeared.

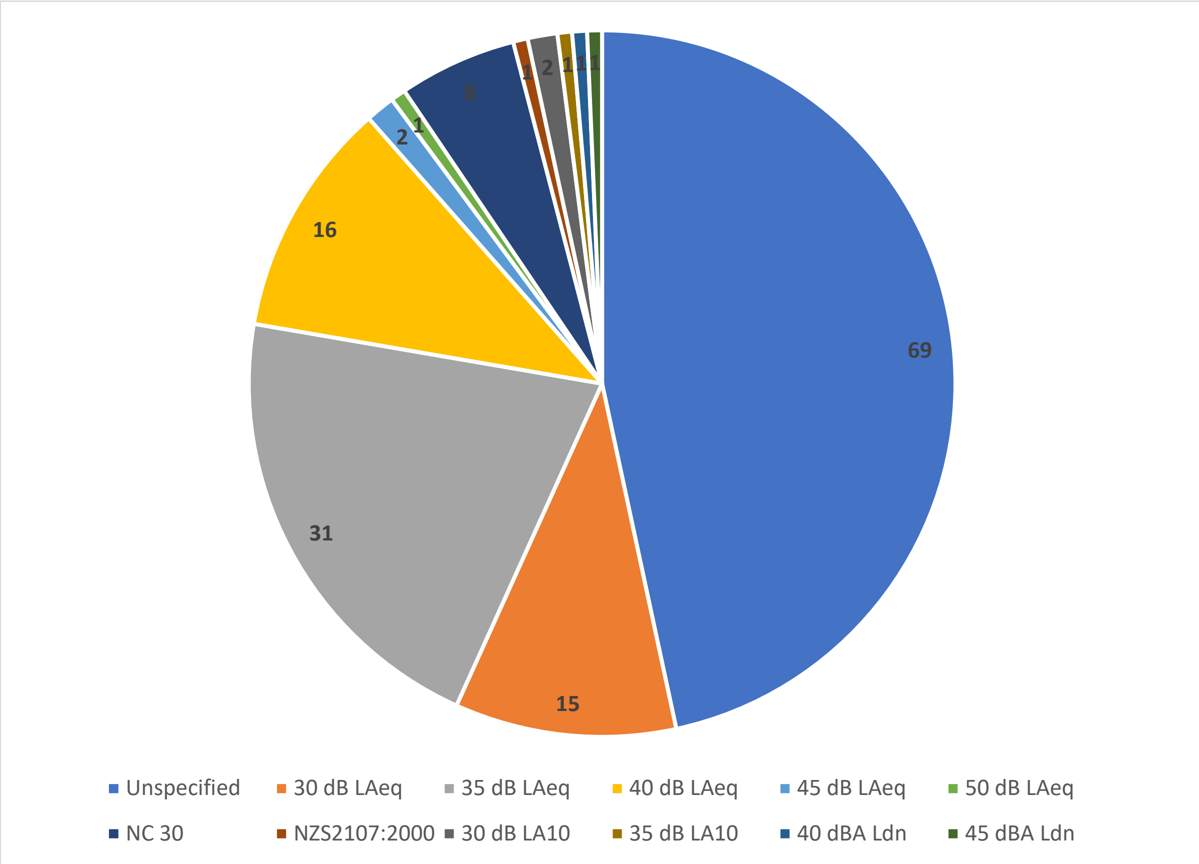

Figure 5.1 – Noise levels referenced in District Plan rules

Where rules outlined a specific location where this noise level was to be measured, this was typically at 1 metre from a grille or diffuser (28 rules). The only exceptions were the operative Invercargill City and Proposed Queenstown District Plans which specified 2 metres from the grille or diffuser instead.

5.2 Air changes

The NZBC G4 provisions were referenced by 73 of the rules. Some rules specified the G4 requirements as the minimum rates, with additional requirements for higher rates. 46 rules in total had alternative ventilation provisions which went beyond the NZBC requirements.

For rules which did not discuss an air conditioning option, between 5-15 air changes per hour (ACH) were specified for the system operating on high. The highest rate of 15 ACH was typically required for principal living spaces with lower rates of 5 ACH for other habitable spaces. Some plans only outlined rates of 5-6 ACH on high. Where there was an option which allowed for air-conditioning, much lower air changes were required (0.5 ACH).

Figure 5.2 below summarises the air change rates that appeared in District Plan noise rules as ACH and how frequently they appeared.

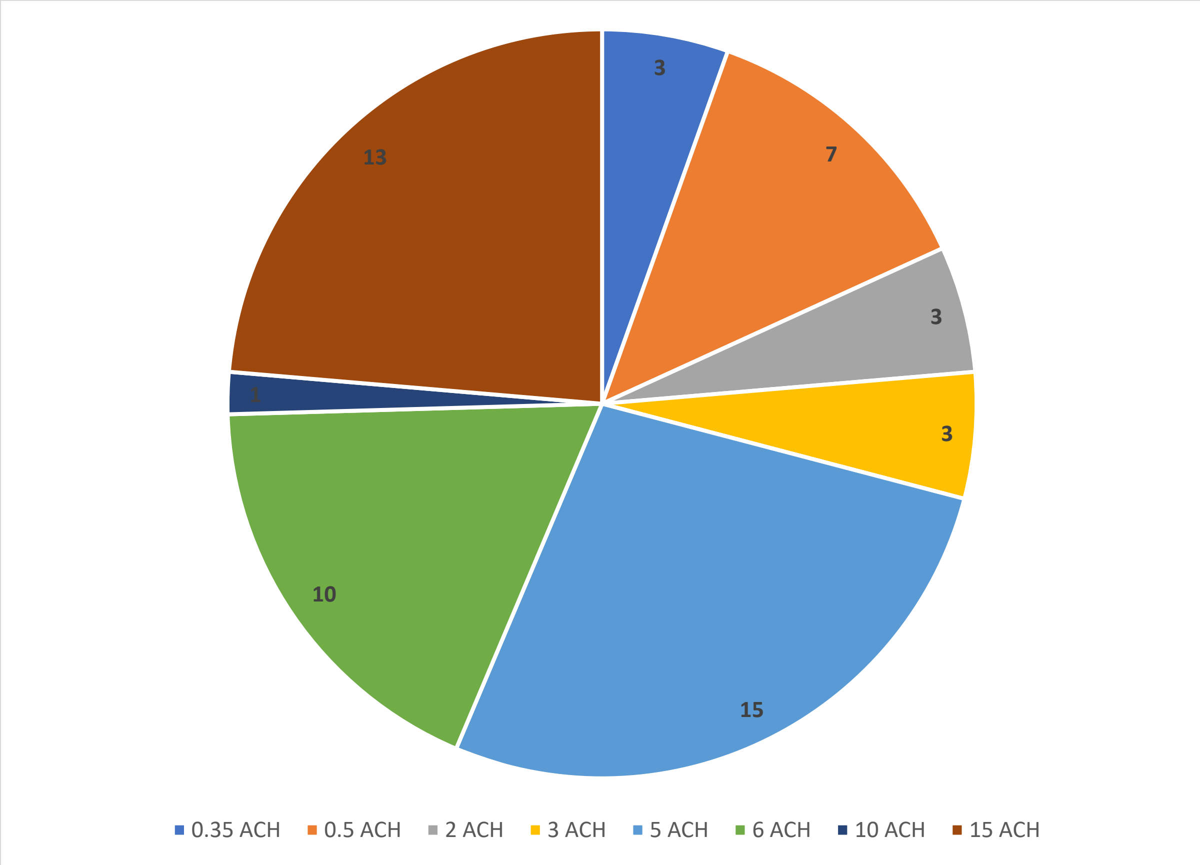

Figure 5.2 – Air changes per hour referenced in District Plan rules

There were a number of rules which outlined a 7.5 L/s or L/s per person requirement. The Auckland aircraft provisions include air change requirements for large spaces such as care centres and halls, where a L/s per person is outlined for the maximum number of people. These spaces also include a L/s per square metre provision. Figure 5.3 below confirms that 7.5 L/s was the most common rate.

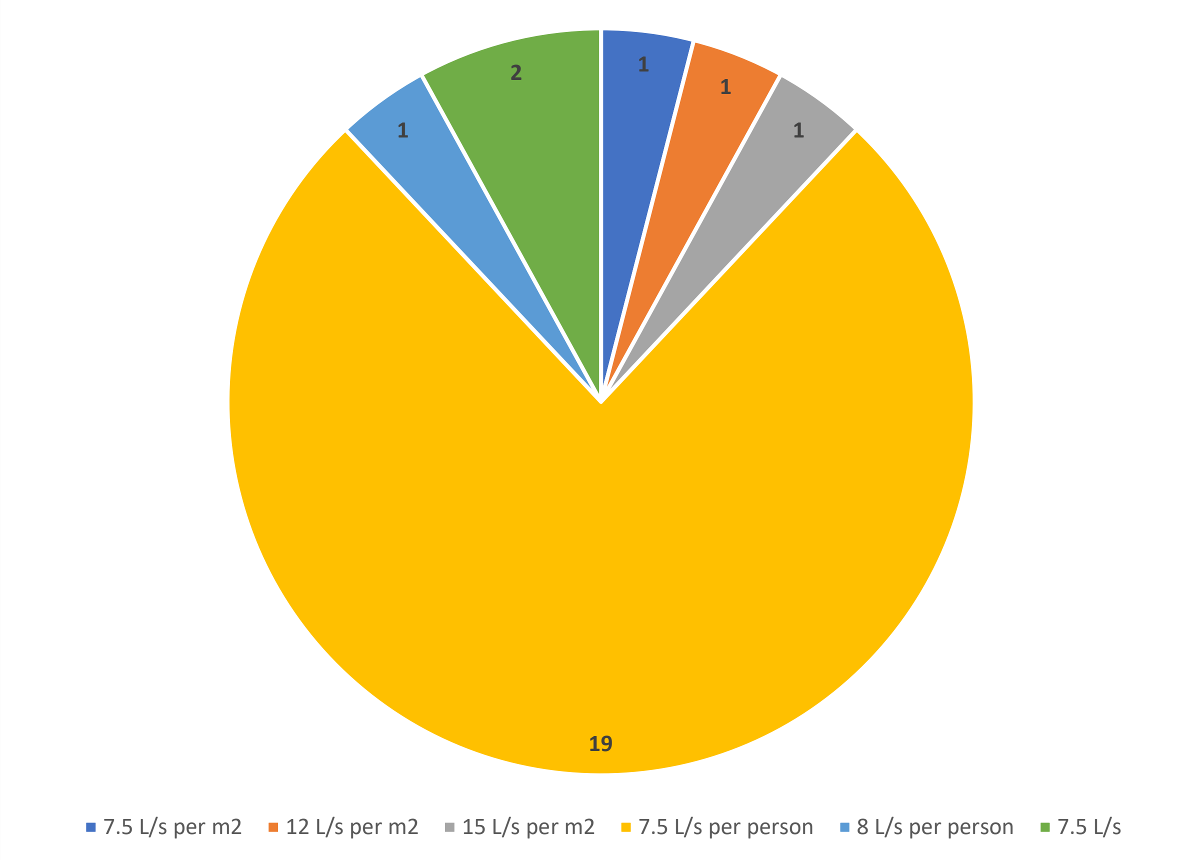

Figure 5.3 – Other air flow provisions referenced in District Plan rules

There were two ventilation rules in the Auckland Unitary Plan which related the required ACH to the orientation of the room and percentage of glazing. Where glazing was less than 30% a rate of only 6 ACH was required. Where glazing was more than 30% a higher rate of 15 ACH was required. For south facing rooms, or those not exposed to direct sunlight a rate of only 3 ACH was required.

5.3 Temperature control provisions

Cooling or heating provisions were not as common in the identified rules, with only 19 rules identified as having these controls.

Heating provisions were particularly rare, with only the Auckland, Waikato, Queenstown and Invercargill rules containing specific provisions. In Auckland, the aircraft provisions provide for a temperature of at least 16°C in care centres, libraries and classrooms. In Waikato, the system must provide a 12°C heat rise for incoming air on the low setting, with two equal heating stages. In Queenstown the system must provide an 18°C heat rise for incoming air with at least 3 equal heating stages. For Invercargill, heating to at least 18°C must be provided.

Cooling provisions are more uniform, with the majority providing a control so that internal temperatures do not exceed 25°C (the exception being care centres, libraries and classrooms in Auckland where the rule allows up to 27°C).

The Nelson and Rotorua rules state that this upper temperature should be achieved at 5% ambient design conditions as defined by NIWA. Some of the Auckland rules provide an outdoor design temperature (dry bulb 25.1°C).

5.4 System control

Sixteen of the rules have provisions relating to occupant control of the systems. Most often, the control will allow the occupant to turn systems on and off individually, and control ventilation rates incrementally across the range. Some rules specified a minimum of three control stages.

Figure 5.6 below shows the different operational control requirements that appeared in the various Plan rules.

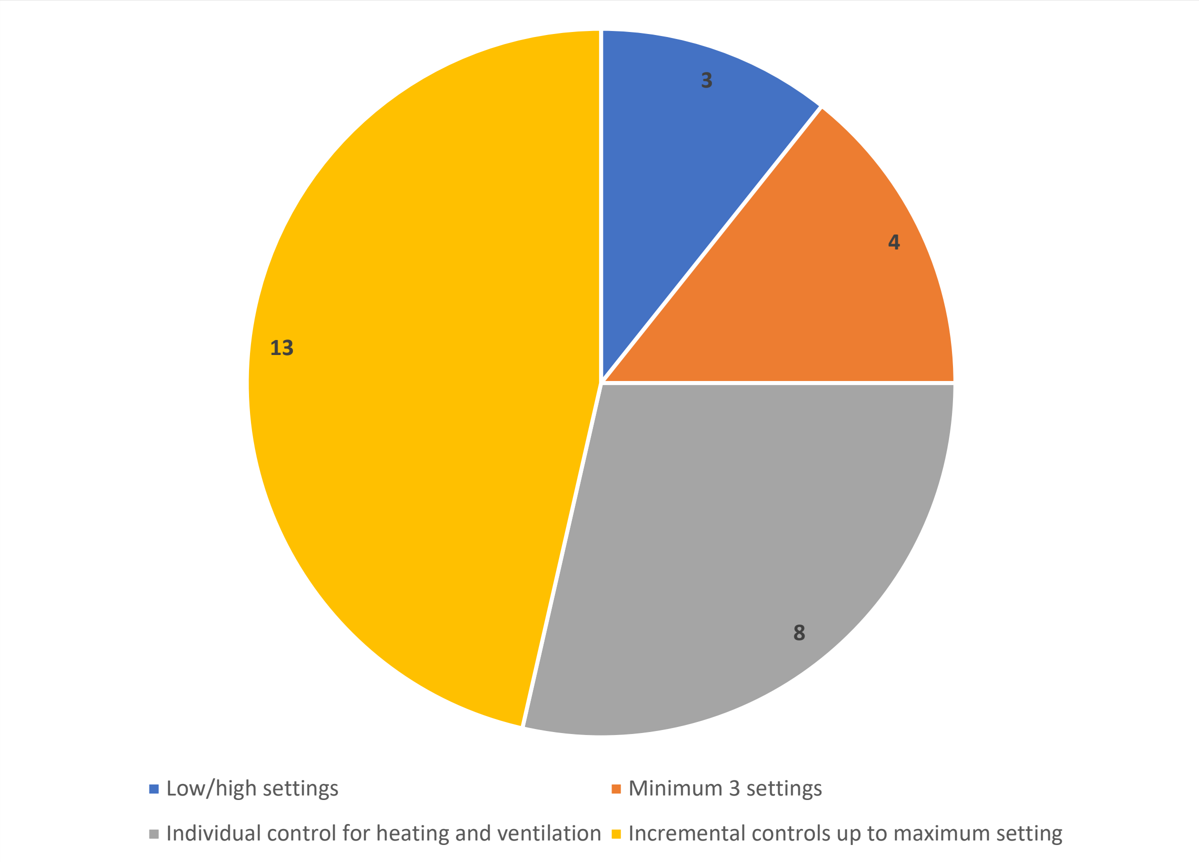

Figure 5.4 – Operational control requirements referenced in District Plan rules

5.5 Other items covered by rules

Several other items discussed in the identified rules are summarised below.

- Several of the more comprehensive ventilation rules included a provision stating that the internal air pressure must not be above the external ambient air pressure by either 10 Pa or 30 Pa.
- The Auckland Unitary Plan aircraft noise rule referenced NZS 4303:1990 *Ventilation for Acceptable Indoor Air Quality* for care centres. For noise sensitive spaces in business zones, the rule allows for design of alternative passive or mixed mode cooling options to provide a suitable thermal comfort level and references ASHRAE S55:2013, CBSIE TM52:2013 and BS EN 15251:2007.
- The Invercargill City aircraft rule discusses how existing ventilation, heating and/or cooling systems may be used to demonstrate compliance with the rule.

- There are Auckland, Wairarapa Combined and Nelson ventilation rules that require an extractor fan to serve cooking hobs.

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FIGURES

Cover image

K. Golik, "State Highway 1 in Manawatu-Wanganui Region, North Island of New Zealand". 2017. Accessed online at https://commons.wikimedia.org/wiki/File:State_Highway_1_in_Manawatu-Manganui_Region_02.jpg.

Figure 3.1

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Appendix A - Summary of ventilation provisions found in standards and guides

Source	Air flow rate	Extract	Infiltration	Temperature	Overheating	Noise from mechanical plant
Approved Document F	13 L/s for one bedroom unit, +4 L/s per bedroom based on 2 people in primary bedroom and 1 person in other bedrooms Not less than 0.3 L/s per m2 7600 mm2 undercut required for doors to habitable rooms	Kitchen intermittent 30 L/s adjacent to hob, 60 L/s elsewhere Kitchen continuous 13 L/s on high Bathrooms intermittent 15 L/s Bathrooms continuous 8 L/s Laundry intermittent 30 L/s Laundry continuous 8 L/s 4 ACH required in each habitable room for purge ventilation	Infiltration rate is used to determine specifications of ventilation system Assumed default rate is 0 ACH, assumed alternative rate is 0.15 ACH	Assumed external/internal temperature difference of 3 degrees C		Not specified under UK regulations
ASHRAE S55	Whole house rate 0.35 ACH Air velocities above 0.2 m/s allow for increased operative temperature Maximum 0.8 m/s for operative temperatures above 25.5 degrees C Maximum 0.2 m/s for operative temperatures below 23 degrees C			Minimum floor temperature of 19 degrees C where occupants are seated Maximum floor temperature of 29 degrees C where occupants are seated Maximum difference of 3 degrees C between head and ankle for seated occupants, 4 degrees C for standing occupants Temperature should not change more than 2.2 degrees C within 1.0 hours, or 1.1 degrees C during any 15 minute period within that hour		
ASHRAE S62.2	From 14 L/s up to 91 L/s dependent on floor area and number of bedrooms Formula provided for calculating required rate	For enclosed kitchens: 50 L/s for rangehood, 150 L/s or 5 ACH for other fans For non-enclosed kitchens: 50 L/s for rangehood, 150 L/s for other fans Bathrooms intermittent 25 L/s, continuous 10 L/s Prescriptive duct sizing given Concept of airflow deficit which takes into account natural airflow in each space, and openable windows if permitted				
International Mechanical Code	Calculated based on air flow required per m2, GFA, air flow required per person and population Natural ventilation must have open area equivalent to 4% of GFA	Kitchens 50 L/s intermittent, 12 L/s continuous Bathrooms 25 L/s intermittent, 10 L/s continuous	If infiltration is less than 5 ACH at 50 Pa mechanical ventilation is required			
EN 15251	Whole house rate 0.5 to 0.7 ACH depending on category Whole house rate 0.35 to 0.49 L/s per m2 depending on category Minimum whole house rate of 0.05 to 0.1 L/s per m2 during unoccupied hours Bedrooms and living areas 4 to 10 L/s per person depending on category Bedrooms and living areas 0.6 to 1.4 L/s per m2 depending on category	Kitchen 14 to 28 L/s depending on category Bathroom 10 to 20 L/s depending on category 7 to 14 L/s in toilets depending on category		Living spaces minimum 18 - 21 degrees C depending on category Other spaces minimum 14 - 18 degrees C depending on category Living spaces maximum 25.5 to 27 degrees C depending on category Other spaces no maximum temperature		
AIVC Survey on minimum ventilation rate in 15 countries	Whole house: Norway 0.5 ACH Sweden 0.35 L/s per m2 Finland 0.35 L/s per m2 Denmark 0.5 ACH France 29 to 58 L/s depending on number of habitable rooms Germany 17 to 33 L/s depending on planned occupancy for natural vent, 17 to 50 L/s for mech vent Switzerland 3-19 L/s per person for high C02 allowance, 0.3 ACH for low CO2 allowance Italy 0.35 to 0.5 ACH Commission of the European Communities 0.4 L/s per m2 Canada during summer 0.5 ACH if mechanically cooled, else 1.0 ACH, during winter 0.3 ACH Japan 0.3 to 0.7 ACH depending on if materials meet a specified emission rate Kitchen: France 10 to 37 L/s depending on number of habitable rooms UK 4000 mm2 opening Italy 1 ACH Greece 10 L/s	Kitchen: Norway 10 L/s plus 20 L/s from rangehood Sweden 10-15 L/s Finland 8 L/s up to 25 L/s on boost Denmark 20 L/s Belgium 1 L/s per m2 minimum 14 L/s France 21 - 42 L/s depending on number or habitable rooms UK 30 L/s next to hob, 60 L/s elsewhere, or passive stack ventilation Bathroom: Norway 10 L/s from openable window or 30 L/s from mechanical extract Sweden 10 L/s from openable window or 30 L/s from mechanical extract Finland 10 L/s up to 15 L/s on boost Denmark 15 L/s Belgium 14 L/s France 15-30 L/s dependent on number of habitable rooms Netherlands 14 L/s UK 15 L/s or passive stack ventilation Italy 2 ACH Canada 10 L/s continuous 25 L/s intermittent				

Source	Air flow rate	Extract	Infiltration	Temperature	Overheating	Noise from mechanical plant
AIVC Survey on minimum ventilation rate in 15 countries (continued)	Bedroom: Sweden 4 L/s per person Finland 6 L/s per person or 0.5 L/s per m2 Denmark 0.5 ACH Belgium 1 L/s per m2 minimum 7 L/s Netherlands 0.9 L/s per m2 minimum 7 l/s UK 8000 mm2 opening Greece 2.5 L/s per person Living: Finland 6 L/s per person or 0.5 L/s per m2 Denmark 0.5 ACH Belgium 1 L/s per m2 minimum 21 L/s UK 8000 mm2 opening Italy 4 L/s per person Greece 2.5 L/s per person Other: Denmark requirements of minimum open areas if natural ventilation used France 3 to 10 L/s unoccupied rate	Laundry: Norway 10 L/s Sweden 10 L/s Finland 8 L/s up to 15 L/s on boost Denmark 10 L/s Belgium 1 L/s per m2 minimum 14 L/s UK 30 L/s or passive stack ventilation Purge ventilation: UK 5% GFA in habitable spaces, opening window in kitchen/laundry/bathroom, 6 L/s mech vent in toilets Other: Norway 10 L/s in toilet Finland 7 L/s up to 10 L/s on boost in toilet Sweden 10 L/s Denmark 10 L/s in basements Belgium 7 L/s in toilets Netherlands 7 L/s in toilets				
CIBSE TM59	Air speed assumed to be 0.1 m/s unless there is a ceiling fan, at which point 0.8 m/s is assumed				Naturally ventilated bedrooms 3% occupied hours 1 degree K above comfort temperature during winter, 1% of annual night time hours above 26 degrees C Mechanically ventilated bedrooms 3% of annual occupied hours above 26 degrees C Naturally ventilated living rooms 3% of winter occupied hours 1 degree K above comfort temperature Mechanically ventilated living rooms 3% of annual occupied hours above 26 degrees C	
NZS 4303:1990	Bedrooms and living areas 0.35 ACH but not less than 7.5 L/s per person	Kitchens 50 L/s intermittent, 12 L/s continuous extract or openable windows Bathrooms 25/s intermittent, 10 L/s continuous extract or openable windows				
Overheating in new homes		Purge ventilation providing 4 ACH in bedrooms and living areas		Maximum 26-27 degrees C depending on category Maximum variation of 4 degrees C from comfort temperature	Bedrooms 1% of annual occupied hours above 26 degrees C Living rooms 1% of annual occupied hours over 28 degrees C	
Passivhaus			Maximum 0.6 ACH at 50 Pa	Optimal indoor temperature 21 degrees C		
BPIE Indoor Air Quality, Thermal Comfort and Daylight	Whole house: Poland 20 m3/h per person Kitchen: Brussels 75 m3/h Bedrooms: Brussels 25 m3/h Air velocity: Brussels 0.24 m/s Denmark 0.15 m/s unless temperature is above 24 degrees C Italy 0.2 m/s Poland 0.2 - 0.6 m/s depending on metabolic rate Sweden 0.15 m/s during heating periods and 0.25 m/s other times UK 0.15 m/s Other: Poland if using natural ventilation window openable area should be 1/8 of GFA	Kitchen: Brussels 75 m3/h if open kitchen, 50 m3/h if closed Poland 30-70 m3/h depending on arrangement Bathroom: Brussels 25 m3/h Poland 50 m3/h Laundry: Poland 2 ACH	Brussels 0.6 ACH maximum Denmark 1.5 l/s per m2 maximum France 0.6 m3/h per m2 maximum Germany 3 ACH maximum for natural ventilation, 1.5 ACH maximum for mechanical ventilation Poland 2.25 m3/h per m Sweden 0.6 l/s per m2 UK 10 m3/h per m2	Minimum: France 18 degrees C Germany 20 degrees C in apartments Italy 20 degrees C Poland 16 degrees C Sweden 16 degrees C UK 18 degrees C in sleeping rooms, 21 degrees C in living rooms Maximum: France 28 degrees C if mechanical ventilation used, based on building category and outdoor temperature if natural ventilation used Germany 25-27 degrees C depending on climatic region Italy 26 degrees C Sweden 26 degrees C UK 23 degrees C in bedrooms, 25 degrees C in living rooms Temperature difference: Brussels maximum difference between internal and external temp 5-7 degrees C Sweden maximum temperature difference of 5 degrees C between rooms	Bedrooms: Brussels 5% of hours above 25 degrees C Denmark 100 annual hours above 26 degrees C, 25 annual hours above 27 degrees C UK 1% of annual occupied hours above 26 degrees C Living areas: UK 1% of annual occupied hours above 28 degrees C	
CIBSE Guide B4						35 dB LAeq in classrooms Recommends dBA used in place of NC and NR
CIBSE Guide B2	5-20 L/s per person depending on required IAQ performance level			Where near-floor temperatures are <22 degrees C, air velocity should not exceed 0.15 m/s		NR 25 in bedrooms

Source	Air flow rate	Extract	Infiltration	Temperature	Overheating	Noise from mechanical plant
AS 1668-2:2012	10 L/s per person in bedrooms and living areas For periods where occupancy is below design the airflow can be reduced, but not to below 0.35 L/s per m2	25 L/s in bathrooms Laundries without dryer 20 L/s Laundries with condensing dryer 20 L/s Laundries with non-condensing dryer 40 L/s If mechanical supply and exhaust air are provided for the same space, the exhaust rate must be at least 10% higher than the supply				
AS1668-4:2012	Simple method (Class 2-4 buildings) 5% of floor area as equivalent opening Complex method (Class 5-9 buildings) 2.5-15% depending on metabolic rate of occupants and floor area per occupant For complex method, require open area must be multiplied by 1.25 for classrooms					

Appendix B - Summary of District Plan ventilation provisions

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Ashburton District	Business	Yes	No	No	No	Yes	No	No	No	No	No
Auckland	Aircraft	Yes	No North Shore, Kaipara, Whenuapai, Ardmore (some) Yes 30 dB LAeq other habitable rooms 40 dB LAeq principal living room, hallways 35 dB LAeq learning area, classroom and sleeping areas 40 dB LAeq library Ardmore (some), Auckland	1 m from diffuser	Yes	Yes	Yes	Yes Auckland airport only 15 principal living room 5 other habitable rooms 0.5 +/- 0.1 all habitable or 0.5 +/- 0.1 all habitable with air conditioning 15 l/s/m2 for the first 50 m2 and 7.5l/s/m2 of remaining (care centres) 8l/s/person for max number of people (minimum for care centres) or 8l/s/person with airconditioning same for classrooms and libraries 12 l/s/m2 max 8 l/s/person max occupancy min for halls	Yes Auckland airport only Cooling to <25 C in dwellings with airconditioning installed 16 C in winter (care centres) Cooling to <27 C in care centres with airconditioning installed 16 - 27 C libraries and classrooms <27 C halls	Yes Individual on/off Controlled across range down to 0.5 ACH	Yes <30 Pa above ambient
Auckland	Port	Yes	Yes 35 dB LAeq at minimum air flows	1 m from diffuser	No	Yes	Yes	Yes 6 rooms < 30% of façade glazed 15 rooms > 30 % of façade glazed 3 rooms facing S between 120 - 240 degrees or where glazing not subject to direct sunlight	Yes <25 C external dry bulb 25.1 and wet bulb 20.1 Cooling for all habitable rooms (excludes bedrooms) and each level of dwelling with habitable spaces (includes bedrooms)	Yes Individual control across airflow/temp range	Yes Spill air relief
Auckland	Business	Yes	Yes 35 dB LAeq at minimum air flows	1 m from diffuser	No	Yes	Yes	Yes 6 rooms < 30% of façade glazed 15 rooms > 30 % of façade glazed 3 rooms facing S between 120 - 240 degrees or where glazing not subject to direct sunlight	Yes <25 C external dry bulb 25.1 and wet bulb 20.1 Cooling for all habitable rooms in residential dwellings (excludes bedrooms) and each level of dwelling with habitable spaces (includes bedrooms)	Yes Individual control across airflow/temp range	No
Auckland	Industrial Maritime (Wynyard Precinct)	No	No	No	Yes	No	No	No	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Auckland	Rail Orakei Point Precinct	Yes	No	No	Yes	No	No	No	Yes Adequately ventilated or air-conditioned to achieve reasonable internal temperatures during all but the extreme summer conditions (G4 at	No	No
Auckland	Substation Takanini Precinct	Yes	30 dB LA10 Includes SAC penalty for tonal noise	1 m from diffuser	Yes	Yes	No	No	No	No	No
Auckland	Traffic	Yes	No	No	Yes	Yes	Yes	No	Yes Heating and cooling to 20 - 25 C with windows closed	No	No
Auckland	Traffic	Yes	Yes 35 dB LAeq other noise sensitive spaces (not dwellings)	1 m from diffuser	No	Yes	Yes	Yes 6 rooms < 30% of façade glazed 15 rooms > 30 % of façade glazed 3 rooms facing S between 120 - 240 degrees or where glazing not subject to direct sunlight dwellings only	Yes <25 C external dry bulb 25.1 and wet bulb 20.1	Yes Individual control across airflow/temp range	Yes Spill air relief
Carterton District (Wairarapa Combined District)	Aircraft	No	30 dB LAeq bedroom 40 dB LAeq principal living room, hallway	1 m from diffuser	Yes	No	Yes	No	No	No	No
Central Hawke's Bay District	Commercial Mixed Use Industrial	Yes	35 dB LAeq(24h)	No	Yes	No	No	No	No	No	No
Central Hawke's Bay District	Aircraft	Yes	No	No	No	Yes	No	No	No	No	No
Central Otago District	Bird scarers Frost fans	Yes	No	No	No	Yes	No	No	No	No	No
Central Otago District	Industrial	Yes	No	No	No	Yes	No	No	No	No	No
Christchurch City	Aircraft engine testing	Yes	35 dB LAeq(30s) at night time in bedrooms	1 m from diffuser	Yes	Yes	Yes	6	No	No	No
Christchurch City	Traffic Aircraft	Yes	35 dB LAeq(30s) at night time in bedrooms 40 dB LAeq(30s) other habitable spaces	1 m from diffuser	Yes	Yes indoor levels option only	No	6	No	No	No
Christchurch City	Port	Yes	40 dBA Ldn(5d)	No	No	Yes	Yes either mech vent or	No	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Christchurch City	Central City	Yes	No	No	Yes	Yes	No	No	No	No	No
Dunedin City	Business Airport Industrial Road Rail Stadium Port Hospital	Yes	No	No	No	Yes	No	Yes 7.5 l/s/pp	No	No	No
Far North District	Commercial Industrial	Yes	No	No	No	Yes	No if air condition	No	No	No	No
Franklin District	Traffic Rail Business	Yes	45 dB LAeq(24h) habitable room (traffic) 35 dB LAeq(24h) bedroom, 10pm to 7am (traffic)	No	Yes	Yes	No	No	No	No	No
Grey District	Traffic Commercial Industrial	Yes	35 dB LAeq(24h) bedroom 40 dB LAeq(24h) habitable space Internal noise levels from traffic and ventilation system 30 dB LA10 (10 pm - 7 am) 35 dB LA10 (7am - 10 pm)	No	No	Yes	No	No	No	No	No
Hamilton City	Traffic	Yes	No	No	Yes	Yes	No	No	No	No	No
Hamilton City	Traffic	Yes	35 dB LAeq	1 m from grille or diffuser	Yes	No	No	No	Yes Provide cooling	No	No
Hastings District	Aircraft Commercial	Yes	NC 30 in habitable room	No	Yes	Yes	No	No	No	No	No
Hauraki District	Traffic	Yes	No	No	Yes	Yes	Yes	No	Yes An air conditioning system may also be necessary to achieve thermal comfort	No	No
Hauraki District	Industrial	Yes	NZS 2107:2000	No	No	Yes	Yes	No	No	No	No
Hurunui District	Rail	Yes	35 dB LAeq(1h) bedrooms 40 dB LAeq(1h) habitable rooms	1 m from grille or diffuser	No	Yes	No	No	No	No	No
Horowhenua District	Commercial	Yes	No	No	No	Yes	No	Yes 7.5 l/s per person	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Hutt City	Commercial	Yes	No	No	No	No	No	Yes 7.5 l/s per person	No	No	No
Invercargill City	Traffic Rail	Yes	No	No	Yes	No	No	No	No	No	No
Invercargill City	Aircraft	Yes	Yes 30 dB LAeq(30s) habitable spaces (low) 35 dB LAeq(30s) habitable spaces (high)	2 m from grille or diffuser	No	Yes	Yes	Yes 0.35 - 0.5 (low, habitable spaces) 5 (high, habitable spaces)	Yes Cooling to <25 C; and Heating to >18 0 C; If cooling with a heat pump, no high flow rate or pressure difference required	No	Yes <30 Pa above ambient
Kaipara District	Dairy processing Industrial Commercial Intensive rural Quarrying Wastewater	Yes	Yes 35 dB LAeq(24h)	No	Yes	Yes	No	No	No	No	No
Kapiti Coast District	Aircraft	Yes	Yes NC 30	No	Yes	Yes	No	No	No	No	No
Kapiti Coast District	Aircraft Civic and Community Centres Industrial / Service Rail Traffic	Yes	30 dB LAeq(30s) habitable spaces (low) 35 dB LAeq(30s) habitable spaces (high)	1 m from grille or diffuser	Yes	No	Yes	G4 on low 6 on high	Yes Provide cooling that is controlled by the occupant and can maintain the temperature at no greater than 25C	Yes Incremental contorl to max	Yes <10 Pa above ambient
Lower Hutt District	Commercial	Yes	No	No	No	Yes	No	Yes 7.5 L/s in bedrooms	No	No	No
Mackenzie District	Rural Pukaki Village	Yes	No	No	No	Yes	No	No	No	No	No
Manawatu District	Business	Yes	No	No	No	Yes	No	Yes 7.5 L/s in bedrooms	No	No	No
Manawatu District	Aircraft	Yes	No	No	Yes	Yes	No	No	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Matamata-Piako District	Traffic Rail	Yes	No		Yes	Yes	No	No	No	No	No
Napier City District	Traffic Willowbank	Yes	NC 30	No	Yes	Yes	No	No	No	No	No
Napier City District	Aircraft	Yes	No	No	Yes	Yes	No	No	No	No	No
Napier City District	Port	Yes	No	No	Yes	Yes	No	No	No	No	No
Napier City District	Port	Yes	No	No	Yes	Yes	No	No	No	No	No
Napier City District	Inner City Commercial Zone	Yes	NC 30	No	Yes	Yes	No	No	No	No	No
Napier City District	Inner City Commercial Zone Fringe Commercial Zone Suburban Commercial Environments Foreshore Commercial Zone Large Format Retail Zone Main Industrial Zone Suburban Industrial Zone West Quay Waterfront Zone Marine Industrial Zone Business Park Zone	Yes	NC 30	No	Yes	Yes	No	No	No	No	No
Napier City District	Business Park Zone	Yes	NC 30	No	Yes	Yes	No	No	No	No	No
Napier City District	Port Industrial Zone	Yes	No	No	Yes	Yes	No	No	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Napier City District	Business Park Traffic	Yes	NC 30	No	Yes	Yes	No	No	No	No	No
Napier City District	Traffic	Yes	NC 30	No	Yes	Yes	No	No	No	No	No
Napier City District	Aircraft	Yes	No	No	Yes	Yes	No	No	No	No	No
Nelson City District	Port	Yes	40 dB LAeq(15m) in principal living room 30 dB LAeq(15m) other habitable rooms 50 dB LAeq(15m) in hallway	1 m from diffuser	No	Yes	Yes	Yes 15 ACH principal living room 5 ACH in other habitable rooms 0.5 ACH habitable spaces with aircon	Yes If air conditioning used, indoor temperatures not greater than 25 degrees C at 5% ambient design conditions defined by	Yes Individual on/off Controlled across range down to 0.5 ACH	Yes <30 Pa above ambient
Nelson City District	Inner City	Yes	30 dB LAeq(15m) in bedrooms	1 m from diffuser	No	Yes	Yes	Yes 5 ACH with mech vent 0.5 ACH with aircon	Yes If air conditioning used, indoor temperatures not greater than 25 degrees C at 5% ambient design conditions defined by	Yes Individual on/off Controlled across range down to 0.5 ACH	Yes <30 Pa above ambient
New Plymouth	Port	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth District	Traffic	Yes	30 dB LAeq(30s)	1 m from grille	Yes	Yes	No	15 ACH in principle living space and 5 ACH in all other habitable spaces	No	No	No
New Plymouth District	Business Zone Industrial Zone	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth District	Traffic	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth District	Rail	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth District	City Centre Town Centre Local Centre	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth District	Mixed Use General Industrial	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth	Aircraft	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth	Port	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth District	Industrial Methanex	Yes	No	No	Yes	Yes	No	No	No	No	No
New Plymouth District	Traffic	Yes	30 dB LAeq(30s)	1 m from grille	Yes	Yes	No	15 ACH in principle living space and 5 ACH in all other habitable spaces	No	No	No
Opotiki District	Industrial	Yes	No	No	Yes	Yes	No	No	No	No	No
Otorohanga District	Electricity generation	Yes	No	No	Yes	Yes	No	No	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Otorohanga District	Rail	Yes	No	No	Yes	Yes	No	No	No	No	No
Otorohanga District	Traffic	Yes	No	No	Yes	Yes	No	No	No	No	No
Palmerston North City	Traffic	Yes	No	No	No	Yes	Yes	Yes 7.5 L/s per person	No	No	No
Palmerston North City	Rail	Yes	No	No	No	Yes	Yes	Yes 7.5 L/s per person in bedrooms	No	No	No
Palmerston North City	Aircraft	Yes	No	No	No	Yes	Yes	Yes 7.5 L/s per person	No	No	No
Palmerston North City	Traffic	Yes	No	No	No	Yes	Yes	Yes 7.5 L/s per person	No	No	No
Palmerston North City	Traffic	Yes	No	No	No	Yes	Yes	Yes 7.5 L/s per person	No	No	No
Palmerston North City	Golf club	Yes	No	No	No	Yes	Yes	Yes 7.5 L/s per person	No	No	No
Palmerston North City	Business Zone	Yes	No	No	No	Yes	Yes	Yes 7.5 L/s per person	No	No	No
Palmerston North City	Industrial zone	Yes	No	No	Yes	Yes	Yes	7.5 L/s per person in bedrooms and sleeping areas	No	No	No
Palmerston North City	Aircraft	Yes	No	No	Yes	No	No	7.5 L/s per person in bedrooms and sleeping areas	No	No	No
Queenstown Lakes District	Aircraft	Yes	35 dB LAeq on high setting 30 dB LAeq on low setting	1 m from diffuser	No	Yes	No	Yes 1-2 ACH on low setting in all critical listening environments 5 ACH on high settings in bedrooms 15 ACH on high settings in other critical listening environments	Yes 18 degrees C heat rise on incoming air Minimum of 3 equal heating stages	Yes Min 3 settings	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measuremen t location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Queenstown Lakes District	Quail Rise Zone	Yes	No	No	No	No	Yes	Yes 1-2 ACH on low setting in all critical listening environments 5 ACH on high settings in bedrooms 15 ACH on high settings in other critical listening environments	Yes 18 degrees C heat rise on incoming air Minimum of 3 equal heating stages	Yes Min 3 settings	No
Queenstown Lakes District	Aircraft	Yes	35 dB LAeq(30s) on high setting 30 dB LAeq(30s) on low setting	2 m from diffuser	No	No	Yes	Yes 0.35 to 0.5 ACH on low setting 5 ACH on high settings in bedrooms	Yes Heating that maintains internal temperature at 18 degrees C or higher Cooling that maintains internal temperature at maximum of 25 degrees C	Yes Low/high Cooling and heating occupant control	Yes <30 Pa above ambient
Queenstown Lakes District	Town Centre Local Shopping Centre Business Mixed Use	Yes	35 dB LAeq(30s) on high setting 30 dB LAeq(30s) on low setting	2 m from diffuser	No	No	Yes	Yes 0.35 to 0.5 ACH on low setting 5 ACH on high settings in bedrooms	Yes 18 degrees C heat rise on incoming air Minimum of 3 equal heating stages	Yes Low/high	No
Rotorua Lakes District	Aircraft	Yes	40 dB LAeq in principal living room 30 dB LAeq in all other habitable rooms	1 m from diffuser	No	Yes	Yes	Yes 15 ACH principal living room 5 ACH other habitable rooms	No	Yes Controlled across range down to 0.5 ACH	Yes <30 Pa above ambient
Rotorua Lakes District	Aircraft	Yes	40 dB LAeq in principal living room 30 dB LAeq in all other habitable rooms	1 m from diffuser	No	Yes	Yes	Yes 0.5 ACH in all habitable rooms	Yes Maximum of 25 degrees Celsius at 5% ambient design conditions as defined by NIWA	Yes Controlled across range down to 0.5 ACH	Yes <30 Pa above ambient
Rotorua Lakes District	Traffic	Yes	40 dB LAeq(30s) in the largest habitable room 35 dB LAeq(30s) in all other habitable rooms	1 m from diffuser	No	No	No	Yes 6 ACH largest habitable room 5 ACH all other habitable rooms	Yes Maximum of 25 degrees Celsius User controllable cooling	No	Yes <10 Pa above ambient
Rotorua Lakes District	City Centre 1, City Centre 3m Commercial 1-6 zones	Yes	35 dB LAeq(1h) in bedrooms between 10pm and 7am 40 dB LAeq(1h) in other habitable rooms and in bedrooms between 7am	No	Yes	Yes	No	No	No	No	No
Ruapehu District	Commercial Zone	Yes	45 dB LAeq(15m)	No	No	Yes	Yes	No	No	No	No
Ruapehu District	Rail	Yes	No	No	Yes	Ye	No	No	No	No	No
South Taranaki District	Traffic	Yes	No	No	Yes	Yes	No	No	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
South Taranaki District	Rail	Yes	No	No	Yes	Yes	No	No	No	No	No
South Taranaki District	Traffic	Yes	No	No	Yes	Yes	No	No	No	No	No
South Taranaki District	Rail	Yes	No	No	Yes	Yes	No	No	No	No	No
South Taranaki District	Commercial Industrial	Yes	No	No	Yes	Yes	No	No	No	No	No
South Taranaki District	Aircraft	Yes	No	No	Yes	Yes	No	No	No	No	No
South Waikato District	All zones other than Rural or	Yes	35 dB LAeq(24h)	No	Yes	No	No	No	No	No	No
Tararua District	Dairy processing	Yes	No	No	No	Yes	No	Yes 7.5 L/s per person	No	No	No
Tauranga City	Traffic Rail	Yes	40 dB LAeq(30s) in the largest habitable room 35 dB LAeq(30s) in all other habitable	1 m from diffuser	No	No	Yes	Yes 15 ACH (largest habitable room) 5 ACH (other habitable rooms)	No	No	Yes <10 Pa above ambient
Tauranga City	Port	Yes	45 dBA Ldn	No	No	Yes	Yes	Yes 5-10 ACH in habitable rooms	No	Yes Controlled within the	No
Upper Hutt City District	Traffic	Yes	No	No	No	No	Yes	7.5 L/s per person	No	No	No
Waikato District	Aircraft	Yes	30 dB LAeq sleeping areas (low) 35 dB LAeq sleeping areas (high) 35 dB LAeq habitable spaces (low) 40 dB LAeq habitable spaces (high)	1 m from diffuser	Yes	Yes	Yes	1 - 2 (low, sleeping areas, principal living rooms and habitable rooms) 15 (high, principal living rooms) 5 (high, other habitable spaces, sleeping areas)	Yes 12 degC heat on low. Minimum of 2 equal heating stages	Yes Low/high Individual on/off Controlled across range with 3+ stages	No
Waikato District	Nau Mai Business Park	Yes Caretakers dwelling	No	No	Yes	No	No	No	No	No	No
Waikato District	Rail	Yes	40 dB LAeq(30s) in the largest habitable room 35 dB LAeq(30s) in all other habitable rooms	1 m from diffuser	No	Yes	Yes	Yes 15 (largest habitable room) 5 (other habitable rooms)	No	Yes Controlled with 3+ stages to max	Yes <10 Pa above ambient
Waikato District	Industrial	Yes Caretakers dwelling	No	No	Yes	No	No	No	No	No	No
Waikato District	Aircraft	Yes	30 dB LAeq sleeping areas (low) 35 dB LAeq sleeping areas (high) 35 dB LAeq habitable spaces (low) 40 dB LAeq habitable spaces (high)	1 m from diffuser	Yes	Yes	Yes	No	No	No	No
Wellington City District	Aircraft	Yes	No	No	No	Yes	No	Yes 7.5 L/s per person	No	No	No
Wellington City District	Port	Yes	No	No	No	Yes	No	Yes 7.5 L/s per person	No	No	No

Council	Activity control applies to	Controls apply to new residential	Noise from system	Measurement location	NZBC/G4 referenced	Rule defines windows open /	Mechanical ventilation required	Other air changes (per hour)	Temperature control	Operational control	Internal air pressure
Wellington City District	Centres Zone, Business 1 Zone, Business 2 Zone, Curtis Street Business Area	Yes	No	No	No	Yes	No	Yes 7.5 L/s per person	No	No	No
Wellington City District	Central Area Zone	Yes	No	No	No	Yes	No	Yes 7.5 L/s per person	No	No	No
Wellington City District	Port	No	No	No	No	No	No	Yes 7.5 L/s per person	No	No	No
Western Bay of Plenty District	District wide	Yes	No	No	Yes	Yes	No	No	No	No	No
Western Bay of Plenty District	Post Harvest Zone	Yes	No	No	Yes	Yes	No	No	No	No	No
Western Bay of Plenty District	Within Post Harvest Zone	Yes	No	No	Yes	Yes	No	No	No	No	No
Western Bay of Plenty District	Tara Road Structure Plan	Yes	No	No	No	Yes	Yes	No	No	No	No
Western Bay of Plenty District	Within 200 m of Post Harvest Zone	Yes	No	No	Yes	Yes	No	No	No	No	No
Whakatane District	Rural Zone, Residential Zone	Yes	35 dB LAeq(30s) in bedrooms 40 dB LAeq(30s) in other habitable rooms, teaching spaces and office areas	No	No	Yes	No	Yes 6 ACH in habitable rooms (including bedrooms), teaching spaces, and general office areas	Yes Temperature no higher than 25 degrees Celsius	No	Yes <10 Pa above ambient
Whakatane District	Any zone other than Rural Zone or Residential Zone	Yes	35 dB LAeq(24h) in habitable rooms	No	Yes	No	No	No	No	No	No
Whakatane District	Aircraft	Yes	35 dB LAeq(30s) in habitable rooms	1 m from diffuser	Yes	No	No	No	No	No	No
Whakatane District	Dairy processing	Yes	35 dB LAeq(30s) in habitable rooms	1 m from diffuser	Yes	No	No	No	No	No	No
Whakatane District	Rail	Yes	35 dB LAeq(30s) in habitable rooms	1 m from diffuser	Yes	No	No	No	No	No	No
Whakatane District	Geothermal	Yes	35 dB LAeq(30s) in habitable rooms	1 m from diffuser	Yes	No	No	No	No	No	No
Whanganui District	Rail Traffic Commercial	Yes	35 dB LAeq(30s)	1 m from grille or diffuser	Yes	Yes	No	6 ACH	No	Yes Incremental control to max	No
Whangarei District	Business Town Basin Rural Village Centre	Yes	No	No	Yes	Yes	No	No	No	No	No