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Background

This paper provides an introduction to issues of temperature and humidity as they relate to healthy homes. It starts with a brief background to our understanding of 'air', and then introduces the Psychrometric Chart as a mechanism to aid understanding of the inter-relationship of temperature and relative humidity. Research results from the measurements of the relative humidity at carpet level can then be interpreted in terms of the moisture carried in the air.

The requirements of the New Zealand Building Code (NZBC) pertaining to health and moisture prevention in houses, hot water and energy efficiency are then briefly outlined. These are **Clause E3 Internal Moisture**; **Clause G12 Water Supplies**; **Clause G5 Interior Environment**; and **Clause H1 Energy Efficiency**.

Air – A Learning Experience

"We must begin by taking note of the countries and climates in which homes are to be built if our designs for them are to be correct." "The town being fortified, the next step is the apportionment of house lots within the wall and the laying out of streets and alleys with regard to climatic conditions. They will be properly laid out if foresight is employed to exclude the winds from the alleys. Cold winds are disagreeable, hot winds enervating, moist winds unhealthy."

Table 1: Guidance of the ancients - Vitruvius

Vitruvius, writing his 'Ten Books On Architecture' in the 1st century B.C. summarized his experiences and the knowledge of earlier generations of builders and architects (Table 1)[1]. Even today his approach provides guidance, but the difference is that we better understand the reasoning behind his recommendations.

Nature	Humans
Fire	Blood
Air	Yellow Bile (Liver) (until 18th cent 'choler')
Water	Phlegm
Earth	Black Bile (Spleen) (Cause of melancholy)

Table 2: Ancient Greece's links between nature and humans

Vitruvius was building on the knowledge of the first scientists to attempt to understand the linkages between humans and nature. Empedocles and Hippocrates (Greek c 460 BC) could link the natural world around them to the human body. Unable to deal with microscopic or atomic size issues, they believed that the air was a homogeneous material that could be either 'good' or 'bad'.

It was not until Boyle's 1650s research into air temperature & air density that it was realised that the density of air changed with temperature, and over a hundred years later than Joseph Priestly (1780's) identified that part of the air was required to sustain life. Around the same time Antoine Lavoisier's (1780s) experiments with heating lead discovered oxygen. (Unfortunately the French Revolution decided 'the Republic has no need of savants' and cut short the life of this scientist (1794)). Over the next hundred years the research of English and Irish scientists lead to the understanding that air was not just a mixture of gases, but also included water vapour. However it was not until the turn of the 20th century that Willis Carrier (USA) brought this knowledge together in a graphic form with his 'Hygrometric Chart' (1906), now called the 'Psychrometric Chart'.

Psychrometric Chart

The Psychrometric Chart brings together the relationship between the air temperature, the relative humidity and the amount of moisture contained in the air. It is constructed around two measurements – the Dry Bulb Temperature (DBT) and Wet Bulb Temperature (WBT).

Figure 1: Whirling Hygrometer

The terms 'dry' and 'wet' refer to the state of the thermometer bulb from which the temperature measurements are made. The measurements are traditionally made with a whirling hygrometer, as shown in Figure 1, although more modern electronic instruments are now available.

The top thermometer bulb is left exposed to the air, while the lower bulb is encased in a damp cloth wick (feeding from a water reservoir) which ensures an even coverage of the bulb. The dry bulb measures the air temperature, while the wet bulb records the lowest temperature to which the air can be cooled by evaporation. These two readings can be converted to the Relative Humidity (RH) or the absolute amount of moisture in the air (Humidity Ratio) by the use of a special purpose nomograph or the Psychrometric Chart.

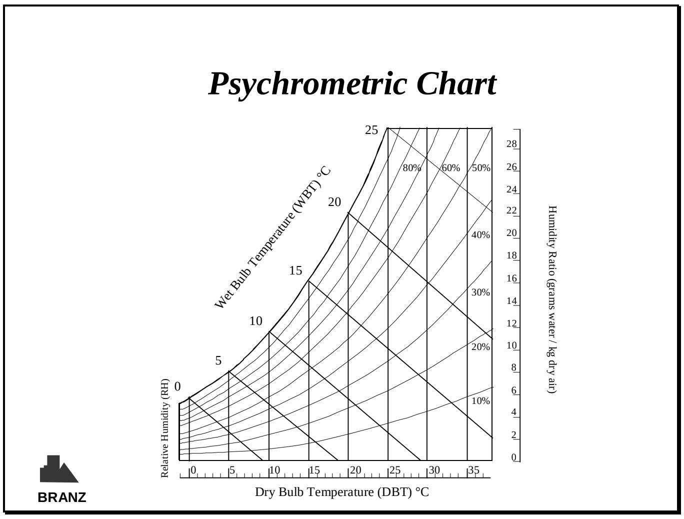

Figure 2: Psychrometric Chart

Figure 2 provides a sketch of a Psychrometric Chart. A formal chart would include far more detail, providing lines for each degree of temperature and each percent of relative humidity.

The chart is used by plotting two of the measurements and reading the other two (WBT, DBT, RH or Humidity Ratio). The DBT is plotted vertically from the lower scale, the WBT is plotted at the angled markers from the upper curved scale, the RH from the vertical left-hand scale, and the Humidity Ratio from the vertical right-hand scale.

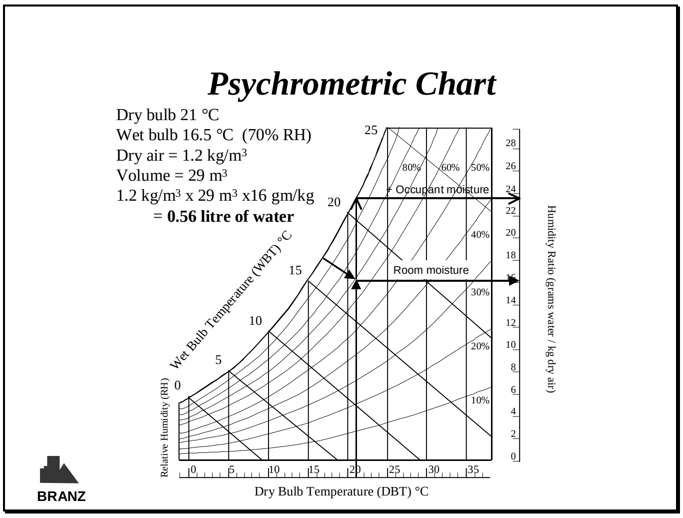

Figure 3: Psychrometric Chart - example

Figure 3 provides an example of the use of the Psychrometric Chart. For a bedroom the Dry Bulb Temperature is 21°C and the Wet Bulb Temperature 16.5°C . The curved Relative Humidity lines give a 70% RH, and taking this across to the vertical Humidity Ratio scale shows that the air contains 16 grams of water per kilogram of dry air.

At normal room conditions, air weighs 1.2 kg per cubic metre. The bedroom is 4m long by 3m wide by 2.4m high, to give a total enclosed volume of 29 m^3. Thus the room contains 0.56 kg (or 0.56 litres) of water. However in addition to the moisture naturally in the air, a considerable amount more moisture is added by people and their activities.

Moisture Source	Rate
Unflued LPG or Natural Gas heaters	0.3 to 0.6 kg/hr
Cooking	2 kg/day electric cooker 3 kg/day gas cooker
Bathing (showers, baths, hand washing)	200 gm/day/person
Clothes drying (unvented)	1 to 1.5 kg/person/day
Indoor plants, heated fish tanks	0 to a lot per day
Humans	40 gm/hour sleeping, 55 gm/hour active

Table 3: Domestic Moisture Sources (BS 5925)

Table 3 lists the amount of moisture that different activities can add to the house[2]. Unflued natural gas or LPG heaters create water as a by-product of combustion, and can add considerably to the moisture load of the house. The law requires that unflued gas heaters must not be used in bedrooms[3]. Cooking not only drives water into the air from the food being cooked, but in the case of a gas cooker the water from the gas combustion must also be taken into account. Bathing and washing can provide large amounts of water vapour, and hence increase the water load in the air, as can clothes drying, particularly with an unvented dryer. Externally vented dryers and gas heaters provide little additional moisture load.

In the bedroom there are two people in bed, reading, watching TV, or sleeping. Over the nine hours of night they will add 0.72 litres of moisture to the room air (2 people x 9 hour (rest + sleep) x 40 g/hr = 0.72 kg), so by morning the air could have up to 1.3 litres of water. Figure 3 shows that if all this water remained in the air, then the Humidity Ratio would be 38 g/kg (1.3 kg water / 34.8 kg air). However, the Psychrometric Chart shows that at 20°C the air can only hold 23 g/kg, so the rest (15 g/kg x 34.8 kg = 0.52 litre water) must condense out on something or be extracted by ventilation. If there are no windows open, or mechanical ventilation provided, then this water will condense (form dew) on the nearest cold surface – most likely the window. Clothes, room linings, framing and furnishings act as a buffer – absorbing moisture during the cool, damp night, and releasing it during the warm day.

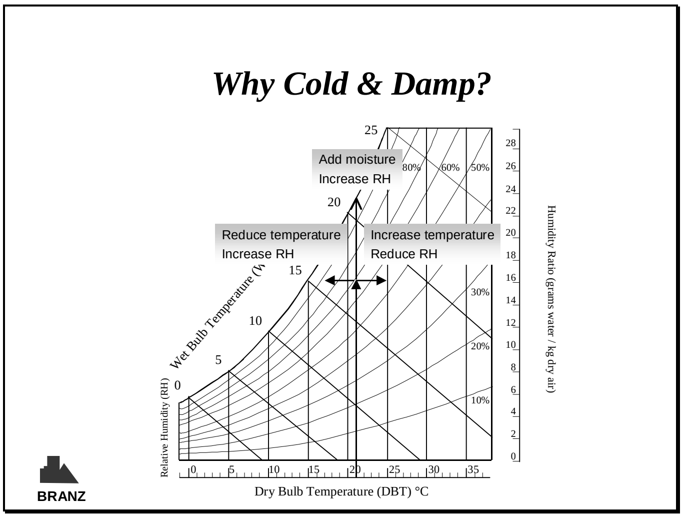

Figure 4: RH and Changing Temperatures

Figure 4 illustrates how temperature impacts on the RH. If the amount of moisture (Humidity Ratio) in the air does not change, then:

- **increasing** temperature (shifting to the right on the DBT scale) will **reduce** the RH; while
- **decreasing** the temperature will **increase** the RH.

If the amount of moisture in the air is increased (by people or their activities), then the RH will increase until the air can hold no more water (100% RH), and then the water will condense on the coldest surface available.

Bioclimatic Chart

For those who have lived in or visited a hot, humid place it will come as no surprise to find that most people are uncomfortable in hot humid environments. Research has shown that hygrothermal comfort varies with culture, the individual, their physical condition and their psychological expectation. Just as importantly, comfort is not a precise measurement (± little).

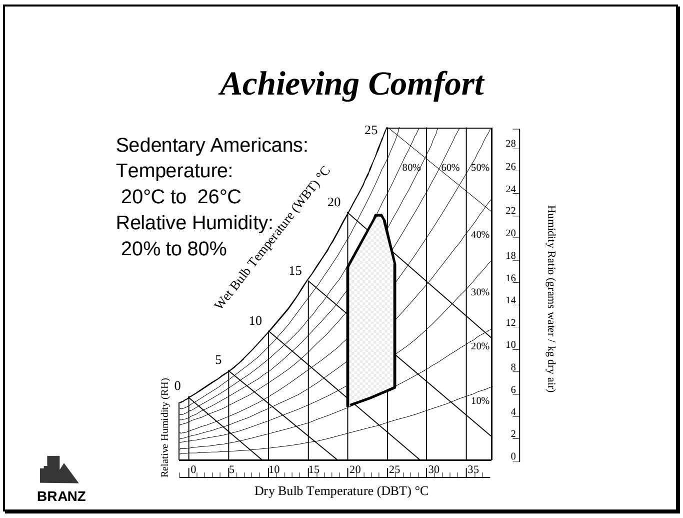

Figure 5: Bioclimatic Chart

Figure 5 shows the bioclimatic comfort zone based on measurements and experiments with sedentary Americans wearing a standard unit of clothing. The temperature range is from 20°C to 26°C with a RH between 20% to 80%.[4]

It is highly likely that different cultures will have different temperature and humidity comfort zones, but the 'Bioclimatic Chart' provides one form of guidance.

Collins has suggested that the four dwelling temperature zones given in Table 4 are significant for human health.

Temperature	Issue
18 °C to 24 °C	Comfort zone
16 °C	Increasing risk of respiratory diseases
12 °C	Cardiovascular strain due to cold
6 °C	Failing thermoregulation and risk of hypothermia

Table 4: Temperature Zones for Human Health

The BRANZ Household Energy End-Use Project is currently collecting information on energy use and temperatures in New Zealand homes, but to-date has only a small sample (under 100 houses), so it is not possible to draw statistically valid conclusions[5]. The analysis thus far suggests that a significant number of houses are not maintained above 16 °C for a significant period of the winter days.

Dust Mite Comfort

There is currently considerable research being carried out in New Zealand and overseas to better understand the linkages between asthma, dust mites and housing. Research being undertaken at BRANZ by Dr Malcolm Cunningham is investigating the environments within which dust mites actually live[6]. Purpose designed, humidity micro-sensors have been developed to permit the measurement of Relative Humidity within carpets.

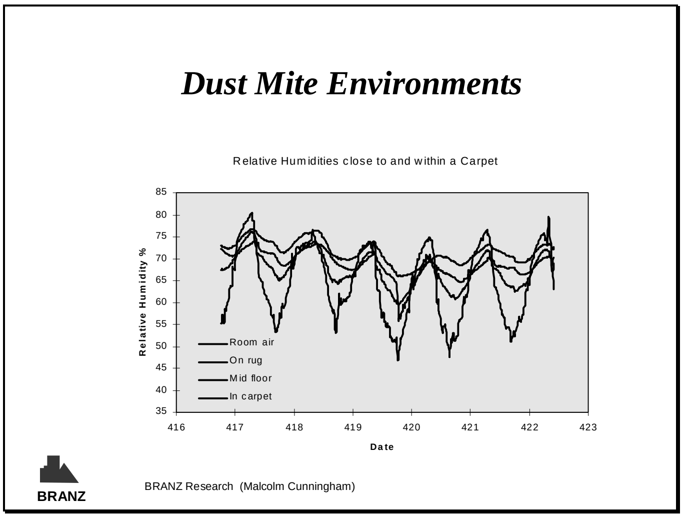

Figure 6: Dust Mite Environments

Figure 6 is taken from this work. It shows that the room air Relative Humidity closely follows the diurnal cycle – lower RH during the warmer day and higher RH during the cooler night – but with large swings.

The RH within and on the carpet also follows the diurnal cycle, but with smaller swings, and a higher average – the carpet RH ranges from 65% to 75% over the six days shown in the graph, while the room RH swings from 45% to 80%. As dust mites are in the carpet they will experience a high RH, which for them is more comfortable. Room dehumidification may not be the complete answer to controlling carpet RH. Current research is also examining the effects of warmer floor surfaces. These can be achieved by under-floor heating or under-floor thermal insulation slowing down the escape of room heat.

Airtightness

Ventilation is essential to our very existence – inadequate removal of the pollutants created by ourselves, other humans, appliances, equipment, furnishings and the building itself can be hazardous to health. Those who experienced growing up in, or live today in, cold, draughty houses may feel that there is only one solution – cut out the draughts.

However measurements of the airtightness of New Zealand houses, shown in Figure 7, have found that while older houses do have excessive ventilation, newer houses are far more airtight and likely to be short of ventilation unless windows are opened[7].

This shift appears to be largely due to a change in construction materials and fittings. This includes the shift from 'strip' materials such as tongue and groove flooring to one-piece particleboard flooring and on the walls to sheets of plasterboard, and the introduction of tightly fitting aluminium framed windows.

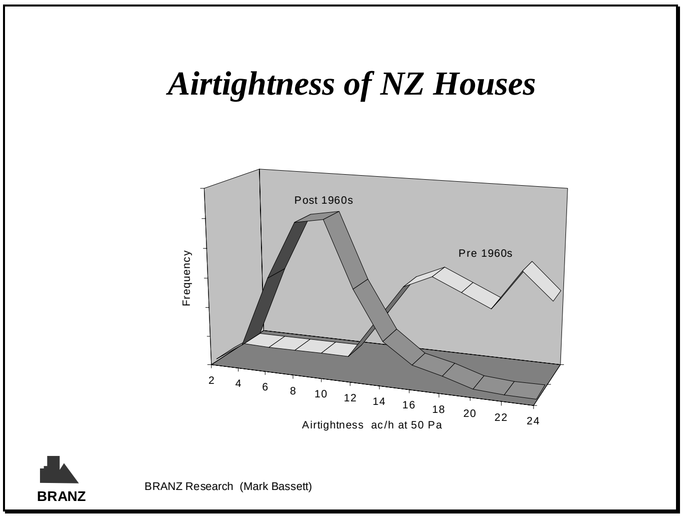

Figure 7: Airtightness of New Zealand Houses

Measurements have also found that 'simple' houses (e.g. single storey with simple roof line) are likely to be far more air tight than complex houses (e.g. two storey with dormer windows cutting the roof line).

It is important that modern, relatively airtight houses do not have all ventilation removed. An option is to seal gaps around doors, windows, etc and replace at least part of that ventilation with controllable passive vents mounted in the windows.

New Zealand Building Code

Human beings exist in a continuum of health – from a state of perfect health ('alive') to perfect non-health ('dead').

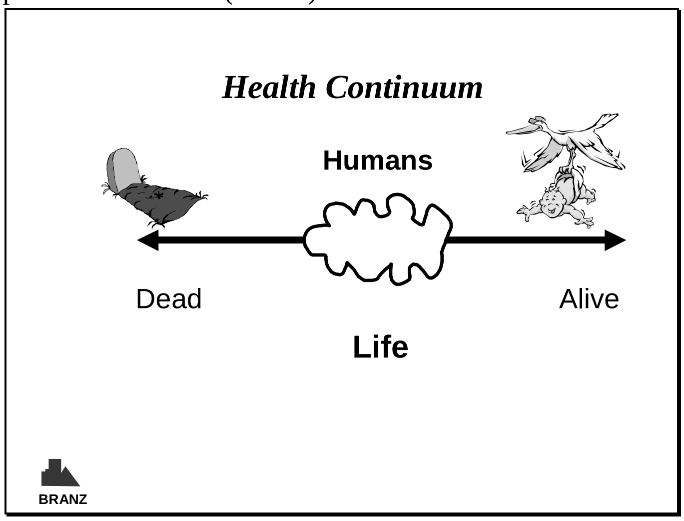

Figure 8: Health Continuum

Figure 8 illustrates the reality that the majority of us are in a broad area between the two extremes. The buildings we spend a large proportion of our time working, living, sleeping and just being inside play an important role in supporting the current state of our health. The aim of the New Zealand building controls is to provide 'safe' conditions to maintain our health, but as a minimum – neither improving it or making it worse.

The Building Act 1991[8] brought together in one piece of national legislation all requirements for buildings. The Building Act created the Building Industry Authority, and charged it with creating only necessary building controls that would ensure that building occupants had buildings that are safe, sanitary & provide means of escape from fire. The controls must co-ordinate with other controls so as not to increase without reason the cost of compliance. In achieving these requirements, the BIA must pay particular regard to safeguarding occupants from injury, illness or loss of amenity, fire, providing protection of other property, ensuring disabled access and the efficient use of energy.

The BIA has achieved this through the 'New Zealand Building Code' (NZBC), which is actually a set of regulations[9] made under the Building Act 1991. The 35 Clauses of the NZBC deal with aspects of building design and construction that are deemed to be of such importance as to require specific legislation. Aside from the clauses providing definitions or assisting with interpretation, each clause provides a social objective, a requirement that sets out the functions required to achieve that objective and an appropriate performance statement(s). Whilst the NZBC contains the mandatory provisions for meeting the purposes of the Act, it is performance-based – that is it says only what is to be achieved, not how to do it.

The full set of NZBC clauses is a comparatively small document (approximately 50 pages) and written as far as possible in non-technical language. It is implemented through Approved Documents, which set out one or more Acceptable Solutions (do it this way, and you have met the requirements of the NZBC); and Verification Methods (this is how you verify you have achieved the performance required by this clause). The Approved Documents are (non-mandatory) documents written by the Building Industry Authority to assist people in complying with the NZ Building Code.

There are four NZBC performance clauses relevant to the topic covered by this paper:

- **Clause E3** Internal Moisture
- **Clause G12** Water Supplies
- **Clause G5** Interior Environment
- **Clause H1** Energy Efficiency

Clause E3 Internal Moisture

Clause E3 deals with issues of moisture within a building, whether liquid (running water) or gas (airborne moisture). Table 5 provides the text of Clause E3.

OBJECTIVE	E3.1 The objective of this provision is to: (a) Safeguard people against illness or injury which could result from accumulation of internal moisture, and (b) Protect household units from damage caused by free water from another occupancy in the same building.
FUNCTIONAL REQUIREMENT	E3.2 Buildings shall be constructed to avoid the likelihood of: (a) Fungal growth or the accumulation of contaminants on linings and other building elements, (b) Free water overflow penetrating to an adjoining household unit, and (c) Damage to building elements being caused by use of water.
PERFORMANCE	E3.3.1 An adequate combination of thermal resistance and ventilation shall be provided to all habitable spaces, bathrooms, laundries, and other spaces where moisture may be generated. E3.3.2 Accidental overflow from sanitary fixtures or laundering facilities shall be constrained from penetrating to another occupancy in the same building. E3.3.3 Floor surfaces of any space containing sanitary fixtures or laundering facilities shall be impervious and easily cleaned. E3.3.4 Wall surfaces adjacent to sanitary fixtures or laundering facilities shall be impervious and easily cleaned. E3.3.5 Surfaces of building elements likely to be splashed or become contaminated in the course of the intended use of the building shall be impervious and easily cleaned. E3.3.6 Water splash shall be prevented from penetrating behind linings or to concealed spaces.

Table 5: Clause E3 Internal Moisture

Performance E3.3.1 requires adequate (defined as "Adequate to achieve the objectives of the Building Code") levels of thermal insulation in locations where moisture may be generated. This is to ensure these surfaces are warm, and hence minimise condensation and the opportunity for unhealthy mould growth.

Clause G12 Water Supplies

Clause G12 deals with issues of water supply within a building. Table 6 provides the text of Clause G12, but note that limitations are not given in this extract.

OBJECTIVE	G12.1: The objective of this provision is to: (a) Safeguard people from illness caused by infection from contaminated water or food, (b) Safeguard people from injury due to the explosion of a pressure vessel or from contact with excessively hot water, (c) Safeguard people from loss of amenity arising from a lack of hot water for personal hygiene, or from a water supply which is offensive in appearance or odour, and (d) Ensure that people with disabilities are able to carry out normal activities and functions within buildings.
FUNCTIONAL REQUIREMENT	G12.2: Buildings, provided with drinking water outlets, sanitary fixtures or sanitary appliances, shall have a safe and adequate piped water supply.
PERFORMANCE	G12.3.1: Piped water supplies intended for human consumption, food preparation, utensil washing or oral hygiene shall be potable. G12.3.2 : Piped water supply and outlets provided with non-potable water shall be clearly identified. G12.3.3 : Sanitary fixtures and sanitary appliances shall be provided with hot water when intended to be used for: (a) Utensil washing, and (b) Personal washing, showering or bathing. G12.3.4 : Where hot water is provided to sanitary fixtures and sanitary appliances, used for personal hygiene, it shall be delivered at a temperature which avoids the likelihood of scalding. G12.3.5 : Water supply systems shall be installed in a manner which: (a) Avoids the likelihood of potable water contamination within both the system and the water main, (b) Provides water to sanitary fixtures and sanitary appliances at flow rates which are adequate for the correct functioning of those fixtures and appliances under normal conditions, (c) Avoids the likelihood of leakage, (d) Allows reasonable access for maintenance of mechanical components, and (e) Allows the system and any backflow prevention devices to be isolated for testing and maintenance. G12.3.6 : Vessels used for producing or storing hot water shall be provided with safety devices which: (a) Relieve excessive pressure during both normal and abnormal conditions, and (b) Limit temperatures to avoid the likelihood of flash steam production in the event of rupture. G12.3.7 : Storage water heaters shall be capable of being controlled to produce, at the outlet of the storage water heater, an adequate daily water temperature to prevent the growth of Legionella bacteria. G12.3.8 : Water supply taps shall be accessible and usable for people with disabilities.

Table 6: Clause G12 Water Supplies

The specific health issues of interest in this paper are dealt with in performance statements G12.3.4, which requires hot water to be below scalding temperature, and G12.3.7, which requires that the hot water storage not be permitted to drop below the temperature at which Legionella bacteria can survive. The BIA commissioned research found Legionella bacteria in around 10% of houses, although no live bacteria were found in the hot water cylinders[10].

Table 7 provides an extract from Acceptable Solution G12/AS1, which in G12/AS1 4.13.2 sets maximum hot water delivery temperatures of 45 °C in early childhood centres, schools and old people's homes and 55 °C for all other buildings. G12/AS1 4.13.3 sets a minimum storage temperature of 60 °C to deal with Legionella. In order to meet these two different requirements, a tempering valve will be required in houses with storage hot water cylinders.

Instantaneous hot water systems must incorporate a mechanism to ensure that the water temperature does not exceed either 45 °C or 55 °C as appropriate.

4.13 Safe water temperatures	
4.13.1 Maximum temperatures	The delivered hot water temperature at any sanitary fixture used for personal hygiene shall not exceed: a) 45°C for early childhood centres, schools and old people's homes, and b) 55°C for all other buildings. *Comment:* *1 At greatest risk from scalding are children, the elderly, and people with physical or intellectual disabilities, particularly those in institutional care.* *2 Sanitary fixtures used for personal hygiene include showers, baths, hand basins and bidets.*
4.13.3 Legionella `bacteria	Irrespective of whether a mixing device is installed, the storage water heater control thermostat shall be capable of being set at a temperature of not less than 60°C to prevent the growth of Legionella bacteria.

Table 7: G12/AS1 Safe Water Temperatures

As noted earlier, the Acceptable Solution is not mandatory, and if a suitable alternative method can be found to ensure the performance requirements are meet, then this is likely to be acceptable to the relevant local authority or the Building Industry Authority.

Clause G5 Interior Environment

Clause G5 deals with the interior environment within a building. Its text is given in Table 8.

OBJECTIVE	G5.1: The objective of this provision is to: (a) Safeguard people from illness caused by low air temperature, (b) Safeguard people from injury or loss of amenity caused by inadequate activity space, (c) Safeguard people from injury caused by unsafe installations, and (d) Ensure that people with disabilities are able to carry out normal activities and processes within buildings.
FUNCTIONAL REQUIREMENT	G5.2.1: Buildings shall be constructed to provide: (a) An adequate, controlled interior temperature, (b) Adequate activity space for the intended use, and (c) Accessible spaces and facilities. G5.2.2: Heating appliances in buildings shall be installed in a way that reduces the likelihood of injury. Requirement G5.2.1(a) shall apply only to habitable spaces, bathrooms and recreation rooms in old people's homes and early childhood centres.
PERFORMANCE	G5.3.1: Habitable spaces, bathrooms and recreation rooms shall have provision for maintaining the internal temperature at no less than 16°C measured at 750 mm above floor level, while the space is adequately ventilated. Performance G5.3.1 shall apply only to old people's homes and early childhood centres. G5.3.2: Heating appliances, and any attached cables, pipes or other fittings shall be securely fixed in place. G5.3.3: Habitable spaces shall have sufficient space for activity, furniture, and sanitary and mobility aids. G5.3.4: Where reception counters or desks are provided for public use, at least one counter or desk shall be accessible. G5.3.5: Buildings shall be provided with listening systems which enable enhanced hearing by people with hearing aids. G5.3.6: Enhanced listening systems shall be identified by signs complying with Clause F8 'Signs'.

Table 8: Clause G5 Interior Environment

Functional Requirements G5.2.1 and G5.2.2 are only applicable to habitable spaces, bathrooms and recreation rooms in old people's homes and early childhood centres.

Clause G5 does not imply that other buildings, notably houses, do not require safe heating appliances or the ability to achieve an acceptably comfortable temperature. Rather the NZBC sets out that these uses are special and therefore require specific controls, while providing the freedom to the owner or occupier of other building types to achieve a suitable comfort level with appropriate heating appliances.

Clause H1 Energy Efficiency

Clause H1 deals with issues of energy efficiency within a building. Table 9 provides the text of Clause H1.

OBJECTIVE	H1.1: The objective of this provision is to facilitate efficient use of energy.
FUNCTIONAL REQUIREMENT	H1.2: Buildings, throughout their lives, shall have provision for ensuring efficient energy use in controlling indoor temperature when that energy is sourced from a public electricity supply, or any other depletable energy resource.
PERFORMANCE	H1.3.1: The building envelope shall be constructed to ensure that the building performance index shall not exceed 0.13 kWh. (Performance H1.3.1 applies only to Housing.) H1.3.2: Where any space within a building is intended to have a controlled temperature, construction of building elements affecting energy use shall take account of: (a) Thermal resistance to heat loss through the building envelope, (b) Heat gains (including solar radiation) through the building envelope, (c) Airtightness, (d) The contribution to space heating of heat losses from building services (including hot water systems, and lighting), (e) Control systems for heating and ventilating, and for other services, and (f) Utilisation of waste heat from internal processes. (Performance H1.3.2 shall not apply to Housing, Outbuildings, Ancillary buildings, or buildings with a floor area of less than 50 m².)

Table 9: Clause H1 Energy Efficiency

Under the current Clause H1 only issues of space heating are considered, and thus only thermal insulation in the building envelope. However, approximately one third of an average household energy is used for space heating, one third is used for water heating and one third for all other uses. The current Clause H1 deals only with the third used for space heating, so the energy used for water heating (including the storage cylinder and distribution network) will be included in the future.

The new Standards to be used with the Acceptable Solution for the proposed Clause H1 are now available for use, and although in excess of the current requirements may be used in place of the current standards [11].

Summary of NZBC Requirements

Table 10 provides a brief summary of the various Acceptable Solutions discussed in this paper.

NZBC Clause	Acceptable Solution
E3 Internal Moisture	• Thermal insulation to control condensation & mould
G12 Water Supplies	• Maximum temperature at tap under 55°C (scalding) • Storage temperature over 60°C (legionella)
G5 Interior Environment	• Ability to provide a minimum of 16°C ONLY old people & child care (thermal insulation and space heating)
H1 Energy Efficiency	• Now: Envelope thermal insulation (roof, wall & floor) • Future: Envelope thermal insulation and hot water storage cylinder and pipe insulation

Table 10: Summary of Relevant NZBC Requirements

Acknowledgement

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Further Information

Additional information on the New Zealand Building Code is available from:
Building Industry Authority, PO Box 11846, Wellington.
Telephone: (04) 4710 794, Toll-free: 0800 242 243 Facsimile: (04) 4710 798
Web: http://www.bia.co.nz/index.htm

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Bishop S., Camilleri M., Dickinson S., Fitzgerald G., Isaacs N., James B., Jowett J., Pollard A., Pool F., Ryan G., Sanders I., Stoecklein A., 1998. **Energy Use in New Zealand Households: Report on the Household Energy End Use Project (HEEP) - Year 2** Wellington: Energy Efficiency & Conservation Authority (EECA)

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[7] Bassett M.R. 1992 *Ventilation trends in New Zealand housing* Paper to **PHA Conference**, Lincoln. BRANZ Conference Paper 17

[8] **The Building Act 1991 and Amendments** Wellington: Government Printer

[9] **The Building Regulations 1992 and Amendments**. Wellington: Government Printer

[10] Building Industry Authority 1998 **Legionella in Hot Water** BIA News No 86, November 1998

[11] New Zealand Standards used in the Acceptable Solution for the proposed NZBC Clause H1
Houses or <300 m²: **NZS 4218:1996 Energy Efficiency Housing and Small Building Envelope**
>300 m²: **NZS 4243:1996 Energy Efficiency Large Buildings**
Hot water: **NZS 4305:1996 Energy Efficiency Domestic Type Hot Water Systems**
Wellington: Standards New Zealand