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Home is where the health is: New Zealand responses to a "healthy" housing crisis

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ABSTRACT

It is accepted in both popular culture and the academic literature that 'cold and damp' housing leads to poor health outcomes for occupants. Many solutions have been proposed to remedy this from voluntary healthy home checklists, green building ratings tools to mandatory government legislation. This study reviews the responses comparing the different mechanisms and drawing conclusions about the potential effectiveness of each. While each approach has admirable aims flaws are identified with the design and application. These include a static assessment methodology (one off inspection), a reliance on simplified checklists and prescriptive interventions and a focus on cold and damp with no counterbalancing consideration of overheating in a climate of recognised global warming. The Healthy Home Standards are identified as the most flawed approach containing multiple exemptions that can be exploited to avoid compliance. Homestar is recognised as the most comprehensive and detailed mechanism currently available to provide healthy housing in NZ.

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Introduction

It is frequently claimed that housing quality, most especially indoor environment quality, affects occupant health with cold and damp homes postulated as a key cause of illness in many publications (Ingham et al., 2019; Keall et al., 2012; Telfar-Barnard et al., 2019) and in the popular media (Donnel, 2018; Miller, 2017; Watson, 2019). In New Zealand proposed inventions for sub quality housing range from government legislation such as the Residential Tenancies (Healthy Homes Standards) Regulations 2019 to voluntary undertakings like a rental housing Warrant of Fitness (WOF) and green building rating tools like HomeFit and Homestar. However, the efficacy of these mechanisms has not been reviewed to date. This study reviews the different responses to the issue subpar housing in New Zealand, comparing the different mechanisms and drawing conclusions on the effectiveness of each mechanism.

Literature review

Poor quality (cold, damp, mouldy and unsafe) New Zealand housing stock is strongly correlated with poor health (Ingham et al., 2019; Keall et al., 2012; Telfar-Barnard et al.,

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2019). According to Telfar-Barnard et al. (2019) two-thirds of New Zealand housing stock is uninsulated and inadequately heated which is linked to higher respiratory-illness hospital admission rates in winter (74%) and excess winter mortality. This can be further exacerbated by poverty, with a quarter of New Zealand households estimated to be in fuel poverty (Howden-Chapman et al., 2012) with linkages to fuel poverty and New Zealand's high rate of excess winter mortality and hospitalisations (Howden-Chapman et al., 2008, 2009, 2012). Unaffordable and/or poor-quality housing is also linked to mental health conditions such as depression and anxiety (Baker, Lester, Bentley, & Beer, 2016; Baker, Lester, Mason, & Bentley, 2020; Paterson, Iusitini, Tautolo, Taylor, & Clougherty, 2018; Rollings, Wells, Evans, Bednarz, & Yang, 2017; Singh, Daniel, Baker, & Bentley, 2019; Suglia, Duarte, & Sandel, 2011). Building indoor environment quality (IEQ) is comprised of four key metrics; thermal comfort, visual comfort, aural comfort and indoor air quality with thermal comfort further delineated by temperature, humidity and ventilation (Al Horr et al., 2016).

Temperature

In 2018, the World Health Organisation (WHO) published a report titled *Housing and Health Guidelines* recommending a healthy temperature range for housing of 18°C to 24°C however a recent review of the literature found little evidential basis for this temperature range (Ade & Rehm, 2019b) with the WHO itself stating there is only a moderate linkage between a minimum temperature of 18°C and improved health outcomes. This is supported by Howden-Chapman et al.'s (2007) study which documents significant improvements in self-rated health, wheezing and absenteeism from school/work, despite only an increase in mean temperatures from 13.6°C to 14.2°C in houses retrofitted with ceiling and floor insulation. However this study does not provide any definitive conclusions on the cause of the self-reported health improvements unable to link it to increased temperature, improved thermal comfort or reduced damp/mould. Indeed whilst self-reported health improved difference in visits to general practitioners and hospitals were not statistically significant. In addition key pieces of structural building information are not disclosed in this highly cited study. The orientation, height, size, type, presence of mechanical ventilation/extracts and/or occupancy levels of the dwellings are not disclosed. Key elements of occupant behaviour, such as operation of windows etc., were not recorded and of particular concern is the fact that the vintage of the dwellings is not disclosed. Different decades have utilised different construction techniques (i.e. solid brick, weatherboard cladding) and differences in thermal mass could result in different indoor environment qualities in dwellings, despite all being uninsulated. It is possible that some or all of these factors could have affected the results of this pivotal study. Whilst likely not represented in the sample studied research by Howden-Chapman et al. (2007) the type of dwelling can also affect the temperature with Langer and Bekö (2013) finding the mean indoor temperature to be slightly lower in Swedish single-family houses than in apartments (21.4°C vs. 22.5°C). They discuss the potential for this to be caused by building characteristics (e.g. less exposed façades, sharing internal walls in case of apartments) but also consider the potential of occupant heating set-points, but do not reach any definitive conclusions. They also find the mean relative humidity to be higher in the single-family houses compared to the apartments (34% vs. 31%), however this can be likely attributed to the aforementioned difference in temperature.

Humidity/Dampness

Dampness can be a function of humidity as is often linked in the literature with research papers titled "*Damp housing and childhood asthma; respiratory effects of indoor air temperature and relative humidity*" (Strachan & Sanders, 1989) or statements like "*Damp or humid indoor air encourages mould growth*" common (Agyekum, Salgin, & Danso, 2017). No guidance is provided by the WHO or academic literature on an acceptable threshold of humidity or dampness, other than a recommendation that dampness and mould be prevented. Previous studies have linked damp housing with adverse health outcomes; however, none determines a threshold that causes ill health (Howden-Chapman et al., 2007; Rangiwhetu, Pierse, Viggers, & Howden-Chapman, 2018; Telfar-Barnard et al., 2017; Telfar Barnard, Howden-Chapman, Clarke, & Ludolph, 2018; Venn et al., 2003; Watson, 2019; World Health Organization, 2018). As noted by Howden Chapman "*it is not possible to define a damp building in health relevant terms, or to specify which agents in damp buildings have detrimental effects on health.*" (Howden-Chapman et al., 2007). The 2018 WHO report thus concludes that relationships between dampness, microbial exposure and health effects cannot be quantified precisely, so no quantitative health-based guideline values or thresholds can be recommended for acceptable levels of contamination with microorganisms.

Green building certification is frequently postulated as a solution to damp housing with statements like "*Homestar means warmer, drier homes*"(New Zealand Green Building Council, 2019). Internationally researchers have found that green certified homes had fewer indicators of mould and damp (Bonde & Ramirez, 2015; Colton et al., 2015, 2014) however none of these studies have differentiated between newly constructed green certified and conventional dwellings and older vintage dwellings. For instance Colton et al. (2014) compared newly constructed LEED-certified apartments to apartments from the 1940/50s. Similar to Howden-Chapman et al. (2007) Colton et al. (2014) disclose minimal structural information on the buildings studied with no analysis undertaken on height above ground, orientation, mechanical ventilation, occupant behaviour etc.

Ventilation

In terms of ventilation there exists a delicate balance between green building considerations like energy efficiency and indoor environment quality with improved airtightness frequently proposed as an effective way to reduce energy consumption of buildings. However improving building airtightness, particularly in existing buildings that have historically relied on infiltration for air changes, can result in insufficient ventilation rates which may in turn lead to poor indoor air quality, increased risk of condensation and reduced occupant comfort, risk (Hashemi & Khatami, 2015; Leardini & de Groot, 2010; Leardini, Rosemeier, & Ong, 2012). The extant literature is conflicted on this topic with some studies finding that increasing airtightness in new buildings does not degrade indoor air quality (Staepels, Verbeeck, Roels, Van Gelder, & Bauwens, 2013) whilst others determined that increasing airtightness, whilst improving energy efficiency, considerably increases the risk of poor indoor air quality (Hobday, 2011). Some researchers discuss poor ventilation as constructive faults of mandatory or voluntary green building codes that prioritise energy efficiency measures (such as increased airtightness) without subsequent increases in mechanical ventilation dwellings (Sundell, Wickman, Pershagen, & Nordvall, 1995; Van Strien, Verhoeff, Brunekreef, & Van Wijnen, 1994).

Spaces that have high CO_2 are often viewed as having poor ventilation with a general acceptance in the literature that levels above CO_2 1000 ppm are indicative of poor air quality (Satish et al., 2012). Although the established threshold for indoor air concentrations of CO_2 is 1000ppm this relates predominately to human comfort, as toxicity typically only occurs at thresholds twentyfold (Rosemeier, 2014). However researchers like Satish et al. (2012) have also determined that CO_2 itself may be a pollutant, rather than just an indicator of ventilation rates with Strøm-Tejsen, Zukowska, Wargocki, and Wyon (2016) determining that sleep quality and subsequent ability to concentrate and performance the following day were impaired at higher CO_2 levels. In bedrooms where windows were kept closed the CO_2 levels ranged from 1730ppm to 3900ppm while in the bedrooms where windows were kept open the CO_2 levels were underneath the 1000ppm threshold ranging from 525ppm to 840ppm. These findings are corroborated by Mishra, van Ruitenbeek, Loomans, and Kort (2018) who also found that lower CO_2 levels resulted in better (self-reported) sleep depth, sleep efficiency, and lesser number of awakenings.

Air quality

In buildings volatile organic compounds (VOCs) are frequently implicated as a cause of poor air quality and sick building syndrome (Ghaffarianhoseini et al., 2018; Kraus & Šenitková, 2017) with the concept of total volatile organic compounds (TVOCs) frequently utilised. Several studies have been completed on indoor air quality (and sick building syndrome) with green building often postulated and studied as a mechanism for enhancing the health status of occupants through improved indoor air quality (Ghaffarianhoseini et al., 2018; MacNaughton et al., 2016; Steinemann, Wargocki, & Rismanchi, 2017; Thatcher & Milner, 2016). However there is a concern that whilst green buildings promote energy efficiency and other aspects of sustainability they may not necessarily improve the health and well-being of occupants through better indoor air quality (McGill, Oyedele, & Keeffe, 2015; McGill, Qin, & Oyedele, 2014; Steinemann et al., 2017). Only a small number of studies have reviewed the indoor air quality of green dwellings (Colton et al., 2014; Derbez et al., 2014; Wells et al., 2015; Yu & Kim, 2011) with these studies present mixed results and no clear determination that green building results in improved indoor air quality.

Wells et al. (2015) conducted a longitudinal study on 12 low-income single-family homes renovated to either a deep energy retrofit or the energy star standard finding no difference between the two types of dwellings. In counterpoint Colton et al. (2014) found that occupants of green homes experienced 47% fewer sick building syndrome symptoms with concentrations of particulates, nitrous dioxide and nicotine lower in the green buildings (differences in formaldehyde and CO_2 were not statistically different). Derbez et al. (2014) also found mixed results over various VOCs measured, with some higher and some lower than the median concentrations of standard French housing.

Exposure to dampness, high CO_2 concentration, particulate matter and indoor chemical and microbial pollutants such as VOCs and fungi are associated with childhood health problems (Zhang et al., 2016) with the emission profile of VOCs from building materials altering markedly with increases of humidity or 'dampness (Wolkoff, 2018).

A complex relationship exists between occupant health and comfort and sustainable/green building and if an appropriate balance is not struck then attempts to improve one factor can negatively affect another. For example the introduction of airtightness measures to improve energy efficiency can decrease indoor air quality and negatively affect occupant health and comfort if not balanced with increased ventilation (Leardini & de Groot, 2010; Leardini et al., 2012). It is therefore implicit that mechanisms seeking to improve indoor environment quality, such as building codes and green building rating tools must strike the correct balance in the drive for energy efficient, warm, dry and comfortable healthy homes.

New Zealand mechanisms to deliver healthy homes (new and existing)

New Zealand building code (mandatory)

New Zealand's first national building code was implemented in 1924, however adjacent councils often had different rules causing difficulties and the 1931 Napier earthquake therefore acted as a catalyst for changing New Zealand building regulations (Isaacs, 2017). In 1971, the Waimairi County became the first local authority to implement a thermal insulation bylaw and in 1977 national legislation was introduced (coming into force on 1 April 1978) making it compulsory for new homes to be insulated. The Building Act of 1991 merged existing acts and regulations, introducing for the first time the concept of performance-based building controls through the 1992 building code (Isaacs, 2017).

New Zealand's building code undergoes periodic updates with Table 1–1 detailing recent thermal envelope performance requirements. However a review by the International Energy Agency (International Energy Agency, 2017) found that the current building code is below the standard required in most IEA countries with comparable climates, recommending that the government focus on supporting the adoption of efficient heating systems, draught proofing, ventilation and moisture prevention measures; with a further recommendation that an effective monitoring and enforcement regime be implemented for both tenancy legislation and building code.

Healthy Homes Standards (HHS) (mandatory)

In 2019 the New Zealand government enacted legislation to make a significant change to the quality of rental homes (HUD, 2020). A particular focus of the HHS is existing rental housing, and the requirements in standards are broadly in alignment with the current NZBC to bring older housing up to the same standard as the current code. The HHS contain minimum standards of heating, insulation, and ventilation also addressing issues of moisture ingress and drainage and draught stopping (Residential Tenancies (Healthy Homes Standards), 2019). All private rentals must comply within 90 days of any new or renewed tenancy after 1 July 2021, all houses rented by Kāinga Ora and registered community housing providers must comply by 1 July 2023 with all private rentals complying by 1 July 2024.

Table 1. New Zealand Building Code building thermal envelope component R-Value requirements from 1978 to current day for a non-solid construction (glazed area < 30% of total wall area).

	1978 NZS4218P (1977)a	H1 1st Edition (1992)	H1 2nd Edition (2000)	H1 3rd Edition (2007)	H1 4th Edition (2017)
Performance Requirements					
Zone 1	none	BPI ≤0.13kwh	BPI ≤0.13kwh warm climate	BPI ≤0.13kwh warm climate	BPI ≤1.55
Zone 2			BPI ≤0.12kwh cool climate	BPI ≤0.12kwh cool climate	
Zone 3				BPI ≤1.55	
Prescriptive Requirements					
Building Thermal envelope component *R-value (m^2°C/W)*	1978 NZS4218P (1977)a		NZS4218:1996		NZS4218:2009
Zone 1		none			
Ceiling	1.9		1.9	2.9	2.9
Wall	1.5		1.5	1.9	1.9
Floor	0.9		1.3	1.3	1.3
Window	none		none	0.26	0.26
Zone 2					
Ceiling	2.6		1.9	2.9	2.9
Wall	1.2		1.5	1.9	1.9
Floor	0.9		1.3	1.3	1.3
Window	none		none	0.26	0.26
Zone 3					
Ceiling	3.0		2.5	3.3	3.3
Wall	1.0		1.9	2.0	2.0
Floor	0.9		1.3	1.3	1.3
Window	none		none	0.26	0.26

anote there were no climate zones in 1977 and these R-value combinations could be used anywhere in the country
BPI = Building Performance Index
See Figure 1–2 for climate zones

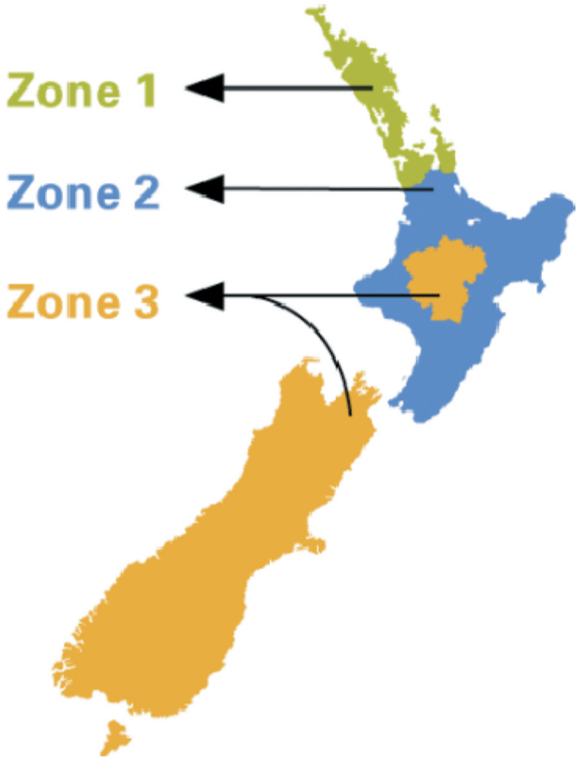

Figure 1. New Zealand Building Code Climate Zones (current).

The HHS also contains general exemptions from compliance including if the landlord intends to demolish or substantially rebuild the rental property and has applied for the relevant resource or building consent before the above HHS compliance dates. This exemption lasts 12 months from the HHS compliance date if (i) the tenant is the immediate former owner of the rental property and the tenancy started immediately after the landlord acquired the property from the tenant or (ii) if a rental property is part of a building and the landlord does not own the entire building (i.e., an apartment in a larger building). A final exemption is that landlords only need take all reasonable steps to ensure the rental property or building complies with the HHS to the greatest extent reasonably practicable.

Healthy housing index and warrant of fitness (voluntary)

In the early 2000s, the University of Otago's He Kainga Oranga/Housing and Health Research Programme, in conjunction with the Building Research Association of New Zealand (BRANZ; an independent and impartial research, testing and consulting organisation) developed the Healthy Housing Index (HHI) as a research tool for measuring housing quality in existing homes. It was a comprehensive building checklist, with 26 areas of interest and multiple sub-elements for review and while it met the research needs well, the 2 to 3 hours required for inspection made it impractical for use as a broader rental quality inspection standard (Telfar-Barnard et al., 2017).

At a similar time, other organisations (such as the NZGBC) were also considering housing checklists for purposes beyond health, such as sustainability or building longevity. He Kainga Oranga, the NZGBC, and the Accident Compensation Corporation (ACC) collaborated to develop criteria that would cover areas with the strongest health and injury prevention evidence base. This collaboration resulted in the development of a housing WOF (Gillespie-Bennett, Keall, Howden-Chapman, & Baker, 2013). The draft WOF had 31 criteria covering heating, ventilation, insulation, structural stability, sanitation, and injury hazards.

The HHI/WOF resulted in a proposed two-phase approach to healthy housing in New Zealand, the first being the pass/fail WOF assessment as to whether the home meets basic health and safety standards, and the second being the HHI output which was proposed (in 2013) to rate each major assessment area (health, safety and energy efficiency) on a 5-point scale (Gillespie-Bennett et al., 2013). The HHI assessment report was to be provided to the homeowner, identifying problems along with prioritised solutions and remediation options to improve the health, safety and energy efficiency of the house.

It was expected that HHI/WOF inspections would be carried out a maximum of once every 5 years or when a house is rented or sold. However, at this time, neither the HHI or the WOF are mandatory anywhere in New Zealand, although the WOF is being currently being trialled in Wellington (Wellington City Council, 2017), with minimal uptake (two compliant properties listed) (Newton, 2018; Wellington City Council, 2019). This has led to calls for the scheme to become mandatory, with Professor of Public Health, Philippa Howden-Chapman, saying the voluntary nature of the scheme would have contributed to the low uptake (Newton, 2018).

Homestar and HomeFit (voluntary)

In 2009, the New Zealand Business Council for Sustainable Development gained support from key industry leaders for a National Housing Upgrade Action Plan with the residential green building rating tool, Homestar, subsequently born from this plan. Homestar was developed in 2009 by three partners: (i) the NZGBC, (ii) BRANZ and (iii) Beacon Pathway (an incorporated society) (Ade & Rehm, 2020).

Homestar originally offered three types of assessment: (i) a free online self-assessment, (ii) an assisted online assessment (Homecoach) and (iii) a third-party certification (Homestar™ Certified) for both new and existing houses, and was released for public use in 2010. The Homestar version 1 technical manual states that the overarching objective of the Homestar rating tool was "to improve the performance and reduce the environmental impact of new and existing New Zealand homes, making them warm, healthy, comfortable places to live" (p. 6).

Homestar utilises a star rating system, with the original 0- to 5-star band range, from the overall available 10 stars, in place to encourage consumers to upgrade their homes, to make them more insulated and warmer, through the free online tool. The higher star ratings (6 to 10) and the official certifications were to encourage new homes to be constructed better (New Zealand Green Building Council, 2017).

Similar to the HHI/WOF, Homestar version 1 did not experience any significant uptake. Homestar version 2, released in 2013, facilitated the ability of the rating tool to be used on new constructions with a "Design Rating" option added to the existing "Built Rating" certification. However, version 2 of the rating tool still did not experience any significant uptake. Further iterations of the tool, version 3 and version 4, were released in 2016 and 2017 respectively with version 4 making substantive changes to the rating tool. Version 4 eliminated all star ratings below 6 stars, increased the minimum heating-demand temperature threshold from 18°C to 20°C, and deleted many WOF-esque items from the tool. With the NZGBC stating that most of the existing housing stock would have previously only achieved 2 to 4 stars on the Homestar rating scale, this has effectively limited Homestar to being a new home or major renovation rating tool. The reasoning behind these changes is not explained in the new version of the technical manual for the rating tool; however, the change left a large gap in the market for lower performing, existing homes that were no longer eligible to achieve a certification.

To fill this self-created gap, the NZGBC then developed and released to the market a new rating tool called HomeFit (New Zealand Green Building Council, 2018). This tool encapsulated the elements that were removed from Homestar version 4 as well as covering many similar items to the WOF. HomeFit is billed as a straightforward tool to help New Zealanders see if homes meet NZGBC-defined minimum standards of insulation, ventilation, heating, safety and energy efficiency. Similar to version 1 of Homestar, HomeFit comprises two elements.

The first is an online check that homeowners and landlords can use to understand if the home is healthy and warm. The online check will provide a recommendation report if the dwelling does not meet the standards. The second is an independent assessment to verify that the dwelling meets the HomeFit standard. The NZGBC states that home-owners and landlords can use the HomeFit tick to say it is approved independently to be healthy and warm, is less likely to get mould, and is better ventilated and warmer (New Zealand Green Building Council, 2018). In October 2019 the NZGBC launched an update to the HomeFit standard to align it with the new government Healthy Home Standards (HomeFit, 2019; New Zealand Green Building Council, 2019).

At this time, there is no publicly available register of HomeFit-certified dwellings, so it is impossible to determine the uptake of the rating tool. Similar to HomeFit, there is no publicly available register of Homestar-certified dwellings and it is therefore also not possible to determine the current uptake of this rating tool. The NZGBC claims that there is a pipeline of 25,000 dwellings for Homestar; however, recent research reviewed this claim, finding that the number of homes that have gained certification or were actively going through the Homestar process in July 2018 was only 2,459, roughly a 10th of the numbers promoted by the NZGBC at the time (Ade & Rehm, 2019a).

At this time, the use of Homestar and/or HomeFit is not mandated by government or any organisation. The NZGBC is, however, promoting HomeFit certification as a compliance pathway for the Healthy Homes Guarantee Act and Healthy Home Standards (New Zealand Green Building Council, 2019). Whilst Homestar is not mandated by the government, the national social-housing provider Kāinga Ora (2019) and Auckland Council-controlled developer Panuku (2017) have both adopted 6-Homestar certification for new constructions.

Summary

In New Zealand, there are currently two distinct mechanisms in place for the provision of healthy housing. The first is mandatory government standards (the building code for new housing and the healthy home standards for existing rental housing) and the second are voluntary solutions (the 6 Homestar green building rating tool that has been adopted for use by some national and local government agencies). Two other voluntary rating mechanisms exist (HomeFit and the HHI/WOF), but these have not been adopted by any organisation at this time, despite calls for them to become mandatory.

To date no one has analysed the potential effectiveness of these codes/standards and rating tools at delivering healthy housing. He Kainga Oranga researchers have focused attention on the HHI/WOF scheme variously studying barriers to implementing required WOF elements to housing (Chisholm et al. 2019), the practicality of widespread introduction without adverse consequences for tenants (Telfar-Barnard et al., 2017) and a field test to assess the practicality and utility for supporting improved quality of housing (Bennett, Howden-Chapman, Chisholm, Keall, & Baker, 2016) but not evaluating the effectiveness of the HHI/WOF to deliver superior indoor environment quality.

New Zealand building code has also received attention with the IEA publishing a critical review in 2017, however this paid singular attention to energy efficiency rather than more holistic building health. Duncan (2005) reviewed the effectiveness of the New Zealand performance-based building code determining that successful implementation of a performance-based code relies on the concurrent accompaniment of well-focused training programmes for designers, building control staff and the on-site workforce. This is echoed by the IEA (2017) who conclude that an effective monitoring and enforcement regime is in place for both New Zealand building code and the HHS.

Methodology

Content analysis was applied to classify and summarize relative content from different healthy housing mechanisms. As outlined by Krippendorff (2018, p. 38), "*content analyses start with data that are not intended to be analysed to answer specific research questions. They are 'texts' in the sense that they are meant to be read, interpreted, and understood by people other than the analysts*". These texts, such as the Healthy Homes Standards (HHS), are decomposed into meaningful units and structures (see Table 2). Content analysis is widely used to identify themes in built environment studies. Specifically comparative content analysis is often employed to decompose green building rating tools in order to contrast and compare them (see Huo, Ann, & Wu, 2017; Wu, Shen, Ann, & Zhang, 2016; Zuo, Xia, Barker, & Skitmore, 2014). Wu et al. (2016) for example, used comparative content analysis to identify and compare waste management criteria across several green building rating tools.

Comparison of New Zealand mechanisms

Although there is no academic consensus on a definition for healthy housing, policies are being made and implemented with the aim to provide this healthy housing. In New Zealand, there are currently two distinct mechanisms in place. The first is mandatory government standards for rental housing (HHS) and the second are voluntary mechanisms that have been mandated for use by national and local government agencies (6-Homestar). Two other mechanisms exist (HomeFit and the WOF), but these are not required for use at this time, despite calls for them to become mandatory. The HHS defines healthy housing through the use of five standards (insulation, heating, ventilation,

Table 2. Prescriptive thermal-envelope requirements and performance requirements.

		2008 Building Code (clause H1)	HHS	HHI/WOF	HomeFit	6-Homestar
Prescriptive	Floor	1.3	Rental homes must have underfloor insulation which meets the 2008 Building Code	Insulation to NZBC requirements	Minimum 60 mm bulk insulant installed to all accessible floor spaces (~ R1.4)	CZ1 1.3; CZ2 1.8; CZ3a 2.3; CZ3b 3
	Wall	CZ1 & 2 1.9; CZ3 2	none	Insulation to NZBC requirements	none	CZ1 2.1; CZ2 2.2; CZ3a 2.9; CZ3b 3.2
	Windows	0.26	none	Curtains/blinds/double glazing present	Windows in all living rooms and bedrooms are either fitted with good curtains or are double glazed *HomeFit optional:* *Windows: in all living rooms and bedrooms are both double glazed AND are fitted with good curtains*	CZ1 0.26; CZ2 0.32; CZ3a 0.43; CZ3b 0.43 *6-Homestar Optional Point* *All window frames are thermally broken = 1 point*
	Ceiling	CZ1 & 2 2.9; CZ3 3.3	Rental homes must have ceiling insulation which either meets the 2008 Building Code, or (for existing ceiling insulation) is at least 120 mm thick	Insulation to NZBC requirements Clearance for lights, ducts and roof	Ceiling: Minimum 120 mm bulk insulant installed to all accessible roof spaces *HomeFit optional:* *Ceiling: Zone 1 and 2: Minimum R3.2, Zone 3: Minimum R3.6*	CZ1 3.6; CZ2 3.8; CZ3a 4.1; CZ3b 4.9
Performance	Option 1	Heat loss of the proposed building is no more than the heat loss of the reference building	No performance pathway	No performance pathway	No performance pathway	Predicted heating-energy demand in kWh/m^2 from ALF CZ1 ≤35; CZ2 ≤60; CZ3a ≤70; CZ3b ≤80
	Option 2	BPI < 1.55.	No performance pathway	No performance pathway	No performance pathway	Predicted heating-energy demand in kWh/m^2 from dynamic modelling software* CZ1 ≤76; CZ2, 3a & 3b ≤84
	Option 3					Passivhaus certification*

NZBC = New Zealand Building Code, HHS = Healthy Home Standards, HHI/WOF = Healthy Home Index/Warrant of Fitness, CZ = Climate Zone
typically only used for 8-Homestar and above

moisture ingress and drainage, and draught stopping) and these titles will be used as the framework for comparison.

Insulation

Insulation specification can typically be approached in two ways. The first is a prescriptive pathway that specifies minimum insulation levels in different climate zones. The second is a performance approach where a target (typically a heating-energy demand) is specified and it is up to the designers to achieve this performance level. The HHS and HomeFit utilise prescriptive approaches, while Homestar and NZBC allow both prescriptive and performance compliance. In terms of internal minimum temperature thresholds, HHS and HomeFit focus on achieving a minimum temperature of 18°C, while NZBC and Homestar version 4 utilise a minimum temperature of 20°C (Homestar versions 1, 2 and 3 utilised 18°C).

A comparison of the prescriptive requirements of each mechanism (Table 3–1) indicates a large disparity in insulation levels. Whilst all mechanisms require minimum levels of floor and ceiling insulation, only 6-Homestar and NZBC require wall insulation as well as double glazing. None of the mechanisms require the implementation of any strategies to address overheating, although Homestar does require consideration of cooling loads at higher star rating levels.

NZBC has two different performance metrics available for use. The first is the calculation method (described in New Zealand Standard NZS 4218) which allows building components with lower R-values to be used, provided the additional heat loss from these components is offset by reduced heat loss in other building components. For example, windows with lower R-values can be used if higher R-values in the walls, floor or roof offset the increased heat loss through the windows. The second method is the Building Performance Index (BPI). The BRANZ ALF (Annual Loss Factor) method must be utilised to calculate the heating-demand energy of the dwelling and takes into account the climate, together with the building's dimensions, design, orientation,

Table 3. Pace-heating requirements.

	NZBC	HHS	HHI/WOF	HomeFit	Homestar
Efficient Space Heating	none	Fixed heating devices in living rooms, which are sized (in accordance with Schedule 2) to maintain a temperature of at least 18°C*	Heating to living room, fixed, effective and safe	Main living spaces with a heating load greater than 2.4 kW must have a fixed, cost-effective, clean-burning form of space heating	An adequately sized, fixed, heating source is provided in the main living area *6-Homestar Optional Point: Fixed space-heating source is a heat pump (air/ ground to air/ water) = 1 point*

NZBC = New Zealand Building Code, HHS = Healthy Home Standards, HHI/WOF = Healthy Home Index/Warrant of Fitness,
**The main living room need not comply with the regulation if the tenancy building is a certified passive building. A building is a certified passive building if:*
(i) the building has been certified as a passive house under the Passive House Standard of the Passivhaus Institut, Germany
(ii) the International Living Future Institute has issued one of the following in respect of the building:
(a) a Living Building Certification
(b) a Petal Certification that includes a heating-related requirement
(c) a Zero Energy Certification.

insulation and construction. The heating-demand energy is then used to calculate the BPI, and NZBC requires the BPI to be no more than 1.55. However, ALF is not ASHRAE 160- or BETEST-approved software and is only for use on standalone dwellings (BRANZ, 2019, section 1.0.6), meaning that terraced houses and apartments (which represent a growing percentage of new building consents) cannot be assessed using this compliance pathway.

Three pathways are available for a dwelling to illustrate 6-Homestar performance compliance. These are (i) heating load calculations using the BRANZ ALF calculator, (ii) energy modelling using NZGBC approved software and modelling protocol and (iii) Passivhaus Certification, with options (ii) and (iii) typically only used for 8-Homestar and above.

Despite a clear restriction in the ALF user guidelines, the NZGBC allows ALF to be used on terraced houses and apartments to demonstrate Homestar thermal compliance. Anecdotal evidence from industry experts indicates that the use of ALF on terraced houses and apartments can lead to perverse outcomes with centrally located apartments (with another dwelling both above and below and on each side) typically only having to analyse potential heat loss through one exterior wall, resulting in high thermal performance scores.

All mechanisms have a strong focus on minimum temperature thresholds to prevent cold and damp interior environments, using passive heating mechanisms such as increased insulation levels. However this is not balanced with a focus on passive cooling, an oversight in a warming world. The Ministry for the Environment (2018) predicts that temperatures in Auckland are likely to be 0.7°C to 0.9°C warmer by 2040 and 0.7°C to 3.1°C warmer by 2090, with 11 to 70 extra days per year where maximum temperatures exceed 25°C. Auckland Council (2019) also recognises a warming climate, acknowledging the expectation of increasing annual average temperatures and extreme temperatures, and significantly more hot days each year.

Globally, a significant body of literature exists documenting a tendency for more insulated dwellings to overheat (Gupta & Kapsali, 2016; McLeod, Hopfe, & Kwan, 2013; Mitchell & Natarajan, 2019; Sameni, Gaterell, Montazami, & Ahmed, 2015; Toledo, Cropper, & Wright, 2016); however, in New Zealand, the focus is on cold and damp housing, with the new HHS solely concerned on rental housing achieving minimum temperature thresholds, with no consideration for upper temperature thresholds. In addition, NZBC, HomeFit and the WOF, as well as Homestar (at the 6-star certification level), do not contain any requirements on overheating. Moving forward, in a warming world, it is clear that any healthy housing mechanisms should include overheating analysis for dwelling typologies that are particularly at risk (such as terraces, duplexes, apartments and other multilevel dwellings). New building standards such as building code or green building rating tool certifications (Homestar), as well as existing building standards like the HHS and HomeFit, should balance their cold and damp criteria with additional criteria that address hot and humid/cool and comfortable.

Heating

In terms of active heating, four of the five mechanisms require a fixed heating source in the living room (Table 3–2), with NZBC the only mechanism that has no specific space-heating requirements. The HHS requires that a heater capable of heating the room to a minimum temperature of 18°C be provided (a detailed heating capacity calculation is provided in Schedule 2 of the legislation). The WOF, HomeFit and 6-Homestar do not have any requirements around the heating device, other than a fixed one must be provided.

A significant flaw of all these mechanisms is that they only require a heating source in the living room, with no heating source required in bedrooms. The Household Energy End-Use Project (HEEP) found a mean temperature of 12.6°C in bedrooms and 13.5°C in living rooms over the winter (Isaacs et al., 2010). Assuming that dwelling occupants sleep in their bedrooms and not the living room, providing a heating source in the living room will make little to no difference to the temperature of bedrooms, where the majority of dwelling occupants will spend most of their time. The drive to heat only the living room could potentially lead to the situation where this is the warmest room in the house. If the bedrooms are colder than the living room, this could encourage all occupants to sleep in the living room, leading to overcrowding, which, along with bed sharing, is identified in the literature as a key contributor to poor health (Oliver, Pierse, Stefanogiannis, Jackson, & Baker, 2017; Tin et al., 2016)

Fuel poverty is another identified issue in New Zealand, estimated to affect one in four New Zealand households (O'Sullivan, Telfar Barnard, Viggers, & Howden-Chapman, 2016) and is more frequently experienced in rental housing. In this context, the requirement by HHS, HomeFit and 6-Homestar to provide a heater that is capable of heating the living room to a temperature of 18°C has two direct financial consequences. The first is a capital cost to landlords for the purchase of active devices. The second is an operational cost to tenants should they wish to utilise these fixed heating devices. The particular issue with the specification of the 18°C temperature threshold, and use of the heating capacity calculation in Schedule 2 of the legislation, is the subsequent size of the heating device that is required (which is typically a large heat pump).

An additional flaw in the HHS is that they contain particular exemptions to the heating standards. Specifically, the main living room need not comply with the regulation if the tenancy building is a certified "passive building." The first qualification of a passive building, as being certified under the Passive House Standard of the Passivhaus Institut, is eminently sensible as the Passive House Standard contains a requirement for a dwelling's temperature to be maintained between 18°C and 24°C. There is a small overheating allowance in the Passive House Standard that allows the temperature to be above 25°C for 10% of occupied hours. The second exemption is not as sensible. This exemption states that if the International Living Future Institute has issued either a (i) Living Building Certification (LBC), (ii) Petal certification that includes a heating-related requirement or (iii) Zero Energy Certification, then Regulation 8 does not need to be complied with. However, none of these certifications from the International Living Future Institute have minimum or maximum temperature thresholds. The LBC is primarily concerned with energy generation and the stipulation that all heating and cooling loads be accounted for when determining if all energy has been generated on site by renewable energy sources. The LBC does not contain energy efficiency or minimum temperature thresholds, with the exception that if the Healthy Interior Environment imperative is targeted, then the building must be compliant with the current version of ASHRAE 62 (Ventilation for acceptable indoor air quality) or international equivalent. In the context of New Zealand, the international equivalent is AS 1668.2 and this standard has been accepted by the

International Living Future Institute. Therefore, there is no guarantee that certification under these standards will deliver a home that operates within the healthy temperature bands desired by the legislation. If the government is concerned about minimum and maximum temperature thresholds in New Zealand homes, these exemptions should be removed and Passive House certification from the Passivhaus Institut should be the only exemption.

Ventilation/Moisture ingress and drainage/Draught stopping

Again, commonalities in approach exist across the different mechanisms. The HHS, HomeFit and 6-Homestar all require mechanical moisture extraction from bathrooms and kitchens (although the HHS exempts any building older than 1 July 2019 from compliance), with the WOF only requiring "fixed, effective and safe ventilation" (Table 3–3). No mechanism requires mechanical ventilation for bedrooms or living rooms, with these spaces allowed to be ventilated via opening windows alone. The WOF and 6-Homestar both require restrictor stays to be installed to openable windows, effectively minimising the ability to actually exchange air effectively.

Each mechanism requires a vapour barrier to prevent rising damp in suspended timber floors. The existing building mechanisms (HHS, WOF, HomeFit) also require there to be no water ponding under or around foundations, with the WOF and HomeFit also requiring no visible mould. Finally, HHS, WOF and HomeFit all have subjective requirements around draughts, using language such as "unnecessary gaps" with no definition of unnecessary provided. 6-Homestar does not include any requirements here, likely because of an assumption that newly built houses would not contain large gaps in the façade.

Whilst not worsening performance, none of the required measures are likely to enable dwellings to stay within the recommended 40% to 60% RH range. Traditionally, New Zealand has relied on background air infiltration (in addition to the NZBC-required 5% openable window/door area) which occurs as a consequence of poor construction practices and materials used for the envelope. Each of these mechanisms focuses on reducing background air infiltration through the elimination of draughts. However, there is no subsequent requirement for the inclusion of additional ventilation sources in the majority of rooms in any mechanism. BRANZ has concluded that more airtight construction is less forgiving of a "closed window" lifestyle and that dampness problems can develop (Bassett, 1983; Overton, Bassett, & McNeil, 2013). Therefore, it is possible that dwellings that meet the requirements of HHGA/HHS, WOF, HomeFit and 6-Homestar may suffer from increased damp due to a lower rate of air exchange, as there are no requirements for the inclusion of an active, fresh air supply.

In terms of moisture generated within the dwelling, additional extraction systems are only required in two of the four mechanisms (6-Homestar and HomeFit). However, these extraction systems are located in the kitchen and bathroom and are not balanced with additional fresh air supplies in the habitable spaces. This is of particular concern for sleeping areas as the highest moisture loads overnight are in bedrooms, something that is not addressed by any of the promoted healthy homes mechanisms.

The risk of condensation is not actively addressed by any mechanism. In fact, one mechanism, HomeFit, actually promotes a prescriptive requirement that increases the risk of condensation. HomeFit requires that single-glazed houses have "good" curtains in living rooms and bedrooms. However, hanging good curtains will keep the glazing cooler and increase the condensation risk as the treatment for condensation is ventilation (to vent moisture-bearing air to the outside) and heating (to raise surfaces above dew point temperature). With the other mechanisms requiring a heating source to be provided to the living room, but nowhere else in the dwelling, the risk of condensation also increases. All of the heating sources referenced are intermittent space heaters, rather than continuous centralised heating sources. New Zealanders are generally not familiar with centralised heating and typically only operate space heaters (heat pumps, fireplaces and electric heaters) when they are occupying the dwellings. The use of these devices (to heat only the living room) will result in a constant fluctuation in the temperature of not only the living room, but also the adjacent rooms as the living room heat leaks away. Constantly changing temperatures (from below 18°C to above and then back below) will result in a constantly changing RH that will potentially enable and encourage the growth of biotic agents such as mould and asthma-causing dust mites as well as interstitial condensation.

It is clear that the current mechanisms for addressing damp are not sufficient and may actually lead to a worsening of the crisis.

Assessment protocols

Each of the mechanisms comes with a prescribed assessment protocol (detailed in Table 3–5). These assessment protocols vary from consultants submitting compliant drawings to a local government authority (NZBC), self-assessments by homeowners or property managers (HHGA/HHS) to independent assessors being engaged to complete on-site assessments (WOF, HomeFit, 6-Homestar). Each of these assessment protocols has a common theme, that being a single inspection (of either drawings or physical dwellings) at a single point in time. If, at that point in time, the dwelling is compliant, then a certification or notification of compliance is issued.

Immediate commonalities are apparent in the five New Zealand approaches to healthy homes. Firstly, all mechanisms are predominantly prescriptive, with a detailed list of items that are required to either be present (i.e., insulation) or absent (i.e., mould) for a dwelling to be deemed healthy. This is in alignment with current international practice that also focuses on prescriptive lists.

Secondly, the prescriptive requirements rely on estimated performance, and compliance is assumed, rather than proven through post-occupancy measurement and verification, through the application of the prescriptive criteria. For example, the HHS expresses a desire for living rooms to be maintained at 18°C, with a requirement for appropriately sized heaters. However, the HHS does not require proof (i.e., the logging of actual temperature measurements) that the installed heaters are achieving this threshold.

Thirdly, each of these mechanisms utilises a static assessment protocol. A homeowner/property manager or independent assessor is required to only visit a property once to determine if compliance is achieved. Once compliance has been issued, there is no requirement for this compliance to be updated should things change on site. A heating source could be removed or replaced in a dwelling, but under the WOF, HomeFit and 6-Homestar this would not invalidate the certification previously issued. HomeFit

Table 4. Comparison of the humidity criteria of NZBC, HHGA/HHS, WOF, HomeFit and Homestar.

	NZBC	HHS	WOF	HomeFit	Homestar
Ventilation	Kitchens, bathrooms and laundries can be naturally ventilated subject to different requirements (Clause G4)	Rental homes must have the right size extractor fans in kitchens and bathrooms, and opening windows in the living room, dining room, kitchen and bedrooms*	none	Kitchens and bathrooms have a mechanical extract to outside and other living spaces have adequate ventilation	A bathroom extract has been installed in every bathroom and is ducted to outside. A kitchen extract hood ducted to outside is mounted over the main steam source in the kitchen *6-Homestar Optional Point* *Heat-recovery ventilation system = 1 point*
	There is a net openable area of windows to the outside of no less than 5% of the floor area. (Clause G4)	In each room, the size of the openable windows, doors and skylights together must be at least 5% of the floor area of that room. Each window door, window or skylight must be openable and must be able to remain fixed in an open position	Effective ventilation to the outside Opening window with secure latch Window security stays (where required)	none	There is a net openable area of windows to the outside of no less than 5% of the floor area. Windows/openings required for passive ventilation (at least one in each room) are constructed in a way that allows them to be secured against intruder entry while open on ground floors and fixed open on other floors (i.e., to at least 10 mm along one edge) ORBackground (trickle) vents have been installed in each habitable room in accordance with the areas set out in Building Code ClauseG4
	none	none	none	*HomeFit optional*: *Clothes dryers are either vented to the outside or are condensing/heat pump dryers. Alternatively, there is an external covered washing line*	A washing line in a dedicated space is provided outside the thermal envelopeOR There is a heat pump dryer

(*Continued*)

Table 4. (Continued).

	NZBC	HHS	WOF	HomeFit	Homestar
Damp	Ground vapour barrier (Clause E2)	If a rental home has an enclosed subfloor, it must have a ground moisture barrier if it is possible to install one	Dry underfloor Ground vapour barrier No ponding	Ground vapour barrier, adequate subfloor ventilation, no obvious signs of pooling water or pipework leaks (where accessible) in the subfloor	Ground floors are either slab on grade, or ground cover (e.g., polythene sheeting) is provided to all suspended floors.
	Homes must have efficient drainage and guttering, downpipes and drains (Clause E1)	Rental homes must have efficient drainage and guttering, downpipes and drains	Spouting, storm/waste water functioning, no leaks	none	none
	none	Rental homes need to be free from mould and dampness	Surfaces clear of mould	The home is free of visible mould	none
Draughts	none (gaps in the façade are addressed via moisture ingress requirements – clause E2. Air tightness is not addressed)	Rental homes must have no unnecessary gaps or holes in walls, ceilings, windows, floors, and doors that cause noticeable draughts. All unused chimneys and fireplaces must be blocked	Wall, ceiling and floor linings intactNo cracks, holes in roof No cracks, holes in external cladding No cracks, holes or missing panes in windows	The home has no obvious air leaks: holes or large gaps in windows, doors, walls, floors, or ceilings	none

NZBC = New Zealand Building Code, HHS = Healthy Home Standards, HHI/WOF = Healthy Home Index/Warrant of Fitness
Only applies to dwellings constructed after 1 July 2019.

Table 5. Assessment protocols and fees (for a Single Dwelling) for each Mechanism.

2008 Building Code	HHGA/HHS	WOF	HomeFit	6-Homestar
Marked up drawings submitted to local government agency for assessment	No formal assessment protocol	Independent assessor	Independent assessor	Independent assessor
Varies based on local government agency[1]	Property managers charging circa 100 USD for an inspection	$250[2]	$100 + independent-assessor fees	Fixed admin fee – 295 USD Admin fee per dwelling – 150 USD for members, 195 USD for non-members[3] + independent-assessor fees (circa 900 USD+ GST) (Ade, 2018)

NZBC = New Zealand Building Code, HHS = Healthy Home Standards, HHI/WOF = Healthy Home Index/Warrant of Fitness
1.https://www.aucklandcouncil.govt.nz/building-and-consents/understanding-building-consents-process/apply-for-consent/Pages/apply-for-building-consent.aspx
2.https://wellington.govt.nz/services/rates-and-property/property/rental-warrant-of-fitness
3.https://www.nzgbc.org.nz/Category?Action=View&Category_id=278

certifications are valid for 3 years, whilst WOFs and Homestar certifications do not expire. Therefore, these certifications could be used to promote properties for rent or sale, even though they are no longer compliant.

In addition, timing of assessments is up to homeowners/property managers or independent assessors. There are obvious inherent issues with systems that undertake assessments in this manner. Savvy assessors (who are engaged by the client seeking the assessment – not an independent agency) can game the system, undertaking assessments at "suitable" times when key issues such as mould may not be present.

Even though the independent-assessor approach of mechanisms like HomeFit, Homestar and the WOF are not truly independent, with the assessor engaged by the client, they are stronger than the self-assessment approach allowed by the government's HHGA/HHS. However, New Zealand is not alone in implementing this approach; private landlords in Scotland are responsible for ensuring their properties meet the Tolerable Housing Standard. A truly independent implementation of healthy housing legislation is demonstrated by England and Wales which require assessments to be carried out by environmental health officers from the local council, with the council required to take action if serious problems are found. The New Zealand government should consider implementing this approach for their new legislation.

Discussion and conclusion

There is no commonly agreed definition of healthy housing, a situation that has not changed since 2007 when Bonnefoy stated that there were major gaps in the knowledge not only on how housing conditions may affect health but also limited knowledge on which mitigation strategies may show the best results. Despite this, the discourse around cold and damp housing is strong and mechanisms are specifically geared towards remediation of a cold and damp housing crisis with little to no consideration of hot and humid or cool and comfortable conditions. With temperatures documented as warming across the globe this myopic focus on resolving a single issue, without also addressing the counterbalance of hot and humid or cool and comfortable raises the risk of a new health crisis. The frequency of heat waves is increasing, with the record-breaking European heat wave of 2003 estimated to have caused an additional 2,045 deaths in the UK, with as many as 70,000 excess deaths between June and September, across Europe as a whole.

A secondary key concern is that the mechanisms centre on prescriptive and static compliance methodologies with no requirement for post-implementation measurement and/or verification. An assessment can occur once and remain valid with limited requirements for ongoing re-assessment. Many mechanisms are reactive, with the HHSRS and HHS relying on occupants lodging complaints before action will be taken. This disadvantages tenants who may be reluctant to lodge complaints for fear of subsequently being evicted. Whilst containing many flaws, Homestar is the most comprehensive of the mechanisms available in New Zealand currently and provides the best chance at a healthy interior environment.

A further flaw of the majority of the mechanisms is that assessment is undertaken by a supposedly independent assessor. However, this assessor is typically engaged and paid by the landlord/homeowner and therefore can never be truly independent, as a related-party financial transaction has occurred. An assessor can therefore choose when to undertake an assessment for certification. If an assessment occurs during the heat of summer, it is unlikely that mould and condensation will be present. However, if the assessment occurs during winter these items might be prevalent in a dwelling. This highlights the flaws of intermittent assessment and the importance of continuous monitoring and measurement.

Rather than utilise prescriptive measures of potential building performance as an industry, property should be moving towards the utilisation of absolute performance metrics. Design and construction checks points could be implemented for new buildings; however, final certification should only be issued on actual performance data.

With new disruptive technologies involving real-time building-performance data becoming increasingly mainstream, an opportunity exists for new policy approaches to be adopted. Temperature, humidity, carbon dioxide and energy use could be logged and disclosed to demonstrate compliance with IEQ and energy-efficiency standards. Occupants of dwellings, as well as landlords, would have instant transparency on the health of their dwellings, and, with an educational feedback loop, would have the ability to directly influence and improve their environment.

This research contains important policy implications documenting that the current mechanisms for the provision of healthy housing in New Zealand are flawed. The New Zealand government, local government, policy researchers and the wider property industry should pay particular attention to the conclusions of this research.

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