National SCIENCE Challenges

BUILDING BETTER HOMES, TOWNS AND CITIES

Ko ngā wā kāinga hei whakamāhorahora

TOITŪ TE KĀINGA TOITŪ TE ORA TOITŪ TE TANGATA

Healthy homes, healthy people

Editors Tepora Emery and Ian McLean

2019

TOI OHOMAI INSTITUTE OF TECHNOLOGY

MATEKUARE WHANAU TRUST, UNITEC, SCION, TALLWOOD

This report has been compiled for Kāinga Tahi Kāinga Rua research programme of the Building Better Homes, Towns and Cities National Science Challenge.

The report editors are Tepora Emery and Ian McLean of Toi Ohomai Institute of Technology.

The authors of the report are:

- Hinerangi Goodman, Tony Goodman
  Matekuare Whānau Trust

- Tepora Emery, Ian McLean, Shirley Lyford, Sylvia Tapuke, Brian Dillon, Phillip Grimmer, Shane Conquer, Daniel Martin
  Toi Ohomai Institute of Technology

- Bin Su, Lian Wu
  Unitec Institute of Technology

- Andrea Stocchero
  Scion

- Daiman Otto, Charlotte Farquharson, Cory Nock
  Tallwood.

Toi Ohomai Institute of Technology acknolwedges contributions from:

- Passive Housing Institute of New Zealand

- Darryl Church Architecture

- Prendos New Zealand Ltd

Citation:

Authors name/s. In Emery, T. & McLean, I. (eds.), *Toitū te kāinga, toitū te ora, toitū te tangata: Healthy homes, healthy people*. Rotorua: Toi Ohomai Institute of Technology.

Citation example:

Emery, T., Tapuke, S., Lyford, S. & Martin, D. (2019). Toiora – whānau health and wellness. In Emery, T. & McLean, I. (eds.), *Toitū te kāinga, toitū te ora, toitū te tangata: Healthy homes, healthy people*. Rotorua: Toi Ohomai Institute of Technology.

Table of Contents

Executive Summary

Toitū te Kāinga, Toitū te Ora, Toitū te Tangata

Affordable housing has become a primary focus of political and economic discourse in the current socio-economic environment in New Zealand. However, much of the discussion centres on supply of houses, availability of land for development, and demand arising from immigration and regulatory processes. Further, housing "affordability" is most often linked to the direct costs of construction and compliance and is routinely and inappropriately confused with the notion of "*cheap*". In contrast, the principle of human wellbeing usually references health (often defined in terms of sickness), poverty and inequality. As a result, the established links between housing performance and human wellbeing are routinely poorly defined or considered in relation to the whole-of-life affordability of housing.

Relative to the norms for the Aotearoa New Zealand (ANZ) population, Māori people are known to be disadvantaged on a variety of economic, environmental and social parameters. Examples are education (low), income (low), health (high rates of chronic diseases), housing (low quality, including overcrowding), incarceration (high rates), and more. To address these issues, Toi Ohomai Institute of Technology (lead research agency) initiated the Toitū te Kāinga, Toitū te Ora, Toitū te Tangata (Healthy homes, healthy people) research project in partnership with the Matekuare Whānau Trust (partner and client), Unitec Institute of Technology, Scion, and Tallwood (an Auckland-based design and technology company).

Partners in the collaborative project aimed to improve understanding of issues of housing affordability and living conditions affecting human health, and wellbeing for the Matekuare whānau in their specific context. Many whānau members live locally in old and run-down housing, including in some of the worst housing in New Zealand, at Minginui. The research project built upon the pre-existing Matekuare Trust planning of a papakāinga development on ancestral whenua at Tāwhitiwhiti, Te Whaiti, Eastern Bay of Plenty. The project focussed on developing culturally appropriate and sustainable housing design and construction solutions delivering life-time affordability, wellbeing and healthier living environments.

Among the research objectives was the development of modular prefabricated housing design solutions to be used in the papakāinga development that would deliver improved life-time affordability and a high-quality indoor environment for health and wellbeing. In so doing, the research aimed to support the whānau to realise their vision of living in affordable, sustainable, and healthy homes built on their self-sustaining papakāinga (tūpuna whenua/ancestral land).

The research project was established and run as a broad, holistic programme, using both quantitative and qualitative research methodologies, with a multi-cultural collaborative approach. Members of the research teams brought expertise in kaupapa and mātauranga Māori, design, construction, public health, architecture and sustainability to support the research.

The different research strands were interwoven as a kete (flax basket), with each informing and supporting the other. Research themes included:

i) design and construction of prefabricated, modular housing (including site layout for the papakāinga);
ii) the health and wellbeing of whānau members; and
iii) the environmental (living) conditions in their current housing.

Although focused on a particular whānau in the eastern Bay of Plenty, the research has wider implications for people experiencing similar conditions and issues throughout New Zealand. Thus, the research has specificity in that it supports a particular whānau, and generality in that it could be used to support the ambition and vision of any similar group of people.

Findings

Toiora: Whānau health, housing status and aspirations

Te tino rangatiratanga o te whānau, ā, koe te ora o te whānau, te tino pūtake o te papakāinga ki Tāwhitiwhiti

Whānau self-determination and wellness are the foundation stones of the papakāinga development at Tāwhitiwhiti

Data gathering methods included face-to-face interviews, respiratory surveys, monitoring of internal house environments (temperature and humidity), and sampling of dust mites and mould. The environmental monitoring period ran from March 2018 to January 2019. Sixteen Matekuare whānau and extended whānau members (10 women and six men) from Te Whaiti, Minginui and Murupara participated in the study, and a reference group consisting of three Rotorua houses was also established. Face-to-face toiora interviews with Matekuare whānau participants were guided by the Te Wheke health model (Pere, 1991).

Toiora interviews

The toiora strand articulates the Matekuare Whānau Trust members' knowledge, understanding and state of health and wellbeing in relationship to the papakāinga development. The findings offer a unique framework of whānau-defined toiora (health and wellness) indicators. In summary:

- Toiora is a dynamic phenomenon that is holistic, and is not framed in terms of the preence or absence of disease.
- Toiora (health and wellness) are directly linked to the collective wellbeing of whānau (family), hāpori (community), whenua (land), and taiao (environment), and the strength of their interrelationships. Reciprocally, healthy relationships are integral to toiora.
- Despite 80% (n=14/16) of the whanāu members suffering multiple medical conditions at the time of the study, sickness and ill health were not mentioned during face-to-face interviews.
- Strong whānau leadership, connection to place, having significant roles in the whānau, cultural continuity, and intergenerational support and succession, are the backbone of healthy relationships.
- Despite poor living conditions, the people in Minginui village have strong support networks underpinned by interdependent relationships that contribute to health, wellness and 'mauri' (life spirit). Conversely, inability to contribute to the wellbeing of whānau, hapū, iwi and hāpori due to a lack of employment opportunities impacts mana (sense of pride) and mauri which, in turn, impacts toiora.
- Owning (belonging to) and knowing the whenua provides a sense of permanance, security, peace of mind and continuity, and is a main foundation of whānau wellbeing.

- The health and wellbeing of the whenua and te taiao is linked to the mental and emotional wellbeing of the people of the rohe (area). The seamless connection of whenua, whānau, wairua (spirit) and tūpuna (ancestors) are a source of self-identity and mana. The concept of Papakāinga is an expression of the combination of these taonga.

The papakāinga development and the impending return to land and home provides hope for a healthy and sustainable future for successive generations of the Matekuare whānau.

Housing and health

Field studies of indoor microclimatic conditions were carried out by researchers from Unitec Institute of Technology, Auckland, supported by Toi Ohomai. Air temperature and relative humidity (RH) were recorded inside 16 houses (six in Minginui, five in Te Whaiti, five in Murupara) and in shaded outdoor spaces in each town. HOBO data loggers placed in the houses recorded data at 15-minute intervals, 24 hours a day, from March 2018 to January 2019. Data were also collected in three reference houses in Rotorua from May 2018 to January 2019.

The data were analysed by Unitec and Toi Ohomai researchers separately to address complementary research questions. Toi Ohomai's emphasis was on the effect of variability in house quality on living environments using data from both winter and summer. Unitec's emphasis was on the links between living environments and health, using data from winter only. Temperature and RH were correlated, and the Toi Ohomai researchers used temperature data only, whereas Unitec researchers analysed profiles for both temperature and RH. Both sets of analyses were guided by United Nations' recommendations for healthy human living environments (WHO Europe, 1987; 2007).

Toi Ohomai researchers addressed:

- variability in living (experienced) environments in relation to houses of different quality
- the effectiveness of the house at buffering external (ambient) conditions in relation to quality of house
- the management of internal environments using passive (e.g. design, insulation) and active systems (e.g. heating, ventilation)

Unitec researchers addressed:

- the temperature and RH ranges experienced by residents in the houses with reference to UN guidelines for human comfort and wellbeing
- the occurrence of mould and dust mites in relation to conditions in the houses
- health outcomes for people living in the houses.

Toi Ohomai results summary

For reference:

- Summarised profiles for individual houses linked to the analyses performed on the data are in the body of the main report.
- The winter and summer temperature profiles of individual houses (with full data ranges) are in Appendix 2.
- Examples detailing how the data were analysed are also given in Appendix 2.

- Individualised reports detailing the results for each house have been delivered to each resident.

A house quality index was developed to enable exploration of experienced environments in relation to variation in house quality; details of the index are in the main report.

Experienced (living) environments varied with house quality; the lowest quality houses delivered the lowest quality environments, but with considerable variation among houses of similar quality (due primarily to the amount of active heating).

Although house quality varied among the four towns studied, “town” did not predict experienced environment; house quality was a much better predictor, independently of town.

Houses of lower quality buffered ambient conditions less effectively than houses of higher quality (= houses of lower quality followed ambient conditions more closely).

All but one of the sample houses were operated at substandard temperatures relative to UN recommendations. The World Health Organisation (WHO) recommends a minimum indoor temperature of 18 °C; 20–21 °C for more vulnerable occupants such as older people and young children; with temperatures above 28 °C treated as overheating.

Adding heat to houses created comfortable living environments even in some low quality houses; a few houses were sometimes overheated in winter.

In summer, poor buffering of ambient conditions resulted in some houses becoming overheated in the hot part of the day, although they usually cooled quickly as well.

In summer, houses of lower quality often cooled to below UN-compliant temperatures during part of the day.

Adding heat from a single source (usually in the living room) did not create a fully-compliant temperature environment throughout the house; most residents slept in cold bedrooms, even if the living area was heated.

The availability of free or cheap energy (as firewood) in some towns meant that the living rooms of some low quality houses were routinely heated to UN-compliant temperatures.

The cost of heating influenced the extent to which houses were heated; the highest quality house in the study - the only house with central heating - was frequently cold, likely due to the cost of operating the central heating.

Temperatures at floor level were routinely several degrees lower than at ceiling level; thus the temperatures experienced by adults (who are the likely decision-makers about whether houses are comfortable) may be several degrees warmer than temperatures experienced by young children who live and play at floor level, especially in houses with no under-floor insulation. Small children also live in much closer proximity to mould and dust mites than adults.

Unitec results summary

With or without insulation, the houses in the study provided substandard living conditions in time (through the day, at different times of year) and space (in different parts of the house).

Some extremely low indoor temperatures were found. In winter mean indoor air temperature was <12°C for 55% of the time (range 3–96%) and 13.2 hours per day (range 0.7–23 hours). In autumn mean indoor air temperature was <12°C for 16% of the time (range 0–52%) and 3.9 hours per day (range 0–12.5 hours). Equivalent values for <10 °C were: winter, 34% (0–81%) and 8.1 hours (0–19.4%); autumn, 8% (0–32%) and 2 hours (0–7.7 hours).

In both autumn and winter, indoor RH met the threshold conditions for mould to germinate and dust mites to thrive. Some sample houses were likely to have had a dust mite problem during both autumn and winter.

There were strong links between dust mite and mould occurrence in indoor spaces of the sample houses. 88% of occupants in the sample houses have long-term physical or mental illness diagnosed by a doctor. Respiratory survey results were strongly linked to dust-mite and mould test results.

Retrofitting the local houses according to the current building codes and using adequate temporary space heating can maintain indoor RH below the threshold for mould to germinate and dust mites to thrive. If there was no mould-spore germination, there would be no problem of mould growth on indoor surfaces. If dust-mite allergens were controlled at a low or undetectable level, there would be no dust-mite allergy problems in indoor spaces.

These results support the broad and previously-established conclusion that older New Zealand housing delivers substandard living environments with poor health outcomes for residents (Barnard & Zhang, 2018). The value of the analyses presented here is in the detail and specificity with respect to the living experience of a Māori community living in very low-quality housing under relatively extreme conditions in the New Zealand environment. An important confounding variable in this study is the availability of cheap or free energy (firewood) in two of the four studied communities. Even with heating cost removed, these communities struggled to reliably operate their low-quality homes to UN-compliant recommended standards.

Papakāinga design - Tallwood

The offsite construction company Tallwood undertook the design and development of the papakāinga, which included provisions for:

- Kaumatua housing and inter-generational housing needs.
- Areas that foster and promote whanaungatanga (shared living and recreational spaces).
- Land to be used for permaculture and the creation of job opportunities for the community.
- Economic self-sufficiency through the incorporation of visitor accommodation.

Through the research and design process Tallwood concluded that:

- The housing stock in New Zealand is not suited to Māori (and Pasifika) families, which are typically large and involve shared inter-generational living.

- Papakāinga must focus on relationships between individual dwellings to promote community interaction.
- The design aims to support the vision of the Matekuare Whānau Trust that the papakāinga will act as a catalyst for future development of the Tāwhitiwhiti site, within the region, and throughout Aotearoa.

There is demand for the (re)introduction of papakāinga living arrangements across New Zealand, including suburban papakāinga. The community wishes to be involved in the construction of the homes to provide opportunities for education and future employment. Once implemented, the housing designs for Te Whaiti would leverage more affordable housing opportunities for similar communities (and others).

A simple house design was proposed. Many aspects of the design were optimised for rapid construction on-site (using modular pre-fabricated building components), minimisation of materials costs, and applying standards well above the building code minimum. The design was modelled hygrothermically by Scion (see below) to optimise the thermal envelope, particularly in relation to heat and moisture flows management, heat loss due to thermal bridges, air tightness, and acoustics. A high quality thermal envelope helps create a healthy and comfortable living environment while also reducing operating costs over the building life-time.

Tallwood's design system utilises a series of modular prefabricated building elements assembled on site. The system optimises material usage and minimises construction waste. Emphasis is on ease of construction and sustainable building materials. In the context of the project, Tallwood's design was an opportunity to create a prototype for future papakāinga development.

Hygrothermal modelling - Scion

The assessment of the co-developed Tallwood system by Scion involved modelling and simulating the hygrothermal performance (heat and moisture flows) of the construction systems (proposed or adopted) for the construction of three different case study buildings known as M1, M3 and M4. The aim was to provide proof of concept for the development of a Te Whaiti Prototype, Tallwood Designed Building, for construction by the Matekuare Whānau Trust.

The case study buildings M1, M3 and M4 are described below followed by the findings of the comparative study:

M1 Building: Standard Building Code – "Rotorua Thermal Holiday Park Bedroom Cabin M1" (already built by Toi Ohomai students)

M3 Building: Enhanced Performance Building – "Rotorua Thermal Holiday Park Bedroom Cabin M3" (already built by Toi Ohomai students)

M4 Building: Tallwood Design – "Rotorua Thermal Holiday Park Bedroom Cabin M4" (potentially to-be-built by Toi Ohomai students)

M1 and M3 building components follow the detailed design documentation prepared by Darryl Church Architecture (DCA), owner of the design rights (note the M2 building is the same as M1 and was not considered in this report). M4 building components have been assembled following and modifying the detailed design documentation provided by Tallwood. The M4 modifications were designed to enable performance comparison of different construction options.

The M4 design is the adapted M1 design, to be built using Tallwood construction technology.

Buildability - Toi Ohomai

Following hygrothermal modelling by Scion, Tallwood's draft concepts and working drawings were used to create a series of mock-ups (models) in order to test the buildability of the plans.

The draft concepts and drawings produced by the design team were indicative rather than complete. With further design and construction innovation, they were used to create a series of mock-ups (models) that incorporated key design features: panelisation, modular construction, off- and on-site assembly, and the maintenance of key performance aspects such as a complete insulation envelope.

Buildability was the foremost criterion in all re-design iterations and mock-ups from the base drawings. Issues addressed included practicalities of component construction, connectivity of components, and convenience of on-site assembly.

Two mock-ups were built. First was a section of flooring with two partial portal frames. Second was in two parts, a 1/8th scale of the entire building shell, and a full-size detail of the critical floor-wall junction.

Having identified issues for the build of the Tallwood system, the construction team then proposed solutions detailed in the full report.

A feature of the design was flexible, variable opening configurations without compromising structural integrity. The construction team found no impact of that flexibility on buildability, either in a factory environment or on site.

Key Findings

The analysis and comparison of the hygrothermal calculations of the different wall, floor and ceiling structure options for the buildings (M1, M3, M4) has shown that:

- M4 building components provide improved U-values and better transient thermal transmission performance compared to both M3 and M1 buildings.
- The positioning of the rigid insulation on the exterior side of the M4 building structure improves the thermal performance of the structural section of the components (structural thermal bridging reduction).

The M4 wall frame section has a lower thermal performance compared to the M4 wall insulation section (expected). However, the M4 wall frame section thermal performance is better than M1 and M3 walls over both frame and insulation section cases.

At 20°C + 2 and 60% + 10 RH indoor conditions, the RH level within the wall component layers for all buildings (M1, M3, M4) is below 100% during the calculation period of three years, showing no interstitial condensation risk.

At 20°C + 2 and 60% + 10 RH indoor conditions, for the RH level within the wall component layers for all buildings (M1, M3, M4), the water content check in each layer showed a decreasing trend for all buildings.

Lower RH peaks in both M3 and M4 wall component layers show improved moisture flow management within the structure, due to the use of moisture control layers (a vapour check and air tight membrane coupled with an exterior weathertight and moisture control membrane).

Relative to WHO Europe (1987; 2007) recommended indoor conditions, the Mould Growth Risk assessment for the same wall component at different indoor climate scenarios (air temperature and RH) indicated a higher risk of mould growth at lower indoor air temperatures and higher RH. This result was consistent across all the M1, M3 and the highly insulated M4 building components selected for this analysis.

Design issues aside, the effectiveness of the building envelope also depends on the management behaviour of residents, and installed technology for heating and ventilation. We did not analyse the quality and performance of the transparent building envelope (windows), or model issues that depend on local conditions, such as layout and orientation. The M4 building demonstrates an optimised opaque building envelope performance, but further work is needed on these other issues.

He Mihi

Nau mai, haere mai

Ngā karu, ngā mata o whenua kē.

Hīkoi mai kia rongo o waewae ki te pātukituki o tōna ngākau.

Whakatau mai ki te whāriki i whakatakotoria e te Matekuare.

Te tīmatatanga o te oranga tinana, oranga whenua, oranga wairua, oranga whānau.

Welcome oh eyes and faces of other lands.

Walk your feet (on the land) and feel her beating heart.

Welcome to the mat that was laid before us by Matekuare.

A start for the resurecction of the health and wellbeing of our whānau.

Moemoea: Kia u ki te whenua (be as one with the land)
Our Lands: Tāwhitiwhiti ki Te Whaiti-nui-a-Toi
Umanganui: To improve the wellbeing of Ngā Uri o Te Whānau Matekuare

He kura kāinga e hokia, he kura tangata e kore e hokia
(A treasured home will endure, not so a treasured person)

This whakatauki attests the importance accorded to the land held and cared for by a group.

Hinerangi Goodman

Chairman, Matekuare Whānau Trust

Introduction

It is appropriate, as we finalise the reporting for the Toitū te Kāinga, Toitū te Ora, Toitū te Tangata research project, that the government has just released NZ's "first ever" wellbeing budget (Charlton, 2019). In principle, this budget puts people before economy, health before productivity, environment before industry, and homes before housing (Statistics NZ, 2019). The realities of these hypothetical shifts in perspective will play out over some years, and only some are relevant to this report. Most relevant is that government is tentatively shifting ground from its traditional role investing in infrastructure, economy, productivity and services, to investment in health, happiness, and wellbeing of people and environment.

This project addressed wellbeing through an essential feature of our daily lives: housing. Specifically, it has documented the housing experiences and health consequences for severely disadvantaged whānau who live in the eastern Bay of Plenty in some of the worst housing in the country (Newshub, 2016). It further aimed to support their aspirations to improve living conditions by building affordable and sustainable housing as a papakāinga on traditionally-owned whenua. "Affordable" in this context incorporates whole-of-life housing issues, particularly construction style, materials cost, operating costs, waste management, maintenance, social preferences, cultural traditions, and spiritual wellbeing. The report by Tallwood discusses some of these issues.

"New Zealand has a great tradition of miserable building standards"

(McKay, W., interview on Radio NZ National Programme, 12 June 2017).

There is nothing unusual about people living in substandard housing in Aotearoa New Zealand (BRANZ, 2015). Before 1979, all houses were significantly substandard relative to the current building code. Cold houses, air contaminated by smoke and ash, high humidity, poor ventilation, and mould in wet areas, were all the norm. Almost anybody born before 1975 will have been exposed as a child to these (now) known risk factors. Fortunately, frequency of smoking has decreased, fewer houses are heated by fires (whether open or enclosed), access to healthcare has improved, and people now understand that wellbeing is linked to much more than money in the hand. Mould, dust, unheated rooms and high relative humidity continue to be problematic, especially in older houses (BRANZ, 2015), and many people continue to live in old houses. Retrofitting to a more modern standard has helped create warmer homes, but has also introduced new problems with moisture control, ventilation and costly repairs (MBIE, n.d.).

Thus, in some respects, the whānau at the centre of our study are simply continuing to live in conditions experienced as normal by many older New Zealanders as young people. However, there are several important differences. First, their houses are 40 years older and most have continued to degrade with age. Second, they have very limited resourcing due to isolation and lack of job opportunities. Third, they are living in villages designed by other people for other purposes. Fourth, the environment in which they live is extreme by New Zealand standards. Fifth, their current living conditions are not consistent with their whakaaro of cultural revival and spiritual wellbeing. Most of these issues are raised in Chapter One in the Toi Ohomai Toi Ora report which reviews the stories of the residents of the studied houses. Chapter One is preceded by a Foreword from the Matekuare Whānau Trust.

The relationship between housing and health issues for people living in substandard conditions in New Zealand are reviewed in the Unitec chapter (Chapter Two) on housing environments. Together, the Unitec report and the analysis of house environmental data by Toi Ohomai give a detailed analysis of the current living conditions for Matekuare whānau members living in Minginui, Te Whaiti and Murupara. A reference group of Rotorua houses was used in some analyses. The reports are complementary, looking at the same data from different perspectives.

The Unitec report concentrates on general trends in data for temperature and relative humidity, specifically in relation to the average living conditions experienced by residents of the studied houses. The analysis focuses on winter, because cold temperatures and associated high relative humidity are known to be primary causative factors in the development of chronic health challenges (refs in Unitec report). The results include data on the occurrence of mould and dust mites, and reference interview and measurement information about health outcomes for the residents of the houses. The analysis confirms that these people experience substandard living conditions as the norm, even if they live in houses with retrofitted improvements. The predicted high levels of chronic health effects were found (although with a small sample).

Using the temperature data exclusively, in Chapter Three the Toi Ohomai environmental report explores variation in living environment among houses between seasons and in relation to outside conditions. An initial prediction that living environment would vary with town was not supported. However, a strong effect was found for variation in quality of house, where "quality" is linked to effectiveness of the house as an environmental buffer. An originally unrecognised factor affecting the results was the availability of free (or cheap) firewood in Minginui and Te Whaiti, which enabled high heat loads to be dumped into low quality houses, although not all residents chose to do so. The complex data set required use of innovative statistical procedures in order to explore polynomials of widely varying shape. Overall, the patterns found were both consistent with the results found by Unitec, and added perspective on aspects of the data that the Unitec report does not explore.

The cost of operating a house was always a significant part of a family budget in New Zealand, but today the cost of housing has become a national obsession (Cheung, 2011; NZIER, 2014). "Cheap" housing exists, but is associated with high risk factors for wellbeing. The "wellbeing budget" from 2019 is an attempt by government to respond to those issues. Houses are now built to a much-improved building code, although the current standards are still low compared with many other OECD countries (IEA, 2017). Most people who build to optimise (= minimise) the long-term operating costs of a house will build to standards well in excess of minimum code. This theme was central to the work by Tallwood, Scion and the Toi Ohomai building team in their development and testing of an affordable housing design for the Matekuare whānau.

In Chapters Four and Five Tallwood and Scion have applied state of the art modelling principles to optimise the house thermal envelope, linked to prefabricated construction with innovative materials that deliver high thermal resistance. Testing Tallwood and Scion's work, in Chapter Six, the Toi Ohomai Construction Team show that the design can by erected quickly on site by relatively untrained workers. Key aspects of the design were tested and improved using models constructed in the Toi Ohomai workshops. House design issues are reviewed in the Tallwood and Scion chapters, and we believe that the design is now fit-for-purpose to whānau requirements and, potentially, for anybody seeking to build affordable housing.

To this end, with the intent of building a full size prototype, in March 2019 Toi Ohomai commissioned Darryl Church Architects (of Rotorua) to take the existing relocatable cabin design (M1) and incorporate the modular and prefabrication technologies into the existing design to create an M4 design. The outcomes of the design process and subsequent quantity surveying and energy modelling, are presented in Chapter Seven.

Combined, the following chapters represent the work of each research team. While standing alone, when read together, the chapters constitute a comprehensive response to the research questions outlined below. References are located at the end of the report.

Research questions

Our research questions, as stated in the original research proposal, are:

- Can we apply the vision of Te Ao Māori, a holistic systems approach guided by mātauranga and tikanga, to create buildings and built environments that become part of the whakapapa?
- Will those designs be affordable? [defined as cost-effectiveness that integrates both development (building) and operational (living) outcomes]
- Will the designs deliver optimised internal living environments? [specifically relative to how people originally lived (before/after research design), and more generally in relation to accepted baseline standards for human housing]
- Can the designs deliver measurable improvements to wellbeing?

Foreword from the Matekuare Whānau

Hinerangi and Tony Goodman

Prior to the participation in the National Science Challenge, the Matekuare Whānau Trust had, for many years, been planning and commencing the necessary infrastructure development for the construction of our own papakāinga. Adopting a largely ad-hoc, necessity driven approach at the outset, opportunities indavertently took precedence over research and planning. However, as a result of our engagement in the Challenge, this approach has changed dramatically.

Engagement in the Challenge has convinced us that research is a tremendous opportunity to enhance the planning and practical side of the papakāinga development. There is much to more to do; some of which has been identified during this project.

The research has encouraged us to look at a wide variety of subjects in relation to the papakāinga and to ask and seek answers to the following questions:

- Who will live there and how can they be enabled to do so?
- How will the buildings relate to each other?
- How will the residents relate to each other?
- How will the building design benefit the residents and promote good health?
- How does the papakainga plan and building design support intergenerational living?
- How, through papakāinga living, can the residents experience “wellness” in its fullest sense?
- What are the opportunities to generate economic and financial sustainability from (within) our local surrounds and how do we ignite and develop these?
- How can technology enhance and support the creation of a self sustaining (rural) papakāinga?

The research has forced us to re-think our notions of housing and cost. That is, to distinguish between “cheap” and “affordable” and shift our focus to ‘affordability over a life time’ rather than bulding costs at the time of the build. For us, cheap refers to lowest price construction costs at the time of the build, while affordable means that the occupant can pay the deposit and service a loan. Affordability over a life time, however, incorporates blanket living costs as well as the loan servicing (or rental fee), lifetime building maintenance including insurances, etc. Affordability over the lifetime integrates, and is enhanced by, the design of an energy efficient healthy home that produces cost savings over the lifetime of the house through reduced heating costs. This multifaceted and important feature has been a key focus of the papakāinga housing design within the Toitū te Kāinga, Toitū te Ora, Toitū te Tangata – Healthy homes, healthy people research project.

The papakāinga development takes account of all the things that can now be done on the land and within the surrounding rural environs that embrace it. To this end we have applied thought to the new opportunities that are arising as a result of the declining cost of distance. We are seeing a plethora of new opportunities arising from the end of a high speed internet connection. Also from the automation and localisation of many former aspects of jobs, and life, that were formerly associated with living in the city or suburbs for example, virtual health services.

Perhaps the most enduring thing about our involvement in the Challenge has been the association with researchers, writers, scientists and practitioners of health in relation to housing with whom we have been, and still are, associated. This has been a great addition to our on-site, land based development organisation (i.e. the Matekuare Whānau Trust) that previously operated without much thought given to the wider aspects of living, health, relationships and wellness.

CHAPTER ONE

Toiora – whānau health and wellness

Tepora Emery, Sylvia Tapuke, Shirley Lyford, Daniel Martin
Toi Ohomai Institute of Technology

Introduction

The objective of the Toiora component of the research was to provide an holistic (self-defined) view of the research participants' health in relation to their housing and associated environmental conditions. Juxtaposed with the quantitative analyses in the Unitec and Toi Ohomai reports, this report provides a broader understanding of the health and wellbeing of the whānau based on their individual and collective experiences, concepts, understandings, and definitions of toiora.

Methodology and Research Philosophy

Qualitative interviews were undertaken with 16 whānau members (study participants) - ten women and six men - living in Minginui, Te Whaiti and Murupara. Interview questions were developed using the Te Wheke health model (Pere, 1991) as a guide (Appendix 1). Recorded interviews were transcribed and transcripts were returned to participants for validation. Participants were also offered copies of their recorded interviews and received copies of both the initial findings and final reports.

Data were thematically analysed by the toiora research team over a series of three one day wānanga. Emergent themes were identified from individual interview transcripts through a process of 'reading together and across' the data. Identified sub-themes were then grouped under main themes being, whakapapa, whānau, hāpori, whenua, taiao, papakāinga and tūrangawaewae. The themes are interrelated and mutually dependent. Preliminary findings from the research were presented to, and validated by, the Matekuare whānau (study participants). In addition to this report, final results were also reported in individual housing and toiora profile reports given to the study participants.

Te Wheke

Using Te Wheke as a framework for developing the research questions enabled a multidimensional depiction of health incorporating: taha tinana (physical); whatumanawa (emotional); hinengaro (intellectual); taha wairua (spiritual); turangawaewae (heritage); whanau (social); te tuakiritanga o te tangata (individual mana); and mauri (life force and essence) to emerge. Together, these dimensions are embodied within the korowai hihimā (woven cloak, Figure 1) which is the philosophical framework for the overall research project.

Figure 1. Philosophical framework of the research project, Te Korowai Hihimā

Te korowai hihimā is the graduation cloak of the Department of Nursing at Toi Ohomai Institute of Technology. Woven from natural hemp fibre with undyed tassels and threads (hukahuka), the name hihimā means rays of light and refers to the movement of the hukahuka catching the light as the korowai is worn. In the context of this research, te korowai hihimā symbolises fundamental human needs of warmth, shelter, waterproofing and safety. The Te Wheke (Pere, 1980) health model forms te hihimā and lies within the whatu (weave) of the korowai as an expression of holistic whānau health.

Representing whānau, the upoko (head) of the wheke (octopus) is embodied within the nape of te hihimā. Ngā karu o te wheke (eyes) represent individual and collective toiora (total whānau wellbeing), while the eight wekeweke (tentacles) represent the holistic health dimensions. The wekeweke are depicted within the whenu (weft threads of te hihimā) that descend from Te Wheke's head at the nape. The aho (main thread) of te hihimā is the binding force that pulls the multidimensional health strands (wekeweke o te wheke) together resulting in overall (holistic) wellbeing. The constant movement of the whenu (wekeweke o te wheke), represents the dynamic nature of health and wellbeing in relation to the different lives, experiences, and changing circumstances of whānau/families, including those at the centre of this study.

In her completeness, te hihimā epitomises Te Wheke (Pere, 1991) as a traditional Māori approach to health and wellbeing. Holistic, unified and natural, this approach recognises the connection between hinegaro (mind and female elements), tamaroto (mind and male elements), wairua (spirit or the two waters that flow within humans), whānau/topuranga[1] (Emery, T., Cookson, H., Raerino, N.), and te aō tūroa (the physical enduring world).

Te Hihimā and the study

In the context of this study, the Tāwhitiwhiti lands and the papakāinga form the aho matua (main thread) of te hihimā, which is the āhurumōwai (sheltering cloak and philosophical framework) for the research. Based on this framework, everything that happened in the research was designed to connect to, support, and work in harmony with, the papakāinga (development) as the aho matua. To this end, the research findings articulate the participants' knowledge and understanding of health and wellbeing, in an everyday context and in relationship to the papakāinga vision. The stories gathered can be likened to the threads of the korowai hihimā; they breathe life into, bind, strengthen and invigorate the kaupapa (te papakāinga me te orangatonutanga o te whānau).

---

[1] *Human connection and the realm of significant relationships a person has.*

Through the whānau stories, the research revealed two key outcomes (findings) that were extrapolated in the results section under the main (thematic and interrelated) headings: whakapapa- whānau- hāpori-pūrakau and whenua-taiao-papakāinga-tūrangawaewae.

Results

Key Finding One

Te tino rangatiratanga o te whānau, a, ko te ora o te whānau, te tino pūtake o te papakāinga ki Tāwhitiwhiti. Ko te whenua te oranga o te whānau.

Whānau self-determination and wellness are the foundation stones of the papakāinga development at Tāwhitiwhiti. The land is the fundamental source of whānau social and economic wellbeing.

Healing, returning to, and sustainably reoccupying their ancestral lands is seen by the whānau as a pathway to economic wealth and wellbeing for successive generations.

Key Finding Two

In an everyday context, health and wellbeing are considered synonymous. Health is holistic and not confined to the absence of disease; rather, it is dynamic and constantly changing.

What whānau told us is that health and wellness are the same and you can't have one without the other. Even with the multiple medical conditions that some of them have, nobody spoke of being sick or unwell. For one participant, to be in good spirits was to be well: "to me being healthy just means like, in good spirits. You know what I mean". As such, all participants were well (at the time of their interviews) despite, for example, some being in pain, having high blood pressure, diabetes, asthma and, at times in their life, varying degrees of depression. This said, the toiora interviews took place in late March 2018 when the days, and memories of summer were still warm and people were feeling good and, in early 2019, one of the research whanau died suddenly, and very sadly, from heart related illness.

Also noted was the integral role of the doctor in the Minginui Village and Te Whaiti Valley areas with his fully subscribed fortnightly visits. Routine, or 'must', visits to the doctor were the norm for participants. For example, according to a relative (and carer) of a participant, despite not needing to go to the doctor, and having a standing prescription at the chemist, the participant regularly insisted on going to the doctor at Minginui for a consult and to get a prescription. As the only remaining social service (of any kind) in the Te Whaiti-Minginui area, visits to the doctor have become an opportunity for whānau to commune with others, maintain relationships and take advantage of a last bastion of Government support – all of which contribute to health and wellbeing.

Themes underlying the Key Findings

Whānau participants had a strong sense of self and collective whānau identity, coupled with an interminable sense of belonging to place. Whānau stories (as told during interviews) were shown to hold, propagate and strengthen this security of identity. Shared by blood as well as love lines, the interview summaries show how a secure identity contributes to whānau participants' mana (prestige), mauri (life force) and toiora (overall sense of health and wellbeing).

What whānau told us about their health and wellbeing is presented below. Summarising statements are given first followed by supporting participant quotes. To ensure confidentiality and anonymity of participants, the direct quotes used in the following sections are unreferenced. All whānau participants are quoted at least once in the findings section. The quotes were selected based on their relevance to the key findings and are representative rather than definitive. Each has both specificity in relation to the context where it is used, and generality in that it may encompass several themes in the results.

Whakapapa-whānau-hāpori-pūrakau

- **The essence of who you are (your mauri) and the vitality of your being are sourced through whānau, whenua, hāpori and taiao (family, land, community and the unique environment).**

For my daughter, her wellbeing, I want her to know how to live off the land. Her connection with the land, whānau and with wairua I feel is important. Her tūpuna. Those things give me strength to know that I come from a long line of chiefs that go all the way back to our beginnings. I would rather have this life than the city.

It straight away puts me into a beautiful space where we live - our maunga, I love being here.

The bush is a spiritual place for anybody I think – like for all of us in the village here and down in Te Whaiti, Ruatāhuna and places like that. I just normally, you know, have a bit of a quiet karakia to myself when I'm in there.

I'm blessed to belong here. I am not manuhiri, I am from here.

- **Mauri is essential to maintaining toiora. Mauri comes from having a strong sense of identity and self-worth (mana). Mauri and mana are strengthened through 'tūrangawaewae' or, a strong sense of connection and belonging to land, place and people, past and present (whakapapa). Inability to contribute to the wellbeing of whānau, hapū, iwi and hāpori, for example through paid employment, negatively impacts mana and mauri which, in turn, impacts toiora.**

The mahi [work] I am choosing at this moment is in the maara [garden] and connecting to the land. So there's a whole wellness journey going on. There is an instant connectedness and instant love and oneness for where I am and appreciation of all that is. Especially when I put my hands in the soil. Everything about being on the whenua, from the moment of walking into the maara.

They were healthy working; they were mill workers, the mill got taken away and they got sick…lost their jobs; no work and then they just sat down on the couch…

I was in that down buzz [when I first came back to live in Te Whaiti]. It was the first time in my life that I've ever been out of work.

- **The wellbeing of the whānau is not determined by the wellbeing of its individual members but rather, by the wellness of the whānau as a collective unit. The collective health of the whānau is reflected by the strengths of the relationships (whanaungatanga/connectivity) that whānau have to each other. Whānau relationships and connectivity are multidimensional and rely on strong whānau leadership and recognition of the place, role and gifts of the young.**

Now I am busy doing my Matekuare whānau standing tall with them helping one another to make a future for ourselves, for the mokopuna tuarua. Yeah I might not see the results of what we are doing but I know it's going to be done. For me that's what is important. My whakapapa, my whānau, my marae. Kāre e ko atu kāre e ko mai ... kāre e ko atu kāre e ko mai.

The leader would have to take a stand on being united because divided we fall...

We see the leader step forward and you shine ... and we know who you are because we are a family that are close, we laugh, we cry and we carry. Because the ones who are fighting are important. If we fight I can't just leave her there, I have to take her home and sort it out. That is a strength.

Our children are paramount here; they bring us together. They can empower us and put us in places we wouldn't take ourselves.

- **The modesty, stature and visionary qualities of the tūpuna Te Hira i.e. his self-transcending values, has provided Te Matekuare whānau with an exemplar, and a vision, that they are endeavouring to follow. Love lines (in laws) as well as blood lines are committed to the vision.**

Koro Te Hira ... he was before my time when I think about Te Hira and what for me, what he has done is he has secured a future for his generations by being who he is...

That's all he had to do. To be himself... so imagine if we just be who we are. Imagine the potential and the capacity there.

I always believe these things are lead. Koro Te Hira has been instrumental in his wairua (spirit) - this land, Tāwhitiwhiti was going to unite all of us. The land had been lonely and quiet for a long time but it was always there. And now its brought us together. It's an awesome journey. Nearly thirty years.

- **Holding, sharing and practicing common beliefs, values and aspirations are the cornerstones of whānau relationships and, thereby, the collective health of whānau.**

My house is like a marae always open to everybody.

We all care for each other. We all come together if something is wrong, but you have your space.

Having whānau around helps me feel well; it makes you feel a bit stronger and you know you have something to live for especially when it comes to your moko. Moko are the most important thing. They are the future.

- **As exemplified in the story excerpts in the quotes below, storytelling breathes life into whānau; it binds, strengthens and heals and is integral to whānau connectivity, enduring presence and mauri.**

…the sea was calling him that night. The brothers were sitting beside me with him. They all disappeared. The house we were in was three or four miles from the sea. They could hear the sea, it was loud, loud.

…you can be a big family but still be alone – but I didn't want that for her. She had a father. My grandmother helped to bridge the gap. I knew then I was a grandchild. There was no way was I giving my children away. It was my grandmother's idea to do that, to bridge the gap.

I loved it when you guys [the researchers] came down and we sat around as whānau. We love talking about the past... also for my mum as well. Sharing. I really enjoyed that day.

- **While there is some insecurity around ownership of land, and despite cold, damp living conditions, the people of Minginui Village have strong support networks underpinned by close interdependent, reciprocal relationships that contribute to a strong sense of identity and home. Strong connectivity among whanau protects against loneliness and contributes to overall health and wellness.**

We think it's awesome [the Papakāinga development] it's just the land you own it. The land we sit on here belongs to the Ngāti Whare Trust.

They come from this house to that house. The moko come every holiday; they go fishing, eeling and hunting. That one wants to go for the roar.... They are free. We feel safe, we know they are safe ... they all know everybody, they are all related; there is no danger. They are not allowed in the bush without me but in the village yes. We are all family we are all related somehow.

There's no loneliness [here]. In a city you can have people all around you but you can still be lonely. In Minginui and Te Whaiti, loneliness doesn't exist.

- **Maintenance of relationships, staying connected and communing with each other is important; as is the need for privacy and solitude. Papakāinga planning needs to accommodate these dual, human and social needs.**

To me [living at the Papakāinga] means stronger communities and whanaungatanga - building strong bonds through generations. Looking after our old people. Creating layers of generational community and goodness. We are all just connected with kui and koro and the moko ... And looking after our people in the urupā – we bury our dead and a lot of time someone else tends to them.

- **Through critical dialogue around the papakāinga development process, and through engagement in the research, whānau unity (that had not been overt) has become more apparent. Hearing their own words back (through the research) has enlivened and reinvigorated the papakāinga vision and strengthened the voice of whānau unity and oneness of mind.**

Hearing the korero back from the research puts you in a comfort zone. We're opening up about different things - our private lives ... I think it's a good thing. It shows we are all thinking along the same lines and I can see we are all on the same page. Now I won't be so shy to say something when I see somebody because we all thinking the same.

Discussion

Whānau vision, unity, authority, oneness of mind and purpose, have been strengthened through papakāinga visioning and the research process. Combined, research and development has contributed to whānau transformation in three ways. Firstly, through improved communication the individual voices of the whānau have been heard and appreciated and their collective agenda reinforced with lived experience. Secondly, a deeper understanding of individual needs, and individual understanding of the needs of the collective, has developed. This knowledge has helped to improve critical decision-making processes at the Whānau Trust board table. Finally, the opportunity to better understand their dire housing conditions (in relationship to their health conditions) now exists in ways as never before. That is, armed with 'hard' research evidence, and proposed solutions, the whānau are empowered to make informed change/s to better themselves.

As articulated in the following quote, the opportunity to choose healthy, affordable (over a life time) housing solutions for the papakāinga is a whānau aspiration:

> [Whatever the research result] good or bad, that we can better it. Always to better ourselves. If our homes are not good inform us and give us the knowledge that we can use to make it better. We want to know, to look at all the possibilities for making our homes better and we can take it from there (Anon. research participant, 2018).

Aspirations for a healthier home were also articulated in the following way by a resident of Minginui. Hoping everything “just works out” she said:

> A very healthy home. If you can rectify what’s wrong; intergenerational – for the little ones here the mokos. [They] are the most important thing. When we get older we are going to get sicker if our homes are unhealthy. I hope everything just works out (Anon. research participant, 2018).

Whenua – Taiao – Papakāinga - Tūrangawaewae

The study found that the health and wellbeing of the whenua and the taiao is linked to the mental and emotional wellbeing of the people of the rohe (area). The seamless connection of whenua, whānau, wairua and tūpuna (ancestors) are a source of self-identity, mana (pride) and hope for the people. The papakāinga is an expression of the combination of these taonga (treasures). Through the papakāinga, the whānau see themselves as re-establishing their tūrangawaewae (at Tāwhitiwhiti) and rebuilding the strong community that once was at Te Whaiti. Creating a “positive generative space for successive generations” (Anon. research participant, 2018) is the goal.

For the participants, their houses alone are not a home; rather, home constitutes a range of factors as expressed in the findings below.

- **The house is a shelter, the taiao/environment is home. The pull of home is visceral (organic) and it is people (past and present) and the land who are the home.**

It’s in our best interest to keep up to date with what’s going on in our home. It’s not a house – for me this home is a self- investment of manawa, of ngākau, of aroha and not just for myself but for my children. I have one mokopuna and a legacy, compared to a house. A house is just a building with doors, and walls and windows. If you don’t invest in your home and fill it up with love and caring and nurturing… This is a place of respite – our home is a place of respite; a sanctuary a haven for myself and my family. That’s the difference between a house and a home.

In this village; we are altogether as one. It’s like a big family, that’s what it is. Home it’s really home – the land; being around the people, the tupuna. We all care for each other. We all come together if something is wrong.

- **Owning (belonging to) and knowing the land provides a sense of permanence, security, peace of mind and continuation; and is a main foundation of whānau wellbeing.**

Pai ki āhau nga kōrero. Ko ahau ko te maunga, ko te maunga ko au. Ko au ko te whenua ko te whenua ko au. Kare e ko atu, kare ko mai.

For me the kōrero is good. I am the mountain and the mountain is me; I am the land and the land is me and that is final.

It is like a papakāinga here but we don’t own the land. It will be a class thing if [we] pull it [the papakāinga at Tāwhitiwhiti] off. To be able to come back as a whole. Joining the circle back together on that land YEAH ... that is the only place I will move to I will be proud to. Beautiful place.

The value, freedom, and potential of the unique Te Whaiti environment, and what it offers, is tantamount. Ongoing loss of knowledge (of the whenua) and environmental degradation and damage undermines this potential.

The hunting, the fishing, the trout, this place is magic ... exciting its exciting, you see things and it's like, that wasn't there yesterday…

A lot of people don't go out and get food now. In the old days they did. Now they're on their computers and phone, there's too much of that. They drive to Murupara to get a pie. It's how it is today, been unemployed too long, nothing for them get back into work. It's pretty hard.

[1080?] The effects are quite obvious. You could get very sick and the proof is in the pudding. Go in the bush after a 1080 drop and it's quiet as. Every animal has gone. The bush is quiet and eerie. It's quite scary - they killed them. Boy. [It] effects my mind because the mind is thinking why do that? The health of forest and the birds. All is poisoned. The piko piko, do you really want to pick that – the poison stays in the soil; we take the pikopiko… I won't go right in the bush, I call it dead land. It affects the kai and the birds and happiness - no birds no happiness. Doc is the kaitiaki, the guardian – why do they do that?

- **Inclusion in planning, contributing ideas and being heard, included and updated on papakāinga developments is critical to the success of the whānau vision.**

If I had a choice on Tāwhitiwhiti I would have a centre, a mini marae, a place for when our people come home. Where we can rock on in and feel comfortable. Where we can know, I belong, just like a mini marae.

- **Maintenance of relationships, staying connected and communing with each other is important; as is the need for privacy and solitude.**

Everybody likes to have their privacy, you have to be able to have your bit of privacy. Even this here [in the village] is too close but I'm just lucky I've got good neighbors.

[My] Feelings are mixed. You try to move down to get space and there it there goes.... have you got a cup of sugar? My dream view is about to be crushed but on the other hand, the whānau are gathering again and they are all whānau. You have to have these developments to get the whanau down. I can see what it's all about. I can see the good points of it all. I think it's going to bring back a lot of the Māori tikanga, communities raising children and working together as whanau.

Discussion

"Our time will come. Maybe not for us, but for the young ones here…" (Anon. research participant, 2018).

The research has shown that all the dimensions of life (the wekeweke) of the wheke (the whole) are constantly moving, shifting and rebalancing to maintain a sense of wellbeing (toiora) that is grounded in whānau, hāpori, whenua and the taiao. For the Matekuare whānau in the study, wellbeing doesn't exist in isolation. Rather, it lies within these four dimensions which co-exist, are interrelated and dependent. Further, despite 88% of participants suffering from respiratory and other illnesses as a direct result of their poor housing conditions (Su & Wu, 2019), the whānau are survivors. Supportive and protective of each other; they are spirited, determined, resilient and strong together.

Through the storying process, and guided by Te Wheke, unique, all encompassing (self-defined) health and wellbeing indicators have emerged that run counter to conventional (Western medical) health narratives. Tools of self-empowerment, these indicators enable the whānau to rise above physical (house and health) realities and to recognise, and draw from whānau, hāpori, whenua and the taiao as the sustaining essence of toiora.

Toiora, as defined by the whānau participants, is not about the absence of disease. Rather, it "acknowledges the link between the mind, the spirit, the human connection with whānau, and the physical world in a way that is seamless and uncontrived" (MoH, 2017). Whenua (caring for the land and maintaining an enduring presence upon the land); whānau (connections, relationships and leadership); whakapapa (knowledge of self through the web of generations); tūrangawaewae (having a sense of ownership of land and a place to stand and call home); ngā uri whakaheke (consideration for subsequent generations and continuance) and ngā korero o mua (stories from past, present and future) were shown (in this research) to be integral to health and wellbeing.

Tāwhitiwhiti, the papakāinga, is seen as the place where these phenomena intersect and the whānau journey to optimum wellness, can be brought home through the goodness of the whenua. In keeping with this vision, when speaking of her personal Tāwhitiwhiti journey a mother, grandmother and kaitiaki whenua (carer of the land) said:

> The mahi [work] I am choosing at this moment is in the maara [the garden at Tāwhitiwhiti] and connecting to the land. So there's a whole wellness journey going on. There is an instant connectedness and instant love and oneness for where I am and appreciation of all that is. Especially when I put my hands in the soil. Everything about being on the whenua, from the moment of walking into the maara …

Through praxis (Freire, 1996) the whānau have recognised the papakāinga development as a journey rather than a destination. Part of the journey has been about familiarising themselves (and engaging with and activating) the hierarchies, laws, languages and rules of the bureaucracies who hold the resources they need. Utilising cultural methodologies such as hui, wānanga, whakapapa, whanaungatanga and kai, has assisted the whānau to navigate this new terrain and also, to recognise and understand that the responsibility for securing the future for their tamariki-mokopuna lies, ultimately, with themselves. That is, through reflection and action (praxis) the whanau have revolutionised their thinking, transformed their whānau structures and, thereby, their reality.

He kupu whakamutunga – some final words from the whānau

In her summation of the whānau legitimisation of findings wānanga, a whānau member made reference to the reliability of the research findings around the health and wellbeing of the community. Referring specifically to the comments the research team had made about nobody saying they were sick or unwell in their interviews, she said:

> There's an undercurrent that flows with the people here some of us call it whakamā – shame. So we won't share our deepest pain and fears ... and that flows here amongst us too. I have seen it on the TV… [in the negative portrayals of Minginui]. The undercurrent. We're not actually like that. You have to come here and be amongst us. It's not for me to say how great I am. [Sickness] It's a part of our life but it's not something we are going to highlight either. We have undercurrents, ebbs and flows. All our families. You have to come and feel how we are.

The research team invested much time, energy and aroha going to, and staying in, Te Whaiti to 'feel' how the research participants 'are'. The honesty and directness of participant feedback, as demonstrated in the quote above, was evidence that the relationships established by way of this 'investment', had born fruit. Further supporting this notion are the words of Hinerangi Goodman, the matriarch of the Matekuare whanau, who is also the haukāinga leader of this project. A testament to the rich research relationships that exist, Hinerangi's quote below encapsulates and attests to the power of kaupapa Māori research processes to achieve outcomes that go far beyond contracted research milestones and outcomes:

> I always believe these things are led. Koro Te Hira has been instrumental in his wairua [spirit]. This land, Tāwhitiwhiti, was going to unite all of us. The land had been lonely and quiet for a long time but the land was always there. And now it's brought us together. It's an awesome journey. Nearly thirty years. We go away and leave her behind, come back she's still there. Her time has arrived, it's our time. The spirit that has moved us along. It's time. I'm marvelling at you, my angels for taking this beautiful journey with us.
>
> The land has always been there beckoning to us... all around what's going on… the global picture. It's all there for us. All we have to do is move with it, it's a huge healing thing. Let's come together, heal each other and get well. Become truly whānau. Our tūpuna would be so happy this is happening a living moving breathing thing.
>
> That spirit is what is moving with us. We, each other, is what is important. What has been brought to life is real. It's now.

Whatungarongaro te tangata, toitū te whenua. People perish but the land remains.

CHAPTER TWO

House Occupants’ Health Conditions and Their Living Conditions

Bin Su and Lian Wu
Unitec

Introduction

This study focuses on participants’ health conditions, related to their living conditions, in the Minginui, Te Whaiti and Murupara areas of New Zealand. Sixteen sample houses in these areas were randomly selected for this study. Field studies of indoor microclimatic conditions in the 16 sample houses related to indoor health conditions, and involved collecting dust mite and mould samples, and testing dust-mite allergens, testing mould and spores and identifying types of mould in 13 of the sample houses.

Respiratory Health Surveys were carried out with occupants in nine of the sample houses, and lung function tests of occupants in some sample houses were carried out during the winter of 2018. Four sample houses in Rotorua were randomly selected for this study as reference houses. Rotorua was chosen as the site for the reference houses, as it’s close to the study area and has similar climate conditions. The sample houses in Rotorua have basic insulation, in contrast to the houses in the Minginui, Te Whaiti and Murupara areas, which have either inadequate or no insulation.

Research Methods

Field studies of indoor microclimatic conditions were carried out by researchers from Unitec Institute of Technology, Auckland, in 2018. Air temperatures and relative humidity adjacent to floors and ceilings of different indoor spaces in the 16 sample houses (six houses in Minginui, five houses in Te Whaiti and five houses in Murupara) and shaded outdoor spaces were continuously measured and recorded at 15-minute intervals, 24 hours a day, by HOBO temperature and relative humidity (RH) loggers, from March 2018 to January 2019. Air temperatures and relative humidity adjacent to floors and ceilings of different indoor spaces of the four sample houses in Rotorua were also measured and recorded during the winter of 2018 as reference data for the study.

Field study tests of dust mites and mould in 13 sample houses were carried out by Unitec researchers in the winter of 2018. According to the instructions for the Ventia™ Rapid Allergen Test, dust mite samples on the carpets of living rooms and bedrooms of the 13 sample houses were collected by a vacuum cleaner fitted with a DUSTREAM® collector, and dust-mite allergens were then tested using the Rapid Test cassette. Comparing the colour intensity of the test line with the indicator lines shown on the test cassette can identify four different levels of dust mite allergens:

1. Undetectable dust mite allergen, no action is needed to reduce indoor mite-allergen level.
2. Low level of dust-mite allergen (less than 0.2 micrograms per gram of dust), no action is needed to reduce indoor mite allergen level.
3. Medium level of dust-mite allergen (0.2–1.0 micrograms per gram of dust), take action to reduce indoor mite-allergen level to protect occupants’ health.

4. High level of dust-mite allergen (approximately 1 microgram or greater of Group 2 allergen per gram of dust), take action to reduce indoor mite allergen level to protect occupants' health.

Dust mite allergens of four sample houses in Rotorua were also tested. According to the instructions of Biodet Services Ltd (consulting industrial microbiologists), the researchers used clear, standard Sellotape to collect mould samples from the indoor surface areas of the 13 sample houses in the Minginui, Te Whaiti and Murupara areas. The Sellotape with the mould samples was then folded in non-stick baking paper and placed into a plastic bag; the samples were then sent to the local testing lab, where they were examined both macroscopically and microscopically.

The respiratory survey questionnaire used in this study was adapted from the European Community Respiratory Health Survey, which has been used for 200,000 participants to date. The questionnaire investigates the participant's basic health profile, respiratory symptom prevalence, risk factors, medication and related medical history, and all possible related factors. After the occupants signed the consent form, the Respiratory Health Survey was carried out by the research assistant (a nursing graduate), appointed by Toi-Ohomai Institute of Technology. The research assistant conducted interviews and explained all the questionnaires in both Māori and English, to ensure the quality of research. Survey results were entered into an Excel spreadsheet and analysed using SPSS Statistics software. A total of 11 participants from nine sample houses in the study areas, Minginui, Te Whaiti and Murupara, took part in the Respiratory Health Survey. Seven participants from three of the sample houses in Rotorua also took part in the Respiratory Health Survey to provide reference data.

The lung function tests of occupants in the sample houses were carried out by Toi-Ohomai and Unitec researchers. According to the instructions of the US Medical International Research (MIR), lung functions of participants were measured using a portable spirometer. The lung function results, including forced vital capacity (FVC), forced expiratory volume in one second (FEV1) and their ratios, were downloaded and analysed using the Winspiro PRO® PC software. However, due to the sample size being too small and the variation too large, the analysed results of lung function are not included in this report: additional lung functions tests are required for further analysis.

Data Analysis and Discussion

This report is based on indoor microclimate data of the 16 sample houses; dust mite and mould test data of 13 sample houses; and Respiratory Health Survey results of 11 participants from nine sample houses in the Minginui, Te Whaiti and Murupara areas. Indoor microclimate data from the four sample houses in Rotorua; dust mite and mould test data from three of the sample houses; and Respiratory Health Survey results of seven occupants in three of the sample houses in Rotorua were used as reference data for comparison. All field-study data of temperature and relative humidity of indoors and outdoors have been converted into percentages of time in winter when indoor temperature is equal to or greater than 10 °C, 12 °C, 14 °C, 16 °C, 18 °C, 20 °C, 22 °C, and when indoor relative humidity was equal to or greater than 40%, 50%, 60%, 70%, 75%, 80%, 85%, 90%, 100%, and within the range of 40–60% for the purposes of comparing indoor temperature and relative ranges related to occupants' health conditions, thresholds of mould germination and growth, and thresholds of dust mite growth and survival. For example, the percentage of time in winter when indoor temperature is equal to or greater than 10 °C is from the calculation result of the number of temperature measurements that are equal to or greater than 10 °C divided by the total number of temperature measurements during the winter, for all houses. The autumn data (from 28 March 2018 to 31 May 2019 used for this study are based on 28 indoor spaces (14 north-facing indoor spaces and 14 south-facing indoor spaces) of the 16 sample houses. The winter data (from 01 June 2018 to 21 August 2019 are based on 25 indoor spaces (13 north-facing indoor spaces and 12 south-facing indoor spaces) of the 16 sample houses and four indoor spaces of two sample houses in Rotorua.

Low indoor temperatures

Both low indoor air temperature and high relative humidity can negatively impact occupants' health. The World Health Organisation recommends a minimum indoor temperature of 18 °C for houses; and 20–21 °C for more vulnerable occupants, such as older people and young children (WHO, 1987). Table 1 and Table 2 show profiles of indoor temperatures of the 16 sample houses, which are based on mean indoor air temperatures and percentages of time in autumn and winter related to different ranges of temperatures in each of the 16 sample houses.

Differences of mean indoor and outdoor temperatures of the 16 sample houses were 2.8 °C for autumn and 3 °C for winter. Mean air temperatures adjacent to the ceiling were 2.4 °C and 2.2 °C higher than floor temperatures during autumn and winter respectively. Mean indoor air temperature of the 16 sample houses during winter was 11.8 °C, with a range of 7.4–16.2 °C, which is much lower than 18 °C, the minimum indoor temperature required for maintaining healthy indoor conditions. In winter, the mean indoor air temperature of the 16 sample houses was lower than 18 °C for 93% of the time, with a range of 68–100%. In autumn, the mean indoor air temperature of the 16 sample houses was lower than 18 °C for 65% of the time, with a range of 26–96%.

Previous studies show that the minimum threshold of indoor temperature required for limiting respiratory infections is 16 °C: there is increased risk of respiratory infections when indoor temperatures are below 16 °C (Collins, 1986; Braubach, Jacobs, & Ormandy, 2011). Table 3 and Table 4 show the percentages of time in autumn and winter in relation to different indoor temperature ranges below the thresholds of healthy indoor conditions. For 86% of the time in winter (with a range of 55–100%) and for 20.8 hours per day (with a range of 13.2–24 hours per day), mean indoor air temperature was lower than 16 °C. For 46% of the time in autumn (with a range of 10–88%) and for 11 hours per day (with a range of 2.4–21.1 hours per day), mean indoor air temperature was lower than 16 °C. Indoor temperatures below 16 °C can result in high indoor relative humidity. Most of the factors that adversely affect health, such as bacteria, viruses, fungi, mites, allergic rhinitis, asthma, etc., have increases associated with high indoor relative humidity.

Indoor temperatures below 12 °C can cause short-term increases in blood pressure and blood viscosity, which may increase winter morbidity and mortality due to heart attacks and strokes. When elderly people are exposed to indoor temperatures of 9 °C or below for two or more hours, their deep body temperature can start decreasing (Lloyd, 1990; Hunt, 1997; Goodwin, 2000). This study shows that for 55% of the time in winter (with a range of 3–96%) and for 13.2 hours per day (with a range of 0.7–23 hours per day), mean indoor air temperature was lower than 12 °C. It also shows that for 16% of the time in autumn (with a range of 0–52%) and for 3.9 hours per day (with a range of 0–12.5 hours per day), mean indoor air temperature was lower than 12 °C. For 34% of the time in winter (with a range of 0–81%) and for 8.1 hours per day (with a range of 0–19.4 hours per day), mean indoor air temperature was lower than 10 °C. For 8% of the time in autumn (with a range of 0–32%) and for 2 hours per day (with a range of 0–7.7 hours per day), mean indoor air temperature was lower than 10 °C. For 24% of the time in winter (with a range of 0–67%) and for 5.8 hours per day (with a range of 0–16.1 hours per day), mean indoor air temperature was lower than 9 °C. For 6% of the time in autumn (with a range of 0–25%) and for 1.4 hours per day (with a range of 0–6.0 hours per day), mean indoor air temperature was lower than 9 °C. Very low indoor temperatures can negatively impact occupants' health conditions. According to our Respiratory Health Survey, 88% of occupants in the sample houses have long-term physical or mental illness.

According to the 2014 New Zealand General Social Survey (NZGSS), nearly 50% of New Zealand adults reported living in a cold house and 21% of respondents reported their homes were often or always cold and had a problem with dampness (Stats NZ, 2014). Former housing Minister Phil Twyford has said, "Approximately 1,600 mostly older New Zealanders die premature deaths every winter… Some 6,000 children get bundled off to hospital every year with infectious and respiratory diseases. Many of those children would have life-long health problems as a result" (Cropp, 2019, paras. 5-7). For the 16 sample houses in this study, incidence of health problems associated with low indoor temperatures are likely to be worse than the averages reported in the national survey data.

Table 1. Percentages of time in autumn related to different ranges of indoor temperature (16 houses).

Autumn spaces	Indoor mean	Indoor min	Indoor max	Ceiling mean	Ceiling min	Ceiling max	Floor mean	Floor min	Floor max	Outdoor mean
Mean T	16.3 °C	11.7 °C	19.9 °C	17.5 °C	12.2 °C	22.3 °C	15.1 °C	11.1 °C	15.1 °C	13.5 °C
Time T≥10 °C	92%	68%	100%	94%	71%	100%	90%	64%	90%	79%
Time T≥12 °C	84%	48%	100%	88%	54%	100%	80%	42%	80%	66%
Time T≥14 °C	72%	28%	98%	78%	34%	99%	65%	22%	65%	49%
Time T≥16 °C	54%	12%	90%	64%	17%	94%	44%	8%	44%	29%
Time T≥18 °C	35%	4%	70%	47%	7%	82%	24%	1%	24%	14%
Time T≥20 °C	19%	1%	44%	29%	1%	67%	8%	0%	8%	6%
Time T≥22 °C	9%	0%	28%	16%	0%	52%	2%	0%	2%	2%

Table 2. Percentages of time in winter related to different ranges of indoor temperature (16 houses).

Winter spaces	Mean indoor	Indoor min	Indoor max	Mean ceiling	Ceiling min	Ceiling max	Mean floor	Floor min	Floor max	Outdoor mean
Mean T	11.8°C	7.4°C	16.2°C	12.9°C	7.9°C	19.3°C	10.6°C	7.0°C	15.0°C	8.8°C
Time T≥10°C	66%	19%	100%	75%	26%	100%	58%	13%	100%	42%
Time T≥12°C	45%	4%	97%	56%	6%	98%	34%	1%	97%	19%
Time T≥14°C	27%	0%	78%	37%	0%	92%	16%	0%	69%	5%
Time T≥16°C	14%	0%	45%	22%	0%	77%	5%	0%	28%	1%
Time T≥18°C	7%	0%	32%	13%	0%	64%	1%	0%	12%	0%
Time T≥20°C	4%	0%	24%	7%	0%	48%	0%	0%	6%	0%
Time T≥22°C	2%	0%	15%	4%	0%	30%	0%	0%	2%	0%

Table 3. Time in autumn related to different indoor temperature ranges below the thresholds of indoor health conditions (16 houses).

Different time	% autumn time	% autumn time range	Autumn time (day)	Range (day)	Mean time per day (h)	Range (h)	Outdoor (day)
Time T<9°C	6%	0-25%	5.2	0-23.0	1.4	0-6.0	17.1

Time T<10°C	8%	0–32%	7.6	0–29.4	2.0	0–7.7	22.6
Time T<12°C	16%	0–52%	14.8	0–47.8	3.9	0–12.5	35.5
Time T<14°C	29%	2–72%	26.2	1.8–66.2	6.8	0.5–17.3	50.5
Time T<16°C	46%	10–88%	42.2	9.2–81	11.0	2.4–21.1	67.1
Time T<18°C	65%	26–96%	59.6	23.9–88.3	15.5	6.2–23	79.9
Time T<20°C	81%	56–99%	74.8	51.5–91.1	19.5	13.4–3.8	86.9
Time T<22°C	91%	72–100%	84.1	66.2–92	21.9	17.3–24	90.2

Table 4. Time in winter related to different indoor temperature ranges below the thresholds of indoor health conditions (16 houses).

Different time	% winter time	% winter time range	Winter time (day)	Range (day)	Time per day (h)	Range (h)	Outdoor (day)
Time T<9°C	24%	0-67%	22.3	0-61.6	5.8	0-16.1	49.2
Time T<10°C	34%	0–81%	31.1	0–74.5	8.1	0–19.4	59.1
Time T<12°C	55%	3–96%	50.5	2.8–88.3	13.2	0.7–23	76.9
Time T<14°C	74%	22–100%	67.8	20.2–92	17.7	5.3–24	87.9
Time T<16°C	86%	55–100%	79.6	50.6–92	20.8	13.2–24	91.4
Time T<18°C	93%	68–100%	85.7	62.6–92	22.4	16.3–24	91.8
Time T<20°C	96%	76–100%	88.6	69.9–92	23.1	18.2–24	91.9
Time T<22°C	98%	85–100%	90.2	78.2–92	23.5	20.4–24	92.0

High indoor relative humidity

Low indoor temperatures during the winter can result in high indoor relative humidity. Most of the factors such as bacteria, viruses, fungi, mites, that contribute to health effects like allergic rhinitis, asthma, etc, have increases associated with very high indoor relative humidity. Maintaining indoor relative humidity between 40% and 60% can minimise the indirect health effects (Arundel, Sterling, Biggin, & Sterling, 1986). Mites and mould, two major causes of allergies and asthma in New Zealand housing, increase proportionately with a rise in average indoor relative humidity.

Maintaining indoor relative humidity below 50% can reduce dust mites and their allergens in the home. There are five stages in the life cycle of the dust mite: egg, larva, protonymph, tritonymph and adult. Both indoor relative humidity and temperature can influence dust-mite development and population growth (Arlian, Bernstein, & Gallagher, 1982; Arlian, Rapp, & Ahmed, 1990; Arlian, Neal, & Vyszenski-Moher, 1999; Hart, 1998). A range of 60–80% relative humidity provides ideal conditions for the reproduction of mites. Mites are hardy, surviving and multiplying best when relative humidity is 75–80% and the temperature is around 21 °C (Arundel, Sterling, Biggin, & Sterling, 1986). The indoor relative humidity required by dust mites to thrive is

75–80% or higher, and dust mites prefer temperatures around 18–25 °C. A decrease in dust mite population is associated with a decrease in indoor temperature (Arlian, 2010).

Tables 5 and 6 show percentages of time in autumn and winter in relation to different ranges of relative humidity in the 16 sample houses. For 95% of the time in autumn and 96% of the time in winter, indoor relative humidity was higher than 50%. For 100% of the time in autumn and 100% of the time in winter, relative humidity adjacent to the floor (dust mites often grow in carpet) was equal to or higher than 50%: there would have been no limitations on dust mite survival and growth. For 40% and 22% of the time in autumn, mean indoor relative humidity was equal to or higher than 75% and 80% respectively. For 51% and 30% of the time in autumn, mean relative humidity adjacent to the floor was equal to or higher than 75% and 80% respectively. For 65% and 48% of the time in winter, mean indoor relative humidity was equal to or higher than 75% and 80% respectively. For 81% and 64% of the time in winter, mean relative humidity adjacent to the floor was equal to or higher than 75% and 80% respectively. Some sample houses were likely to have had a dust mite problem during the autumn and a worse situation during the winter.

Table 5. Percentages of time in autumn related to different ranges of relative humidity (16 houses).

Autumn spaces	Indoor mean	Indoor min	Indoor max	Ceiling mean	Ceiling min	Ceiling max	Mean floor	Floor min	Floor max	Outdoor mean
Mean RH	71.2%	58.5%	88.2%	67.4%	50.3%	86.8%	75.1%	63.1%	89.7%	80.7%
Time RH≥40%	99%	90%	100%	98%	80%	100%	100%	99%	100%	100%
Time RH≥50%	95%	73%	100%	91%	46%	100%	100%	95%	100%	99%
Time RH≥60%	85%	46%	100%	74%	19%	100%	96%	73%	100%	96%
Time RH≥70%	59%	2%	100%	44%	0%	99%	73%	3%	100%	83%
Time RH≥75%	40%	0%	98%	28%	0%	97%	51%	0%	100%	70%
Time RH≥80%	22%	0%	94%	15%	0%	89%	30%	0%	100%	57%
Time RH≥85%	10%	0%	80%	7%	0%	66%	13%	0%	93%	41%
Time RH≥90%	3%	0%	40%	2%	0%	30%	4%	0%	49%	22%
Time RH≥100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Time 40%≤RH≤60%	14%	0%	54%	23%	0%	81%	4%	0%	27%	4%

Table 6. Percentages of time in winter related to different ranges of relative humidity (16 houses).

Winter spaces	Indoor mean	Indoor min	Indoor max	Ceiling mean	Ceiling min	Ceiling max	Floor mean	Floor min	Floor max	Outdoor mean
Mean RH	76.8%	59.1%	92.2%	72.1%	46%	91.7%	81.6%	66.7%	92.8%	84.5%
Time RH≥40%	99%	88%	100%	98%	75%	100%	100%	100%	100%	100%
Time RH≥50%	96%	63%	100%	92%	27%	100%	100%	98%	100%	100%

Time RH≥60%	90%	51%	100%	81%	5%	100%	99%	94%	100%	98%
Time RH≥70%	77%	11%	100%	64%	0%	100%	90%	21%	100%	90%
Time RH≥75%	65%	1%	100%	49%	0%	100%	81%	2%	100%	82%
Time RH≥80%	48%	0%	100%	31%	0%	100%	64%	0%	100%	70%
Time RH≥85%	27%	0%	98%	16%	0%	96%	38%	0%	100%	55%
Time RH≥90%	10%	0%	83%	6%	0%	77%	13%	0%	89%	35%
Time RH≥100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Time 40%≤H≤60%	9%	0%	42%	17%	0%	79%	1%	0%	6%	2%

According to international and national standards, indoor relative humidity should be lower than 60% for optimum indoor air quality (The American Society of Heating, Refrigeration and Air-conditioning Engineers [ASHRAE], 1993; Standards New Zealand [SNZ], 1990; Department of Building and Housing [DBH], 2001). The threshold of indoor relative humidity for mould survival and growth conditions is 60%. Mould growth is likely on almost any building material if equilibrium relative humidity of the material exceeds 75–80% (Coppock, 1951; Block, 1993; Pasanen et al., 1992). The threshold of relative humidity for mould germination (Hens, 2000) and time are shown in Table 7. One option to prevent mould growth on indoor surfaces is to control the indoor humidity to a level below the threshold (80%) of mould germination. If the mould spores never start germination then mould will not grow on indoor surfaces (Su, 2006; ASHRAE, 1993).

Table 7. The thresholds of relative humidity and time for mould germination.

Substrate	Threshold of RH	Time needed
Porous and dust- and fat-covered non-porous	100%	1 day
	89%	7 days
	80%	30 days

Source: Hens (2000)

Tables 8 and 9 show time in autumn (days) and time in winter (days) related to mould-germination conditions and dust-mite thriving conditions. On average there were only 20.5 days during the autumn (with a range of 0–86.7 days) when indoor relative humidity was equal to or higher than 80% for the 28 indoor spaces in the 16 sample houses (see Table 8); but on the test points adjacent to the ceilings in five indoor spaces, and adjacent to the floors in nine indoor spaces, the time at this relative humidity was more than 30 days. On average there were only 2.4 days during the autumn (with a range of 0–36.4 days) when indoor relative humidity was equal to or higher than 90% for the 28 indoor spaces of the 16 sample houses, but on the test points adjacent to the ceilings in one indoor space and adjacent to the floors in two indoor spaces, the time at this relative humidity was more than seven days. According to the threshold for mould-spore germination conditions (Table 7), mould spores could have germinated in some sample houses during the autumn. In addition, for 85% of the time in autumn (with range of 46–100%) indoor RH was equal to or higher than 60%, which meets the threshold for mould growth conditions. This high indoor RH could have caused early mould germination and mould problems during the autumn or the beginning of winter in some of the sample houses.

On average there were 41.9 days during the winter (with a range of 0–90.9 days) when indoor RH was equal to or higher than 80% for the 25 indoor spaces of the 16 sample houses (see Table 9), which is clearly higher than the threshold for mould germination conditions. On the test points adjacent to the ceilings in seven indoor spaces, and adjacent to the floors in 19 indoor spaces, the time at this RH was more than 30 days. The time of mean indoor RH for 14 indoor spaces was more than 30 days. In addition, for 90% of the time in winter (with a range of 51–100%) indoor RH was equal to or higher than 60%, which meets the threshold for mould growth conditions. Most of the sample houses were likely to have had mould problems. According to the respiratory survey data of occupants in the sample houses, 90% of participants reported mould problems on indoor surfaces, in response to the question, "Has there ever been any mould or mildew on any surface, other than food, inside the home?"

Table 8. Time in autumn (days) related to mould germination conditions and dust-mite thriving conditions.

Autumn spaces	Indoor mean	Indoor range	Ceiling mean	Ceiling range	Floor mean	Floor range	Outdoor mean
Time RH≥75% (day)	36.6	0–90.4	25.9	0–88.8	47.4	0 to 92	64.8
Time RH≥80% (day)	20.5	0–86.7	13.8	0–81.7	27.2	0 to 91.7	52.7
Time RH≥85% (day)	9.1	0–73.2	6.4	0–60.9	11.8	0 to 85.5	37.4
Time RH≥90% (day)	2.4	0–36.4	1.7	0–27.6	3.2	0 to 45.2	20.6
Time RH≥100% (day)	0	–	0	–	0	–	0

Table 9. Time in winter (days) related to mould germination conditions and dust-mite thriving conditions.

Winter spaces	Indoor mean	Indoor range	Ceiling mean	Ceiling range	Floor mean	Floor range	Outdoor mean
Time RH≥75% (day)	55.9	1.0–91.0	42.0	0–91.0	71.4	2.0–91	75.5
Time RH≥80% (day)	41.9	0–90.9	24.8	0–90.9	54.0	0–91	65.6
Time RH≥85% (day)	22.6	0–89.2	12.0	0–87.4	28.5	0–91	52.6
Time RH≥90% (day)	7.8	0–75.3	5.0	0–69.8	8.9	0–80.8	34.0
Time RH≥100% (day)	0	0–0.1	0	0–0.2	0	0	0

Insulation, space heating and energy of the sample houses

The 16 sample houses were built in the 1920s to the 1970s. Floor areas of the 16 sample houses are 44 m2 to 342 m2. Roof materials are tin (eight houses), iron (five houses), aluminium (one house), tile (one house) and asbestos (one house). Wall materials are old weatherboard (14 houses), brick (one house) and concrete block (one house). Nine of the sample houses do not have any insulation in their envelopes; seven houses have only limited, old insulation in either their roof space only or both roof space and floor. For space heating, 12 sample houses used firewood as fuel for fireplaces, three houses used coal or firewood as fuel for stoves (cooking and space heating), one sample house did not use any space heating. Only one house used both a fireplace and an oil heater. Fifteen of the sample houses did not use any electricity as fuel for space heating.

Only seven sample houses provided their electricity consumption data. Table 10 shows daily mean energy usage per cubic metre of indoor space of these seven sample houses and of 131 Auckland houses that were the subject of a previous study (Su, 2017). The 131 Auckland houses use electricity as the only fuel for space and other types of heating. Of the 131 Auckland houses, 70 have sufficient insulation and double-glazed windows, in compliance with the current building code. Sixty-one of the Auckland houses, built in or after 2000, have basic insulation and single-glazed windows. The seven sample houses used no electricity, only firewood, for space heating, but their annual energy usage (kWh/m3/day) was higher than that of the 70 Auckland houses with sufficient insulation and double-glazed windows and of the 61 Auckland houses with basic insulation and single-glazed windows. The energy efficiency of the seven sample houses without insulation or with partial insulation is very poor.

Table 10. Energy data (kWh/m3/day) of the sample houses and 131 Auckland houses.

	The 7 sample houses			70 houses with double glazing			61 houses with single glazing		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Annual	0.07974	0.1558	0.0284	0.05848	0.16345	0.02004	0.06367	0.14512	0.01570
Space heating months	0.08880	0.1867	0.0314	0.07351	0.19856	0.02177	0.08197	0.20669	0.02007
No heating months	0.08476	0.1547	0.0300	0.04763	0.13812	0.01833	0.05046	0.11741	0.01254
Difference	0.00404	0.0320	0.0000	0.02588	0.11496	0.00235	0.03151	0.12975	0.00478

Many New Zealand homes are inadequately insulated and have inefficient space heating (Ministry of Economic Development [MED], 2011; Energy Efficiency and Conservation Authority [EECA], 2011). Fuel poverty is usually defined as a situation where a household does not have the financial ability, or needs to spend more than 10% of its income on heating energy, to maintain indoor thermal comfort and healthy conditions (Boardman, 1991; Clinch & Healy, 2001). About a quarter of New Zealand households are estimated to be in fuel poverty (Howden-Chapman et al., 2012). Recent studies related to New Zealand fuel poverty issues are based on existing New Zealand designs, space-heating methods, hot-water systems and housing energy (O'Sullivan, Howden-Chapman, & Fougere, 2015; Lawson, Williams, & Wooliscroft, 2015). Retrofitting house envelopes and upgrading space heating for indoor health conditions must consider occupants' ability to afford these modifications.

For example, in an Auckland house with sufficient insulation and double-glazed windows (in accordance with the current building codes), in order to keep winter indoor mean relative humidity at 50% and within the range of 40–60%, the winter indoor mean air temperatures have to be heated up to and maintained at 22 °C by a central-heating system (Su, 2017). Without affordable heating it is impossible, in the 16 sample houses, without sufficient insulation, to heat up the indoor air temperature to 22 °C in order to maintain indoor relative humidity below the thresholds of mould (60%) and mite (50%) survival and growth.

For example, in another Auckland house built in 2000 with insulation in its envelope and single-glazed windows, indoor relative humidity can be maintained, with temporary heating, below the threshold of mould germination conditions and mite thriving conditions for most of the winter (Su, 2017). The house does not have mould and mite problems. It is possible for a house with adequate insulation to use temporary space heating to control indoor relative humidity under the threshold of mould germination conditions and mite thriving conditions to avoid mould problems and minimise mite allergens. The baseline winter indoor temperature of the 16 sample houses without sufficient insulation is very low, therefore it is difficult and not energy efficient to heat up indoor air temperature to control indoor relative humidity below the threshold of mould germination and mite thriving conditions, and it is also too expensive for the occupants.

Dust mite allergens, indoor temperature and relative humidity

Dust-mite allergy symptoms are caused by dust-mite allergens. Dust mite-allergen tests on the carpets of 13 sample houses in the Minginui, Te Whaiti and Murupara areas were carried out by Unitec researchers during the winter of 2018 using the Ventia™ Rapid Allergen Test method. Dust-mite allergens on the carpets of three of the sample houses in Rotorua were also tested during the same winter for reference data. Test results of seven sample houses in the Minginui, Te Whaiti and Murupara areas showed high levels of dust mite allergens, which correspond to exposure to approximately one microgram or greater of Group 2 allergen per gram of dust. At this level of exposure, it is recommended that action needs to be taken to reduce mite allergen levels to protect occupants' health. Group 2 allergens are recognised as major allergens in several mite species, including *Dermatophagoides pteronyssinus* (house dust mite), *Lepidoglyphus destructor*, and *Tyrophagus putrescentiae*. Test results of six sample houses in the Minginui, Te Whaiti and Murupara areas show medium levels of dust mite allergens, which correspond to exposure to approximately 0.2–1.0 microgram per gram of dust; at this level of exposure, it is recommended that action needs to be taken to reduce mite allergen levels to protect occupants' health.

Test results of two sample houses in Rotorua (used as reference data) show low levels of dust mite allergens, which correspond to exposure to less than 0.2 micrograms per gram of dust; no action needs to be taken to reduce mite allergen levels to protect occupants' health. Test results of one sample house in Rotorua (used as reference data) show undetectable dust-mite allergens; no action needs to be taken to reduce mite allergen levels to protect occupants' health. Test results of another sample house in Rotorua show a medium level of dust mite allergen (not used as reference data).

Table 11 shows dust-mite test results related to winter indoor microclimatic data of the sample houses. The winter mean indoor temperature and relative humidity data of seven sample houses with high levels of dust mite allergens are based on the test points adjacent to the floors of nine indoor spaces, because the dust samples were collected from carpets. The winter mean indoor temperature and relative humidity data of six sample houses with a medium level of dust mite allergens are based on the test points adjacent to the floors of nine indoor spaces. As there were no sample houses with low levels of dust-mite allergens in the Minginui, Te Whaiti and Murupara areas, winter indoor temperature and humidity data of two sample houses with low levels of dust-mite allergens (and with insulation in their envelopes and single-glazed windows) in Rotorua were used as reference data, based on the test points adjacent to the floors of four indoor spaces. Unfortunately, the indoor microclimatic data from the sample house in Rotorua without dust mite allergens was lost.

To compare indoor microclimatic conditions between the houses with low levels of dust-mite allergens and the houses with high and medium levels of dust-mite allergens, the mean temperature adjacent to the floor of the houses with low allergen levels is 15.2 °C, significantly higher than that of the houses with high (11.2 °C) and medium (8 °C) allergen levels; the mean relative humidity of the houses with a low level of dust-mite allergens is lower than the threshold (75%) for dust mites to thrive and lower than that of the houses with high allergen levels (78%) and medium allergen levels (87%). The percentages of time in winter (18% and 1% respectively) in the houses with low levels of allergens when relative humidity is ≥75% and ≥80%, are lower than in the houses with high allergen levels (65% and 45% respectively) and medium allergen levels (93% and 88% respectively); and the percentage of time in winter (3.8%) when relative humidity is between 40% and 60% is higher than in the houses with high allergen levels (1.5%) and medium allergen levels (0.4%). The above comparison of physical field-study data suggests that one possible option for a house with sufficient insulation to prevent indoor dust-mite allergy problems, or to maintain indoor dust-mite allergens at low levels, is to control indoor mean humidity below the threshold for dust mites to thrive (75%) and maintain a minimum percentage of time in winter when indoor relative humidity is higher than the threshold for dust mites to thrive by using adequate temporary space heating. Sufficient insulation is the foundation of good indoor health conditions, and increasing insulation in the building envelope of houses is the first step to improve indoor health conditions. “For every dollar we spend on making homes safer, we're saving at least six dollars of further health, particularly health and education, costs down the road,” says Green Party of Aotearoa New Zealand Co-leader, Marama Davidson (Cropp, 2019, para. 8).

Previous studies show that both indoor relative humidity and temperature can impact indoor dust mite populations and allergen levels, and a decrease in indoor temperature (between 10 °C and 25 °C) can result in reducing dust mite populations when indoor relative humidity meets the threshold for dust mites to thrive (Arlian, Bernstein, & Gallagher, 1982; Arlian, Rapp, & Ahmed 1990; Arlian, Neal, & Vyszenski-Moher, 1999; Arlian, Yella, & Morgan, 2010; Hart, 1998). To compare the indoor microclimatic conditions between the houses with high dust-mite allergen levels and the houses with medium dust-mite allergen levels, mean relative humidity (78% and 87.4% respectively) of the houses with high and medium allergen levels are both clearly higher than the threshold (75%) for dust mites to thrive. The percentages of time in winter, in the houses with high and medium allergen levels, when relative humidity ≥75% and ≥80% (the threshold for dust mites to thrive), are significantly and extremely high (65% and 45% respectively for the houses with high allergen levels, and 93% and 88% respectively for the houses with high and medium allergen levels). Although in the houses with both high and medium levels of allergens, the indoor humidity meets the threshold for dust mites to thrive, the mean air temperature (11.2 °C) adjacent to the floor of the houses with high allergens is 3.2 °C higher than in the houses with medium allergens (8.0 °C). If temporary space heating in a house without sufficient insulation cannot increase indoor temperature to the level that can decrease and control the indoor relative humidity to below the threshold for dust mites to thrive, a limited increasing of indoor mean air temperature (a couple of degrees increase from a very low baseline) can relatively increase indoor dust-mite allergens, which can make indoor health conditions worse.

Table 11. Dust-mite allergens, indoor mean temperature and relative humidity adjacent to floor.

Mite allergen level	High	Medium	Low
Tested houses	7 houses	6 houses	2 Rotorua houses
Test points	Floor mean	Floor mean	Floor mean
Mean T	11.2°C	8.0°C	15.2°C
Time T≥10°C	67%	26%	100%
Time T≥12°C	42%	6%	97%
Time T≥14°C	18%	0%	75%
Time T≥16°C	4%	0%	35%
Time T≥18°C	0%	0%	5%
Time T≥20°C	0%	0%	0%
Time T≥22°C	0%	0%	0%

Mean RH	78.0%	87.4%	69.8%
Time RH≥40%	100%	100%	100%
Time RH≥50%	99%	100%	100%
Time RH≥60%	98%	99%	96%
Time RH≥70%	80%	96%	51%
Time RH≥75%	65%	93%	18%
Time RH≥80%	45%	88%	1%
Time RH≥85%	22%	73%	0%
Time RH≥90%	5%	36%	0%
Time RH≥100%	0%	0%	0%
Time 40%≤RH≤60%	1.5%	0.4%	3.8%

Mould, indoor temperature and relative humidity

Mould sampling and testing on the indoor surfaces of 13 sample houses in Minginui, Te Whaiti and Murupara were carried out by Unitec researchers; the mould samples were collected according to the recommended procedures of Biodet Services microbiology lab. In all 13 houses, some mould or mould spores were detected on the indoor test areas. Stachybotrys was not detected in any sample houses. Test results show that the only type of mould identified was Cladosporium. An abundant level of Cladosporium on the indoor surfaces of three sample houses, a moderate level of Cladosporium on the indoor surfaces of four sample houses and a low level of Cladosporium on the indoor surfaces of one sample house were identified. There was no Cladosporium detected on the indoor surfaces of five sample houses. A moderate level of unidentified fungus on the indoor surfaces of five sample houses, and a low level of unidentified fungus on the indoor surfaces of two sample houses were noted. A low level of miscellaneous fungus spores or other fungus spores on the indoor surfaces of four sample houses was noted.

Mould test results can be influenced by occupants' daily life and depend on how often the occupants clean the indoor surfaces, especially for the areas with visual mould. Ninety percent of participants in the respiratory survey reported mould problems on indoor surfaces. Cladosporium is the only identified type of mould and had the highest frequency of detected mould in the 13 sample houses. Cladosporium is the most important indoor allergen, and a well-known trigger for asthma (Peternel, Culig, & Hrga, 2004; Flannigan, Samson, & Miller, 2001; Piecková & Jesenská, 1999). Table 12 shows test results of Cladosporium related to indoor temperature and relative humidity; indoor mean temperature and indoor mean relative humidity related to an abundant level of Cladosporium are based on five indoor spaces of three sample houses; indoor mean temperature and indoor mean relative humidity related to a moderate level of Cladosporium are based on five indoor spaces of four sample houses; and indoor mean temperature and indoor mean relative humidity related to no Cladosporium detected, or low levels of Cladosporium, are based on ten indoor spaces of six sample houses.

To compare indoor microclimatic conditions between the houses with an abundant level of Cladosporium and the houses with a moderate level of Cladosporium, the percentage of time in winter at a relative humidity of 60% or above is 80% in the houses with an abundant level of Cladosporium, and is 87% in the houses with a moderate level of Cladosporium, both of which meet the threshold of mould survival and growth conditions. Time in winter, in the houses with an abundant level of Cladosporium and the houses with moderate levels of Cladosporium, when indoor mean relative humidity is equal to or more than 80%, is 33 days and 38.2 days respectively; in both cases, clearly higher than the threshold for mould germination. The main difference in indoor microclimate for mould growth, between the houses with abundant levels of Cladosporium and the houses with moderate levels of Cladosporium, is the indoor mean temperature. Indoor mean temperature in the houses with an abundant level of Cladosporium is higher than in the houses with a moderate level of Cladosporium. Mould prefers warm and humid conditions for growth. If temporary space heating in a house without sufficient insulation cannot increase indoor temperature to a level that can decrease and control indoor relative humidity to below the threshold for mould germination, a limited increase of indoor air temperature can create better thermal conditions for mould growth. Table 12 shows that the conditions of relative humidity and temperature are similar in houses that showed no or low levels of Cladosporium and houses with abundant or moderate levels of Cladosporium. This result does not necessarily mean there could not be higher levels of Cladosporium in these houses, but that it was present at low levels at the time of testing. This could be explained by cleaning, by the location of sampling, or other factors.

Table 12. Cladosporium related to indoor mean temperature and relative humidity.

Sample houses	5 indoor spaces of 3 houses	5 indoor spaces of 4 houses	10 indoor spaces of 6 houses
Cladosporium	Abundant	Moderate	None or Low
Location of data	Indoor mean	Indoor mean	Indoor mean
Mean T	12.4°C	11.4°C	11.5°C
Time T≥10°C	67%	61%	66%
Time T≥12°C	47%	38%	43%
Time T≥14°C	31%	21%	23%
Time T≥16°C	20%	13%	11%
Time T≥18°C	13%	9%	5%
Time T≥20°C	8%	6%	2%
Time T≥22°C	5%	4%	1%
Mean RH	72.3%	74.5%	75.9%
Time RH≥40%	96%	98%	99%
Time RH≥50%	87%	93%	97%
Time RH≥60%	80%	87%	90%
Time RH≥70%	65%	74%	73%
Time RH≥75%	52%	62%	60%
Time RH≥80%	36%	42%	41%
Time RH≥85%	21%	15%	20%

Time RH≥90%	6%	1%	5%
Time RH≥100%	0%	0%	0%
Time 40%≤RH≤60%	16%	11%	9%
Time RH≥75% (day)	47.4	57	54.7
Time RH≥80% (day)	33	38.2	37.9

Relationship between dust mites and mould

Table 13 shows the sample houses with a high level of dust-mite allergens and mould in test results and Table 14 shows the sample houses with a medium level of dust-mite allergens and mould in test results. Most of the sample houses with a high level of dust-mite allergens also have an abundant or moderate level of Cladosporium. Most of the sample houses with a medium level of dust-mite allergens also have low to moderate levels of Cladosporium. The threshold of indoor relative humidity for mould survival and growth conditions is 60%. The threshold of indoor relative humidity for dust-mite survival and growth conditions is 50%. During most of the time in winter, indoor mean relative humidity of the sample houses was higher than 50% and 60%. The threshold of relative humidity for dust mites to thrive is 75–80% or higher and the threshold of relative humidity for mould spore germination is 80% or higher. If a house has a dust mite problem, the house is likely to have a mould problem, and vice versa.

Table 13. Sample houses with a high level of dust-mite allergens and mould in test results.

Houses	1	2	3	4	5	6	7
Dust-mite allergens	High	High	High	High	High	High	High
Mould or spores detected	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cladosporium	Moderate	Abundant	-	Abundant	-	-	Abundant
Unidentified fungus	-	-	Low	-	-	Low to Moderate	-
Miscellaneous spores	-	-	-	-	-	-	-

Table 14. Sample houses with a medium level of dust-mite allergens and mould in test results.

House	1	2	3	4	5	6
Dust-mite allergens	Medium	Medium	Medium	Medium	Medium	Medium
Mould or spores detected	Yes	Yes	Yes	Yes	Yes	Yes

Cladosporium	Moderate	No	Low	No	Moderate	Low to moderate
Unidentified fungus	Low	Moderate	Low to moderate	Moderate to abundant	Moderate to abundant	Low
Miscellaneous spores	-	-	-	Low	-	-

Relationship between Respiratory Health Survey results and indoor dust-mite and mould problems

According to the New Zealand Health Survey 2017/18 (Ministry of Health [MoH], 2018), respiratory disease affects 700,000 people, causes one in 10 hospital stays, and costs New Zealand $7.05 billion in healthcare every year. Respiratory-related disease is the third-highest cause of death in New Zealand. One in eight adults (12.5%) and one in seven children (14.3%) have asthma (MoH, 2018). For all age groups, hospitalisation rates of Māori and Pacific peoples are respectively 2.0 and 2.5 times higher than those of other ethnic groups (Barnard & Zhang, 2018). The Respiratory Health Survey for the occupants of the sample houses in the study areas of Minginui, Te Whaiti and Murupara was carried out by Toi-Ohomai researchers. The study method and questionnaires for the Respiratory Health Survey were provided by Unitec researchers. A total of 11 participants from ten houses, which were part of the 16 sample houses in the study areas of Minginui, Te Whaiti and Murupara, took part in the Respiratory Health Survey. Eight of the 11 participants were from the seven houses with mould and dust-mite test data showing high or medium levels of dust-mite allergens. Seven participants from the three Rotorua houses with mould and dust mite test results also took part in the Respiratory Health Survey.

According to the Respiratory Health Survey of occupants in the sample houses in the Minginui, Te Whaiti and Murupara areas, 36% of participants (four of 11) had asthma, which is 2.9 times higher than in the results of the New Zealand Health Survey 2017/18. Eighty-two percent of participants (9 of 11) from the 10 sample house with or without dust-mite allergens and mould test data in the Minginui, Te Whaiti and Murupara areas had long-term physical or mental illness that had been diagnosed by a doctor. Seventy-three percent of the participants (8 of 11) had had wheezing or whistling in the chest at some time in the previous 12 months. This result is about two times higher than the prevalence in other studies (Pescatore, Spycher, Beardsmore, & Kuehni, 2015). No participant from the three Rotorua houses had asthma, and 14% of participants (1 of 7) had a long-term physical or mental illness that had been diagnosed by a doctor. No participant from the three Rotorua houses had had wheezing or whistling in the chest at any time in the previous 12 months.

Dust mites can cause allergy symptoms such as sneezing, allergic rhinitis, itchy, red or watery eyes or swollen eyelids, nasal congestion, coughing, eczema and sleep disorders. Mould can cause allergy symptoms such as sneezing, allergic rhinitis, coughing, nasal congestion, watery and itchy eyes, postnasal drip and itchy, dry or scaly skin. Dust mites and mould can also cause allergy symptoms compounded by asthma, such as coughing and wheezing, difficulty breathing, chest tightness or pain, and trouble sleeping caused by shortness of breath, coughing or wheezing. The following symptoms referred to in some questions in the questionnaire of the Respiratory Health Survey could be related to dust-mite and mould allergens, or triggered by the allergens:

- Wheezing or whistling
- Shortness of breath

- Coughing
- Chest tightness
- Difficulty breathing
- Asthma symptoms
- Eczema or any kind of skin allergy
- Sleep disorders caused by shortness of breath, coughing or wheezing

Table 15 shows the partial results of the Respiratory Health Survey: there are two groups of participants. The first group includes eight participants from seven sample houses with dust-mite allergens and mould test data in the Minginui, Te Whaiti and Murupara areas, five of which had high levels of dust-mite allergens and abundant levels of Cladosporium, and two of which had medium levels of dust-mite allergens and moderate levels of Cladosporium. The second group includes seven participants from the three sample houses in Rotorua, two of which had low levels of dust-mite allergens and no Cladosporium, and one of which had no detected dust-mite allergens or mould. The extremely high percentages of participants who had respiratory symptoms are strongly associated with the high levels of indoor dust-mite and mould allergens of the seven sample houses in the Minginui, Te Whaiti and Murupara areas. There are consistent differences in the percentages of participants who had respiratory symptoms between the seven sample houses in the Minginui, Te Whaiti and Murupara areas and the three houses in Rotorua: the low percentages of participants who had respiratory symptoms are apparently associated with the low levels of indoor dust-mite and mould allergens of the three houses in Rotorua.

Table 15. Respiratory Health Survey results of the first and second groups of participants.

The first group	The second group	Questions
75%	0%	Had wheezing or whistling last 12 months
75%	0%	Had wheezing or whistling when they did not have cold last 12 months
50%	0%	Had been woken up with a feeling of chest tightness last 12 months
75%	29%	Had a daytime attack of shortness of breath during rest time last 12 months
88%	14%	Had an attack of shortness of breath during physical activity last 12 months
63%	29%	Had been woken by an attack of coughing last 12 months
75%	0%	Usually coughed first thing in the morning in winter
75%	29%	Usually coughed during the day or night in winter
75%	0%	Coughed during the day or night continuously for three months each year
50%	0%	Usually brought up sputum from their chest first thing in the winter morning
63%	0%	Usually brought up sputum from their chest during day or night in the winter

63%	0%	Brought up sputum during the day or night continuously for 3 months a year
63%	14%	Had trouble with their breathing
88%	14%	Visited doctor because of breathing problems or shortness of breath
25%	0%	Visited a hospital emergency department because of breathing problems
38%	0%	Had asthma
75%	43%	Had eczema or skin allergy
88%	29%	Often woke up at night and had trouble falling back to sleep
88%	14%	Had long-term physical or mental illness diagnosed by a doctor

Summary of current indoor health conditions of the sample houses

For the current sample houses with very low R-value (without sufficient insulation) in their envelopes and inadequate temporary heating, the winter indoor air temperatures are very low, which can directly harm occupants' health. It is impossible for those houses with poor energy efficiency to be heated up to and maintained at the minimum indoor temperature (18–21 °C) required for ensuring good health conditions for occupants. High indoor relative humidity is associated with low indoor air temperatures, and causes dust mite and mould problems. As the baseline of winter indoor air temperature is very low in these houses, it is impossible for the winter indoor relative humidity to be controlled to below 50% or 60%, the respective thresholds of dust mite and mould survival conditions, by temporary space heating. It is also difficult and expensive to increase indoor air temperatures to control indoor relative humidity to below the threshold for dust mites to thrive and mould to germinate. If inadequate temporary space heating cannot control winter indoor relative humidity to below the threshold for dust mites to thrive and mould to germinate, a limited increase of indoor air temperature (a couple of degrees increase from a very low baseline) by inadequate temporary space heating can even make dust mite and mould problems worse, because dust mites and mould prefer warmer indoor conditions, which can also make indoor health conditions worse. In this study, the indoor microclimatic data, Respiratory Health Survey data, dust-mite allergen levels and mould test results show that the sample houses have poor indoor health conditions.

Recommendations for improving indoor health conditions in housing

This report recommends two options for house designs to improve indoor health conditions for the occupants. The first option is house design that incorporates a permanent space-heating or central-heating system or other heating methods to constantly maintain the indoor temperature between 18 °C and 21 °C, for occupants' health and to maintain the winter indoor relative humidity between 40% and 60%. The first challenge for this option, in building new houses or retrofitting existing houses, is affordability of construction costs and energy costs for space heating. The second challenge is that a climate-controlled house doesn't allow for doors and windows to be left open for natural ventilation and connection to the outdoors. The second option is house design that uses temporary space heating, retrofitting existing houses or building new houses with sufficient insulation and double-glazed widows, in compliance with the current building codes. These measures could raise the baseline of winter indoor temperatures and significantly reduce indoor mean relative humidity; it would then be possible in those houses with adequate temporary space heating to maintain the indoor relative humidity below the threshold for mould to germinate and dust mites to thrive. If there was no mould spore germination, there would be no problem of mould growth on indoor surfaces. If dust-mite allergens were controlled at a low or undetectable level, there would be no dust-mite allergy problems in indoor spaces. Indoor mean relative humidity would not have to be maintained below 60% or 50% (the respective thresholds of mould and dust mite growth or survival conditions, which require indoor air temperatures of 20 °C or above to achieve) for the whole winter or the wet season. Occupants could also benefit from using natural ventilation to remove extra indoor moisture generated from daily life, and enjoy less artificially climate-controlled houses. This second option is more affordable for occupants in both construction and energy costs for space heating.

Conclusions

As the sample houses do not have sufficient insulation, the baseline of indoor air temperatures is very low. There were 13.2 and 8.1 hours per day in the winter and 3.9 and 2.0 hours per day in the autumn when mean indoor air temperature was lower than 12 °C and 10 °C respectively. The low mean indoor air temperatures could directly harm the occupants' health. As autumn indoor temperatures of the sample houses were quite low, autumn indoor relative humidity was quite high. High autumn indoor relative humidity could cause early mould germination and mould growth problems on indoor surfaces, and dust-mite problems during the autumn or the beginning of winter in some sample houses.

As winter indoor temperatures of the sample houses were very low, winter indoor relative humidity was very high. According to the winter dust mite and mould test results, all the 13 sample houses tested in Minginui, Te Whaiti and Murupara had a medium or high level of dust mite allergens, which definitely requires action taken to reduce mite allergen levels to protect occupants' health. The 13 sample houses also had moderate or abundant mould growth; Cladosporium was the highest frequency of detected mould in the 13 sample houses, and is a known major indoor allergen and a well-known trigger for asthma.

Dust mites and mould prefer warm and humid conditions. If temporary space heating in a house without sufficient insulation cannot increase the indoor temperature to a level that can decrease and maintain the indoor relative humidity below the threshold for mould to germinate and dust mites to thrive, the limited increase in indoor air temperature can create a better thermal condition for dust mite development and mould growth, and indoor health conditions can become worse.

Most of the sample houses with high levels of dust mite allergens also had abundant or moderate levels of Cladosporium. Most of the sample houses with medium levels of dust mite allergens also had low to moderate levels of Cladosporium. There were strong correlations between dust mite and mould problems in indoor spaces of the sample houses. If a house had a dust-mite problem, it was likely to have a mould problem, and vice versa.

Respiratory survey results were strongly correlated with dust mite and mould test results. The extremely high percentages of occupants who had respiratory symptoms were strongly associated with the high levels of indoor dust mites and mould allergens in the sample houses in the Minginui, Te Whaiti and Murupara areas. The low percentages of participants who had respiratory symptoms were apparently associated with the low levels of indoor dust mites and mould allergens in the sample houses in Rotorua. Further studies could focus on local housing design to improve indoor thermal and health conditions for the occupants. New designs should prioritise affordability of construction, passive thermal design and energy efficiency.

Acknowledgements

The authors would like to thank Tepora Emery, Sylvia Tapuke, Ian McLean of Toi-Ohomai Institute of Technology, and Daniel Martin, Hinerangi and Tony Goodman, who carried out the Respiratory Health Survey and lung function tests, and gave us help and support to visit the sample houses for the field study of indoor microclimate, dust mite and mould levels. We would also like to thank Marcus Williams, Jacquie Reed, Daisy Dang and Marie Shannon, of Unitec Institute of Technology, for help and support in the completion of this report.

CHAPTER 3

Variation in experienced temperature conditions in relation to house quality

Ian G. McLean, Tepora Emery, Sylvia Tapuke
Toi Ohomai Institute of Technology

Introduction

Average environmental patterns experienced by residents of the studied houses are reviewed in the Unitec report (Wu & Su, Chapter 2). Here, we explore variability in experienced environments in relation to variation in quality of houses in the study. Specifically, we explore the environmental management of individual houses in order to better understand how housing standards affect internal environments.

These analyses enable understanding of:

- the effectiveness of the house at buffering external conditions,
- the experiences of the residents relative to UN guidelines for comfortable and healthy internal environments for people, and
- the management of internal environments using passive (e.g. design, insulation) and active systems (e.g. heating, ventilation).

Background and the literature review for this report can be found in Su and Wu (Chapter 2).

Definitions

"Ambient" conditions are the temperatures recorded outside by a data recorder located in the vicinity of each subject house (= within the town environs). The same ambient temperature data were used for comparison with all houses in each town. Ambient data for Rotorua were provided by NIWA from a site on the south side of town.

"Internal" conditions are the temperature records from a data recorder placed near the ceiling of the living room of the house (the room most likely to be heated in winter).

"Buffering" by a house is the process by which the house modifies or manages ambient conditions to reduce variability (in principle, creating a more comfortable internal environment). Buffering can be of both cold and hot ambient conditions, and it contains either or both of two elements: passive and active management. Examples of buffering seen in the graphs used in this report and in Appendix 2 include:

i) a flatter curve for internal relative to ambient conditions (= passive management where extremes of hot or cold are reduced);
ii) a higher internal curve relative to the external curve (= the addition of heat by active management, although passive energy capture from the sun has a similar effect);
iii) a lower internal curve relative to the ambient curve (implying some form of cooling by active management, although insulation can have the same effect);
iv) a delayed internal response to changing external conditions.

House quality and temperature management

The houses in this study varied in design, maintenance standards, age, size, insulation and internal layout. We combined these and other features into a single measure termed "house quality" (see below), and use this measure as an independent variable enabling exploration of the comfort provided by each house in relation to UN guidelines.

During the period of study, ambient temperatures only rarely reached a level where cooling might have been needed or desirable. In this study, only one house had technology for active cooling, although residents of any house could open doors and windows at any time. However, winters were cold and active heat management was needed in all houses to create a comfortable internal environment for much of the period from May to September.

Thus, the comparisons made here enable exploration of the extent to which each house buffered external conditions through passive and active processes. We predicted that, on average, a house of higher quality will provide more comfortable living conditions than a house of lower quality through either or both processes. It is possible to create reasonably comfortable internal temperatures in a house of lower quality, but the cost of adding heat is likely to be high and/or require more work by the residents. Most houses in the study were heated by fires, predicting higher ash loadings and reduced air quality in houses where heat was added consistently (Guo, Lewis, & McGlaughlin, 2008). However, we did not study air quality directly. Winter data enable exploration of both passive and active buffering working together. Summer data enable exploration of passive buffering effects only.

Methods

Temperature data only were used in this analysis, as temperature and relative humidity are correlated. Results for humidity are reported in Su and Wu (Chapter 2). Ceiling data from the living (north) room were used for all but one house, where floor data were used because ceiling data were not available.

Of the houses for which winter data were available, summer data were obtained from: Minginui 5 of 6 houses, Te Whaiti 3 of 5 houses, Murupara 3 of 4 houses, and Rotorua 3 of 3 houses. One house was empty in each of Minginui and Te Whaiti through the analysis period because residents moved out after data recorders were installed.

Temperature data were captured every 15 minutes throughout the 24-hr daily cycle. In Minginui, Te Whaiti and Murupara, data were collected from 28 March 2018. For Rotorua houses, data collection began on 22 May. Data collection was completed in all houses on 8 January 2019.

For winter-summer comparisons, we chose 70 days as the comparison period: "summer" was from 30 October to 7 January; "winter" was from 7 June to 15 August.

For all analyses, average hourly values were used (i.e. the average of the four samples taken each hour) to produce a temperature profile for each day (N=24 points). A worked example showing production of a temperature profile is given in Appendix 2. Those profiles were then used to explore:

- Temperature profile differences among the houses and between towns (interior data)
- Temperature profiles between seasons (summer versus winter, interior data)
- Temperature profiles inside relative to ambient (= outside) temperature conditions
- Variation in temperature profiles in relation to house quality

House "quality" was indexed using features that influenced its internal environment (Table 1). The higher the value for the index, the more energy efficient and comfortable the house should be. Calculated index values ranged from 8 to 29, with the lowest quality houses in Minginui (N=6) and Te Whaiti (N=5), medium quality in

Murupara (N=5), and highest quality in Rotorua (N=4) (Figure 2a). No internal data were obtained for two houses used in Figure 2, and they were subsequently excluded from all other analyses.

The index clearly reflected our qualitative assessment of the state of each house and its overall condition. The houses at the bottom of the range were in poor condition, some with holes in the walls, windows and/or floor, and occasional broken windows. At best, they were substandard for winter residency and two were abandoned by the residents before winter began. At the higher end of the range, the houses were newer and/or fully renovated, included efficient heating technology and insulation, and were properly maintained.

Because house quality varied with town (Figure 2a), we initially predicted that comfort would vary among towns. However, preliminary analyses of the environmental data indicated no relationship with town. Houses were therefore sorted by quality rather than town, and natural divisions in the quality values were used to subdivide the houses into four groups (Figure 2b). Comparison of the two figures indicates that the overall pattern is similar, but the data grouped by housing quality have a larger range for the means and much smaller variance within each grouping. Correlation of house placement in the two groupings was significant (Spearman's r=0.54, P=0.02), supporting the preliminary assessment that house quality varied with town. However, the correlation explained only half the variation in the data, and the stronger discrimination provided by the quality index proved to be important in understanding the links between house quality and environmental variation.

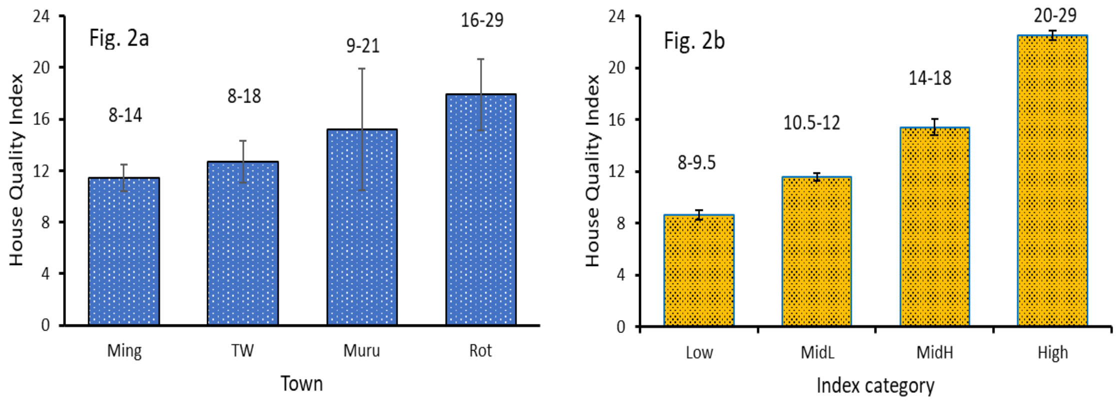


Figure 2. Quality of houses in four towns (Fig. 2a), calculated using a standardised index based on design and functionality criteria listed in Table 1 (Ming=Minginui, TW=Te Whaiti, Muru=Murupara, Rot=Rotorua). Houses were subsequently subdivided into four approximately equal groups using natural breaks in the data to create four groups of houses based only on the quality index (Table 1, Fig. 2b). Bar is mean ± s.e. Index range is shown above the bar. N's are left to right: Fig. 2a, 6, 5, 5, 4; Fig 2b, 4, 5, 6, 5. Two houses with quality indexes of 12 and 16 were not available for subsequent analyses due to missing data.

Description of GAM (General Additive Model)

GAM analysis was used to compare temperature profiles amongst groups of houses defined using the quality index.

GAM is a new statistical technique designed to explore complex data sets that follow a non-linear progression (e.g. through time), such as the data analysed here (Zuur et al., 2009). The analysis is a form of multiple regression, but is non-parametric, so is subject to fewer assumption-based restrictions than for GLM (General Linear Model) analyses such as ANCOVA or parametric multiple regression, which are not appropriate for this data set.

The data in a progression are subdivided into many small units (that are effectively linear), and a regression coefficient is calculated for each unit along the line. Those coefficients are summed. For a pair of lines, the analysis calculates a t value for the difference between the two regression coefficients obtained from the summation. The relative differences among those t values can be used to infer conclusions about relative differences amongst the groups of data. Statistical significance is calculated for each t value, but is of little interest here given the large size of the data sets used and non-independence in the data. The range of t values found is best understood alongside visual inspection of the data; smaller t values indicate curves that are more similar.

Winter and summer data were analysed separately. Sample sizes were:

- Number of houses in each quality index group (low, midL, midH, high); winter: 4, 4, 6, 4; summer: 2, 3, 5, 4
- Days of sampling: 70
- Number of samples per day: 24 (mean of 4 samples per hour)
- Total N's, winter: 30240; summer: 23520 (raw data records were 4x these values)

More houses were available for winter than summer due to missing data. Degrees of freedom (df) for the overall analysis is 3 (from 4 groups). GAM also reports an estimated df for a technical concept called "the smoother" which documents the degree of linearity in the line. These are for the living environment analysis, winter: 6.6, summer: 6.6; for the analysis of difference between internal and ambient temperatures: winter: 6.7, summer: 6.4. An indication of the meaning of these values is; a smoother with 1 df would be a straight line, and values >8 indicate that the data are strongly non-linear (Zuur et al., 2009). The curves are clearly non-linear and are frequently quite different between houses, as can be seen by reference to the graphs.

Deviance is a measure of goodness-of-fit to the model, and is reported for technical reasons. It is not used in the interpretation of the data. The % of deviance explained in the models run here is: for the living environment relative to 18˚C: Winter: 45.3%, summer: 24.1%; for the difference between internal and ambient temperatures: winter: 41.7%, summer: 34.2%.

For both GAM analyses, the data were normalised using a log ratio calculation that eliminates bias and centres the data.

Results

The first sections provide a qualitative summary of the conditions measured in each house in the different towns. In the last section, we explore house and seasonal effects using house quality as the independent variable, in relation to the experienced environment (interior temperatures) and the ambient environment (external temperatures).

Winter temperature profiles between houses in each town

Factors that influenced the internal temperature profiles for each house included:

- Whether residents were present or absent during the day
- Design and condition of house (passive internal management)
- Availability and type of heating equipment (active internal management)
- Availability and cost of fuel

Temperature profiles for individual houses, including variability in the data, are in Appendix 2. Two empty houses in winter indicate the temperature patterns to be found in houses with no residents under cold conditions. Both houses tracked ambient conditions closely. House 4 (Minginui) was in very poor condition. Internal temperatures were slightly colder than ambient throughout the day, although warmed up to match ambient temperatures in the late afternoon. House 1 (Te Whaiti) was well maintained (but without insulation) and remained several degrees warmer than ambient through most of the day; it also warmed more slowly than ambient in the afternoon. Both effects indicate some buffering of ambient conditions by this building. House 7 (Minginui) was empty in the summer, when it tracked ambient conditions very closely.

Table 1. Categories and criteria used to create an index of house quality. For each category, a higher value should deliver a better (= more comfortable) internal environment.

Category	Levels	Criteria*	Comment
Insulation, ceiling	4	0=none; 1=>15 yrs; 2=5-14 yrs; 3=<5 yrs	Most insulation loses capacity with age
Insulation, under floor	2	0=absent; 2=present	If present, was recently installed
Insulation, walls	2	0=absent; 2=present	If present, was recently installed
Double Glazing	2	0=absent; 2=present	Assumes strong effect on heat loss
Heating	5	0=none; 1=portable only (electric, gas); 2=open fire; 3=enclosed fire (pot-belly, coal range); 4=heat pump/flued gas	We were unable to directly monitor how or when these were used, although evidence of use can be seen in the graphs
Curtains	4	0=none, 1=poor, 2=medium, 3=good (with thermal lining)	We were unable to monitor how or when these were used
Age	5	1=pre-1960; 2=1960-1978, 3=1979-1999, 4=2000-2008, 5=2009+	Based on building code changes and other developments in housing
Foundation	2	1=off ground, 2=on ground	Assumes on-ground provides extra temperature buffering
Cladding	2	1=no insulating capacity (e.g. wood, tin, fibro); 2=some insulating capacity (e.g. brick, shared wall)	Attached garages were ignored
Hallway	2	0=yes, 1=no	Assumes a hall creates extra drafts, air movement and heating requirements for bedrooms
DVS or similar	2	0=none, 2=present	Assumes significant improvement to heat management, if present
Damage	4	1=poor (e.g. rot, holes, rust paintwork peeling badly);	Assumes internal environmental management is

		2=no damage but maintenance needed; 3=good; 4=excellent	linked to state of the walls and roof
Mould	5	0=very high; 1=high; 2=strong medium; 3=medium; 4=low; 5=none	Based on results in Su and Wu in this report.

* We accept that distinctions among the criteria used are somewhat arbitrary. Limited information was available for each house, and we used simple criteria in as many different categories as possible with the aim of creating an index specific to this study that gave a spread of values among the houses.

The cost of heating and ability to maintain comfortable internal conditions in badly maintained and uninsulated houses is likely to be significantly higher and more difficult than for houses in good condition. However, (wood) fuel is cheap or free in Minginui and Te Whaiti, and it is possible to maintain comfortable or even overheated conditions at little cost if appropriate heating equipment is installed. In Murupara and Rotorua, most people pay for heating fuel. Thus, although houses were in better condition in those towns, the cost of heating could still be a disincentive to maintaining a comfortable home environment. In summary:

- **Minginui**: on average values, only one house was maintained at close to or above 18˚C (= comfortable conditions) throughout the day in winter. Four houses remained below 18˚C most or all of the time in winter, although all four were heated (>18˚C) on at least some evenings. House 7 had a single resident who was frequently absent, and it followed ambient conditions closely during the day. One house was empty and is ignored here.
- **Te Whaiti:** on average values, two houses were maintained at close to or above 18˚C (= comfortable conditions) throughout the day in winter. Two others were cold on average values, although one of those was heated to comfortable conditions in the evening; the other was consistently cold through the winter. One house was empty.
- **Murupara**: on average values, three houses were maintained at close to or above 18˚C (= moderate to comfortable conditions) throughout the day in winter. Of these three, one was frequently and one occasionally overheated (>28˚C). A fourth house was maintained close to 18˚C throughout the day with low variability, indicating that it was held close to the minimum UN standard. A fifth was cold through most of the day, but was heated on some evenings. This house had very limited heating equipment and no insulation.
- **Rotorua**: on average values, all three houses maintained relatively constant temperatures through the winter. One (an old but renovated house) was consistently warm (around 20˚C), one was moderate (around 18˚C) and one was cool to cold, although heated on some evenings. The coldest house was the most modern and was the only house in the study with central heating (and cooling). Thus, it seems likely that the residents could not afford to operate the heating system consistently.

The summaries above describe living room conditions at the ceiling. Bedrooms in all studied houses were generally cool to cold through the winter. Thus, most residents were breathing cool to cold air while sleeping.

Summer temperature profiles between houses in each town

In general, internal temperatures tracked ambient conditions more closely in summer than in winter.

- **Minginui**: houses were of low quality and average internal temperatures in summer tracked ambient very closely. Only one house (3, with retrofitted insulation) showed evidence of temperature buffering (afternoon temperatures were lower inside the house). House 7 was empty in the summer.

- **Te Whaiti**: houses were of low quality. Houses 9, 10, and 11 showed evidence of buffering of high afternoon temperatures. All three houses were generally several degrees warmer than ambient through the night and morning (c.f. Minginui houses, for which any difference was smaller), and were cooler in the afternoon. In two houses, buffering was due to retrofitted ceiling insulation; one (house 10, no insulation) was in a gully and heavily shaded. The internal temperature values suggest that house 10 received some heating in summer.
- **Murupara**: houses were more modern (most were built in the 1970s). Internal summer temperatures were generally several degrees warmer than ambient, with evidence of buffering of high afternoon temperatures. House 15 had the least buffering, and was the only house with no ceiling insulation.
- **Rotorua**: all studied houses were in good condition with at least some insulation. Internal summer temperatures were warmer and held more constant than ambient in all three houses, indicating some buffering of ambient conditions. Internal temperatures remained below 28˚C in the two older houses (both with retrofitted insulation). But the newest house (20, built in 2005, so with old insulation) was relatively poorly buffered and was regularly overheated.

General Additive Modelling (GAM) analyses of environmental data

This analysis explores the relationship between quality of house and living conditions. We predict that better quality houses should provide more comfortable living conditions, where “more comfortable” means both: i) better maintenance of optimal temperatures for people, and ii) reduced variability through the 24-hr cycle.

Two analytical approaches were taken:

- We explored temperature versus house quality in relation to the UN-recommended minimum standard of 18˚C (for visual analysis, 18 was subtracted from every internal measurement). This analysis enables interpretation of the experienced internal living environment in relation to the minimum standards of comfort below which it is expected that people will increasingly experience health consequences.
- We explored the difference between internal and ambient (= external) temperature. This analysis enables interpretation of the experienced living environment in relation to buffering by passive (house design) and active (heating) processes.

For both analyses, “groups” of houses were defined using the house quality index (Table 1, Fig. 2b). The adjusted data are purposely presented in several different ways for visual inspection to aid understanding of the patterns found. For statistical analysis using General Additive Modelling the data were normalized to compensate for skew.

Variation in internal temperatures around 18˚C in relation to house quality

The raw data for each house are in Appendix 2 where the pattern and variation of internal temperature (and relative humidity) for each house is plotted separately. A summary for all houses coded by quality index is in Figure 3, which shows the non-normalized temperature patterns with 18˚C as the zero point on the Y axis (i.e. with 18 subtracted from the raw data).

The lines in Figure 3 are read as follows:

- Values above the zero line mean the interior was warmer than 18˚C; values below the zero line indicate substandard temperatures for human comfort.
- Flatter lines indicate a more constant interior temperature environment (e.g. Roto18 20.5); wavy lines indicate a more variable interior environment (e.g. Muru16 21).
- Colour of the line indicates quality index group

Together, colour and pattern identify the line for a particular house

Two general patterns can be seen in Figure 3:

- The spread of data is much greater in winter than in summer (compare the Y-axes of both graphs); interior temperatures therefore ranged more widely in winter than in summer.
- In winter, the houses are clumped by colours (=quality index) in the order black<blue<green<red, equivalent to the ordering low<medL<medH<high, where high represents the warmest group of houses. Separation of colours is much less obvious in summer.

The data were summarised by quality index group in order to show the pattern by group, and the variance around each mean (Figure 4). The figure is read as follows:

- Colours are as in Figure 3, but each line represents a mean of all houses in a quality index group
- The groups are; 1=low, 2=midL, 3=midH, 4=high
- The vertical bars are standard deviation of the mean for all data included in the mean (i.e. from all houses in the group)
- The grey block indicates temperature range defined by the UN as comfortable for human living (18-28˚C); values below or above the grey bar indicate increasing threats to human health

The general patterns listed above for Figure 3 can be seen more clearly in Figure 4:

The separation of groups by increasing house quality index is very clear in the winter data, and much less so in the summer data.

Houses in the two lower quality groups were operated at substandard temperatures most of the time in winter; houses in the two upper quality groups were warmer, but were still cool to cold in the early mornings with only the high group being reliably warm in the evenings.

Although houses were within the UN-recommended range most of the time in summer on average values, many houses were cool overnight some of the time. The midL group were the coolest. There were also houses that became hotter than the UN-recommended maximum at times (Appendix 2).

The addition of heat in winter resulted in greater variability of interior temperatures through the day, indicated by longer vertical bars on the winter graphs than on the summer graphs.

The black line (quality index low) has a more strongly waved shape in both winter and summer than for the other groups, indicating greater variability through the day.

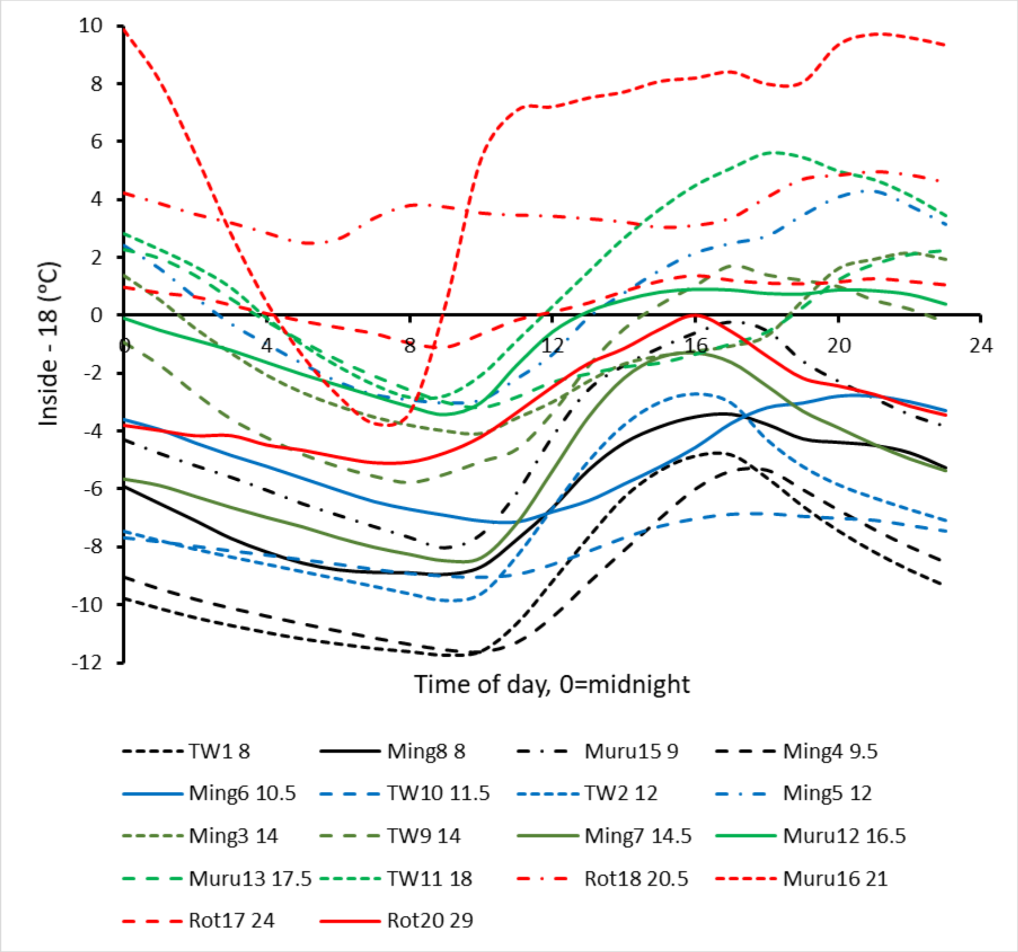
The GAM analysis was performed on the original data used to calculate Figure 4, normalized by conversion using the formula Log10(X˚F/64.4). The conversion standardised the data around 18˚C (=64.4˚F), and eliminated skew. The Fahrenheit scale was used to eliminate negative values in the Celsius range (a log cannot be taken of a negative value).

We predicted that higher quality houses would be warmer on average (= higher on the graphs) and less variable through the day (= a flatter line) than lower quality houses. t values from the GAM analysis for each paired comparison across the four quality index groups are in Table 2.

For the winter data, the t values increase from left to right, and from bottom to top; both sequences support the prediction that higher quality houses are (significantly) warmer. Houses in the low category had the most variability in the line shape, and were therefore the most variable in temperature.

For the summer data, the t values are all much smaller than for the winter data, and the sequence of t values is not consistent. In particular, the quality index groups high and low are very similar. Inspection of Figure 4 shows the black (low) and red (high) lines both crossing and sitting almost on top of each other. Low and medH overlap for some of their length, and medL is the only line that is fully separated from (and colder than) the other three. These patterns are consistent with the t values. The black line (low) is most variable, including becoming hottest in the afternoon.

Overall, the interior temperature patterns in relation to the house quality index were much more similar in summer than in winter. In both seasons, houses indexed as low quality had the most variable results.



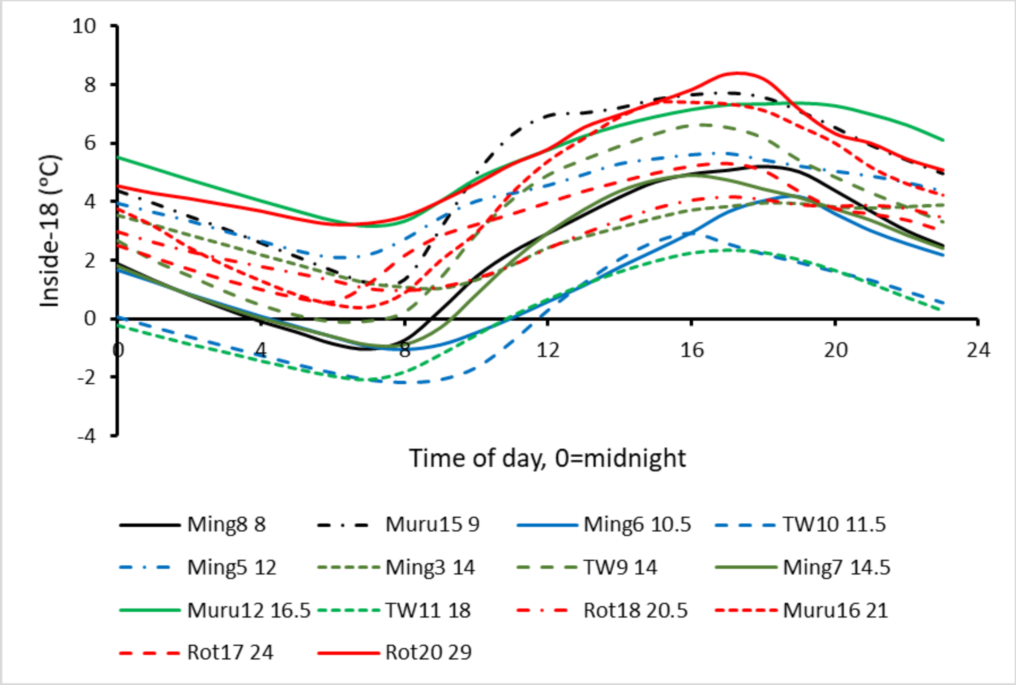
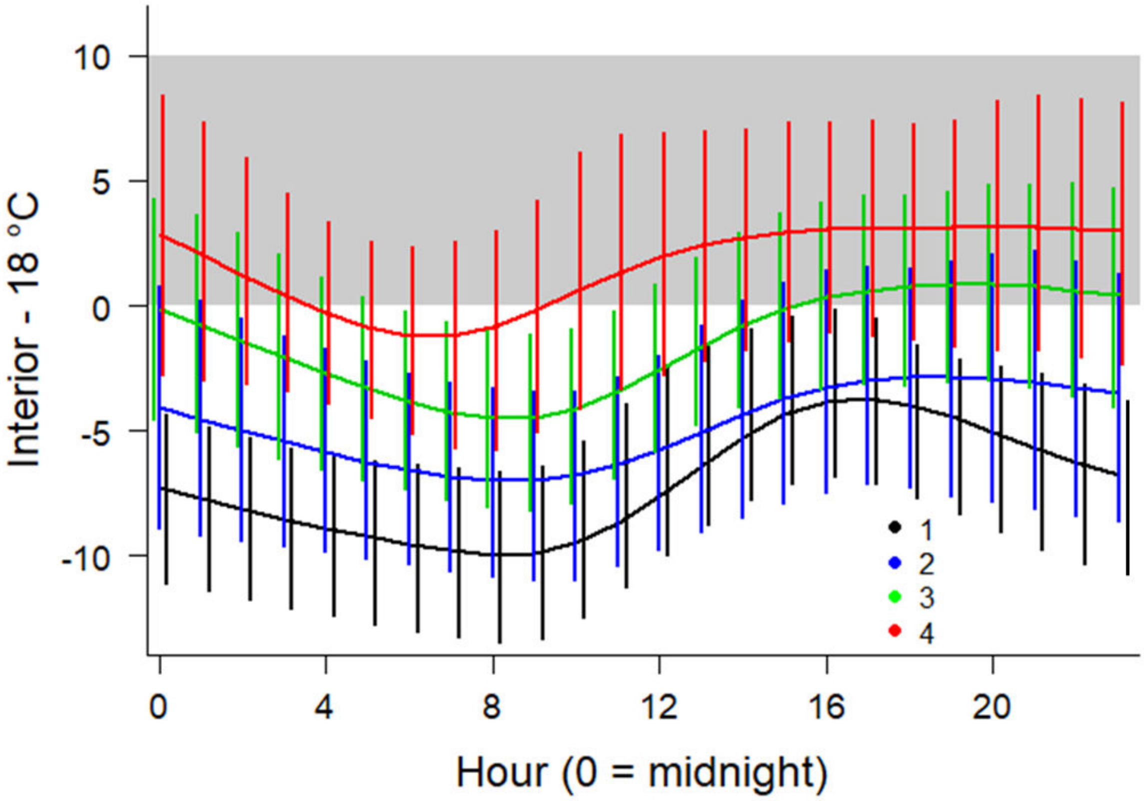


Figure 3 (*above=winter, below=summer*). Internal temperatures with the UN-recommended minimum temperature of 18˚C subtracted, for houses in winter and summer. The zero line is equivalent to 18˚C. All houses can be identified by a combination of colour and line pattern, with the green group using two shades of green. The colours identify the house quality groups, where black=low, blue=midL, green=midH and red=high (see Fig.

2b). Name of each house in the caption gives the location, the house number code in the project, and its quality index (e.g. TW1 8 = Te Whaiti, house number 1, quality index 8). Ming=Minginui, Muru=Murupara, Rot=Rotorua.



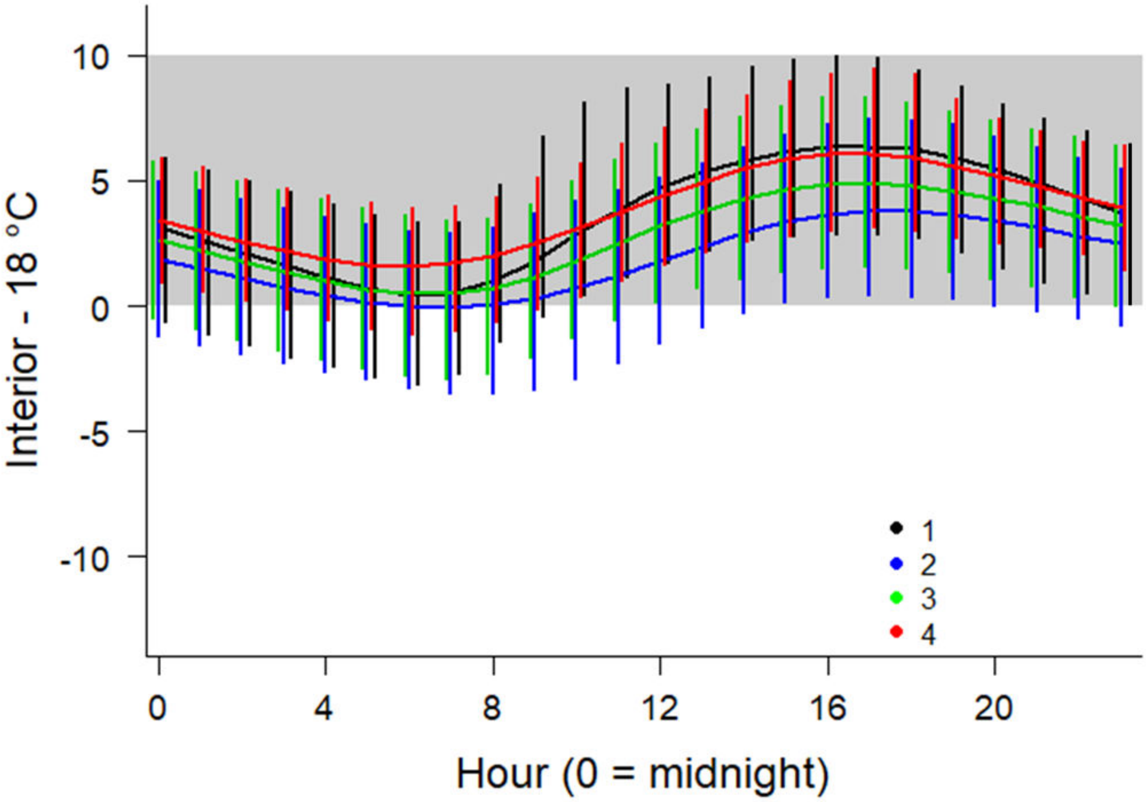


Figure 4 (*above=winter, below=summer*). Temperature patterns through the day for houses grouped by the house quality index. 1=low, 2=midL, 3=midH, 4=high (See Figure 2b). N's indicated in the text.

Data are mean±s.d., with 18˚C subtracted from raw values. Grey bar is temperature range recommended for human comfort by the U.N.

Table 2. t values reported by the GAM analysis for pairwise analyses of temperature data adjusted for the difference between internal values and the UN guideline of minimum 18˚C, and grouped by house quality (defined in Figure 2b); deviance explained is winter: 45.3%, summer: 24.1%. * = P<0.05.

Winter Summer	Low	Mid1	Mid2	High
Low	--	43.8*	89.7*	125.9*
Mid1	24.5*	--	46.0*	94.1*
Mid2	12.4*	16.5*	--	36.2*
High	4.0*	33.9*	20.6*	--

Variation in the shape of the internal temperature lines

Variability amongst the four quality index categories can be seen in two ways in Figure 4. First, variability around the means is shown by the standard deviation bars. That variability is captured by the GAM analysis. Second, although fairly similar, the lines themselves show different shapes. For example, in the summer data, the black (quality index “low”) line rises more steeply with the afternoon sun and then falls more steeply, than the other lines. That pattern indicates poor buffering of external conditions by the houses in the low category.

To test whether the line shapes were significantly different from each other in relation to house quality, we separated the shape of the line from the variance in the data. We used the 24 values (called Xn for this exercise) from which the line for each house was constructed. Beginning with X0, we calculated X0-X1, then X1-X2, and continued along the line, creating 23 values that captured the shape of the line, as follows. Where the line was steep, Xn -Xn+1 would be a relatively large number. Where the line was flat, it would be a relatively small number (and could be zero). Negatives from any calculation were ignored and the mean of all 23 values was then used as the raw datum for statistical comparison across house quality categories. Thus, this analysis looks only at the change in shape along the line (effectively, the steepness of slope independently of orientation). A variable line should deliver a high proportion of larger numbers and a larger mean; a flat line should deliver a higher proportion of smaller numbers and a smaller mean.

Thus, the change in slope through time for the lines in Figure 3 were used to compare across the four groups of houses indexed by quality in Figure 4. A non-parametric repeated-measures ANOVA was used (Friedman’s test, a ranking procedure). The repeated measures design ensures that values for the same position (time) along each line are compared directly. A ranking procedure eliminates relative scale of difference as a contributor to the calculation. The subtraction approach eliminates any influence of absolute differences of scale between the lines. The original, unmanipulated data were used in the analysis.

For winter, Friedman’s F_3=8.0 (P<0.05); for summer, Friedman’s F_3=10.1 (P<0.05) (Figure 5). Thus, there was significant variation among the line shapes in both seasons, with the quality index “low” showing greatest variability in line shape and the other three categories being smaller and more similar to each other.

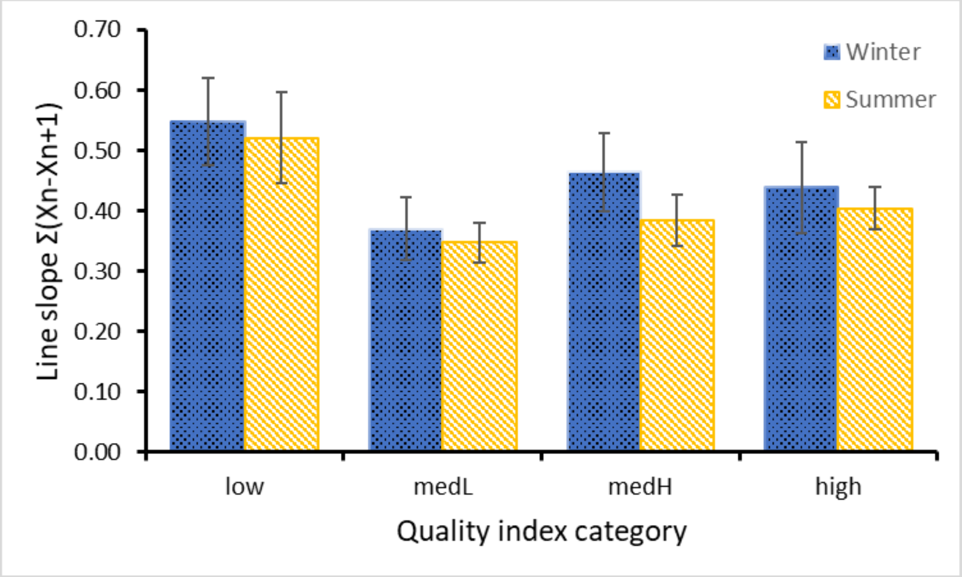


Figure 5. Average change in slope along temperature profile lines in relation to house quality index (using line patterns in Figure 3, original data in Appendix 1). Data are mean ± s.e. of subtracted adjacent values along each the line for each house. A higher value indicates steeper slope segments along the line and more rapid change in temperature through the day. House quality index increases left to right.

Variation in internal temperatures in relation to ambient (external) temperature variation

Ambient temperatures were subtracted from internal temperatures to visually represent the difference between interior (inside) and ambient (outside) conditions (Figure 6). As with Figure 3, the figure allows every house to be identified using a combination of colour and line pattern.

The lines in Figure 6 are read as follows:

- The values are relative differences and are not absolute; e.g., a value of zero indicates no difference between internal and ambient temperatures (i.e. it does not indicate that the temperature was 0˚C); a large value (e.g. +10˚C), indicates that the interior is 10˚C warmer than ambient.
- A negative value indicates that ambient was warmer than internal (e.g. winter Ming4 9.5)
- A flat line is expected if internal and ambient values varied together (e.g. winter Ming8 8; this house was consistently about 2˚C warmer than ambient).
- A fluctuating line is expected if internal temperatures fluctuated differently from ambient (e.g. winter “Muru16 21” fluctuated strongly, being up to 20˚C warmer than ambient in the evening and 8˚C warmer than ambient at 0800 hrs).

Two general patterns can be seen in Figure 6:

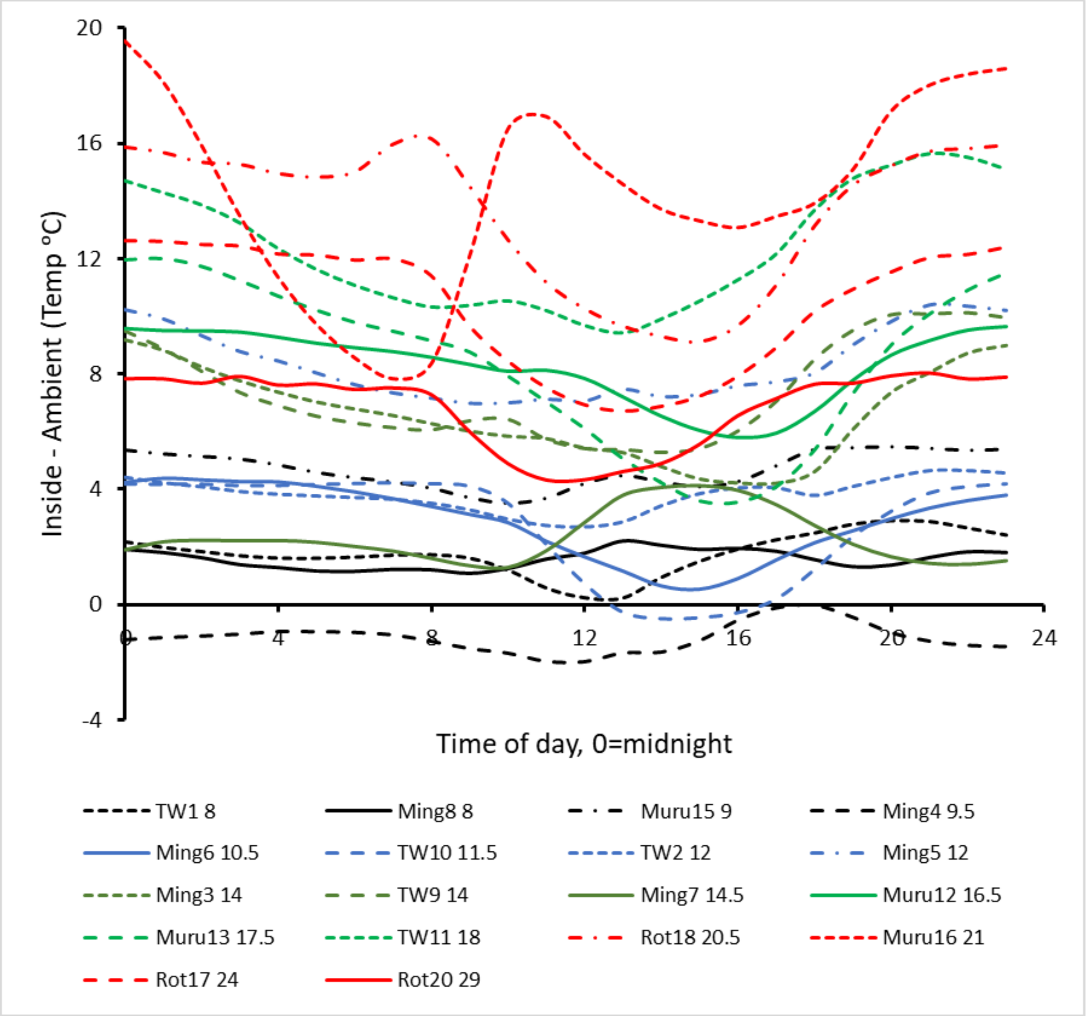
- In the winter data, the lines separate vertically by colour (= house quality) in the order black<blue<green<red (black = lowest, red = highest), suggesting that house quality is linked to the relative difference between internal and ambient temperatures. Vertical separation by colour cannot be seen in the summer data.
- Values in the winter data are more widely spread than values in the summer data (seen by inspecting the Y axis in both figures); as expected, internal temperatures were generally closer to ambient in summer than in winter, but some houses were much warmer relative to ambient than others.

The GAM analysis was performed on data standardised using the formula Log10(internal/ambient); Fahrenheit values were used to avoid negatives in the data.

The data were summarised by quality index group in order to show the pattern by group, and the variance around each mean (Figure 7). Here, a zero means no difference between internal and ambient, values above the zero line indicate interior warmer than ambient, and values below the line indicate interior colder than ambient. The normalized data are plotted to show the data on which the GAM analysis was conducted; the patterns are the same as for the subtraction (interior-ambient). The figure is read as follows:

Colours are as in Figure 6, but each line represents a mean of all houses in a quality index group.

The vertical bars are standard deviation of the mean for all data included in the mean (i.e. from all houses in the group).



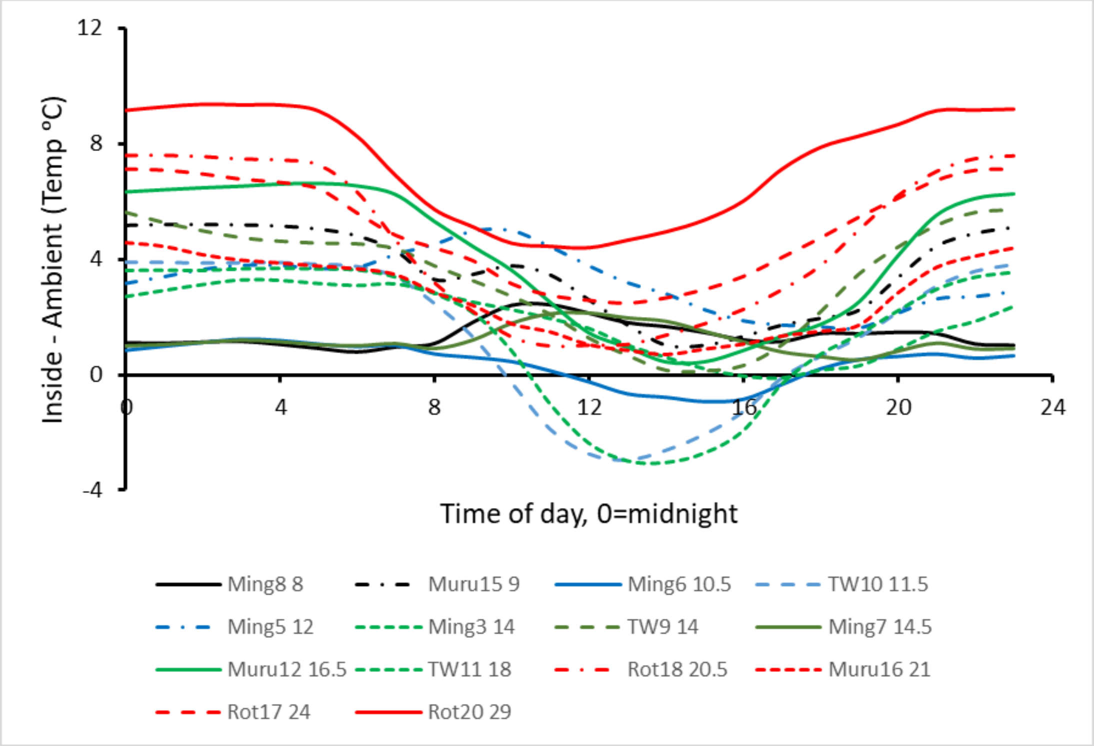
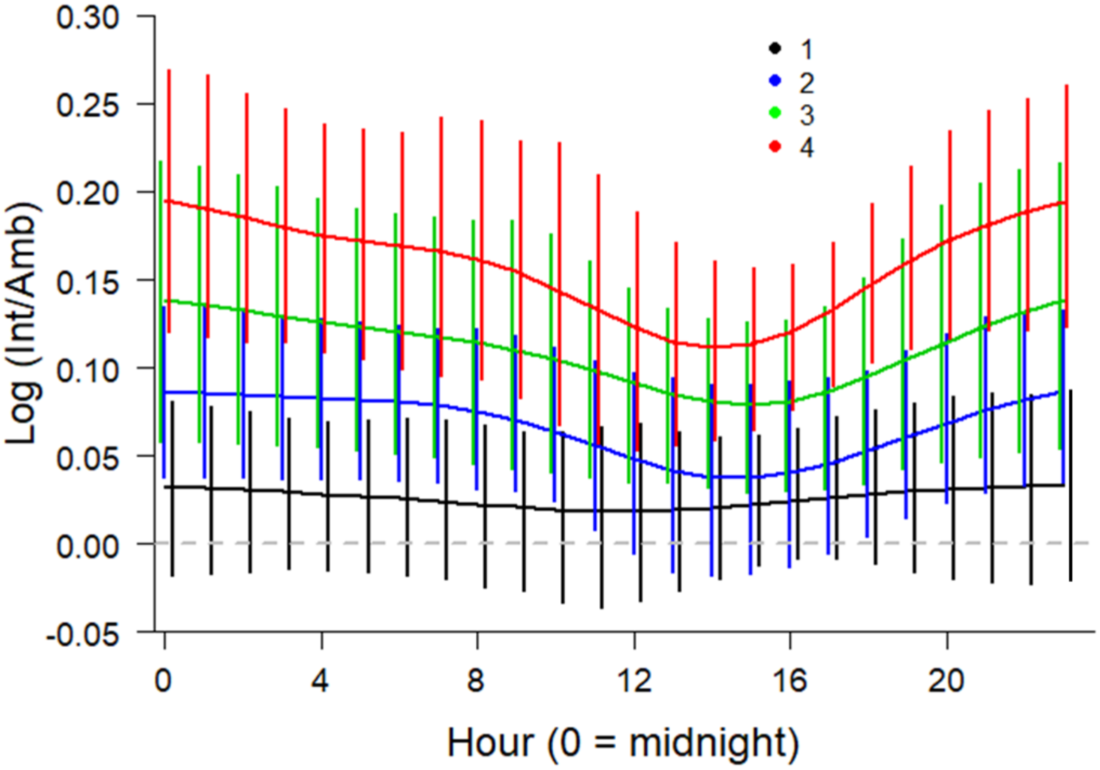


Figure 6. Difference between internal and ambient temperatures for 18 houses in winter (above) and summer (below). Name of each house in the caption gives the location, the house number code in the project, and its quality index (e.g. TW1 = Te Whaiti, house number 1, quality index 8). All houses can be identified by a combination of colour and line pattern, with the green group using two shades of green. The colours identify the house quality groups, where black=Low, blue=MidL, green=MidH and red=High (see Figure 2b). Ming=Minginui, Muru=Murupara, Rot=Rotorua.



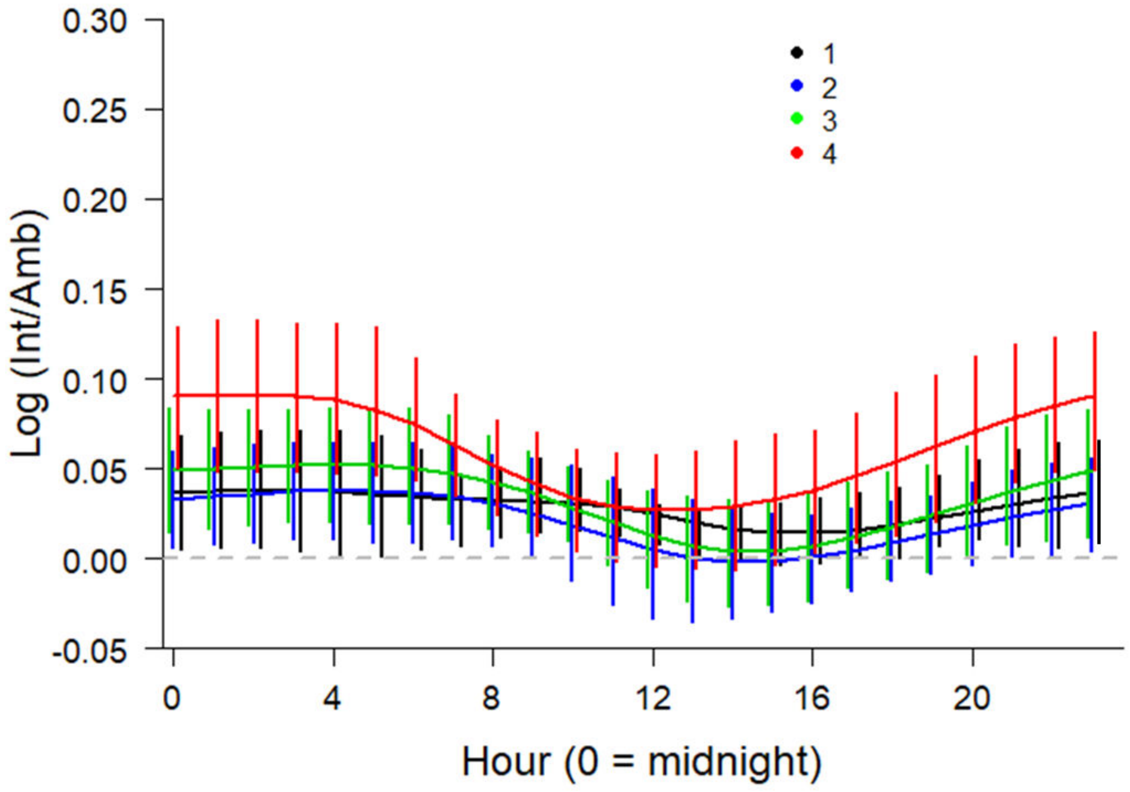


Figure 7. Patterns through the day for houses grouped by the house quality index for winter (above) and summer (below), with internal temperature plotted relative to ambient (outside). 1=low, 2=midL, 3=midH, 4=high (see Figure 2b). N's indicated in the text. Data are mean±s.d. of standardised data. The zero line is where internal and ambient temperatures are identical. Deviance explained is winter: 41.7%, summer: 34.2%.

Table 3 reports t values for pairwise analyses of adjusted temperature data (internal/ambient) of house quality groups. If the prediction of increasing difference with increasing house quality is supported, then patterns in the Table should show:

i) for the winter results, t values will increase towards the right and decrease going down; and
ii) for the summer data t values will decrease towards the right and increase going down.

The winter results fit those predictions perfectly. The summer data do not, with generally lower t values than for winter, and no pattern in the sequence. Houses of high quality were warmest, but an unexpected result was that houses of low quality were (slightly) warmer than houses of intermediate quality. We believe that is due to lack of insulation resulting in houses being heated by the sun.

The trends in these results are consistent with the prediction that houses of higher quality deliver temperatures that are more strongly buffered against variation in ambient conditions, and are therefore more comfortable to live in. The addition of heat to houses in winter increased the range in the data, resulting in stronger support for that overall conclusion.

Table 3. t values reported by the GAM analysis for pairwise analyses of temperature data adjusted for the difference between internal and ambient values, and grouped by house quality (defined in Figure 2b); deviance explained is winter: 41.7%, summer: 34.2%. * = P<0.05.

Winter Summer	Low	Mid1	Mid2	High
Low	--	40.1*	91.2*	129.2*
Mid1	10.7*	--	47.3*	89.1*
Mid2	6.0*	20.3*	--	50.4*
High	48.5*	67.8*	55.1*	--

Discussion

There were clear differences in comfort levels among the houses in relation to the quality index. Houses of poor quality were colder in winter and tracked ambient conditions more closely in summer, than houses of better quality. However, intervention by residents through active management of internal environments (mostly by adding heat) enabled comfortable living conditions to be established in at least some low-quality houses.

Some of the old houses of Minginui and Te Whaiti had recently added insulation (ceiling and floor), which clearly enabled warmer internal temperatures. At least some passive buffering of ambient conditions was evident, although effectiveness was low. The availability of free fuel in Minginui and Te Whaiti resulted in some of those low-quality houses being almost as warm as better-quality houses. Heating fuel is generally not free in Murupara, and it is likely that some residents there struggled to maintain comfortable internal conditions due to those costs. The coldest Murupara house had no fire or insulation and was heated with portable gas heaters, which are expensive to run, dangerous, and add moisture to the air (increasing internal humidity). Availability of appropriate heating equipment and fuel cost are are likely to affect comfort in houses of any quality. Retrofitting insulation into some low-quality houses in this study clearly improved comfort levels, but most such houses were still operated for much of the time at temperatures below the UN standard of 18˚C.

Three issues identified in this study have effects that are difficult to quantify (see review and discussion in Seltenrich, 2015), but are likely to affect long-term health outcomes (Gasparrini et al., 2015). Seltenrich (2015) reviews the mechanisms by which short-term excessive heat and cold affect health outcomes and mortality rates, and notes that global warming could actually increase the rate of deaths due to exposure to acute temperature variation. Acute exposure to heat)”heat waves”) has been publicised as a killer in several extreme international heat-wave events over the last 20 years. However, chronic (albeit relatively mild) exposure to cold is still the biggest temperature-related killer. The three issues identified here are:

i) In most of these houses, even if the living rooms were warm, the bedrooms were cold. Thus, while sleeping, most of these residents were breathing cool to cold air. Respiratory and circulation effects from that regular exposure to cold air are likely, particularly for people who are older or chronically ill.

ii) Houses heated by fires have high ash loadings in the air (Guo, Lewis, & McLaughlin, 2015), are difficult to keep clean due to fires and draughts, and many of the older residents were or are smokers. Overall, the probability of long-term health effects under these conditions are high for all residents (including children).

iii) The long-term health effects of overheating and short-term temperature variation are difficult to study due to confounding variables (Seltenrich, 2015). Maintaining a constant temperature is difficult with wood-burners, and the overheating identified in some houses is likely due to that lack of control. Aside from the living room / bedroom temperature differences already noted, the data indicate that some houses were not reliably heated, and it is likely that some residents were breathing cool air on some days or evenings, and warm or even hot air on others. Insulation buffered some of the very hot days in summer (noting that the hottest days in mid-late summer were not a part of this sample), but some houses were also overheated in summer. Thus, the residents of the lower quality houses in this sample routinely experienced extreme temperature variation on a daily basis. In contrast, higher-quality houses (mostly in Rotorua) were generally maintained at more constant and more comfortable temperatures through the 24-hr cycle.

Evidence from this study suggests that retrofitting old and poorly maintained houses with insulation and basic heating equipment does not reliably achieve the desired outcome of comfortable living conditions compliant with UN guidelines, particularly when heat costs money. Links between these temperature profiles and humidity, mould growth and dust mites are explored elsewhere (Su and Wu, Chapter 2). However, we note here that people may maintain comfortable internal temperatures whenever they are at home, but mould and mites are “at home” all of the time. The cooler temperatures (and higher relative humidity values) experienced by these houses when people are not at home will likely encourage growth of mould and mites. Thus, allowing a home to cool down when people are not resident may still deliver an unhealthy living environment, even if it is routinely comfortable when they are resident.

Whether insulated or not, the poor-quality houses in this study provided substandard living conditions in time (through the day, at different times of year) and space (in different parts of the house), even when fuel was cheap or free. Houses in better condition (in Rotorua) provided better living conditions in terms of temperature, although heating cost likely affected the living conditions in one Rotorua house, and mould was still an issue requiring ongoing attention.

It is possible to upgrade old houses of low quality to a more compliant standard, and government subsidies have enabled some hundreds of thousands of houses to be upgraded in New Zealand for that reason (EECA, 2015). However, while insulation retrofits do improve internal conditions, the evidence from this study is that many residents of retrofitted houses will continue to experience substandard living conditions on both a daily and seasonal basis. Negative health consequences are predicted, and the results reported in Chapter 2 are consistent with that expectation. We believe that the health of the people in this study will benefit much more from moving to the homes designed by Tallwood, than they will from ongoing attempts to retrofit the low-quality houses in which they currently live.

Acknowledgements

Data capture was supported by Bin Su, Lian Wu, and Daniel Martin. Ruth Howison provided essential support, discussion and programming for the GAM analysis. We especially thank the residents of all research houses and the Matekuare Whanau Trust for their tolerance for and support of this research.

CHAPTER FOUR

Papakāinga design

Daiman Otto, Charlotte Farquharson, Cory Nock
Tallwood

In collaboration with Matekuare Whānau Trust members, offsite construction company Tallwood developed the papakāinga masterplan. The plan drew on, and formalised, the whānau ideas concepts and original papakāinga design including the roading layout and provision for:

- Kaumatua housing and inter-generational housing needs.
- Areas that foster and promote whanaungatanga (shared living and recreational spaces).
- Land to be used for permaculture and the creation of job opportunities for the community.
- Economic self-sufficiency through the incorporation of visitor accommodation.

Through the research and design process Tallwood concluded that:

- The housing stock in New Zealand is not suited to Māori (and Pasifika) families, which are typically large and involve shared inter-generational living.
- Papakāinga must focus on relationships between individual dwellings to promote community interaction.

The design aims to support the vision of the Matekuare Whānau Trust that the papakāinga will act as a catalyst for future development of the Tāwhitiwhiti site, within the region, and throughout Aotearoa.

There is demand for the (re)introduction of papakāinga living arrangements across New Zealand, including suburban papakāinga.

The community wishes to be involved in the construction of the homes to provide opportunities for education and future employment.

Once implemented, the housing designs for Te Whaiti would leverage more affordable housing opportunities for similar communities (and others).

A simple house design was proposed. Many aspects of the design were optimised for rapid construction on-site (using modular pre-fabricated building components), minimization of materials costs, and applying standards well above the building code minimum. The design was modelled hygrothermically by Scion (see below) to optimise the thermal envelope, particularly in relation to heat and moisture flows management, heat loss due to thermal bridges, air tightness, and acoustic buffering. A high quality thermal envelope helps create a healthy and comfortable living environment while also reducing operating costs over the life-time of the Building.

Tallwood's design system is a series of modular prefabricated building elements assembled on site. The system optimises material usage and minimizes construction waste. Emphasis is on ease of construction and sustainable building materials. In the context of the project, Tallwood's design was an opportunity to create a prototype for future papakāinga development.

CHAPTER FIVE

Hygrothermal modelling – Summary Report

Andrea Stocchero, Grant Emms
Scion

Introduction

The aim of Scion's work was to optimise the design and detailing of the M4 construction system as a proof of concept for the development of the "Te Whaiti Prototype, Tallwood Designed Building", to be constructed by the Matekuare Whanau Trust (out of scope).

Scion conducted an hygrothermal, structural and acoustic assessment of the building system proposed by Tallwood, and co-developed with the Design Team (Tallwood – Scion – Toi Ohomai) through a design optimisation process. The hygrothermal simulation of M4 building components was compared with the standards in the New Zealand Building Code (NZBC) and the performance of enhanced NZBC components.

An acoustic and structural assessment of the proposed M4 building implemented the pre-construction multi-performance assessment.

The optimised M4 system is intended to inform the development of the "Te Whaiti Prototype, Tallwood Designed Building" to be constructed by the Matekuare Whanau Trust (out of scope).

Methods

The assessment involved modelling and simulating the hygrothermal performance (heat and moisture flows) on the construction systems (proposed or adopted) for the construction of the three different case study buildings (Figures 1, 2, 3):

- M1 Building: Standard Building Code – "Rotorua Thermal Holiday Park Bedroom Cabin M1" (already built by Toi Ohomai students)
- M3 Building: Enhanced Performance Building – "Rotorua Thermal Holiday Park Bedroom Cabin M3" (already built by Toi Ohomai students)
- M4 Building: Tallwood Design – "Rotorua Thermal Holiday Park Bedroom Cabin M4" (potentially to-be-built by Toi Ohomai students)

M1 and M3 building components follow the detailed design documentation provided by Toi Ohomai prepared by Darryl Church Architecture (DCA), owner of the design rights (note the M2 building is the same as M1 and was not considered in this report). M4 building components have been assembled following and modifying the detailed design documentation provided by Tallwood. The M4 modifications have been done to compare the performance of different construction options.

M4 design is the adapted DCA's M1 design to be constructed using Tallwood construction technology.

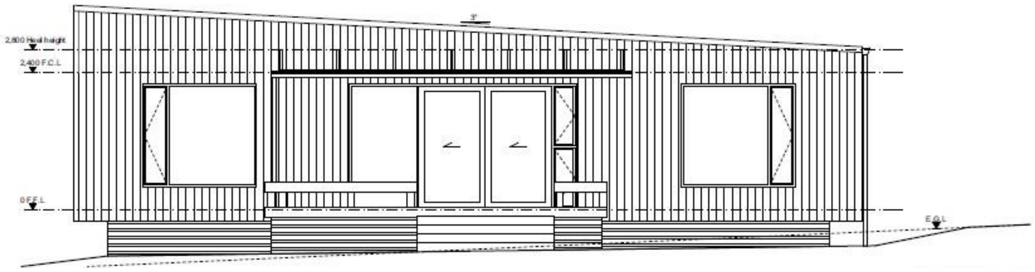


Figure 1. M-type Rotorua Thermal Holiday Park Bedroom Cabin, North Elevation, designed by Darryl Church Architecture.

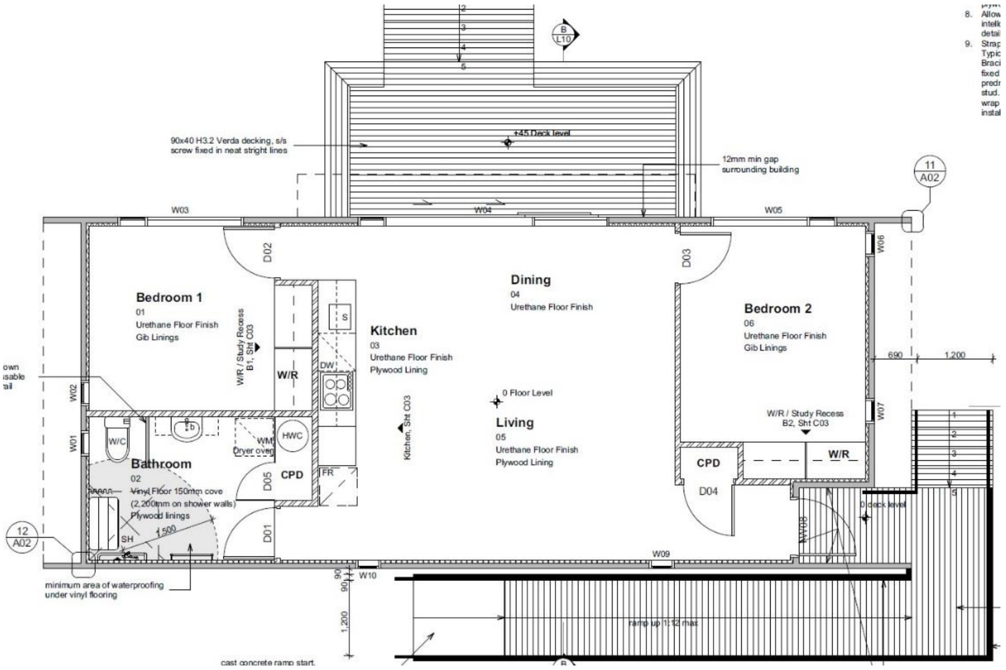


Figure 2. M-type Rotorua Thermal Holiday Park Bedroom Cabin, Plan Layout, designed by Darryl Church Architecture

Figure 3. M1 (left – North and East elevations visible) and M3 (right – South and East elevations visible) Rotorua Thermal Holiday Park Bedroom Cabins. Outdoor elevations, Darryl Church Architecture design. M2 building is the same as M1.

Sixty-six hygrothermal simulations for walls floors and ceiling cases have been run and investigated. The M1 and M3 simulated cases were used as a comparative proof of concept for the proposed M4 building system by the means of comparing the building systems hygrothermal performances.

As the proposed construction methods are intended to be designed to deliver comfort, health and affordability, the performance of the building envelopes was assessed in relation to the WHO guidelines on comfort and indoor air quality (IAQ) and energy efficiency (World Health Organisation, 2009).

The World Health Organisation references 18-22°C, (depending on room function) for safe indoor temperature ranges, with recommended minimum temperatures of 18 °C for houses inhabited by non-risk categories, and 20 °C for houses with young children, elderly people or ill people (WHO, 1987, 2007, 2009, 2011).

The WHO also recognises that the presence of mould and mites in a building is associated with the relative humidity of indoor air. WHO suggest that susceptible surfaces can be kept free of fungal growth by maintaining a RH below 75–80%. However, WHO also suggest that a single limit value is inadequate for the hygrothermal design of building structures as mould formation is affected by time, relative humidity, temperature and building material. Furthermore RH greater than approximately 45-50% may promote increased indoor dust mite levels, therefore the RH during the heating season should be below this value (WHO, 2009).

Research in NZ by Howden-Chapman (2007) and de Groot (2009) found that average indoor temperature in poorly insulated NZ houses is 16 °C. BRANZ (2017) suggested that in New Zealand dwellings, indoor relative humidity (RH) ranges from 30% to 65% during the day-time in a “dry” house, and 50% to 75% in a “damp” house. Cold bedrooms can have a RH of 80% - 90% at night-time. Thus, an indoor RH level of 75% +/-10% was simulated to represent an average “damp” house condition.

Table 1. Simulated indoor climate conditions

	Target indoor conditions	Average NZ conditions
Indoor air Temperature	20°C ± 2 (WHO, 1987; BRANZ)	16°C ± 2 (de Groot, 2009)
Indoor air Relative Humidity (R.H.	R.H. 60% ± 10% (BRANZ; WHO, 2009)	R.H. 75% ± 10% (BRANZ, 2017)

Table 1 summarises the simulated indoor climate conditions. These settings allow simulation of the behaviour of the proposed structures in relation to both Rotorua outdoor climate and the target indoor conditions as recommended by WHO, an approach also recommended by the Canadian Wood Council (Canadian Wood Council, 2018) and consistent with a New Zealand average scenario.

Key results

The analysis and comparison of the hygrothermal calculations of the different wall, floor and ceiling structure options for the buildings (M1, M3, M4) showed that:

- M4 building components are providing improved U-values and better Transient thermal transmission performances compared to both M3 and M1 buildings

- The positioning of the rigid foam insulation on the exterior side of the M4 building structure is improving the thermal performance of the structural section of the components (structural thermal bridging reduction)
- The M4 wall frame section has a lower thermal performance compared to M4 wall insulation section (expected performance). However, the M4 wall frame section thermal performance is better compared to M1 and M3 walls over both their frame and insulation section cases
- At 20°C ± 2 and 60% ± 10% RH indoor conditions, the RH level within the building components' layers for all buildings (M1, M3, M4) is below 100% during the calculation period of three years, showing no interstitial condensation risk at the analysed conditions
- At 20°C ± 2 and 60% ± 10% RH indoor conditions, the water content check in each layer showed a decreasing trend for all buildings (M1, M3, M4)
- Lower RH peaks in both M3 and M4 building components' layers are indicating improved moisture flow management within the structure thanks to the use of moisture control layers (a vapour check and air tight membrane coupled with an exterior weathertight and moisture control membrane)
- The Mould Growth Risk assessment for the same wall component at different indoor climate scenarios (Air temperature and relative humidity) indicated a higher risk of Mould Growth at lower indoor air temperatures and higher RH, compared to the target WHO recommended indoor conditions. This outcome was consistent for all the M1, M3 and the highly insulated M4 building components selected for this analysis.

Conclusions

These findings suggest that:

- Lower energy input to meet and maintain WHO healthy indoor conditions is likely for the M4 building compared to the M1 and M3 buildings.
- The initial moisture content of construction materials will dry out in M1, M3, M4 structures; moisture management will be effective at the design 20°C ± 2 and 60% ± 10% RH indoor conditions and at the considered outdoor conditions and eventual yearly moisture build ups within layers. Durability and performance of building materials will be protected.

Furthermore, the simulation findings also show the relevance of user heating and ventilation behaviours and the impact on the indoor environment healthiness and comfort levels:

- When indoor conditions are below the WHO recommendations for healthy environments, the benefit of higher insulated structures (lower U-values) is not fully realised
- It is important to actively manage the air temperature and RH levels with the aim of achieving and maintaining them within the range suggested by World Health Organisation guidelines to avoid Mould growth risk on indoor surfaces
- M4 building systems are likely to provide better life time affordability for space heating and cooling towards maintaining WHO target indoor conditions
- Both building envelope performance and user behaviours are relevant to maintaining healthy indoor environment conditions

The structural assessment suggests that:

- Achieving a wider portal frame spacing for M4 building would further enhance the overall building envelope (excluding windows and doors to exterior) thermal performance
- The specific structural design and tailored calculations by a registered structural engineered (out of scope for this project) will be required to guarantee structural compliance and earthquake and strong wind resilience to the proposed M4 structure

The acoustic assessment suggests that:

- The proposed M4 construction system indoor noise control performance is no different to a standard building code plasterboard lined house (such as M1 building) as the interior linings are sealed hard surfaces in both cases.
- M4 buildings show external noise mitigation capacity; however, to enable full prediction of the sound levels within the building due to exterior noise, the complete design of the building is required along with the expected exterior noise levels

Considerations of results

WUFI® Pro is a software that allows the one-dimensional (through the component thickness) calculation of the simultaneous heat and moisture transport in multi-layer building components. WUFI® Pro has been validated by comparison with experimental results by Fraunhofer IBP (Fraunhofer IBP, 2018) and it is used both internationally and in New Zealand as a modelling tool for the investigation of the hygrothermal performance in building envelope components such as walls, roofs and floors (McNeil, 2010).

Assumptions (e.g. climate conditions and materials selections) and adaptations (e.g. NZ market available materials' data where possible) had to be made to develop the model.

The necessary assumptions and adaptations have been done following indications from international and New Zealand specific literature and best practice information and basing on the user experience. However, for this reason variations between calculated performance and real-world performance of built components and buildings are possible.

For this reason, this work is representing an initial assessment of the structures aiming to represent as close as feasible the real-world performance of the modelled components in the New Zealand environment. The simulation outcomes and conclusions are valid for the building components and indoor and outdoor environment conditions as defined within this report. If other materials, material thicknesses and their properties along with different indoor (i.e. heating cooling and ventilation strategies and users' behaviour influence) and outdoor (i.e. Te Whaiti specific) environment conditions are specified, the hygrothermal models will need to be adapted and recalculated accordingly.

Furthermore, the performance of windows and doors, the effect of heating, cooling, ventilation and user behaviour and the influence of 2 dimensional materials' hygrothermal behaviour and structures' geometric thermal bridging (e.g. corners) influence could not been considered by the current models. For this reason, an overall building energy performance estimation cannot be made.

CHAPTER SIX

Buildability

Brian Dillon, Phil Grimmer, Shane Conquer
Toi Ohomai

Introduction

Research project partners Scion, Tallwood, and Toi Ohomai worked to develop base designs for eventual implementation as a papakāinga development for Matekuare Trust, at Tawhitiwhiti.

Computer modelling was done to extrapolate findings from data taken from completed buildings, and specifically to consider design for enhanced air quality, and ultimately a healthier home.

Draft details were discussed and modified, to ensure the focus on buildability, affordability, and healthy homes was maintained.

Design and modelling

Draft concepts and drawings were produced, to indicate a likely end design for papakāinga housing. While not a complete set of working drawings, they were used to create a series of mock-ups (models), with consideration given to panelisation, modular construction, off- and on-site assembly, and maintaining key performance aspects such as a complete insulation envelope.

Buildability has been considered in any re-design and mock-up from the base drawings, including practicalities of component construction, how components are connected to each other, and how partial or full elements are assembled and erected on site. These aspects are key given that the plans propose a portal frame of 6m+ at its apex.

Buildability

Part One

The first mock-up created was a section of flooring, with two partial portal frames (Figures 1, 2). This model gave an initial sense of how the key portal/floor junction could go together, and how the floor and wall panels could be integrated.

It was clear from the early modelling that some issues would arise if certain details were to be part of the final design.

What worked well/would work well?

- Modular Design – simple manufacturing process, on-site assembly
- Use of common sized materials and components - less wastage, generally lower purchase cost
- Relatively simple connectivity of components - floor, wall and roof panels
- Flexible design options e.g. skylights, exterior wall cladding type, interior layout

Figure 1. Mock-up #1 completed

Likely/potential issues (and solutions where applicable):

- Design upgrades required to meet NZ Building Code Compliance – durability, structure
- Reduction in overall height to allow the use of non-notifiable scaffolding (<5m) – should make any self-build aspects more manageable too
- Some specific engineering required – floor/wall connection
- Potential use of LVL (Laminated Veneer Lumber) to improve structural integrity and improve assembly tolerances; may also reduce some component sizes
- Lifting equipment required e.g. hi-ab truck on-site - access, cost
- Design and location of services to be confirmed early in the design phase e.g. electrical, plumbing and gas

Figure 2. Elevation of Mock-up #1

Part Two

Based on findings from Part One, two more mock-ups were created. One (Figures 3-8) was an 1/8th scale of the entire building (shell), showing how the portal frames would integrate with the floor, wall and ceiling/roof panels. While this model was built primarily as a demonstration for the Matekuare whanau, it highlighted the value of modular and flexible layouts within a standard shell. An example is the end elevation (Figure 3), where various configurations of openings could be incorporated.

Figure 3. Mock-up #2 - end elevation

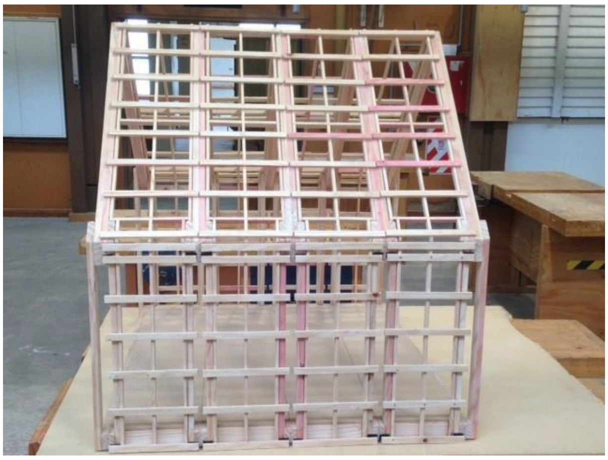


Figure 4. Mock-up #2 - side elevation

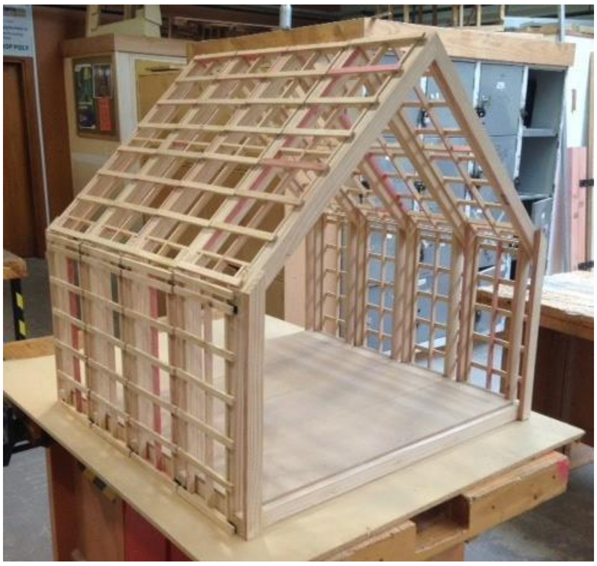


Figure 5. Mock-up #2 - oblique view

Figure 6. Mock-up #2 - underside of roof junction


Figure 7. Mock-up #2 - wall/roof junction


Figure 8. Mock-up #2 - Wall/floor junction

An initial interior layout design was produced by Tallwood (Figure 9), the project design partners. While no models of this layout were produced, the base design can clearly accommodate various interior layouts.

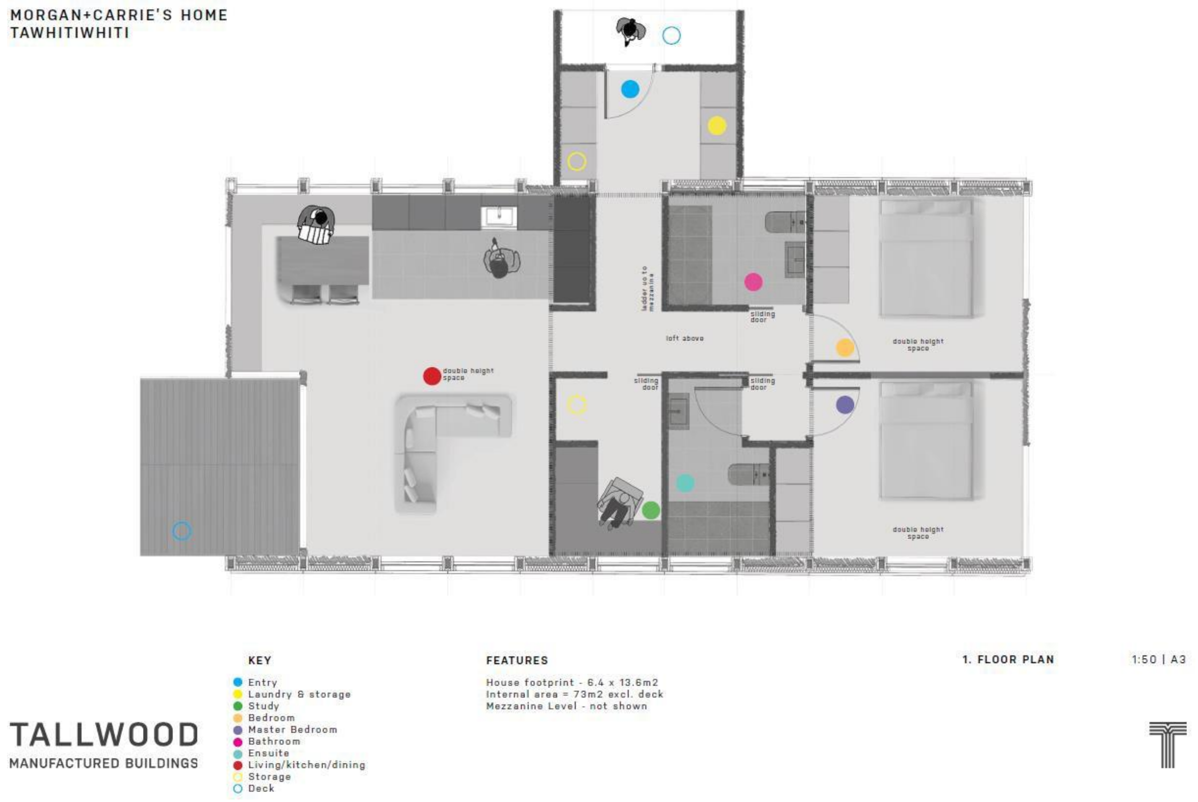


Figure 9. Interior layout option

The second model built in Part Two (mock-up #3) was a full size detail of the critical floor-wall junction (Figures 10-12). This junction ties the floor structure to the portal frame, and supports the wall framing and panels. Findings, and subsequent solutions, from the first mock-up were applied to this model to address the issue of connecting the floor panel/unit.

Toi Ohomai Engineering staff constructed threaded inserts, into which engineering bolts were inserted, to secure a steel plate.

Figure 10. Mock-up #3 - connector plates

What worked well/would work well?

- Steel plates – would need engineering calculations done for structure, but the concept is good. All fixings hidden, but remain accessible for maintenance and replacement
- Cut-away floor section shows how last of the flooring can be installed after the plates are connected, and without compromising the thermal envelope or structure

Figure 11. Mock-up #3 - floor cut-away, showing structural connectors

Likely/potential issues remaining (and solutions where applicable):

- Engineering of the plates (design, manufacture) – will need to meet or exceed building code and account for environment (corrosion potential). Positioning of plates will allow for easy access for assembly and ongoing maintenance checks
- Weight of portal frame structure – even with some in-situ portal assembly, installation of the frame will still require a skilled workforce, and scaffold. There will be limits to the extent to which the apex can be lowered without compromising on architectural aspects, especially the use of volume in the building (loft space)

Figure 12. Mock-up #3 - exterior view

- Integration of services – the objective of limiting any post-construction penetration of the envelope will mean careful and timely planning of services. An interior cavity and vapour barrier is planned (for thermal efficiency), which should allow for easy running of pipes and wires.

Summary

The first mock-up highlighted potential and likely construction issues, especially at the floor/wall junction. The solution identified, and trialled in part two, seems to work well. Further engineering of this aspect will be necessary – calculations, and manufacturing. There may be other solutions to this junction, but only this one has been modeled.

The ability to have flexible, variable opening configurations without compromising structural integrity is a positive aspect and should not impact on buildability, either in a factory environment or on site.

Next steps

With the intent of building a full size prototype, in March 2019 Toi Ohomai commissioned DCA Architecture (of Rotorua) to take the existing relocatable cabin design (M1) and incorporate the modular and prefabrication technologies into the existing design to create an M4 design. The outcomes of the design process, and ensuing quantity surveying and energy modelling, are presented in three parts in the following chapter.

Part One of Chapter Seven presents the M4 design overview; Part Two presents a summary of the quantity survey (QS) and some initial cost comparative results while Part 3 presents a summary of the energy modelling results prodhued by Andrea Stocchero of Scion. The full energy modelling and key parameters reports can be found in Appendices 3 and 4.

CHAPTER SEVEN

M4 Building design and affordabiltiy overview

Werner Naude
DCA Architects

Introduction

Part 1: The M4 building

In 2015, DCA Architects (DCA Architects of Transformation since 2017) was commissioned by the then Waiariki Institute of Technology to design a relocatable holiday cabin (M1). This cabin was developed in compliance with the New Zealand Building Code at the time. In 2017 the design of M1 was updated to include the Pro Clima intelligent moisture management, air-tightness membranes and additional cavity insulation. The subsequent cabin is known as M3. Both cabins are located at the (now) Toi Ohomai Institute of Technology's camping ground in Rotorua where they are used as holiday rental accommodation.

In 2019, DCA was recommissioned to develop another iteration of the same (M1 and M3) floor plan design as part of this (research) project. The 2019 version of the design is known as M4. Using the Tallwood system as an initial reference, DCA's brief was to develop a modular construction system for the Te Whaiti papakāinga (house) that incorporated prefabrication technologies, including timber portal frames and prefabricated cassette systems, for the roof, walls and floor. DCA therefore took the existing relocatable cabin design and incorporated the prefabrication technologies and exterior insulation into the existing design. An initial set of M4 plans was produced that were structurally engineered and quantity surveyed. An initial comparative cost analysis between the M1 (standard code building) and the M4 (above standard code building) was also conducted prior to Scion undertaking a comparative analysis of the M1 and M4 building typologies performance.

The overall focus of the building design is to deliver a system that is affordable, sustainable, and efficient to build while promoting a better, healthier home. The current design is the culmination of all strands of the research.

Approach

To develop a design solution that provided accurate performance analysis data, DCA worked to incorporate all the required performance elements of the M4 cabin, including prefabrication through cassettes / timber portal frames, airtightness, and exterior thermal insulation to remove thermal bridging. Critical performance items such as floor area, roof space air volume, relative area of glazing, and overall building air volume, were the same as for the previous cabin. Design and layout are in Figures 1 and 2.

Design changes required/made from M1

Roof design:
To facilitate an efficient timber portal frame structure the roof shape of the cabin was changed to fall across the short direction of the cabin. This shaping is the opposite of the M1 cabin.

Air Volume:
The pitch of the roof was determined by working up from a minimum roof pitch to where the air volume matched the original roof design. The overall size of the cabin footprint was adjusted to compensate for the changes made to the floor plan layout to ensure that the interior air volume remained the same.

Prefabrication/Cassettes:
To facilitate efficient prefabrication by reducing the number of cassette types DCA adjusted the floor plan by removing the entry door alcove.

Structure:
A project specific timber portal frame structure was designed by BCD Group Ltd (Consulting Engineers and Planners). Through the design process the structure evolved from a double portal leg (Tallwood) frame system to a single portal leg system with steel plate connections at the floor/knee and ridge connections, as this approach was the most effective system for the M4 cabin. The single member frame had the potential to use less timber and create fewer thermal bridges. The portal frame centres were adjusted to provide an efficient span distance to allow for the fabrication of efficient, reasonable size (easy to transport and install) floor, wall and roof cassettes. The adjustment also took the existing cabin window design and layouts into account.

Glazed Area:
The adjustment of the portal frame centres, and creation of prefabricated cassettes, required the adjustment of some of the windows to allow for prefabrication and an efficient portal frame system. The windows proportions were adjusted; however, the relative area of glazing/framing was kept the same as for the M3 cabin.

Cladding:
The installation of prefabricated cassettes required an adjustment in the cladding system to allow for the premade cassettes to be fully weather tight when delivered to site. This requirement involved the addition of a cover board detail/back flashing detail at the cassette junctions to provide the final weather tightness seal.

Roofing:
The installation of prefabricated cassettes required an adjustment in the roofing system to allow for the premade cassettes to be fully weather tight when delivered to site. This requirement involved the addition of a cover flashing detail at the cassette junctions to provide the final weather tightness seal.

Framing:
Exterior wall timber framing has been upsized from 90 mm to 140 mm to allow for maximum thermal insulation within the wall cassette system.

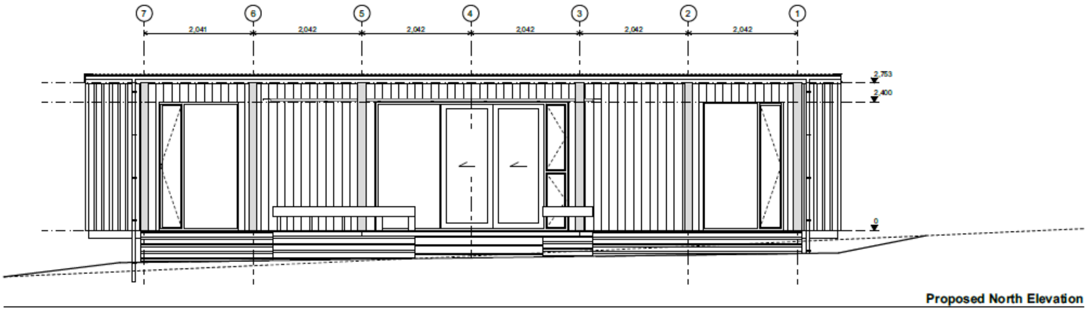


Figure 1. M4 Building - Modular System, designed by Darryl Church Architecture

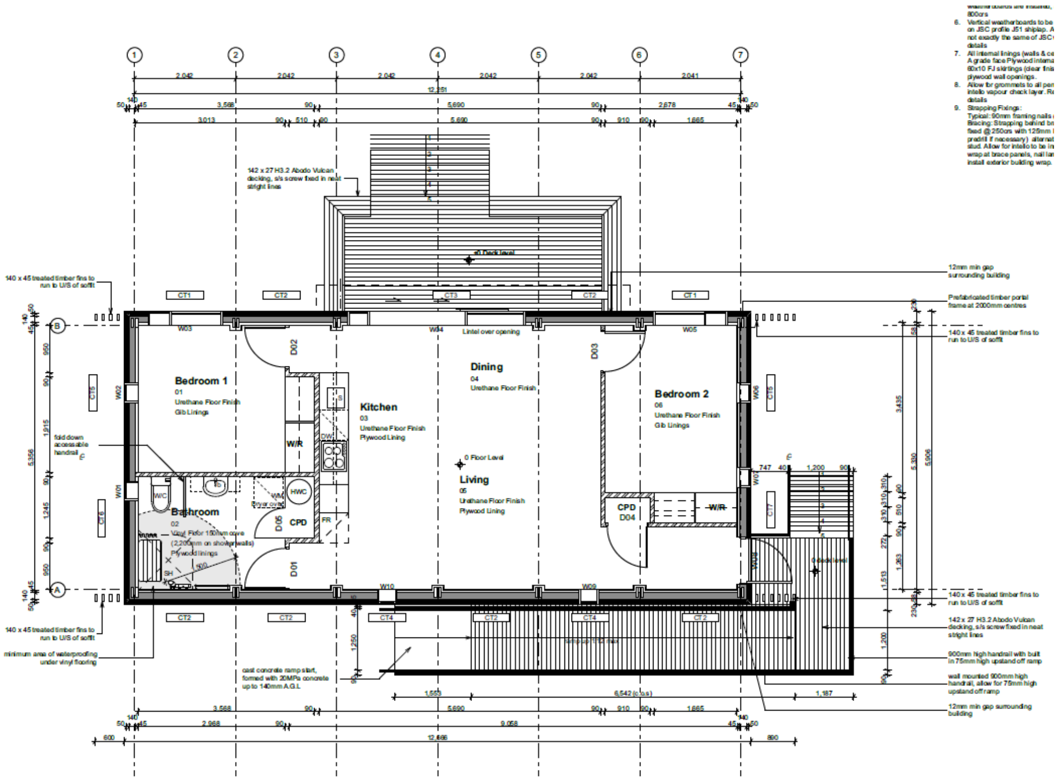


Figure 2. M4 Plan Layout, designed by Darryl Church Architecture

Part 2: Quantity survey - Summary report

Linda Lodetti, Dirk Stahlhut
Prendos New Zealand Ltd

Introduction

The purpose of this report was to provide the research project team with sufficient financial information to assess the costs of manufacturing the proposed M4 Cabin.

The cost estimate provided was based on relevant market data at the date of the estimate and assumed reasonably competitive market conditions.

This appraisal was an attempt to provide an indication of the cost magnitude of the overall budgetary commitment for the building works for financial planning and comparative purposes.

Approach

Assumptions:
The estimate is based on the following assumptions:

- Measurements of the elemental items were taken from the concept drawings provided by DCA Architects, being Transformation Concept drawings L01 to L06.
- Preliminary Structural Design Markup by BCD Group on DCA Architect’s drawings (as dated 20 August, 2019).
- Toi Ohomai Construction, Scion, DCA Architects and Prendos meeting 22 August, 2019.
- Existing water and power supply capacity is adequate and assumed located at building boundary.
- Soil and drainage services to be connected at building boundary and budgetary allowances are included for connection only.
- Off-site pre-fabrication duration of three months and on-site construction period of two to three months; thus overall duration of six months in single stage approach.
- Scaffolding and lifting equipment required assumed in preliminaries.
- Competitive market conditions.
- In the absence of any indicative estimates for mechanical and electrical services, budgetary allowances are included.
- The cost plan has been prepared from the preliminary design information, historical cost data and market testing.

Exclusions

The appraisal did not take into account the costs of the following items:

- Building consent
- Legal and expert fees
- Decking, handrail, steps and concrete ramp
- Site specific supply or upgrades of services (water, gas and power)
- Furniture, appliances and fittings
- Solar PVA or solar water heating

- Water storage; grey water utilization
- Contractors' All-Risk Insurance
- Professional Fees
- Escalation beyond the date of the estimate
- GST

Inclusions

The estimate did include:

- Site preparation and foundations
- Off-site fabrication of all floor, wall, ceiling and roof cassettes
- Delivery and installation of cassettes on site
- Stove and hob appliances
- Vinyl flooring and 2 m high vinyl to walls in the bathroom only
- Urethane floor finish generally elsewhere
- DVS ducted system allowed
- $10,000 design development contingency within the construction costs
- 10% project contingency as client held allowance.

Comparison – M4 to M1

Notable building comparatives:

Based on DCA Architecture's M1 and M4 drawings, M4 building Gross Floor Area (GFA) is 73.22 m^2, while M1 building GFA is 70.84 m^2. This equates to 2.38 m^2 increase in GFA for M4 cabin which is a 3.3% increase and would contribute to increased construction costs in a general analysis exercise.

The floor plan functional layouts, windows and doors, electric and plumbing, space conditioning and hot water heating systems for M1 and M4 are the same, and thus the variances are focussed on the opaque building envelope, Building structure, gross floor area (GFA) and mechanical ventilation with heat recovery (MVHR) system.

Additional Options:

The costs of the following options are not included in the estimate but provide an indicative additional value for consideration.

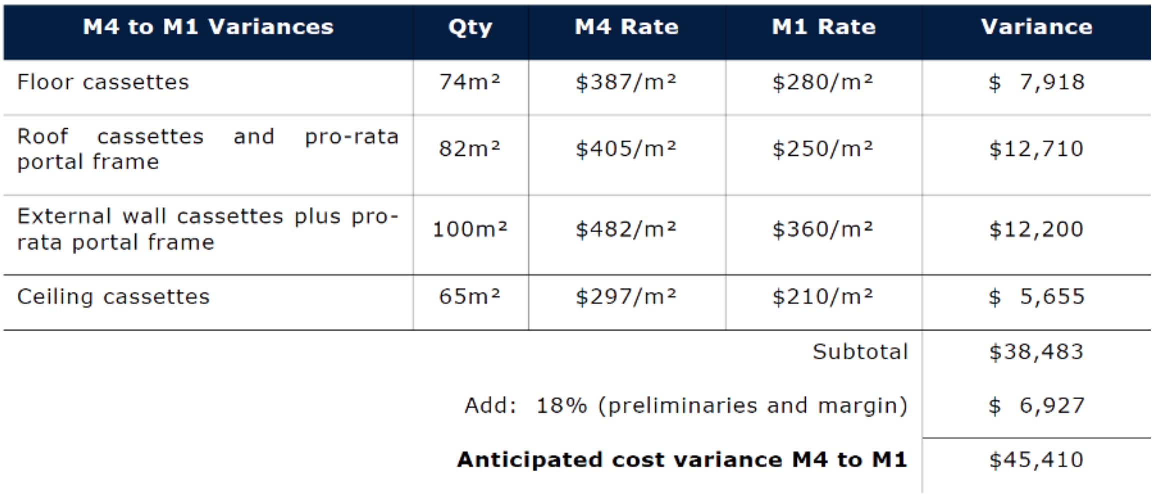
- Zehnder heat recovery and moisture extraction ducted system $12,000 + GST
- Additional protal frame post member for double frame system $8,000 + GST
- External timber decking, steps, rail and concrete ramp $16.000 + GST
- Fridge, dishwasher, washing machine and dryer $8,000 + GST.

Cost variance between M1 and M4

While available, total construction costs for the existing M1 building were considered inaccurate by the Construction Team since the building was built by students during academic curricula activities using predominantly donated materials.

Therefore, the cost comparison between M1 and M4 has been done on a variance base on a $\$/m^2$ rate for building elements priced based on relevant market data at the date of the estimate and assuming reasonably competitive market conditions.

Table 1. Cost variances between M1 and M4 buildings (calculated)



M4 to M1 Variances	Qty	M4 Rate	M1 Rate	Variance
Floor cassettes	74m²	$387/m²	$280/m²	$ 7,918
Roof cassettes and pro-rata portal frame	82m²	$405/m²	$250/m²	$12,710
External wall cassettes plus pro-rata portal frame	100m²	$482/m²	$360/m²	$12,200
Ceiling cassettes	65m²	$297/m²	$210/m²	$ 5,655
			Subtotal	$38,483
			Add: 18% (preliminaries and margin)	$ 6,927
			Anticipated cost variance M4 to M1	$45,410

Part 3: Whole of building energy - Summary report

Andrea Stocchero
Scion

Introduction

Taking account of whole of building energy performance, this summary report compares the key parameters for healthy homes (as identified by the Project Team) - between a base-line, standard-building-code building (known as M1) and an M4 building (M4) which was optimised by the Project Design Team to include an opaque building envelope.

The comparison was conducted by running and analysing results of whole-building dynamic simulations. The analysis of results allowed for a high-level assessment (simulation assumptions were made) of the whole M4 building energy demand in relation to the in-use performance delivered by the different building envelopes and different ventilation strategies considered.

Approach

Two simulation activities were conducted to assess the performance of the final M4 building opaque building envelope (wall, ceiling, floor) and the performance of the M1 standard building code envelope.

The simulation results were used for two purposes. First, to assess the performance of the opaque building envelope proposed by the Project Design Team; second, to compare the results with the standard-building-code M1 building that is already built and in use at Toi Ohomai Campus, Rotorua. The whole-building simulations were used to conduct a high-level assessment and comparison of the performance and energy demand of the two buildings (M4 proposed, M1 existing).

Three building models have been simulated using WUFI® Plus software: M4 Building with natural ventilation, M4 Building using a mechanical ventilation with heat recovery (MVHR) system, and M1 Building.

The whole-building indoor environment simulation entailed the preparation of whole building 3D models using WUFI® Plus software, including opaque and transparent building envelope components (walls, floor, roof and windows), and heating, ventilation and air conditioning (HVAC) systems, for M4 and M1 buildings.

A number of assumptions were made in order to define the full building envelope, including windows and doors, and simulation conditions, including user-defined ventilation and HVAC settings and internal loads.

The simulation design variables and relative assumptions that have been used within the simulation set are presented in Table 2.

Table 2. Variables and assumptions used within the simulation set.

Building Variables	M1	M4
Opaque building envelope	Standard building code	Optimised M4 building envelope
Airtightness (air infiltration rate ACH)	3.5 ACH*	0.9 ACH**
Indoor air temperature (T) *Target levels***	Constant across models** Min: 20 °C Max: 25 °C	
Indoor Relative Humidity (R.H.) *Target levels***	Constant across models** Min: 30 % Max: 65%	
Indoor CO_2 concentration *Target level***	Constant across models** Max: 1000 ppm	
Outdoor climate and unheated attic climate	Constant across models	
Building Volume	Constant across models	
Building Form factor	Constant across models	
Building orientation and shading	Constant across models	
Transparent building envelope (Windows: glazing and frames)	Constant across models	
Occupancy levels	Constant across models Family of 4 people (from WUFI® Plus Database)	
Ventilation	Constant across models Manual, (window opening schedule) [A simulation of M4 building with a mechanical ventilation with heat recovery (MVHR) system with 95% heat recovery performance and a ventilation flow of 0.35 air changes per hour (1/h) was run and results compared within this report.]	
Heating system	Constant across models 1 Heat Pump and 2 Radiant panel heaters	

Notes: *assumed from Rupp, S., McNeil, S., (2018); **assumed from the Toitū te Kainga, Toitū te Ora, Toitū te Tangata project team proposed key parameters and target performance for healthy homes (see Appendix 4).

Key results

The analysis of dynamic simulation results showed that the proposed M4 opaque building envelope (walls, floor, roof) provides overall lower heat losses that will translate into lower energy demand and cost for heating and maintenance of the indoor air temperature at the target levels. In particular:

- Heat losses from M4 exterior walls are 66% lower compared to M1 exterior walls
- Heat losses from M4 floor are 80% lower compared to M1 exterior walls
- Heat losses from M4 ceiling are 52% lower compared to M1 exterior walls

The proposed M4 opaque building envelope enables overall lower energy demand compared to M1 that will translate into lower energy demand and costs for heating and maintaining the indoor environment conditions at the target levels. In particular:

- Total energy demand for the M4 Building is 54% (both cases) lower compared to the M1 Building.
- Heating demand for the M4 Building is 66% (both cases) lower compared to the M1 Building.
- Cooling demand (worst case scenario) for the M4 Building is between 40% (manual ventilation) to 44% Mechanical Ventilation with Heat Recovery (MVHR) higher compared to the M1 Building.
- Cooling demand reduction is possible by using different ventilation schedules both for natural and mechanical ventilation.
- The negligible difference in energy demands between M4 cases with different ventilation strategies is dependent on the specific ventilation settings used in the simulations.
- M-type buildings are designed to maximise natural cross-ventilation efficiency. However, in real life, manual ventilation strategies depending on building users' management are subject to higher variations and inefficiencies that would impact on both indoor air quality, energy conservation and heating and cooling costs. For this reason, the automated mechanical ventilation with heat recovery system, with a heat recovery by-pass, is recommended because it provides more reliable ventilation overall, with a negligible increase in energy demand compared to manual ventilation.

Implications of results for the client

The findings of this work can be used, in conjunction with a construction cost comparison (Part 2), to assess the life-time affordability of the proposed M4 building in comparison to M1 standard building code building. Due to the number and nature of assumptions necessary to develop the 3D models, and running the dynamic simulations, the affordability figures are expressed in percentage (%) of savings rather than economical ($) value.

Conclusions

The findings can be used, in combination with the construction cost, to inform whole-of-life affordability of the building.

- The construction cost of M4 without mechanical ventilation with heat recovery (MVHR) system is 17.1% higher than M1, while the construction cost of M4 with mechanical ventilation with heat recovery (MVHR) system is 22.3% higher than M1.
- The mechanical ventilation with heat recovery (MVHR) system will increase M4 construction cost.
- Total energy demand to mantain the target indoor conditions for the M4 Building (with and without MVHR) is 54% lower than for the M1 Building.
- Heating demand for the M4 Building is 66% (both cases) lower than the M1 Building.

- Cooling demand for the M4 Building is between 40% (manual ventilation) to 44% Mechanical Ventilation with Heat Recovery (MVHR) higher than the M1 Building. However, these figures represent a cooling “worst case scenario”. Cooling demand reduction for the M4 building is possible by optimising ventilation schedules during cooling months using free-cooling strategies for both natural and mechanical ventilation.
- All M-type buildings are designed to maximise natural cross-ventilation efficiency. However, in real life, natural ventilation strategies depend on manual management by building users, and are subject to higher variations and inefficiencies that would impact on both indoor air quality, energy conservation and heating and cooling costs. Therefore, the automated mechanical ventilation with heat recovery system with a heat recovery by-pass for cooling months is recommended, because it provides more reliable ventilation overall with a negligible increase in operational energy demand and a moderate increase in construction costs.

CHAPTER EIGHT

Discussion

Aotearoa New Zealand is currently faced with the compounding challenges of relatively high inequality (Statistics NZ, 2017a), low wages (Holt, 2017), poor economic performance in the provinces (Statistics NZ 2017b), environmental degradation (Ministry for the Environment, 2019), shifting employment opportunities (e.g. volatility in forestry employment, NZ Herald, 2019), high housing costs relative to income (Statistics NZ, 2017a), and reduced investment in social services. For example, policy under the National government (2008-2017) was to withdraw from involvement with social housing (Schrader, 2012). That policy was reversed by the current government, although how such policy swings impact the eastern Bay of Plenty is difficult to determine.

The people of the eastern Bay of Plenty live in a low wage environment (many are on welfare income rather than wages), and it is to be expected that they will minimise living costs to match their limited incomes. Poor quality houses are the only houses available, and so they live in them. But most of these people are not escaping increasingly difficult economic conditions in urban centres. Rather, they are embracing kāinga papatipu (ancestral home). Thus, while the physical living conditions may be challenging, a theme that ran through many of the interviews was that the spiritual and cultural advantages of tūrangawaewae far outweigh those difficulties.

Most of these people have left their ancestral lands for other opportunities at some point in their lives. Therefore, the decision to return is an active process unlikely to be driven by economic issues. As one resident stated, her return began as a quick visit while moving to Christchurch, but she stayed while her husband continued on his way. However, the realities of an extreme environment have not changed, and there is general agreement among the whānau that improved housing is a pre-requisite to improved physical wellbeing, hence their support for this research. Retrofitting may make the houses a little warmer, but this research has shown that a much larger (and possibly inappropriate) expenditure is required to make the houses genuinely serviceable to modern standards. New housing built to an efficient design is likely to be the better option.

The concept of papakāinga began as a dream of the Matekuare Trust, but is fast becoming a reality. With Tallwood and Toi Ohomai support, the original ideas from whānau have been converted into a formally planned village that is now laid out on the ground, with some services in place. Tallwood, Scion and Toi Ohomai have created and tested plans for housing that will be genuinely affordable (over a life time) , while still functioning efficiently in the extreme conditions in the region. Whānau have undertaken significant landscaping, and have created the beginnings of employment with establishment of a nursery and promotion of tourism in nearby Whirinaki forest. Every step has been constrained by resourcing, funding limitations, weather, the requirements of whānau engagement, illness among Trust members, and presumably other unidentified factors. As with many Māori development projects, opportunity to attract credit is severely limited, and limiting (Kingi, 2008). Most funding is sourced from grants, volunteers, and donations. The Trust continues to seek that support, and there is now little doubt that they will succeed through the persistence and determination that have already been demonstrated.

While the papakāinga development should immediately ease chronic illnesses experienced by older people of the whānau, we will need to wait a generation to see the benefits of improved housing for the health and wellbeing of children. Statistically, those effects may not even be measurable due to small sample sizes and confounding causation. However, we know from large-scale research in public health that improved respiratory function specifically, and higher standards of health and wellbeing generally, are linked to improved housing (review in Chapter 2). More relevant perhaps, is that this study anticipates the health and wellbeing pathway of those children if nothing changes. If they are raised in old, run-down and poorly heated houses, as many of their parents and grandparents were, then they face a future of chronic illness and low wellbeing. The environmental realities of high pollen loads in the air and high external humidity cannot be changed, although quality housing will reduce them. Exposure to smoke and ash (from smoking and fires) is easy to change, and is already reducing in relation to smoking. The opportunity to live in a comfortable and warm home is now available if it can be resourced.

Whether the social and economic issues also faced by this isolated community can be resolved is more difficult to ascertain. More effective communications are needed enabling opportunities to work from home. Shopping for food still requires travel through a difficult gorge with high road maintenance requirements, at a significant cost for fuel and vehicle maintenance. An essential role of the papakāinga development is to improve resilience among the residents, enabling stronger bonds, more efficient use of resources, greater independence from energy poverty, increased local production of food, and improved wairua. Better housing is just one aspect of those wider objectives, and the research team are honoured to have been invited to play a small part in the process of recovery.

More generally, we believe that the research reviewed here has much wider application. Our dream is that New Zealand will come to understand that building houses to the minimum standard of the building code represents a poor investment in our children’s future. Even BRANZ (N.D.) has made the same argument. Prefabrication using standard materials has the potential to significantly reduce materials costs, and enable rapid on-site construction (Construction World, N.D.). Pre-design and workshop crafting of key weak points in any construction (e.g. joists, wall-to-floor and wall-to-ceiling connectivity, window and door framing) can ensure tight fits and improved energy and vapour management. The current popularity of house-and-land packages built by specialist companies attests to the willingness of New Zealanders to compromise on bespoke designs. For many groups similar to the Matekuare whanau, building design is almost entirely about affordability, resilience and comfort. Simple design is perfectly acceptable, and the design presented here fits the requirements perfectly.

Conclusion

‘He aroaro ka hui ki te wā kāinga e kore e tau ki raro ...’

A person returning home does not stop to rest

This whakatauki (proverbial saying) implies that if an objective is compelling, one pursues it without pausing. Without doubt, the whakatauki is indicative of the tenacity and determination of the Matekuare Whānau Trust to achieve their longheld moemoea (dream). Handed down through the generations, peopling their land Tāwhitiwhiti through the provision of healthy homes within a self-sustaining papakāinga, is the dream. Healing the land as their healing place has been a fundamental step to bringing the people home (to the land) to heal; being part of the Challenge (as attested to through this report) was another step in progressing the dream on many levels and in many ways, including arrival at another set of research questions.

Signalled in the foreword of this report, the next questions the whānau seek to answer are pertinent and timely:

- Who will live there [the papakāinga] and how can they be enabled to do so?
- How will the buildings relate to each other?
- How will the residents relate to each other?
- How does the papakainga plan and building design support integenerational living?
- How does the building design perform? What are the energy demands, and running costs, and how does it promote good health for occupants?
- How, through papakāinga living, can the residents experience “wellness” in its fullest sense?
- What are the opportunities to generate economic and financial sustainability from (within) our local rural surrounds and how do we ignite and develop them?
- How can technology enhance and support the creation of a self sustaining (rural) papakāinga and community?

In summary, understanding the barriers to, and enablers of, a return by Māori to rural ancestral lands is an important arrival point of this research. It is not an end but a new point of beginning from which to ask:

How can, does, or will, rural papakāinga housing design and development support the rejuvenation of rural Māori communites, alleviate the current housing crisis in Aotearoa New Zealand, and contribute to improved Māori health and wellness?

How do we achieve ‘**he hokinga kāinga, he hokinga oneone, he hokinga whenua’,** a return home to ancestral land?

REFERENCES

Arlian, L., Yella, L. & Morgan, M. (2010). House dust mite population growth and allergen production in cultures maintained at different temperatures. *The Journal of Allergy and Clinical Immunology, 125*(2), AB17.

Arlian, L., Neal, J., & Vyszenski-Moher, D. (1999). Reducing relative humidity to control the house dust mite *Dermatophagoides farinae*. *The Journal of Allergy and Clinical Immunology, 104*(4), 852-856.

Arlian, L., Rapp, C. , & Ahmed S. (1990). Development of *Dermatophagoides pteronyssinus* (Acari: Pyroglyphidae). *The Journal of Medical Entomology, 27*(6), 1035–1040.

Arlian, L., Bernstein, I., & Gallagher, J. (1982). The prevalence of house dust mites, *Dermatophagoides* spp, and associated environmental conditions in homes in Ohio. *The Journal of Allergy and Clinical Immunology, 69*(6), 527-532.

Arundel, A., Sterling, E., Biggin, J., & Sterling, T. (1986). Indirect health effects of relative humidity in indoor environment. *Environmental Health Perspectives, 65*, 351–361.

ASHRAE, (1989). Standard 62-1989 -- Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc. (ASHRAE), 1989. https://www.techstreet.com/ashrae/standards/ashrae-62-1989?gateway_code=ashrae&product_id=452

ASHRAE. (1993). *Thermal Insulation and Vapour Retarders – Applications.* In ASHRAE Handbook – Fundamentals (pp. 20.1–20.16). Atlanta, GA: American Society of Heating, Refrigeration and Air-conditioning.

ASHRAE. (1993). *ASHRAE Standard 62-2000 – Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: American Society of Heating, Refrigeration and Air-conditioning.

Barnard, L., & Zhang, J. (2018). *The impact of respiratory disease in New Zealand: 2018 update (Report of Asthma and Respiratory Foundation NZ).* Dunedin, N.Z.: University of Otago.

Bassett, M. (2001). *Ventilation Effectiveness - Recognition in the Next Ventilation Standards.* Conference Paper presented at the IRHACE Technical Conference, Palmerston North, New Zealand, March 2001. https://www.branz.co.nz/cms_show_download.php?id=8b6a9ea0d3feedbb4f3e369c572171bea2e4dabf

Bean, R. (2010). Mean Radiant Temperature (MRT) - Part I. Healthy Heating.

Block, S. (1993). Humidity requirements for mould growth. *Applied Microbiology, 1,* 287–293.

Boardman, B. (1991). *Fuel poverty: From cold homes to affordable warmth*. London, UK: Belhaven Press.

BRANZ, (2018). *5th House Condition Survey Results*. BRANZ. Available at: https://www.branz.co.nz/5thhcs

Braubach, M., Jacobs, D. E., & Ormandy, D. (2011). Environmental burden of disease associated with inadequate housing: a method guide to the quantification of health effects of selected housing risks in the WHO European Region. Copenhagen, Denmark: WHO Regional Office for Europe.

BRANZ. (n.d.) *Exceeding the minimum.* https://www.branz.co.nz/etm, accessed 11 June 2019.

BRANZ. (2015). *Perceptions of housing quality [in New Zealand] in 2014/2015.* http://archive.stats.govt.nz/browse_for_stats/people_and_communities/housing/perceptions-housing-quality-2014-15.aspx ISBN 978-0-908350-02-5 (online), accessed 7 June 2019.

BRANZ. (2017). *Humidity and condensation.* BRANZ Level website, updated: 16 November 2017. Retrieved from http://www.level.org.nz/passive-design/controlling-indoor-air-quality/humidity-and-condensation/

Braubach, M., Jacobs D., & Ormandy, D. (Eds.). (2011). *Environmental burden of disease associated with inadequate housing: A method guide to the quantification of health effects of selected housing risks in the WHO European Region.* Copenhagen, Denmark: WHO, Europe.

Canadian Wood Council. (2018). *WUFI Analysis assumptions.* http://cwc.ca/resources/wall-thermal-design/wufi-analysis-assumptions/

Charlton, E. (2019). *New Zealand has unveiled its first "well-being" budget.* World Economic Forum, https://www.weforum.org/agenda/2019/05/new-zealand-is-publishing-its-first-well-being-budget/

Cheung, C. (2011). *Policies to rebalance housing markets in New Zealand.* OECD Economics Department Working Papers, No. 878. Paris, France: OECD Publishing.

Clinch, J., & Healy. J. (2001). Cost-benefit analysis of domestic energy efficiency. *Energy Policy, 29,* 113–124.

Collins, K. J. (1986). Low indoor temperatures and morbidity in the elderly. *Age and Ageing, 15*(4), 211-220.

Construction World (n.d.) *Seven benefits of pre-fabricated construction.* http://www.constructionworld.org/7-benefits-prefabricated-construction/, accessed 11 June 2019.

Coppock, J., & Cookson, E. (1951). *The effect of humidity on mould growth on construction material.* Journal of the Science of Food and Agriculture, December 1951, 534–537.

Cropp, M. (2019, February 24). *Tenants will pick up cost of Government's healthy homes standard, investors war.* 1 News Now. https://www.tvnz.co.nz/one-news/new-zealand/tenants-pick-up-cost-government-s-healthy-homes-standard-investors-warn

de Groot, H. (2009). *Indoor air quality and health: An analysis of the indoor air quality and health in New Zealand's homes.* Auckland, New Zealand: University of Auckland.

Department of Building and Housing. (2001). *Compliance document for New Zealand Building Code – Clause G5 Interior Environment.* Wellington, New Zealand: Author.

EECA. (2015). *The warm-up New Zealand insulation programme.* https://www.eeca.govt.nz/news-and-events/news-and-views/the-warm-up-new-zealand-insulation-programme/ accessed 9 July, 2019.

http://cwc.ca/resources/wall-thermal-design/wufi-analysis-assumptions/EHINZ. (2018). About the indoor environment and health. Environmental Health Indicators New Zealand (EHINZ). http://www.ehinz.ac.nz/indicators/indoor-environment/about-the-indoor-environment-and-health/

Emery, T**.,** Cookson-Cox, C. & Raerino, N. (2015). Te Waiata a Hinetitama - Hearing the Heartsong; Whakamate i roto i a Te Arawa; A Māori suicide research project. *Alternative Journal*. Vol.11, (3): Auckland, New Zealand: Nga Pae o te Māramatanga, University of Auckland.

Energy Efficiency and Conservation Authority. (2011). *New Zealand energy efficiency and conservation strategy 2011–2016.* Wellington, New Zealand: Te Tari Tiaki Pūngao.

Flannigan, B., Samson, R., & Miller, J. (Eds.). (2001). *Microorganisms in home and indoor work environments: Diversity, health impacts, investigation and control.* Abingdon-on-Thames, UK: Taylor and Francis.

Fraunhofer IBP. (2018). *WUFI Software User Guide.*

Freire, P. (1996). *Pedagogy of the oppressed.* London, UK: Penguin.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti., A., Schwartz, J.…Armstrong, B. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet, 386*(9991), 369-375.

Goodwin, J. (2000). Cold stress, circulatory illness and the elderly. In F. Nicol & J. Rudge, (Eds.). *Cutting the cost of cold: Affordable warmth for healthier homes* (pp. 48–61). London, UK: E&FN Spon Ltd.

Guo, L., Lewis, J., & McLaughlin, J. (2008). Emissions from Irish domestic fireplaces and their impact on indoor air quality when used as a supplementary heat source. *Global NEST Journal, 10(*2), 209-216.

Hart, B. (1998). Life cycle and reproduction of house-dust mites: Environmental factors influencing mite populations. *Allergy, 53*, 13–17.

Havenith, G. (2004). Thermal conditions measurement. In N. A. Stanton, A. Hedge, K. Brookhuis, E. Salas, & H. W. Hendrick (Eds.), Handbook of Human Factors and Ergonomics Methods (pp. 552-573). Boca Raton, Florida: CRC Press.

Hens, H. (2000). Minimising fungal defacement. *ASHRAE Journal,* October, 30–44.

Holt, J. (2017). Why is New Zealand a low-wage economy? https://thespinoff.co.nz/business/25-09-2017/explainer-why-is-new-zealand-a-low-wage-economy/ (accessed 11 June 2019).

Howden-Chapman, P. (2007). *Housing, heating and health study: Results.* Wellington, NZ: University of Otago, Housing, Heating and Health Group, He Kāinga Oranga, Housing and Health Research Programme. http://www.physics.otago.ac.nz/eman/documents/Philppa%20Howden%20Chapman%20presentatin%20Wellington%202007.pdf

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivan, K., Barnard, L. T., & Lloyd, B. (2012). Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts. *Energy Policy, 49*, 134–142.

Hunt, S. (1997). Housing-related disorders. In J. Charlton & M. Murphy (Eds.), *The health of adult Britain: 1841-1994*. pp. 156–170. London, UK: The Stationery Office.

IEA and IPEEC, (2015). *Building Energy Performance Metrics - Supporting Energy Efficiency Progress in Major Economies*. International Energy Agency (IEA) and International Partnership for Energy Efficiency Cooperation (IPEEC) Building Energy Efficiency Task Group. IEA Publications, Paris, France, April 2015. Available at: http://www.buildingrating.org/sites/default/files/1448011796IEA_IPEEC_BEET4_Final_Report.pdf

IEA. (2017). *Energy Policies of IEA countries: New Zealand.* IEA, Paris. https://webstore.iea.org/energy-policies-of-iea-countries-new-zealand-2017-review

iPHA, (2018). Passive House Legislation & Funding. International Passive House Association (iPHA). Available at https://passivehouse-international.org/index.php?page_id=501

Kingi, T. (2008). Maori land ownership and land management in New Zealand. In: *Making Land Work, Vol II, Case Studies on customary land and development in the Pacific.* pp. 129-152. Canberra, Australia: AusAid.

Laarhoven, K. A., Huinink, H. P., Segers, F. J., Dijksterhuis, J. and Adan, O. C. (2015). Water content influences hyphal growth on gypsum. *Environmental Microbiology, 17:* 5089-5099.

Lawson, R., Williams, J., & Wooliscroft, B. (2015). Contrasting approaches to fuel poverty in New Zealand. *Energy Policy, 81*, 3842.

Lloyd, E. (1990). Hypothesis: Temperature recommendations for elderly people: Are we wrong? *Age and Ageing, 19*, 264–267.

Lucon O., et al. (2014). Buildings. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change C. U. Press. Cambridge, United Kingdom and New York, NY, US.

McNeil, S. (2010). WUFI – Modelling tool for NZ conditions. *BUILD, 119* (August/September).

Ministry for the Environment. (2019). *Environment Aotearoa 2019.* https://www.mfe.govt.nz/publications/environmental-reporting/environment-aotearoa-2019, accessed 11 June 2019.

Ministry of Business, Innovation and Employment. (n.d.). https://www.smarterhomes.org.nz/smart-guides/heating-cooling-and-insulation/insulation-existing-homes/, accessed 7 June 2019.

Ministry of Economic Development. (2011). *Developing our energy potential: New Zealand energy strategy 2011-2021.* Wellington, New Zealand: Author.

Ministry of Health. (2017). *Te Wheke.* Retrieved from: https://www.health.govt.nz/our-work/populations/maori-health/maori-health-models/maori-health-models-te-wheke

Ministry of Health. (2018). *New Zealand Health Survey 2017/18.* Wellington, New Zealand: Author.

Newshub. (2016). *Minginui: Hope for a town that progress forgot.* https://www.newshub.co.nz/home/money/2016/09/minginui-hope-for-a-town-that-progress-forgot.html, accessed 7 June 2019.

Nielsen, K., Holm, G., Uttrup, L., & Nielson, P. (2004). Mould growth on building materials under low water activities. Influence of humidity and temperature on fungal growth and secondary metabolism. *International Biodeterioration & Biodegradation, 54(*4), 325–336. https://www.sciencedirect.com/science/article/pii/S0964830504000782

NZ Herald (2019). *Forestry job losses looming in the central North Island.* https://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=3559675 accessed 11 June 2019.

NZIER. (2014). *The home affordability challenge: Suite of policy reforms needed in New Zealand.* NZIER public discussion paper. https://nzier.org.nz/static/media/filer_public/98/7c/987c99b1-d879-48ca-ac2c-58e05307ac5c/nzier_public_discussion_document_2014-04_-home_affordability_challenge.pdf, accessed 7 June 2019.

NZS (1990). NZS 4303:1990 Ventilation for acceptable indoor air quality. Standards New Zealand (NZS), 1990. https://shop.standards.govt.nz/catalog/4303%3A1990%28NZS%29/view

OSHA. (2018). Section III: Chapter 2 - Indoor Air Quality Investigation. Retrieved from United States Department of Labour – Occupational Safety and Health Amministration (OSHA): https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_2.html#3

O'Sullivan, K., Howden-Chapman, P., & Fougere, G. (2015). Fuel poverty, policy, and equity in New Zealand: The promise of prepayment metering. *Energy Research & Social Science, 7*, 99–107.

Lloyd, B., & Callau, M. (2006). *Monitoring of Energy Efficient Upgrades in State Houses in Southern New Zealand*. Dunedin, New Zealand: Physics Department - University of Otago.

Pasanen, A., Juutinem, T., Jantunem, M., et al. (1992). Occurrence and moisture requirements of microbial growth in building materials. *International Biodeterioration and Biodegradation, 30,* 273–283.

Pere, R. (1991). *Te Wheke: A celebration of infinite wisdom*. Gisborne, New Zealand: Te Ako Publications.

Pere, R., & Nicholson, N. (1991). *Te wheke : A celebration of infinite wisdom.* Gisborne, N.Z.: Ao Ako Global Learning New Zealand.

Pescatore, A., Spycher, B., Beardsmore, C., & Kuehni, C. (2015). “Attacks” or “Whistling”: Impact of questionnaire wording on wheeze prevalence estimates. *PLoS ONE, 10*(6), e0131618.

Peternel, R., Culig, J., & Hrga, I. (2004). Atmospheric concentrations of *Cladosporium* spp. and *Alternaria* spp. spores in Zagreb (Croatia) and effects of some meteorological factors. *Annals of Agricultural and Environmental Medicine, 11*(2), 303–307.

PHAI, (2016). *Dún Laoghaire Rathdown has adopted the Passive House standard*. Passive House Association of Ireland (PHAI). Available at: https://phai.ie/news/dun-laoghaire-rathdown-has-adopted-the-passive-house-standard/

Piecková, E., & Jesenská, Z. (1999). Microscopic fungi in dwellings and their health implications in humans. *Annals of Agricultural and Environmental Medicine, 6*(1), 1–11.

Rupp, S., & McNeil, S. (2018). Airtightness trends. 1 June 2018, Build 166. BRANZ. https://www.buildmagazine.org.nz/index.php/articles/show/airtightness-trends

Schrader, B. (2012). *Housing and government - A property-owning democracy.* Te Ara - the Encyclopedia of New Zealand. http://www.TeAra.govt.nz/en/graph/32430/sale-of-state-houses, accessed 11 June 2019.

Seltenrich, N. (2015). Between extremes: health effects of heat and cold. *Environmental Health Perspectives, 123*(11), A275–A280.

Sharmin, T., Gül, M., Li, X., Ganev, V., Nikolaidis, I., & Al-Hussein, M. (2014). Monitoring building energy consumption, thermal performance, and indoor air quality in a cold climate region. *Sustainable Cities and Society, 13,* 57-68.

Stanton, N. A., Hedge, A., Brookhuis, K., Salas, E., & Hendrick, H. W. (2004). *Handbook of human factors and ergonomics methods*. Boca Raton, Florida: CRC Press.

Standards New Zealand. (1990). *New Zealand Standard 4303:1990 Ventilation for Acceptable Indoor Air Quality.* Wellington, New Zealand: Author.

Statistics NZ. (2014). *New Zealand General Social Survey*. http://archive.stats.govt.nz/browse_for_stats/people_and_communities/Households/nzgss_HOTP2014.aspx

Statistics NZ (2017a). *Income inequality.* http://archive.stats.govt.nz/browse_for_stats/snapshots-of-nz/nz-social-indicators/Home/Standard%20of%20living/income-inequality.aspx, accessed 11 June 2019.

Statistics NZ (2017b). *New Zealand’s regional economies 2017.* https://www.stats.govt.nz/infographics/new-zealands-regional-economies-2017, accessed 11 June 2019.

Statistics NZ. (2019). *Developing a definition for housing quality: Findings from public consultation October 2018*. https://www.stats.govt.nz/consultations/developing-a-definition-for-housing-quality-findings-from-public-consultation-october-2018#summary, accessed 7 June 2019.

Su, B. (2006). Prevention of winter mould growth in housing. *Architectural Science Review, 49*(4), 385–390.

Su, B. (2017). Field study of Auckland housing winter indoor health conditions associated with insulation, heating and energy. In M. A. Schnabel (Ed.), *Proceedings of 51st International Conference of the Architectural Science Association (ANZAScA),* 713-722.

UNICEF New Zealand, (2018). *HOUSING - Counting the costs*. UNICEF New Zealand. Available at: https://www.unicef.org.nz/in-new-zealand/healthy-homes

World GBC, (2017). From thousands to billions - Coordinated Action towards 100% - Net Zero Carbon Buildings By 2050. World Green Building Council, UK Office and Canada Office. Available at: https://www.nzgbc.org.nz/Attachment?Action=Download&Attachment_id=1008

World Health Organisation. (1987). *Health impact of low indoor temperatures.* Copenhagen, Denmark: World Health Organisation, Europe.

World Health Organisation. (2007). *Housing, energy and thermal comfort: A review of 10 countries within the WHO European Region.* Copenhagen, Denmark: World Health Organisation, Europe.

World Health Organisation. (2009). *WHO guidelines for indoor air quality: dampness and mould.* Copenhagen, Denmark: World Health Organisation, Europe.

World Health Organisation. (2011). *Environmental burden of disease associated with inadequate housing.* Copenhagen, Denmark: World Health Organisation, Europe.

Zuur, A., Elena, N., Ieno, E., Walker, N., Saveliev, A., & Smith, G. (2009). *Mixed effects models and extensions in ecology with R.* New York, USA: Springer.

Appendix 1: Toiora Health Questionnaire

Toiora is described in the literature as living well. These questions are designed to ascertain what living well means to you as a resident living in Minginui. The research is aimed at exploring your views of health and wellness as documenting your aspirations for your future wellbeing living in Minginui.

Researcher ☐☐☐☐

Participant number ☐☐☐☐☐☐☐

Date ☐☐ ☐☐ ☐☐

To allow the researchers to capture correct information we will need to voice record this interview (this is a reminder that you have already consented to this). All recordings will be deleted once transcribed. A transcript will be provided at your request. Tick the box below.

Would you like to receive a copy of your transcript? Yes ☐ No

HEALTH HISTORY:

Provide a brief outline of your past health status.

The study is about living well, and what you need to live well and be well … health has a role to play in this. So this interview is about creating a foundation for us to start from

What's gone before has created what things look like now and further into the future.

1: Introductory question: What does being healthy mean to you and why is it important?

2: there been anything that has affected your health and the way you live?

Taha Tinana	Have you had any sicknesses or been hospitalised? What about major injuries?
Whatumanawa Emotional	Have you ever been depressed or really sad? Can you tell us why – what caused you to feel like that? Have you ever been stressed … (how come? What was going on)
Taha Hinengaro Intellectual the way we communicate	Has your health had an effect on your education?

Taha Wairua	Complimentary therapies … In your times of sickness and ill health, what are some of the things you or you whānau do to help heal yourself?
Tūrangawaewae Heritage	Does living here in (M/M/TW) help to make you feel well? Why is that?
Taha Whānau	Who are your support people when you are unwell? Who do you need around you to be well?
Te Tuakiritanga ‘Mana’	What are you really good at?
Individuality who you are, where you stand	What is your life mission?
Te Mauri Life principle Vital essence	What keeps you going?

MAINTENANCE OF TOIORA:

Do you think there is a difference between being healthy and being well?

What do you need to live well?

Appendix 2: Figures for comparison of internal temperature conditions amongst houses and towns

The graphs here provide a portrait of the temperature patterns in each house through the winter and summer seasons, analysed in chapter 3. Average values and variation around those values are both plotted in order to enable interpretation of both long-term patterns, and short-term variability, in the temperature environment experienced by the residents of each house. Considerable variability of internal temperatures can be seen for most houses. Some of that is due to people being absent (a normally warm house will be cold), and some may be due to people choosing not to heat the house either at certain times of day, or on some days. Thus, the graphs describe precisely the interior conditions of the house, but are only indicative of the conditions being experienced by the people who live there.

Description of figures

A Table (1, 2, 3, 4) summarizing the patterns in each graph is provided for the houses from each town at the beginning of each section. Graphs are grouped by town, and ordered by increasing house quality index. The house quality index is described in the Toi Ohomai report: Internal temperature conditions among houses, between seasons, and relative to outside (ambient).

- Each figure shows the mean temperature profile in the living room for the 24-hr cycle (0=midnight to 01:00) over a 70-day period in summer and winter for one house.
- Ambient (outside) data are taken from one data logger in Minginui, one in Murupara, two in Te Whaiti, and a NIWA site in Rotorua, so are usually the same for each house within a town.
- The solid vertical bar is the calculated variability around the mean (standard deviation).
- The 70 data points used to calculate the mean for each hour are plotted vertically, slightly offset for inside and ambient (outside) to enable visual referencing of the two distributions.
- The minimum (18°C) and maximum (28°C) UN temperature guidelines for comfortable living for humans are plotted as horizontal dotted lines. Blue values below (cold) or above (hot) those lines represent substandard living conditions; the scale of the difference between a data point and the line implies degree of discomfort (and threat to health).
- Together, differences in the distributions of red and blue points and size of the red and blue standard deviation bars give an indication of the extent to which the house buffers ambient conditions.
- Note that many data points are hidden by the vertical bars – only the extreme points can be seen.

Examples to aid interpretation

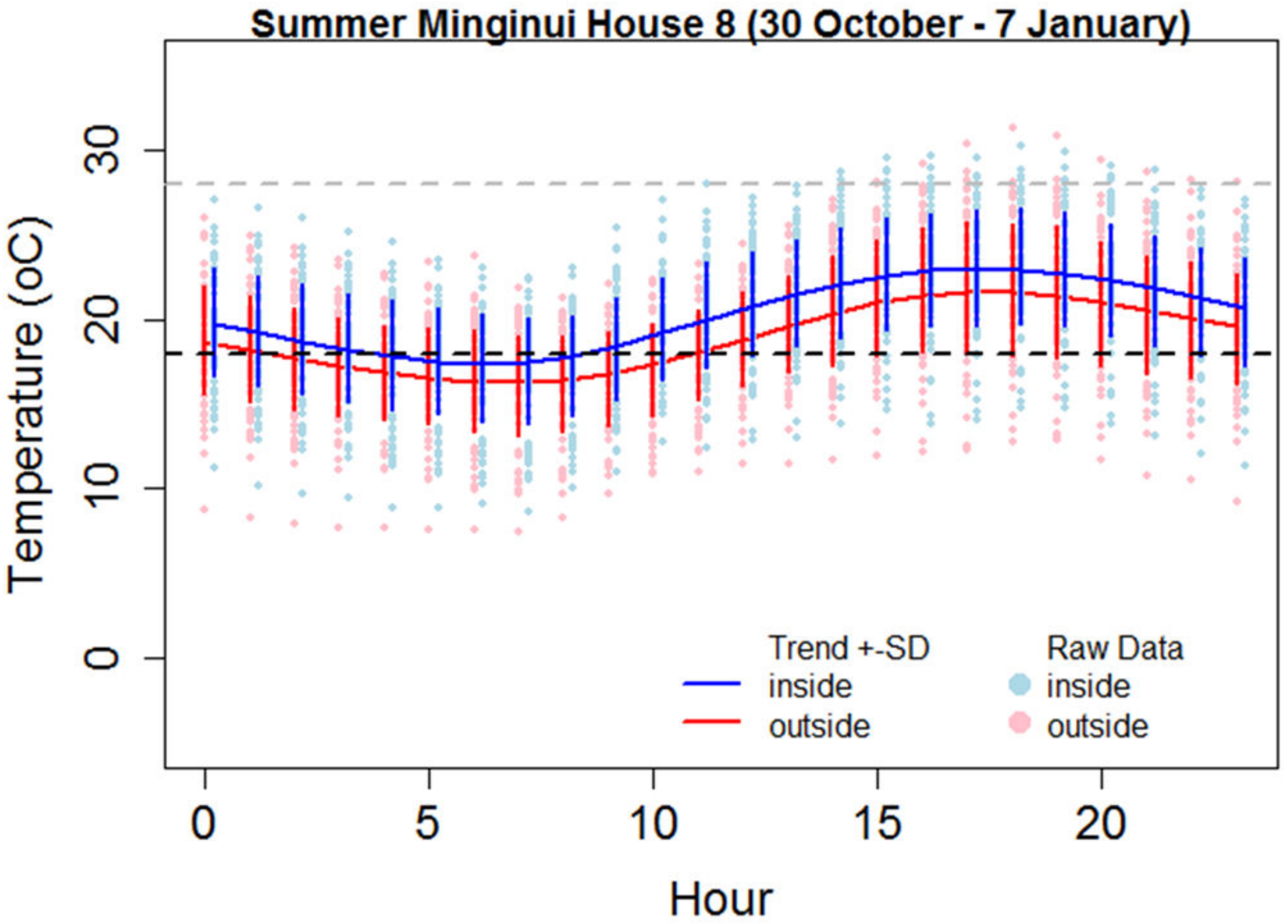
1) The addition of heat to a house (= active management of internal conditions) can easily be seen in the distributions of the vertically offset red and blue dots around each mean value on the winter graphs.
2) Passive buffering of external conditions by the house is most easily seen in the summer graphs for Rotorua houses: the blue line is relatively flat, whereas the red line fluctuates more strongly.
3) Houses in Minginui track ambient conditions very closely in summer, indicating little or no passive buffering.

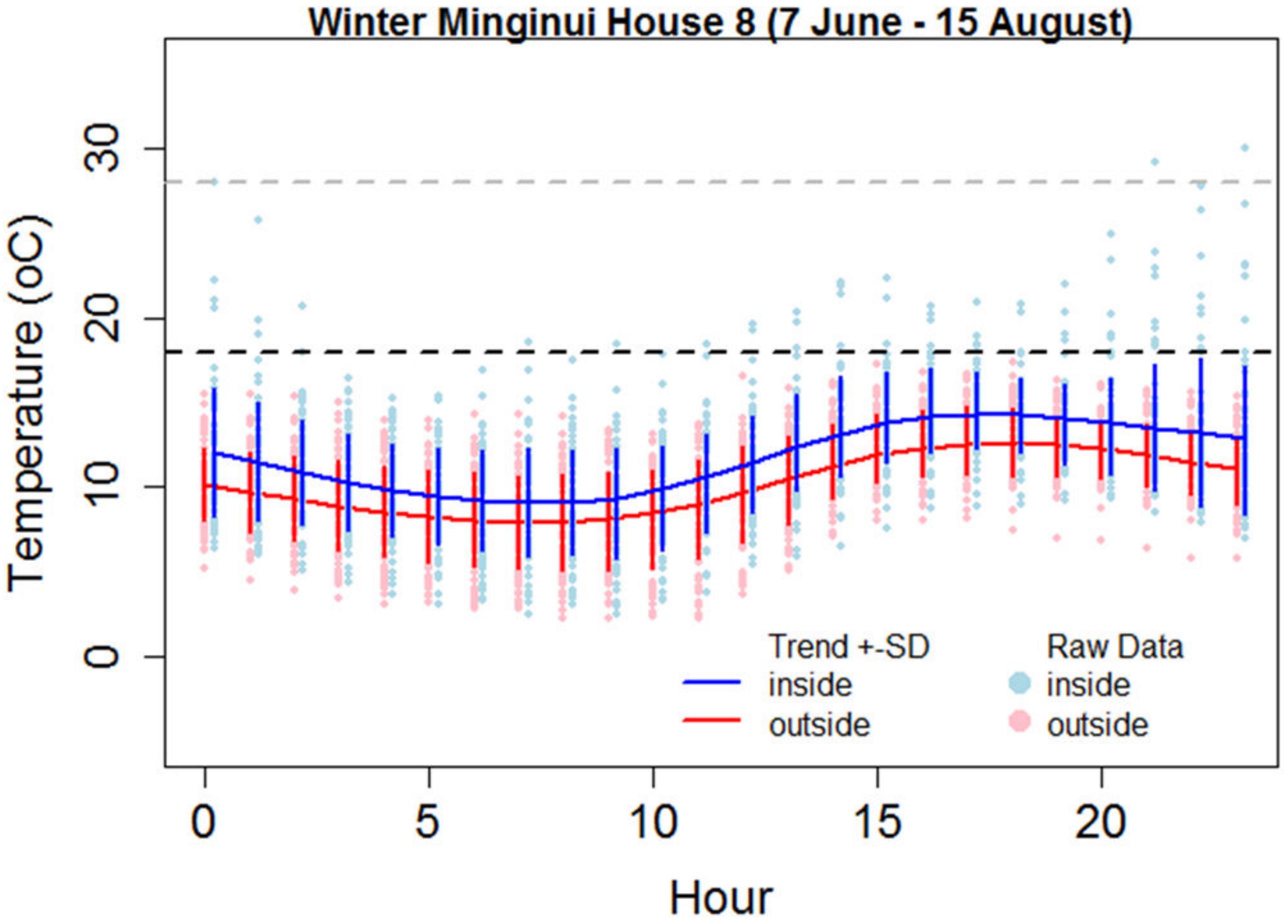
4) The summer graph for house 18 (Rotorua) shows effective buffering of hot ambient conditions in the afternoon. The house warms more slowly than ambient, does not reach the hottest ambient temperatures, there is a lag as the house continues to warm into the early evening (when ambient temperatures are cooling), and then the house cools more slowly than ambient through the night.
5) The unusual winter graph for house 16 (Murupara) shows the ineffectiveness of the relatively old insulation in this house. The house is regularly overheated, but loses heat quickly through the early morning when people have presumably gone to bed and are no longer maintaining the heating source (a wood burner). They may also open doors when they go to bed to promote heat flow through to cold bedrooms.
6) Houses 1 (Te Whaiti) and 4 (Minginui) were both empty, and the interior temperatures for both follow ambient conditions very closely. House 7 (Minginui) similarly tracks ambient conditions very closely and appears to be empty. However, temperature values suggest some heating of house 7 in the late afternoon in winter. In winter, this house had a single resident who was often absent and did minimal heating when present; the house was empty in the summer.

Table 1. Summary of outcomes for individual houses in Minginui (see graphs on following pages)

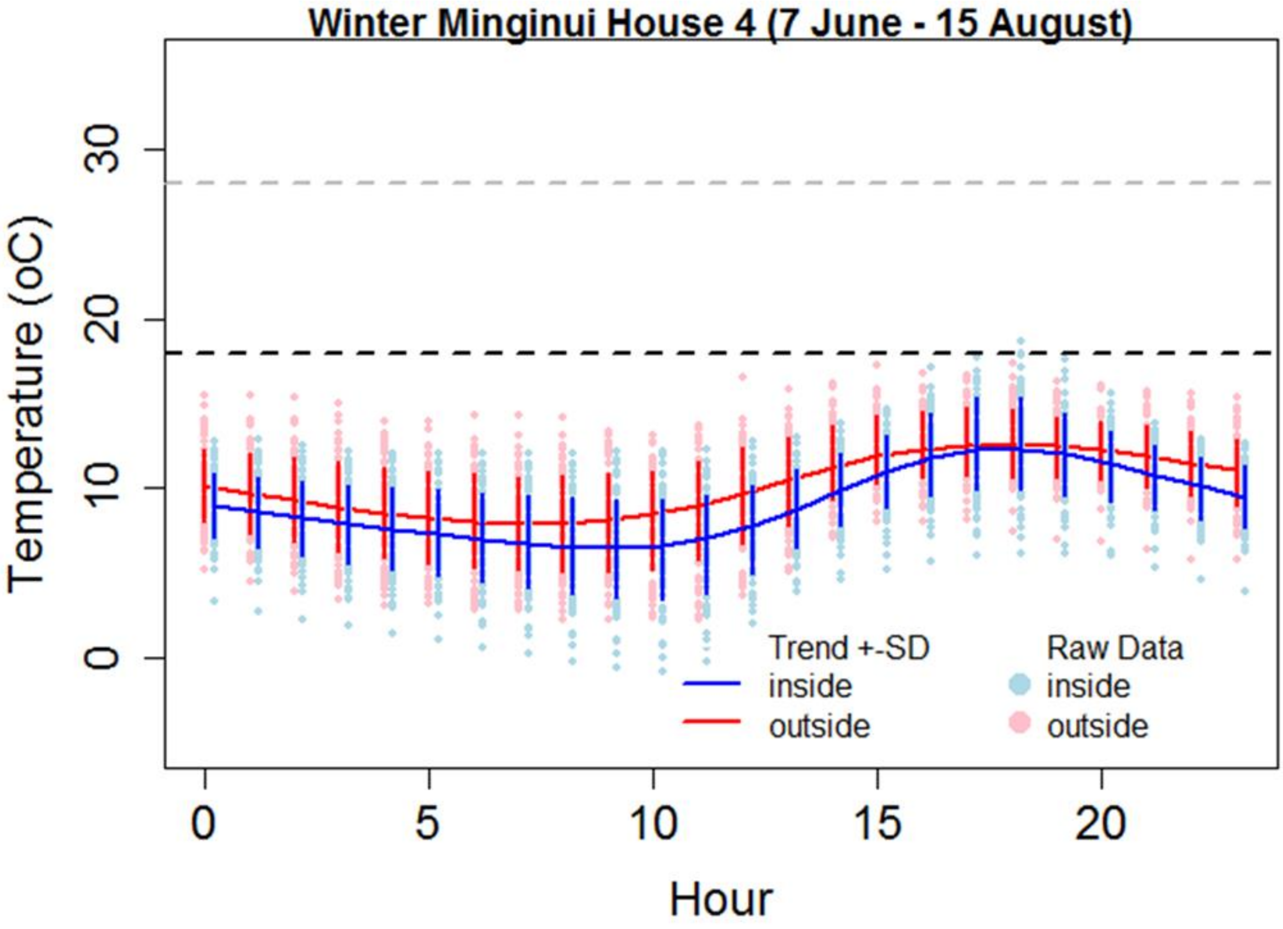
House No	Quality Index	**Summary of outcome** (Sum=summer, Win=winter; *In*=inside, *Am*=ambient=outside)
8	8	Sum: *In* tracks *Am* very closely. Win: *In* very slightly warmer than *Am*, house heated but generally cold; **occasional overheating*.**
4	9.5	Sum: no data. Win: *In* slightly colder than *Am*, tracks *Am* conditions closely; house empty.
6	10.5	Sum: *In* tracks *Am* very closely. Win: *In* slightly warmer than *Am*, house heated but generally cold.
5	12	Sum: *In* consistently warmer than *Am* by several degrees. Win: *In* warmer than *Am*, mostly above 18°C, cool in early morning. **Some overheating**.
3	14	Sum: *In* consistently warmer than *Am* by several degrees, some afternoon buffering of hot *Am* conditions. Win: *In* warmer than *Am*, above 18°C in evening, cool through day.
7	14.5	Sum: *In* tracks *Am* very closely. Win: *In* tracks *Am* closely, heated in late afternoon/early evening, but is generally cold.

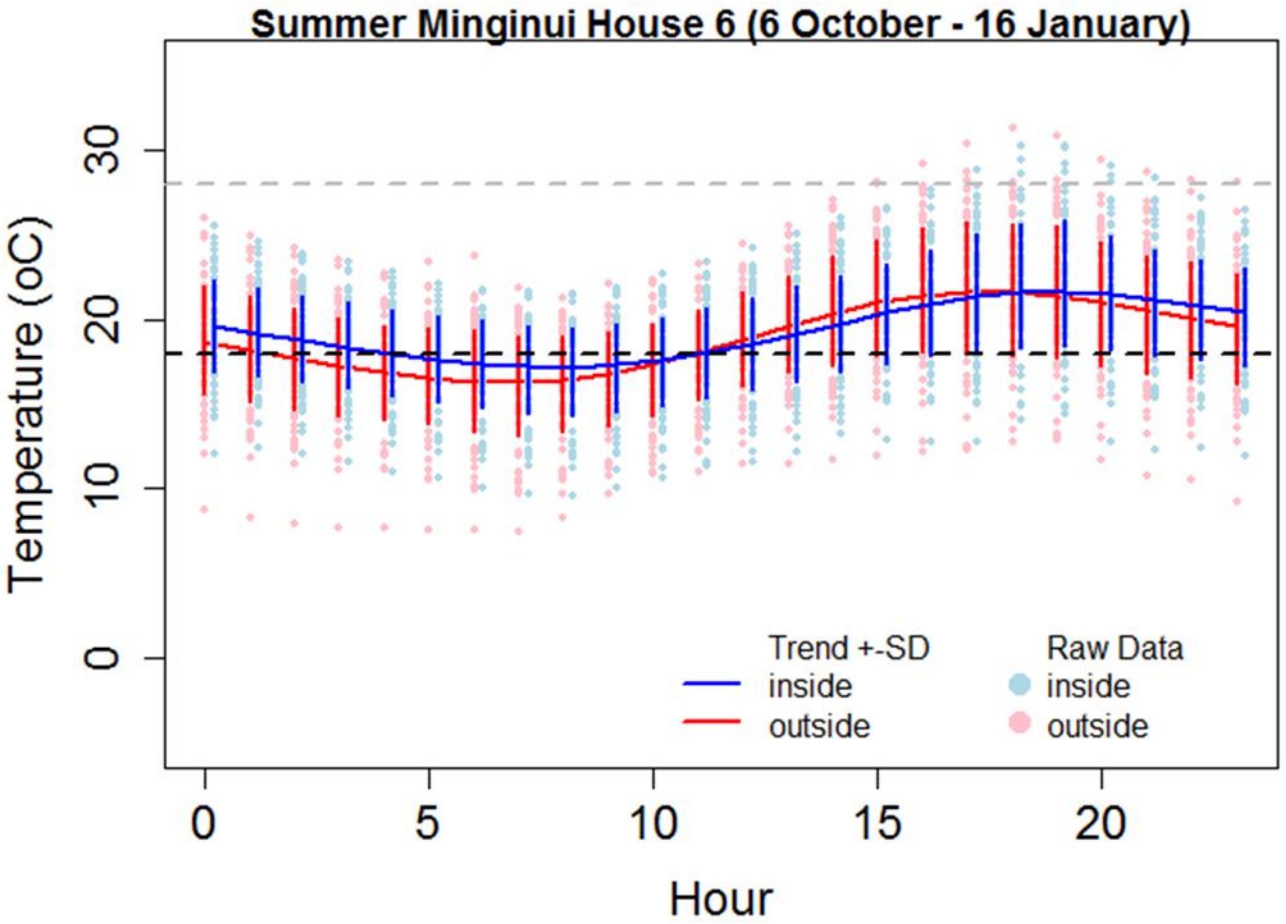
*“Overheating” is defined as temperature exceeding the UN guideline of 28°C.

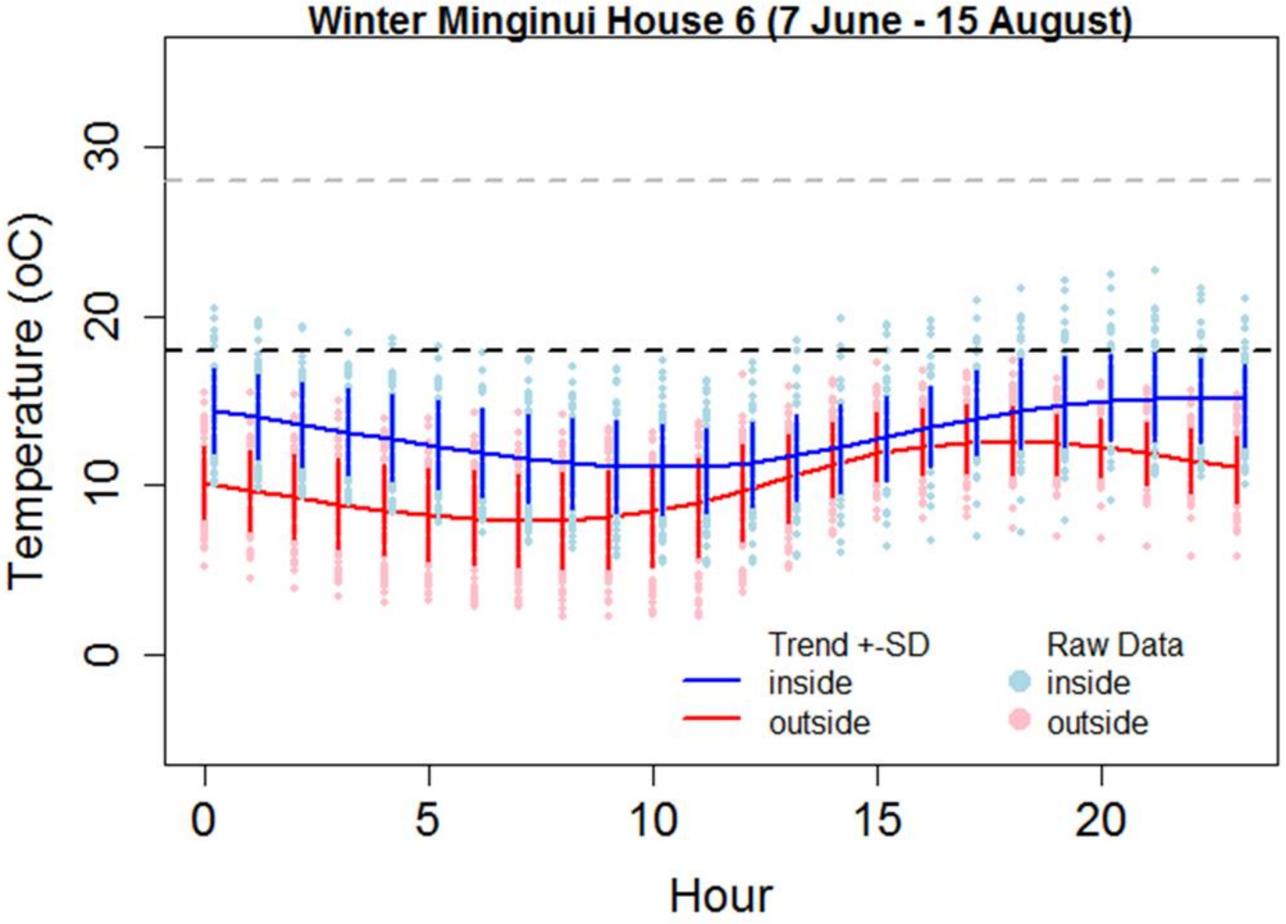

Summer Minginui House 8 (30 October - 7 January)
Temperature (oC)
0
10
20
30
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside

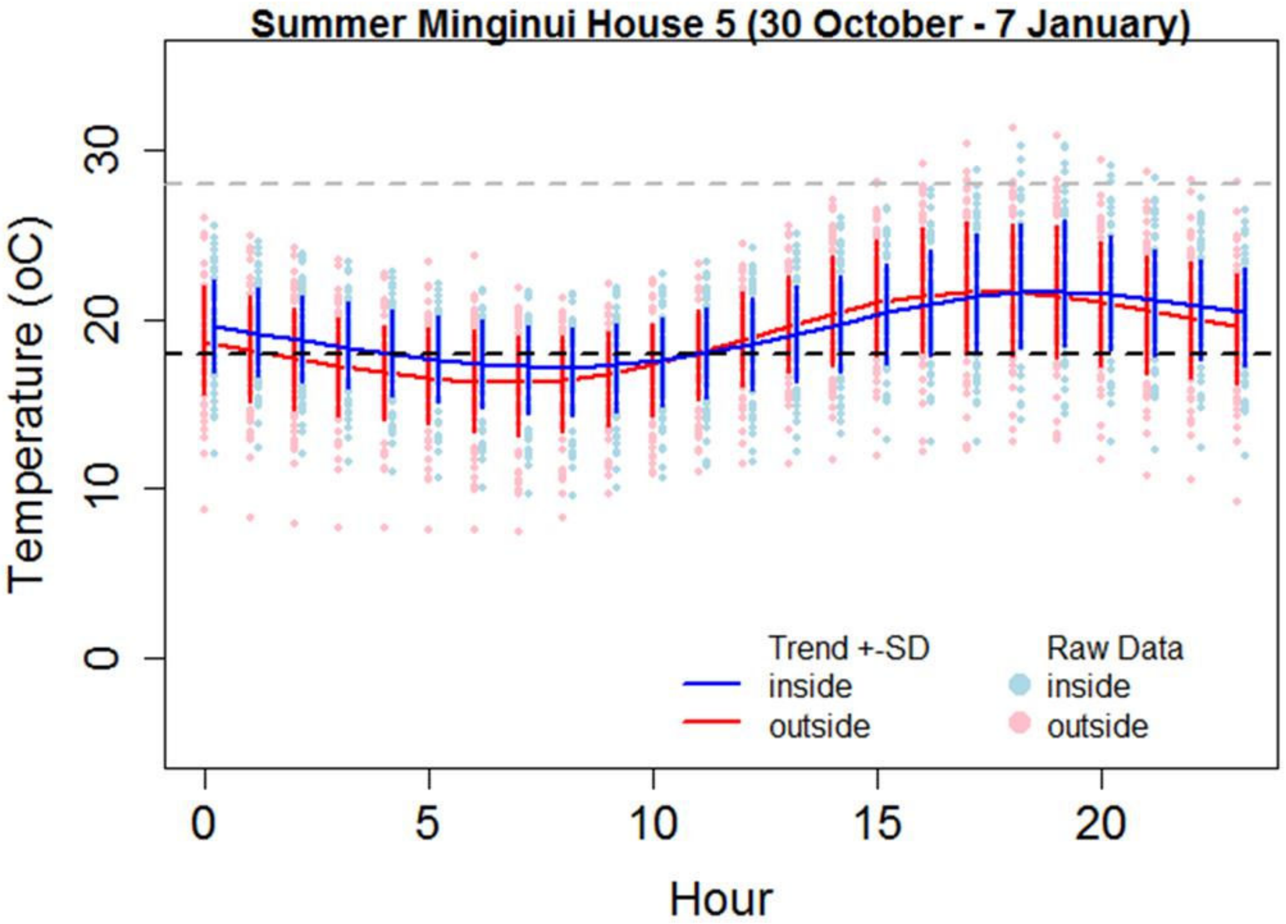

Winter Minginui House 8 (7 June - 15 August)
Temperature (oC)
0
10
20
30
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside

No summer data for House 4.

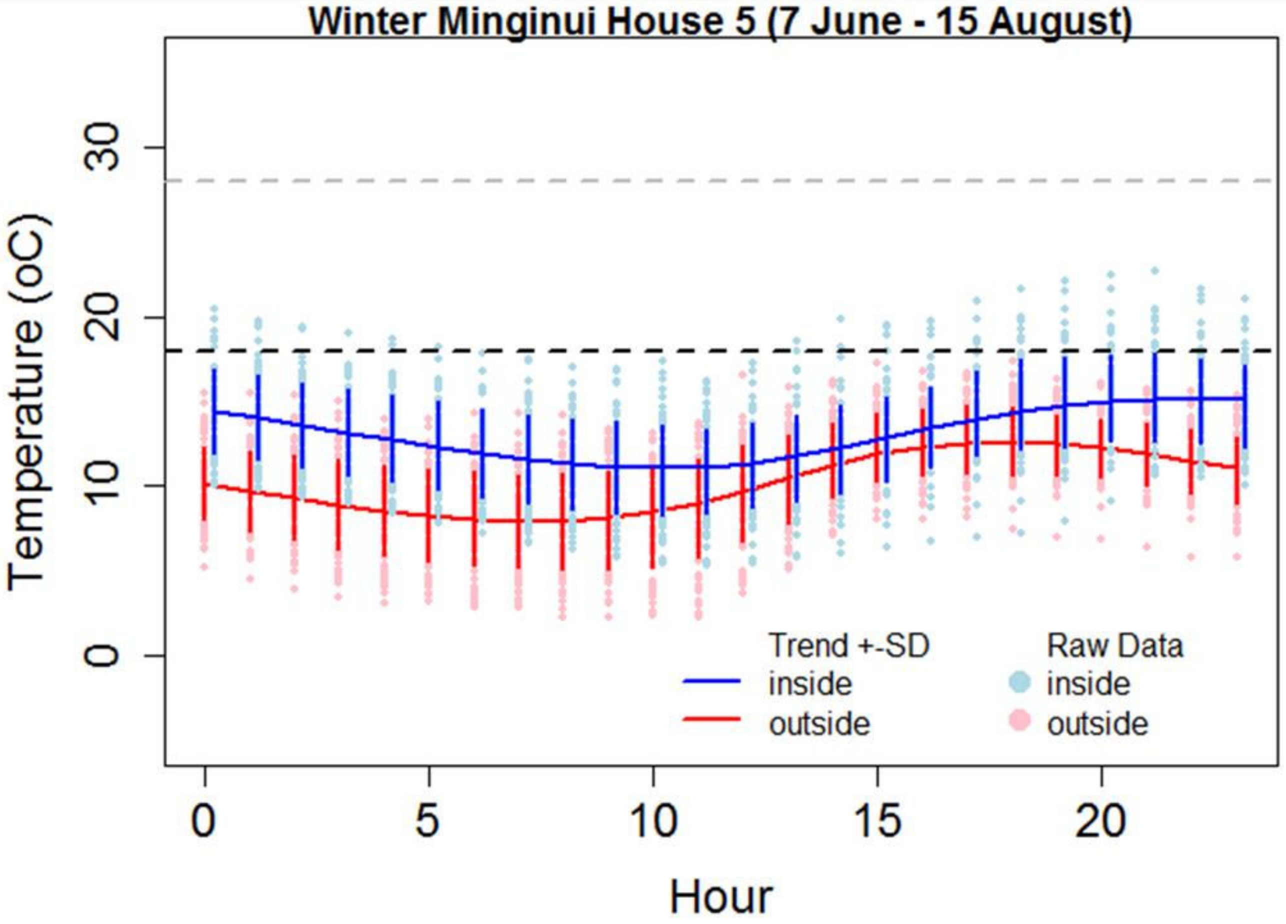



Summer Minginui House 6 (6 October - 16 January)
Temperature (oC)
30
20
10
0
0
5
10
15
20
Hour
Trend +-SD
inside
outside
Raw Data
inside
outside

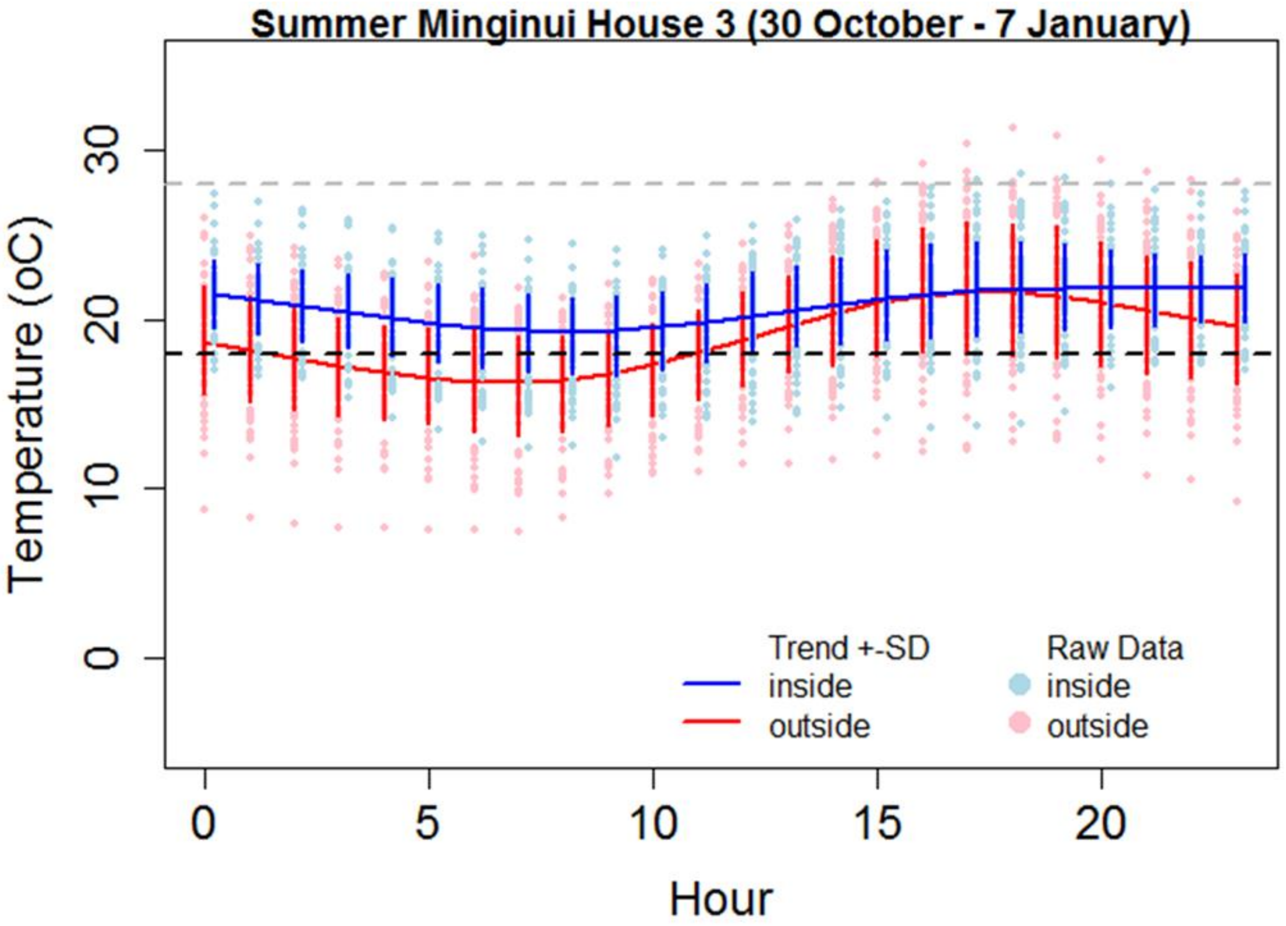

Winter Minginui House 6 (7 June - 15 August)
Temperature (oC)
30
20
10
0
0
5
10
15
20
Hour
Trend +-SD
inside
outside
Raw Data
inside
outside



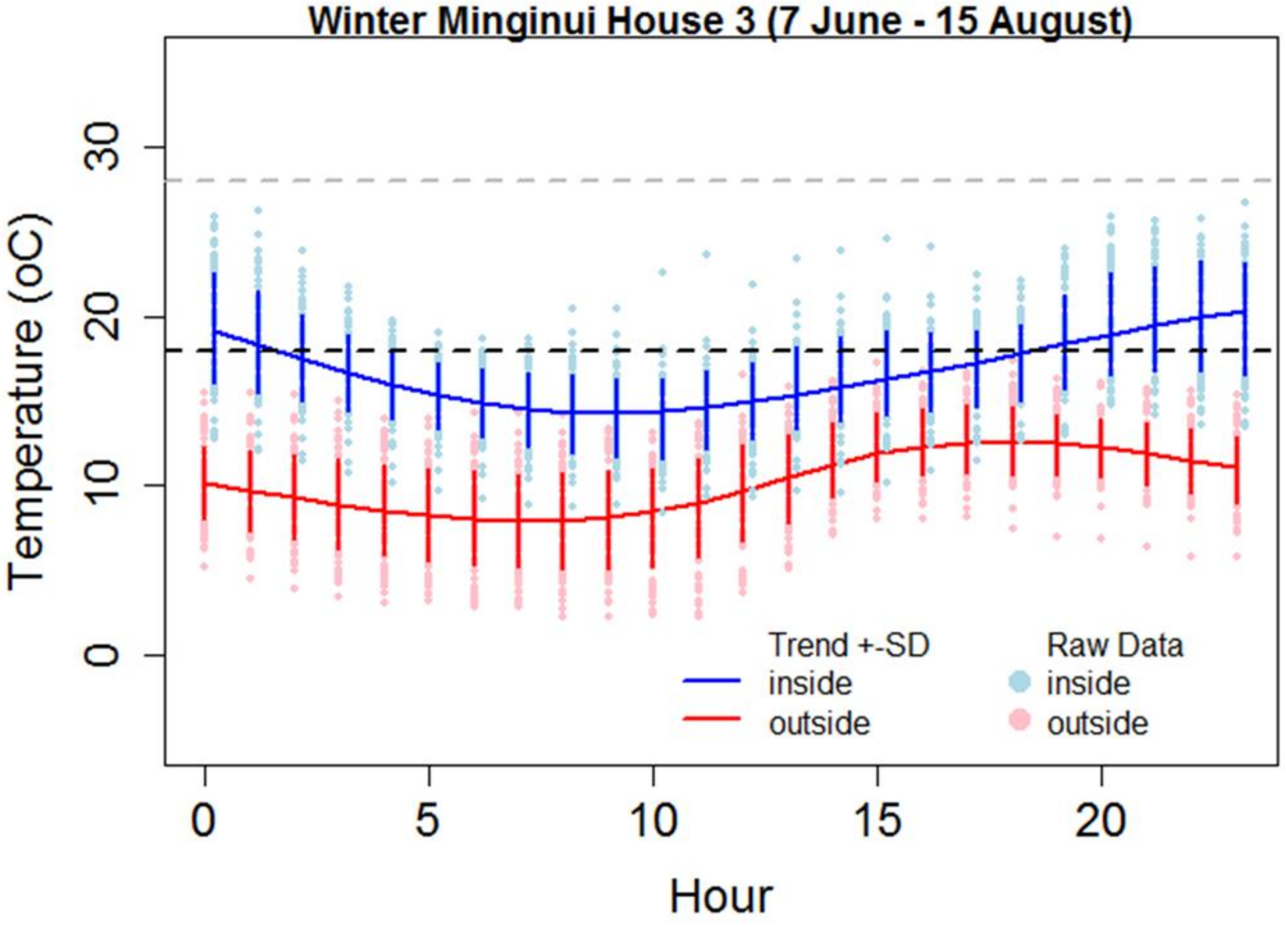
Summer Minginui House 5 (30 October - 7 January)



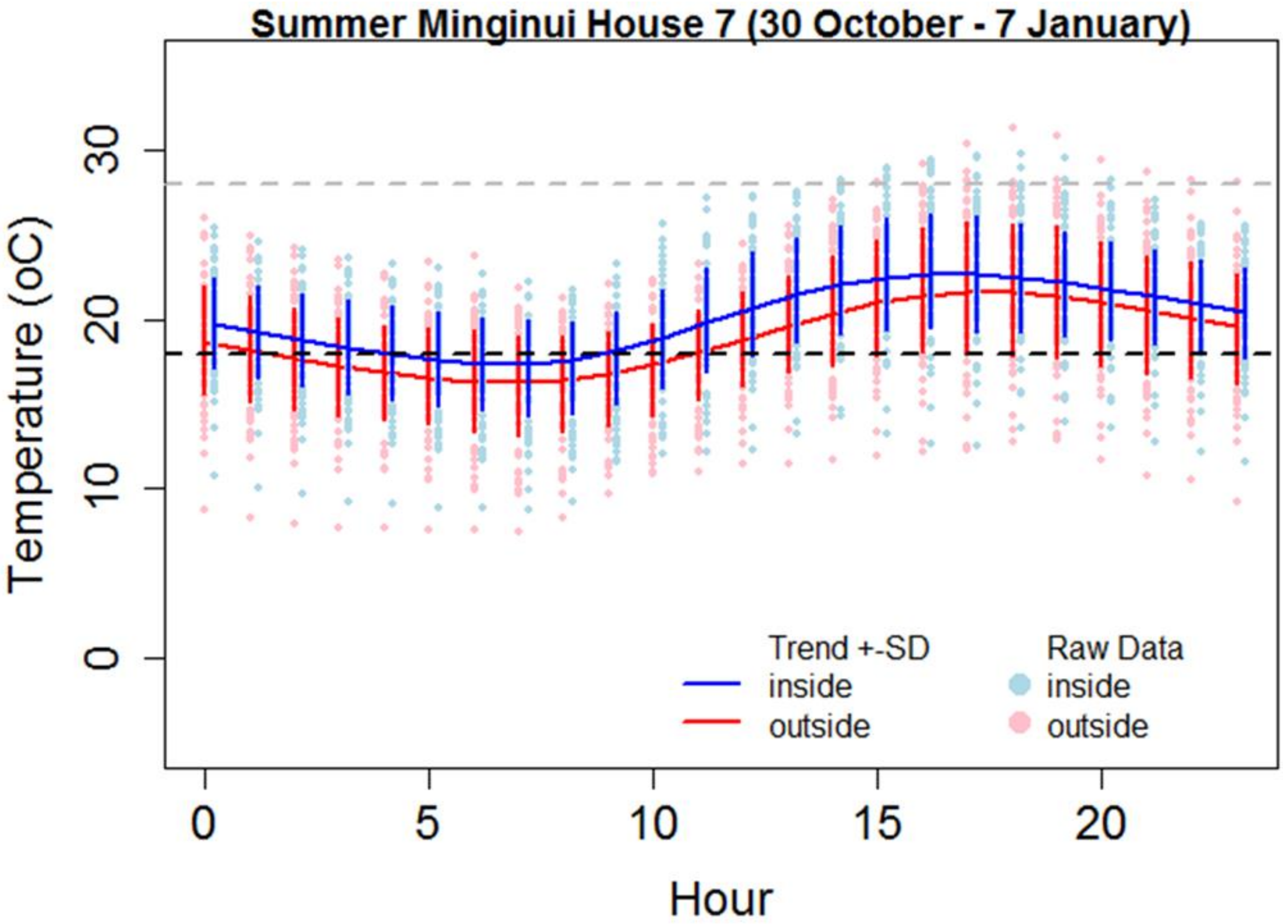
Winter Minginui House 5 (7 June - 15 August)



Summer Minginui House 3 (30 October - 7 January)



Winter Minginui House 3 (7 June - 15 August)


Summer Minginui House 7 (30 October - 7 January)
Temperature (oC)
30
20
10
0
Trend +-SD
inside
outside
Raw Data
inside
outside
0
5
10
15
20
Hour

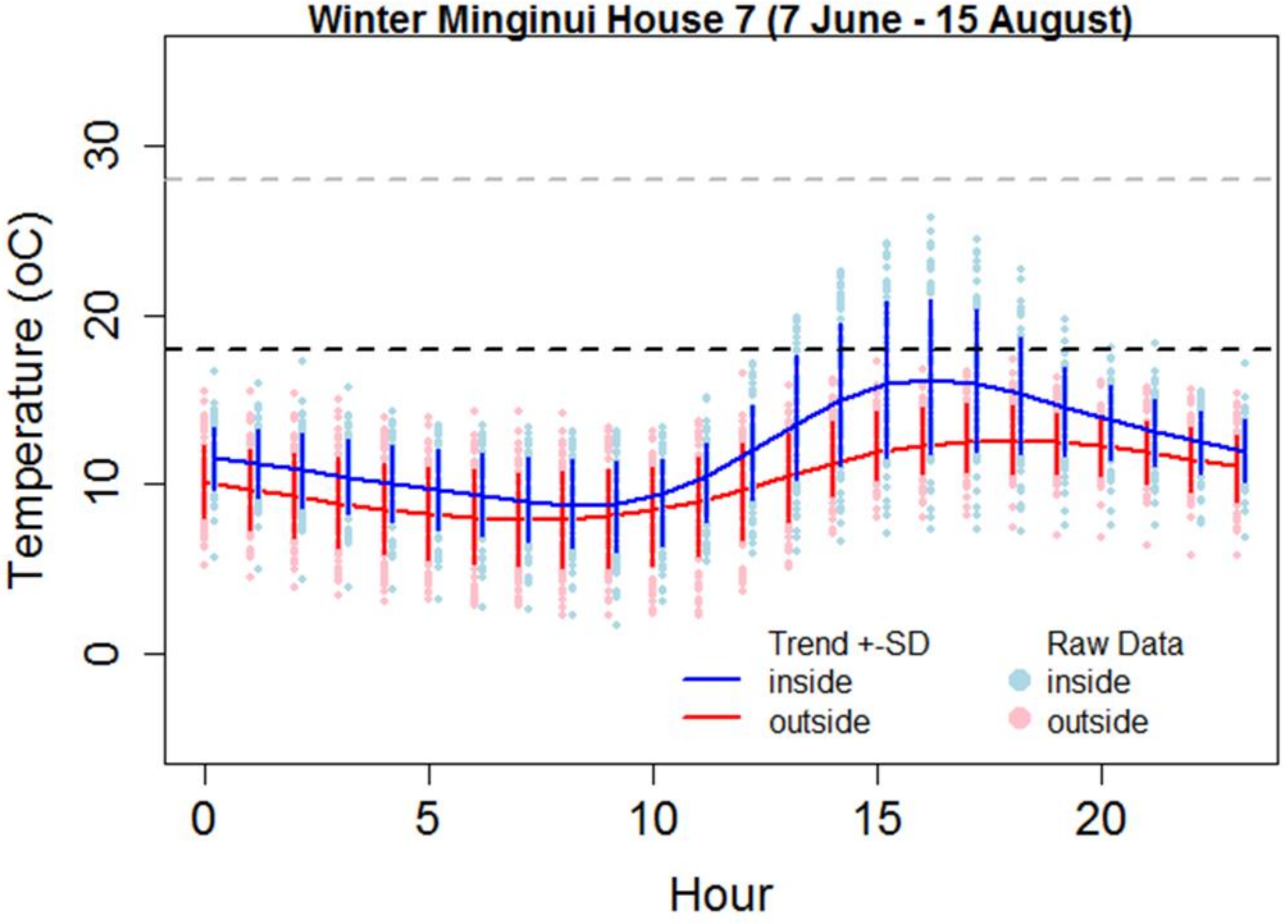
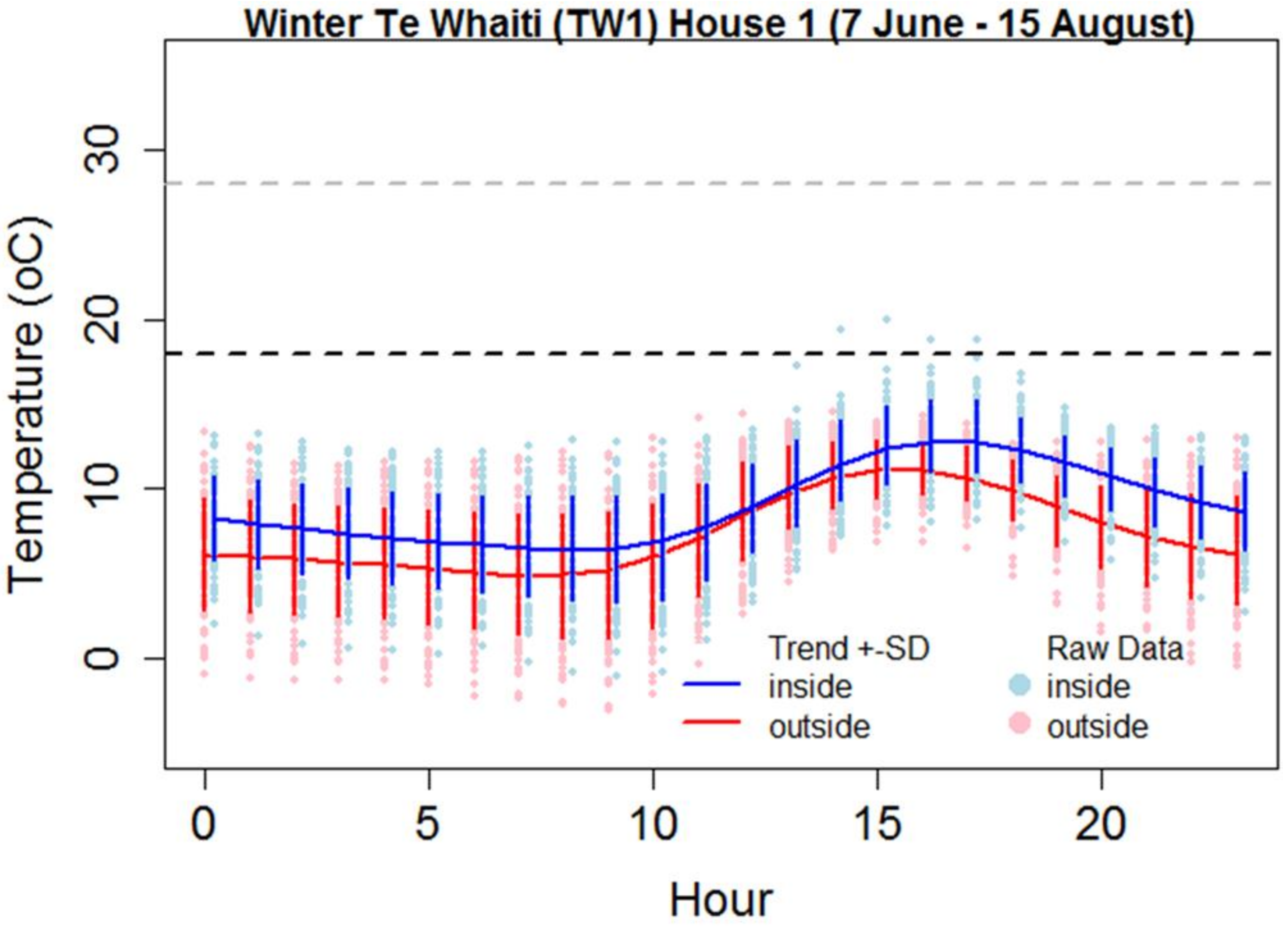

Winter Minginui House 7 (7 June - 15 August)
Temperature (oC)
30
20
10
0
Trend +-SD
inside
outside
Raw Data
inside
outside
0
5
10
15
20
Hour

Table 2. Summary of outcomes for individual houses in Te Whaiti (see graphs on following pages)

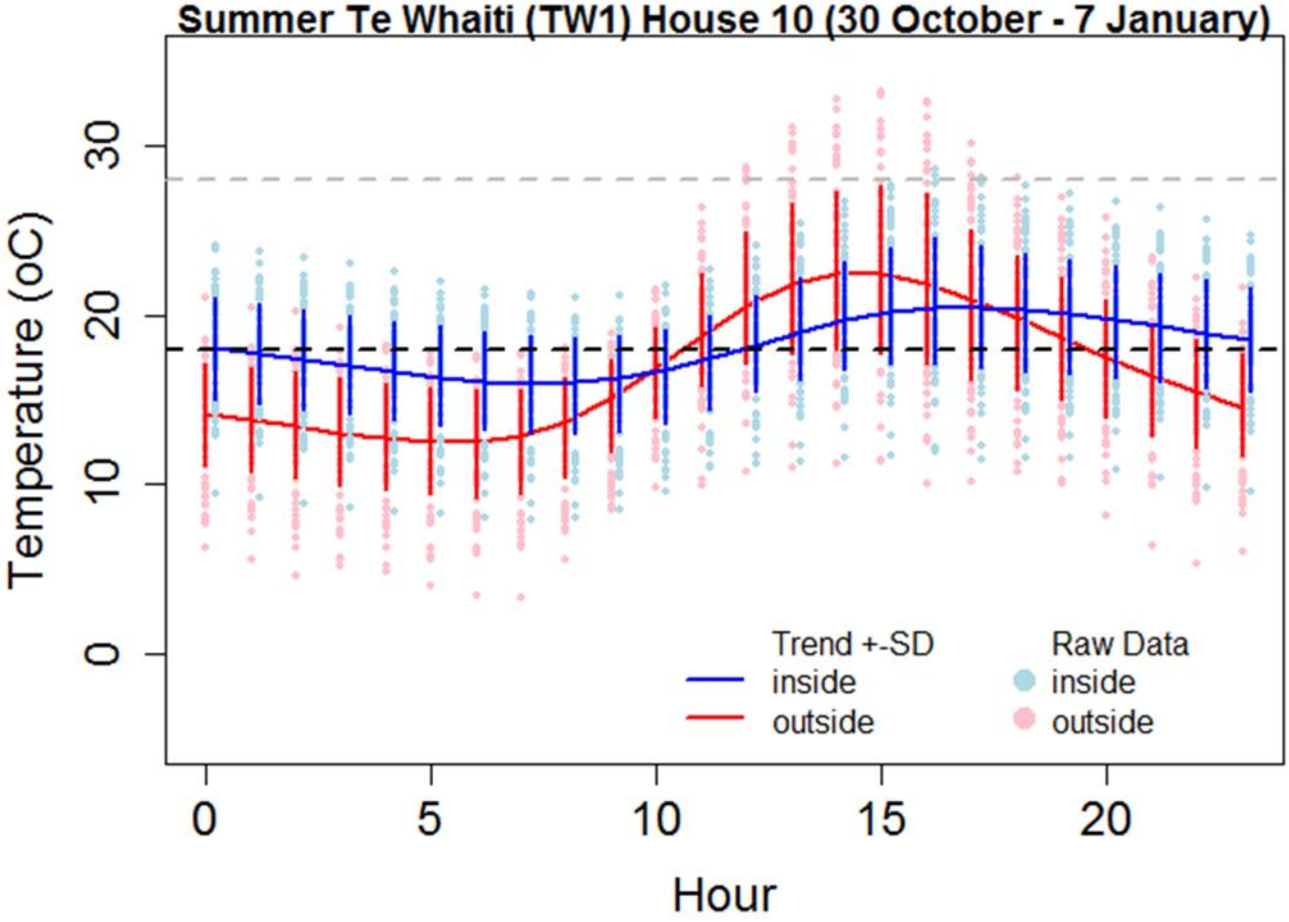
House No	Quality Index	**Summary of outcome** (Sum=summer, Win=winter; *In*=inside, *Am*=ambient=outside)
1	8	Sum: No data Win: *In* tracked *Am* very closely. *In* slightly colder than *Am*, except late afternoon when it was slightly warmer. Variances very similar.
10	11.5	Sum: *In* average remained close to 18°C. In samples reached 28°C on only a few occasions although *Am* climbed well above 30°C. *Am* was much more variable than *In*. House is in a gully and heavily shaded and the cool *In* temps are due to external factors and not house design. Win: The house appears to be heated, but *In* temps stayed close to 10°C.
2	12	Sum: no data. Win: *In* consistently about 3°C warmer than *Am*, possibly due to passive effects as house has insulation. Appears to be some heating in evening only when some measures above 18°C, but average peaks at 15°C. House generally cold. Suspect residents often absent in winter.
9	14	Sum: *In* stays in the optimal temperature range (18-23°C), with good buffering of high *Am* temps in the late afternoon (house is insulated), although is occasional **overheating***. *In* variability often higher than *Am.* Win: *In* consistently warmer than *Am* by 8-10°C, but the house remained cool (below 18°C) through the early morning and day. Extra heat added in the evenings, with occasional **overheating**. Variability high *In* in the evenings.
11	18	Sum: *In* dropping below 18°C through the morning and above 18°C through the afternoon and evening. *In* is less variable, indicating buffering by the building, particularly through the hot part of the day (*In* curve is flatter). Occasional **overheating** on very hot days. Win: In remains close to or above 18°C, well above in the evening with occasional overheating. *In* more variable and much warmer than *Am*.

*"Overheating" is defined as temperature exceeding the UN guideline of 28°C.

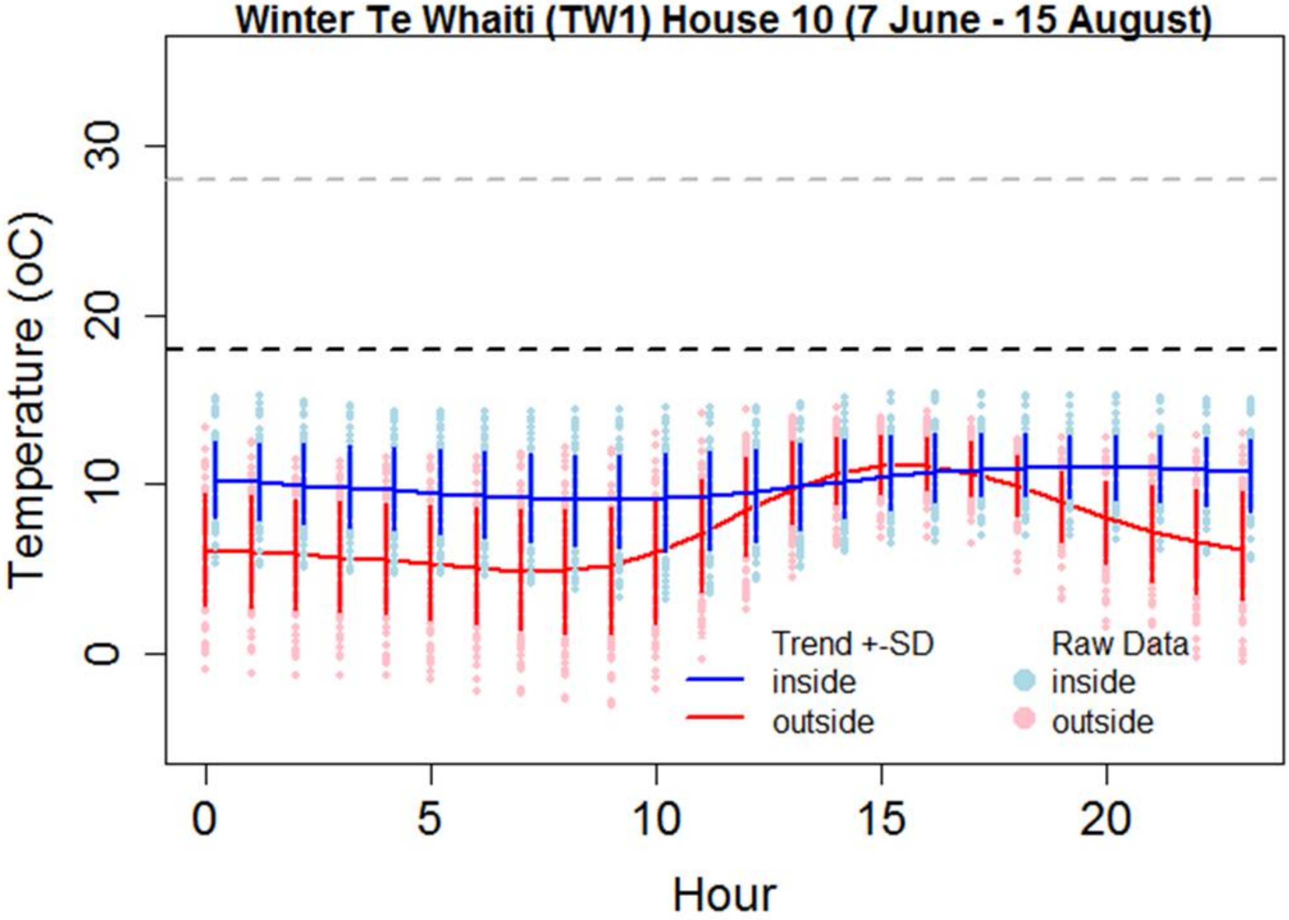
No summer data for House 1



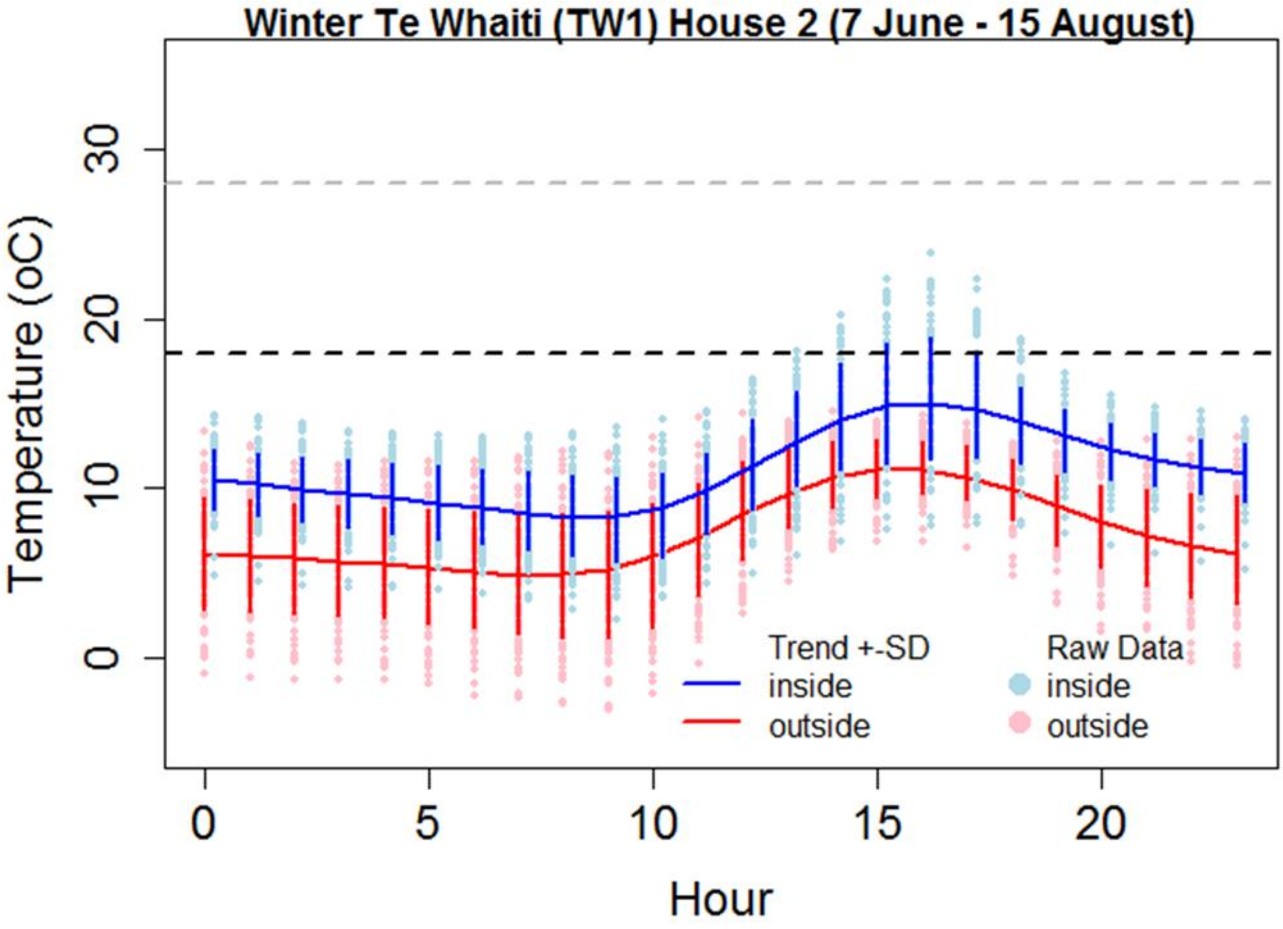
Summer Te Whaiti (TW1) House 10 (30 October - 7 January)

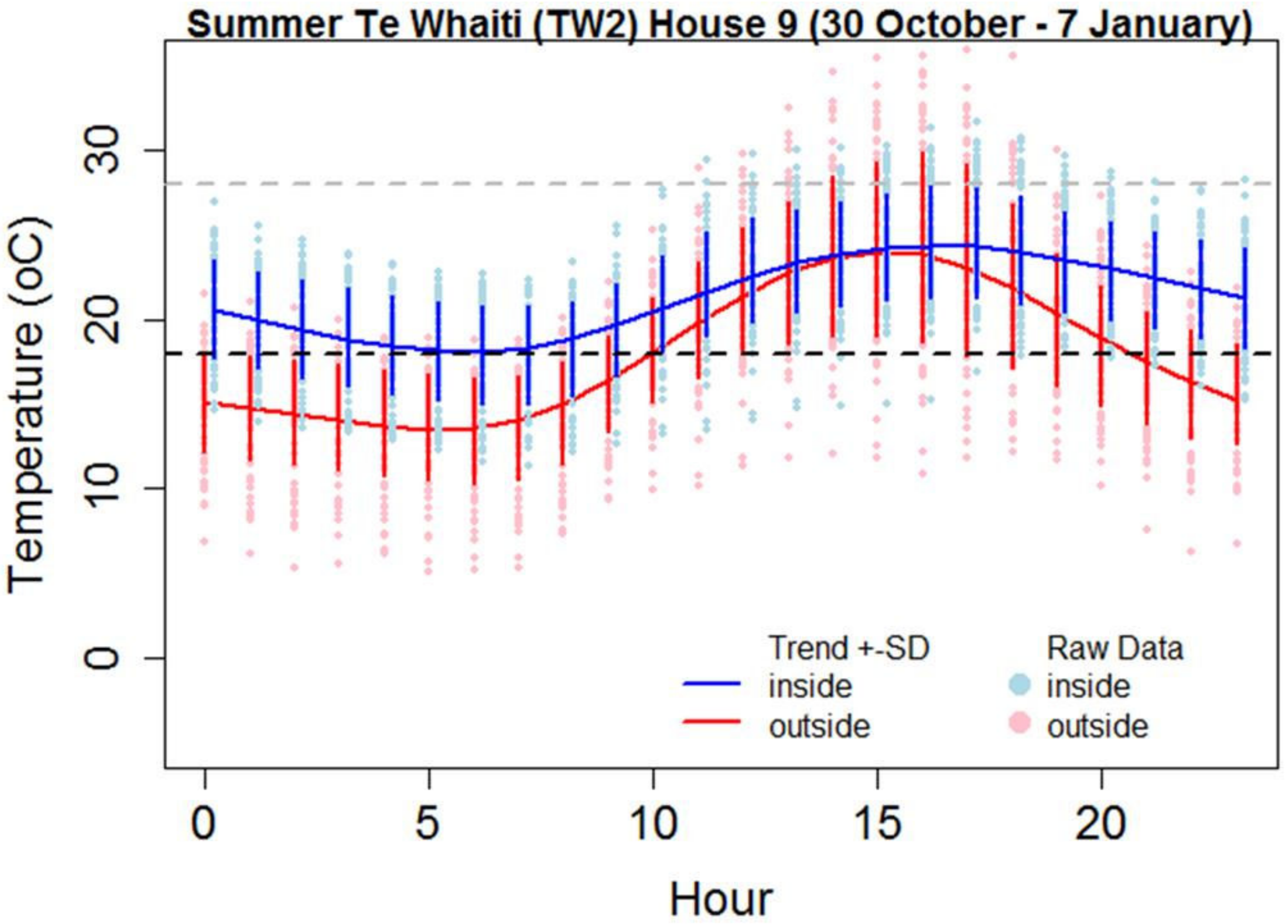


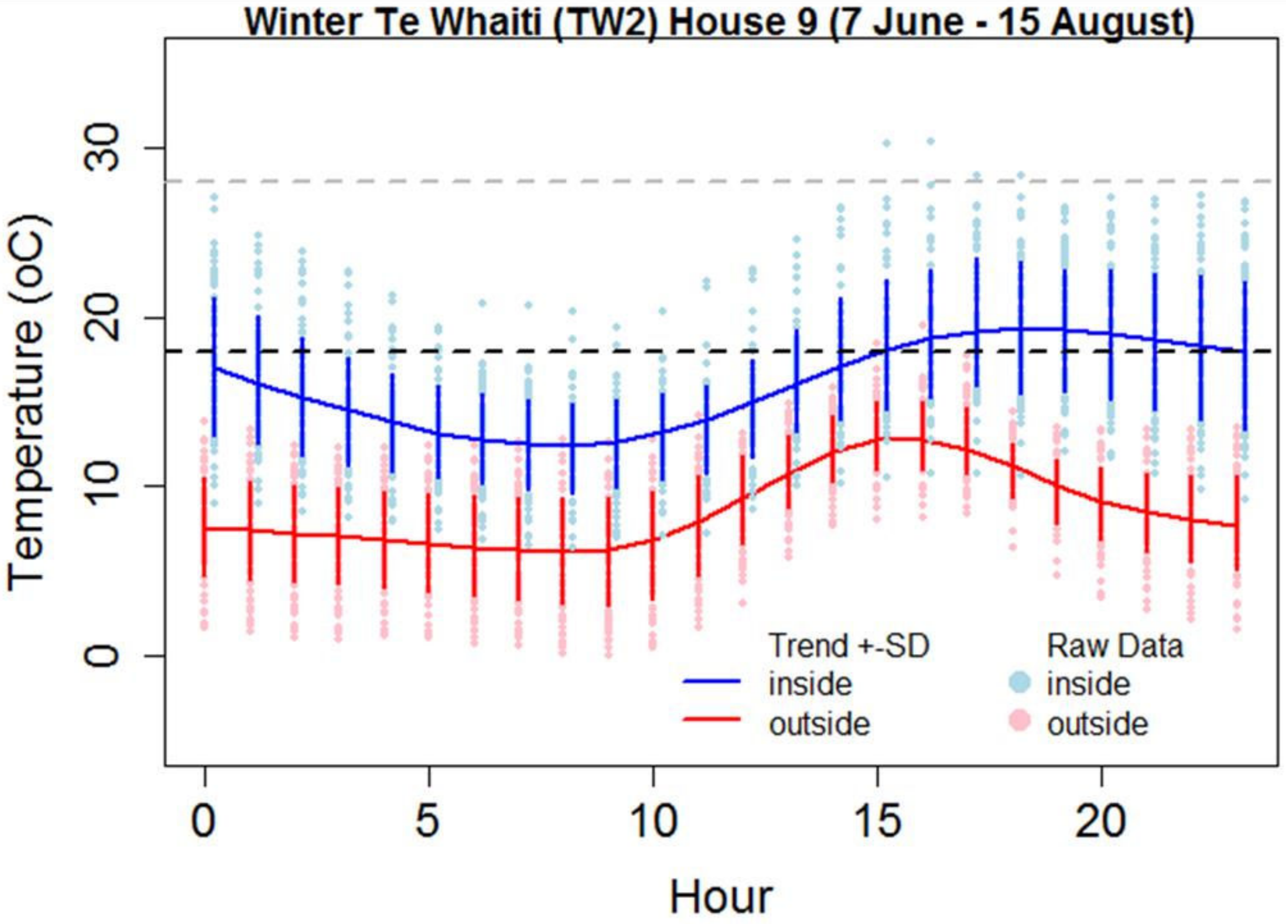
Winter Te Whaiti (TW1) House 10 (7 June - 15 August)

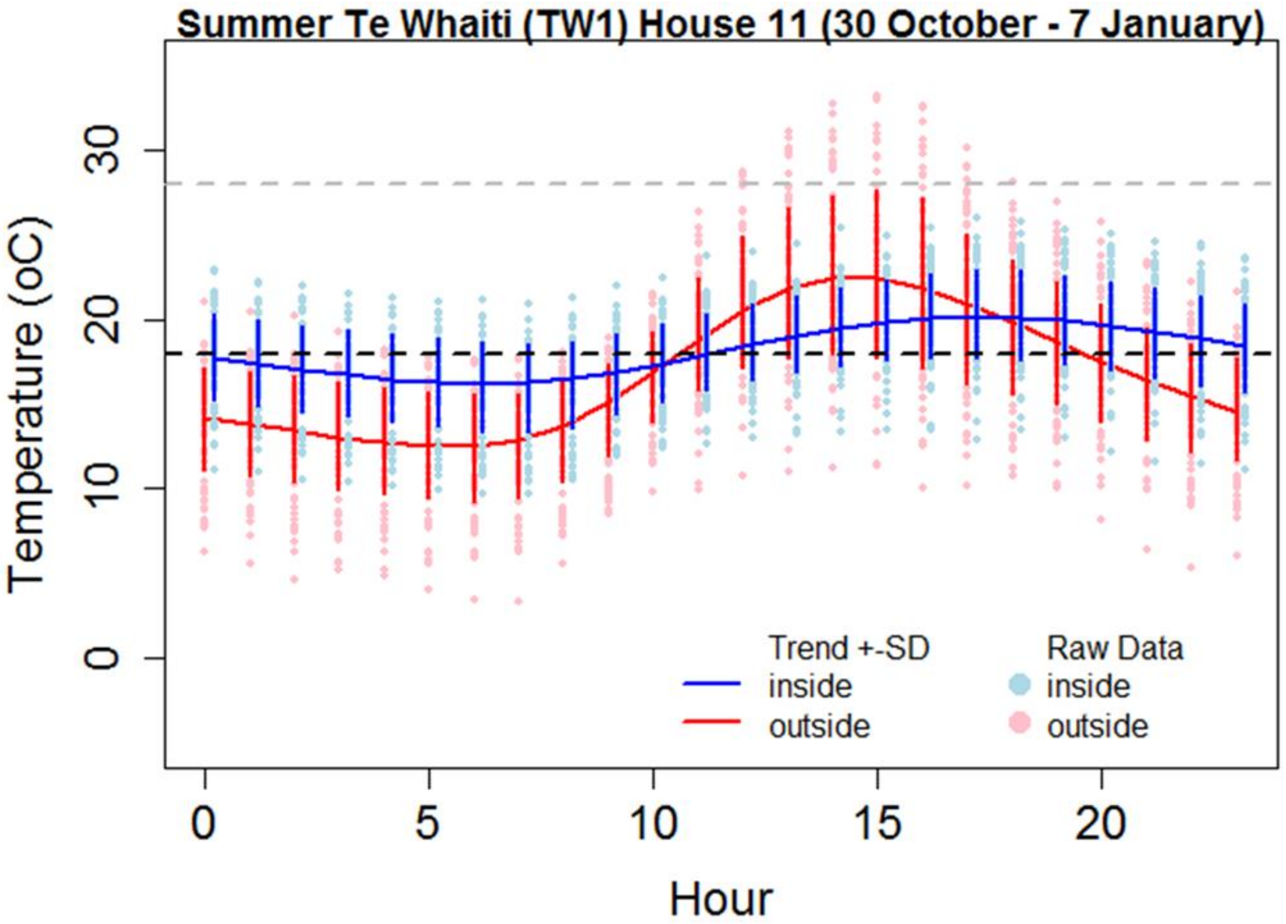


No summer data for house 2.

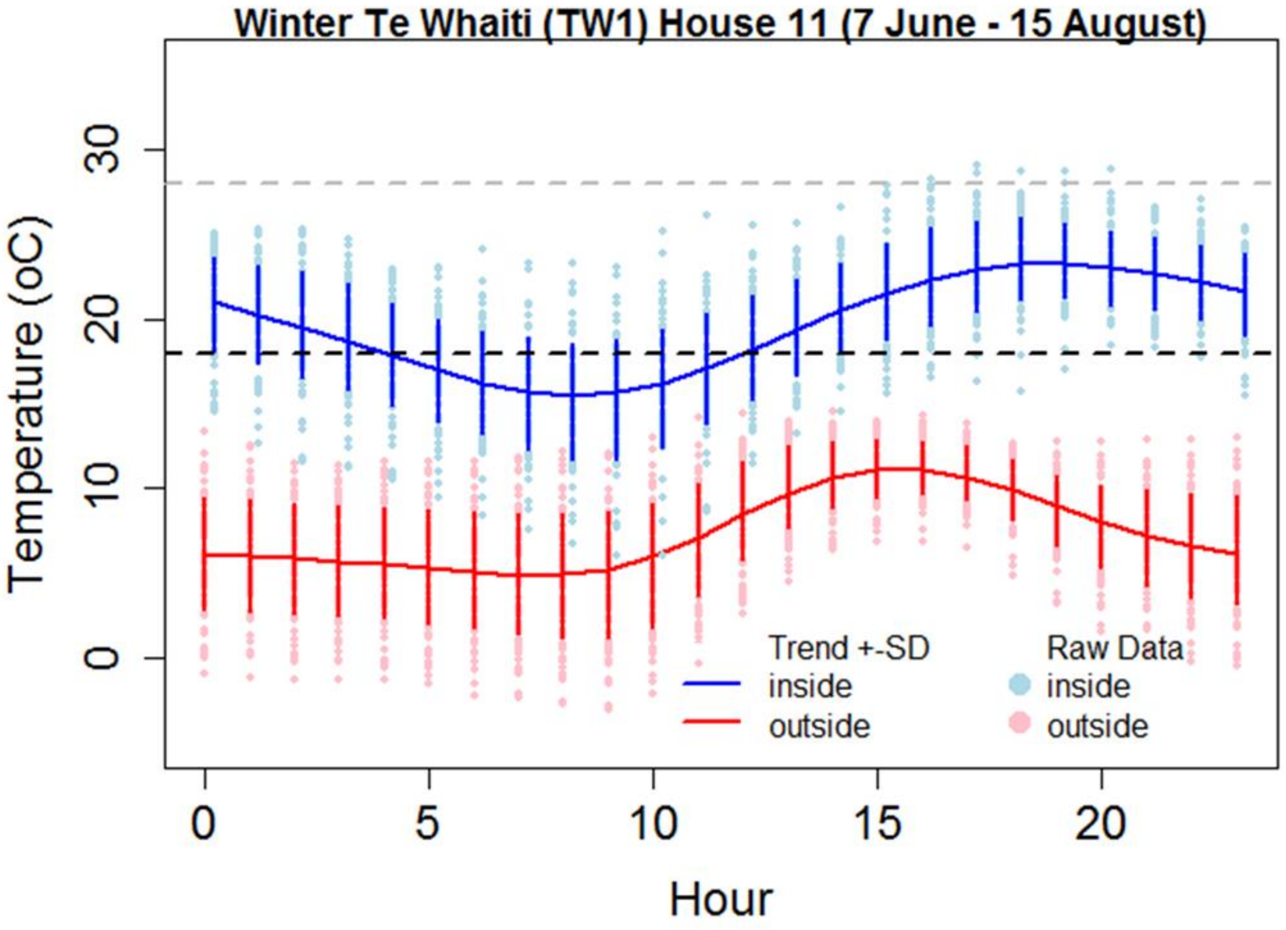



Summer Te Whaiti (TW2) House 9 (30 October - 7 January)
Temperature (oC)
0
10
20
30
0
5
10
15
20
Hour
Trend +-SD
inside
outside
Raw Data
inside
outside


Winter Te Whaiti (TW2) House 9 (7 June - 15 August)
Temperature (oC)
0
10
20
30
0
5
10
15
20
Hour
Trend +-SD
inside
outside
Raw Data
inside
outside



Summer Te Whaiti (TW1) House 11 (30 October - 7 January)

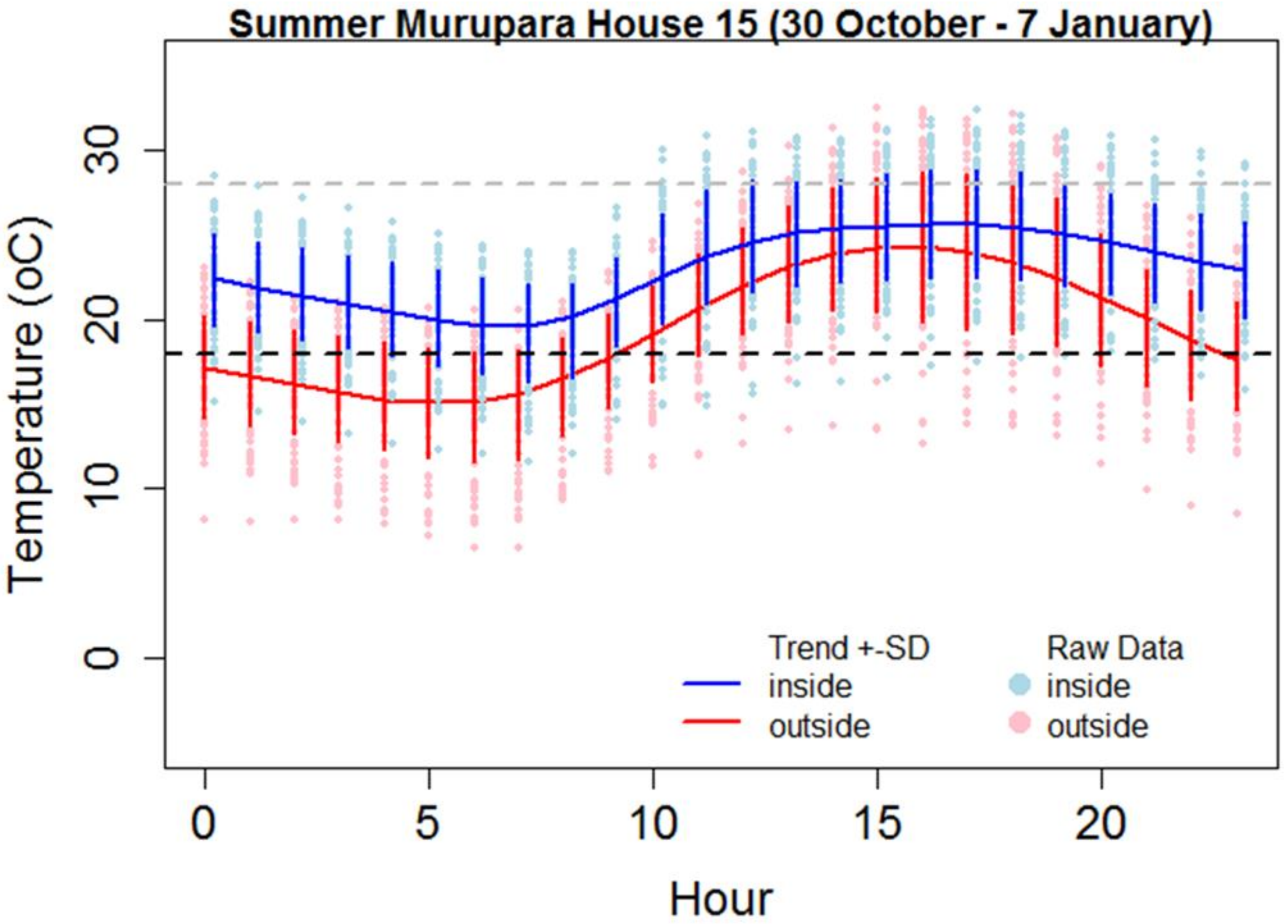


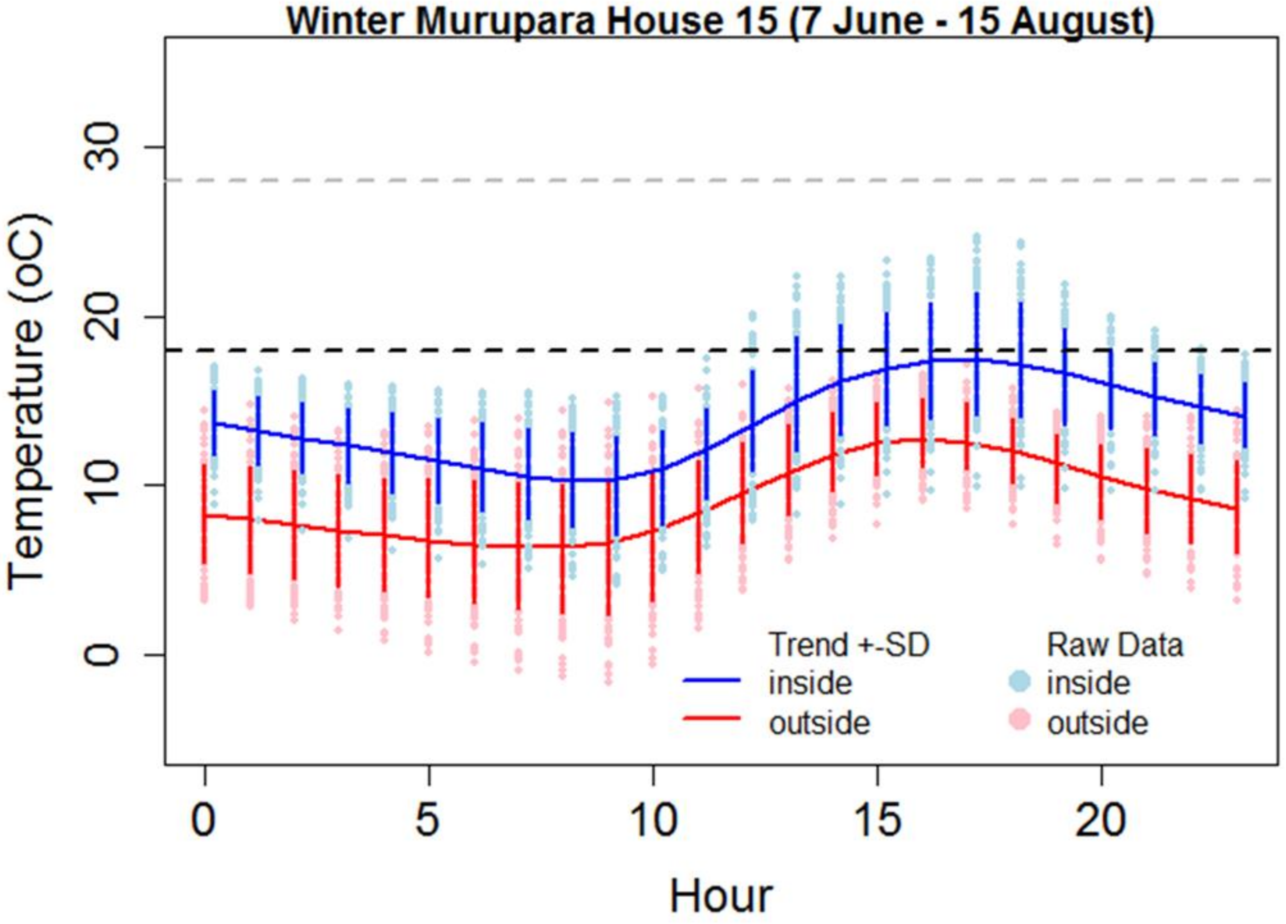
Winter Te Whaiti (TW1) House 11 (7 June - 15 August)

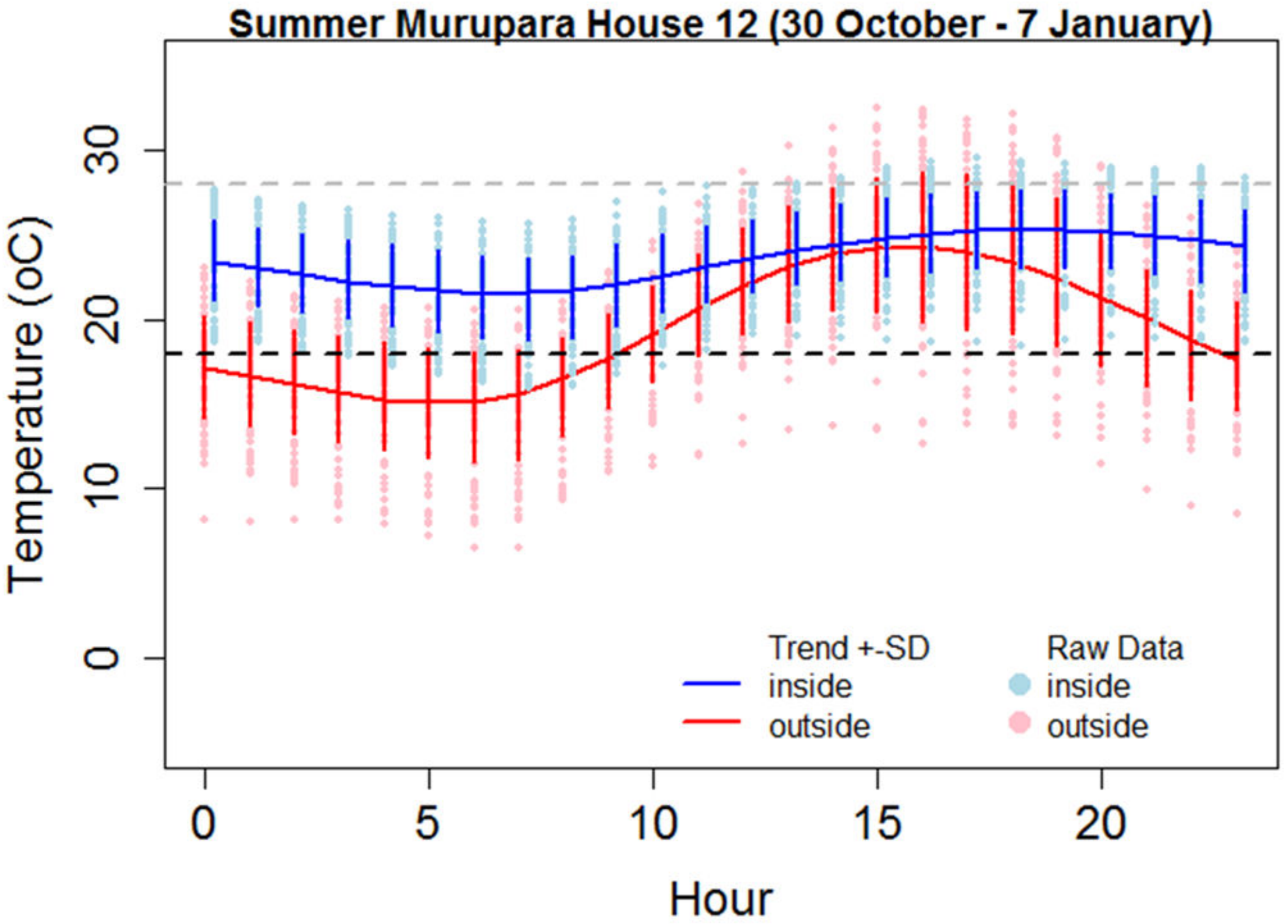
Table 3. Summary of outcomes for individual houses in Murupara (see graphs on following pages)

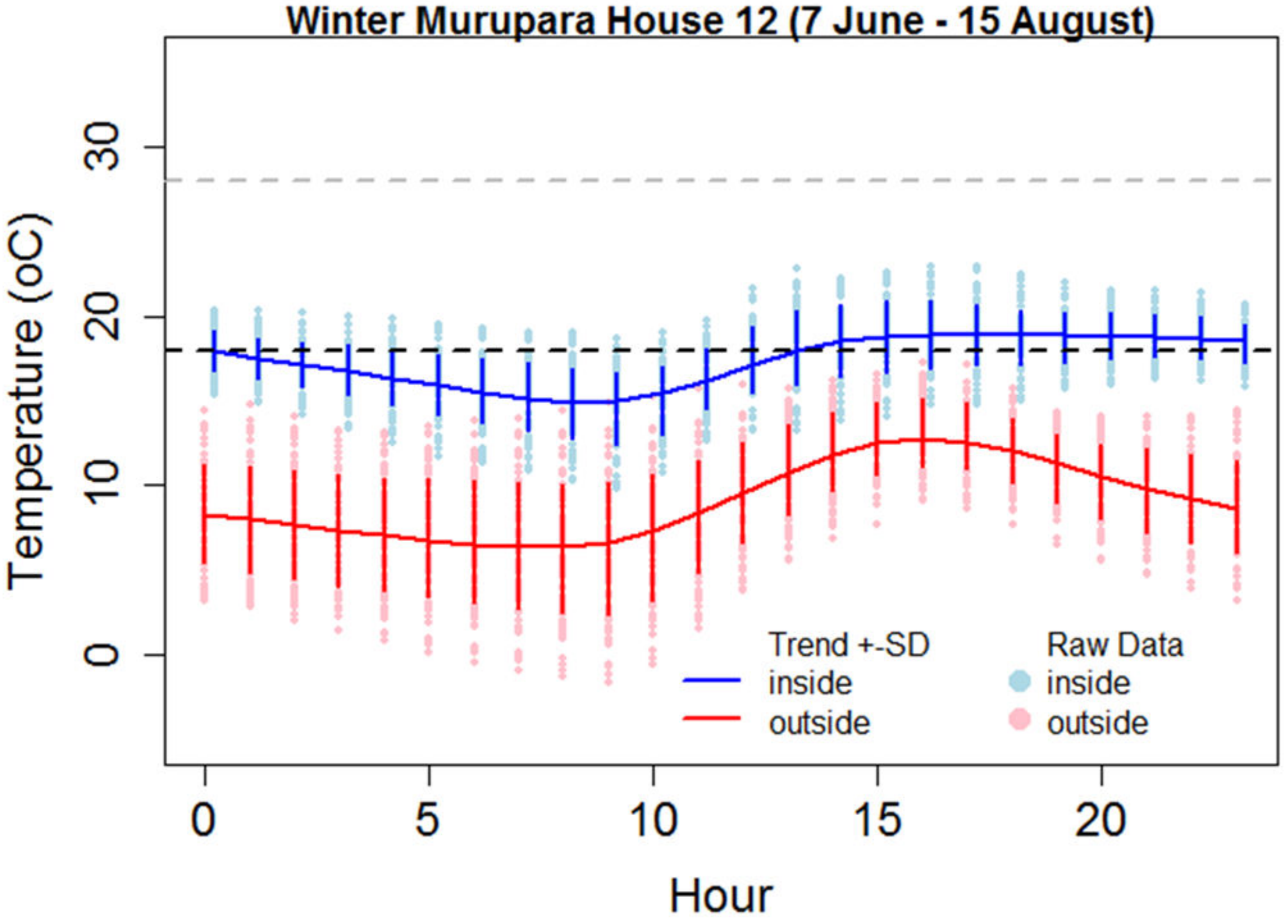
House No	**Quality Index**	**Summary of outcome** (Sum=summer, Win=winter; *In*=inside, *Am*=outside)
15	9	Sum: *In* consistently warmer than *Am* by about 5°C. Some afternoon buffering of hot *Am* conditions Win: In consistently warmer than *Am* by about 7°C (active heating), but *In* temperatures cool to cold, with average just reaching 18°C in late afternoon
12	16.5	Sum: *In* consistently warmer than *Am* by about 7°C. Good afternoon buffering of hot *Am* conditions. Variability of *In* less than *Am* Win: *In* reliably heated close to or above 18°C, and much warmer than *Am. In* temperature very consistent with low variability
13	17.5	Sum: No data Win: *In* temperatures often below 18°C during the early morning and through the day, although much warmer than *Am*. *In* with high variability and **frequent overheating*** at night.
16	22	Sum: *In* warmer than *Am* by about 5°C. Some overheating (>30°C), possibly caused by DVS. Some buffering of high *Am* temps in the afternoon. Win: *In* is **regularly overheated**, but loses heat rapidly through the early morning (=poor insulation?). Mostly kept well above 18°C, but with high variability.

*"Overheating" is defined as temperature exceeding the UN guideline of 28°C.

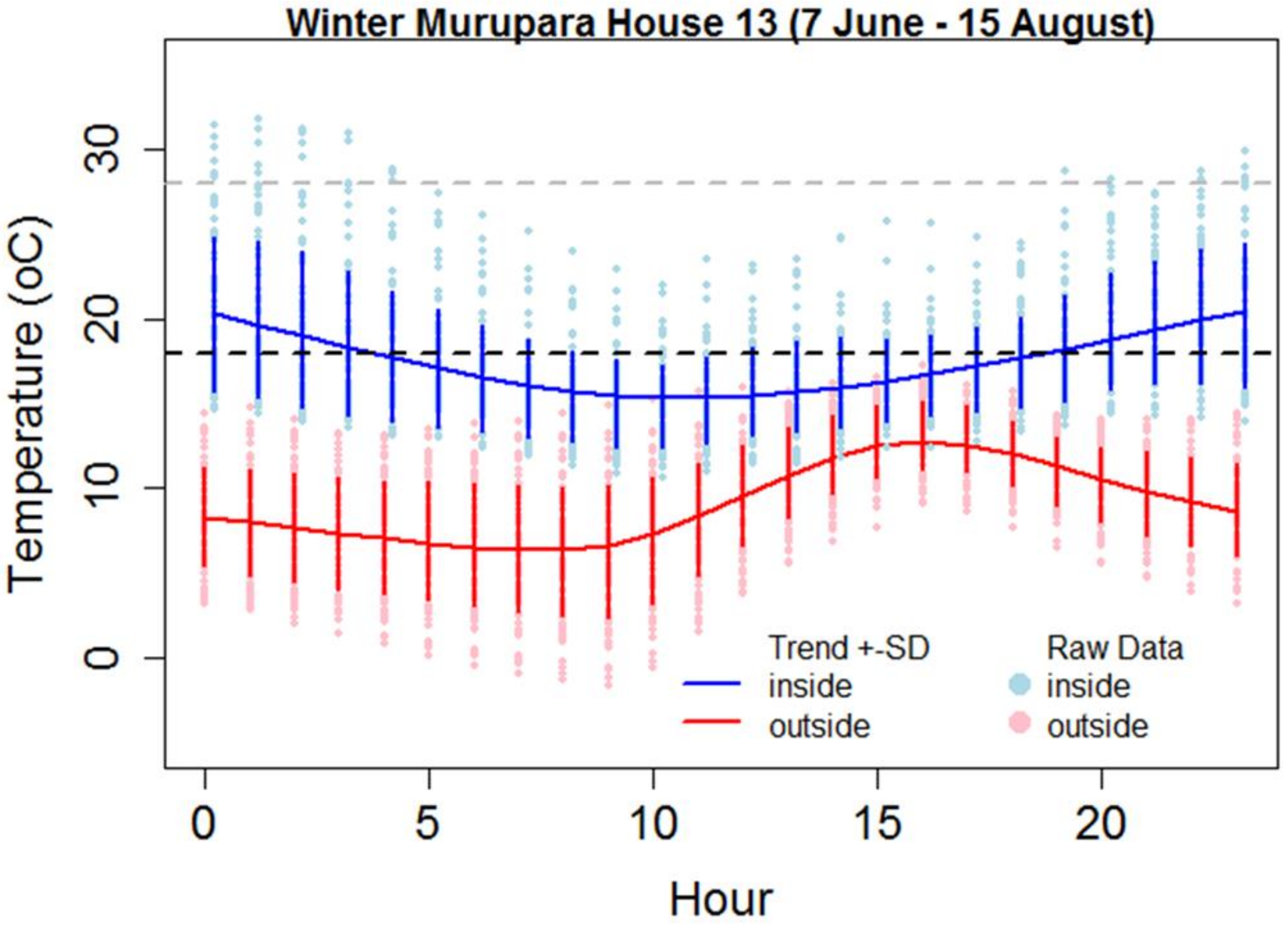

Summer Murupara House 15 (30 October - 7 January)

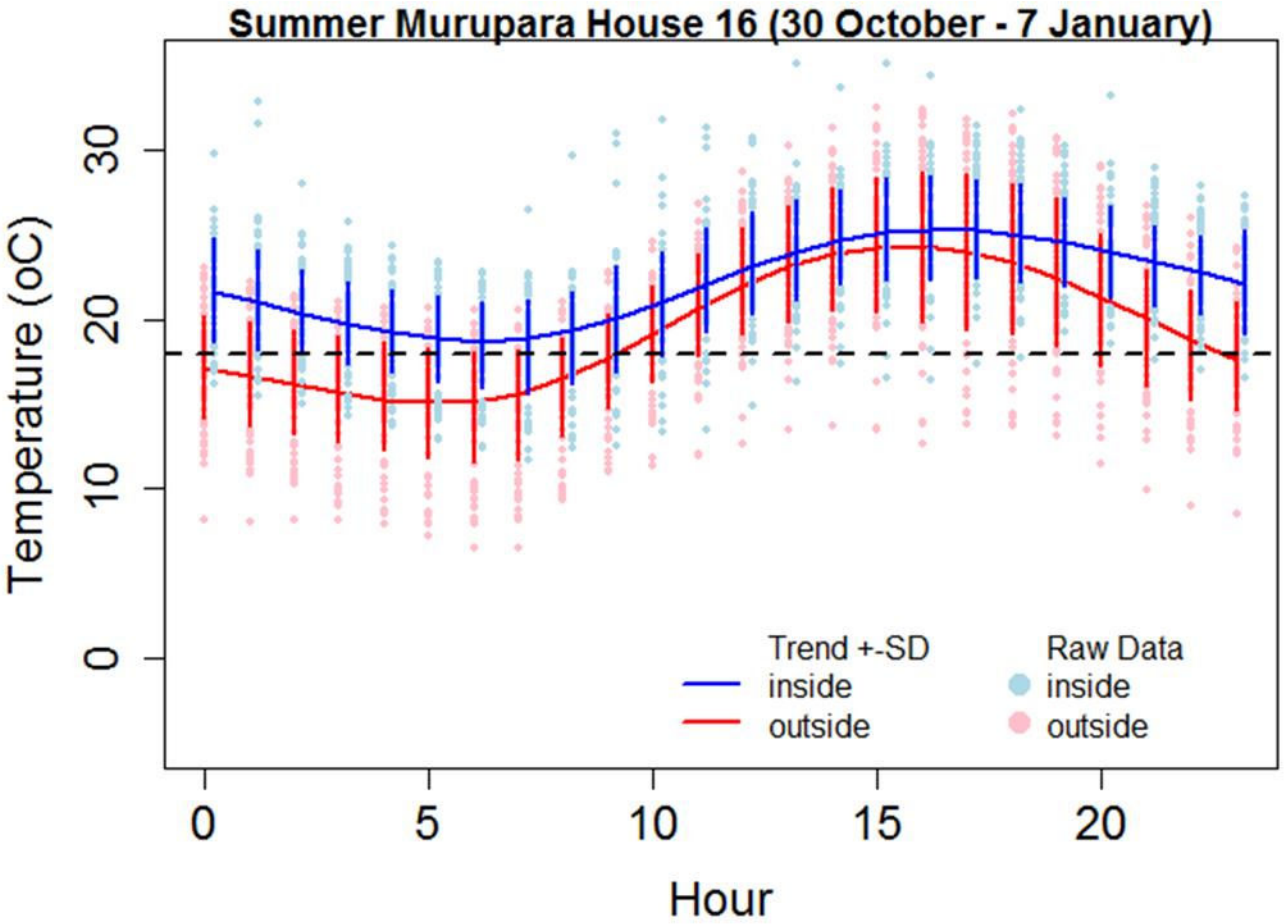

Winter Murupara House 15 (7 June - 15 August)


Summer Murupara House 12 (30 October - 7 January)
Temperature (oC)
0
10
20
30
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside


Winter Murupara House 12 (7 June - 15 August)
Temperature (oC)
0
10
20
30
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside

No summer data for house 13.




Summer Murupara House 16 (30 October - 7 January)

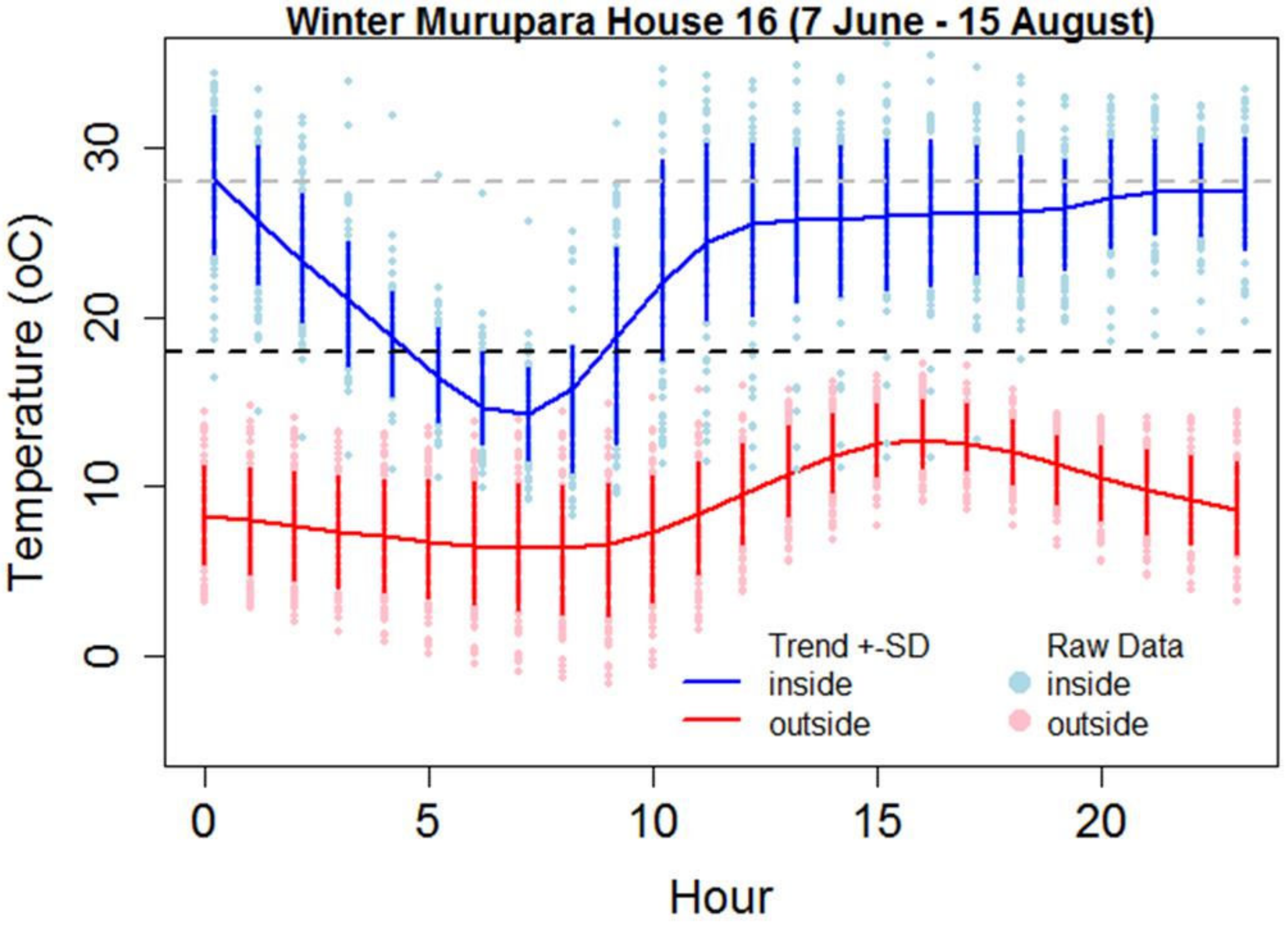
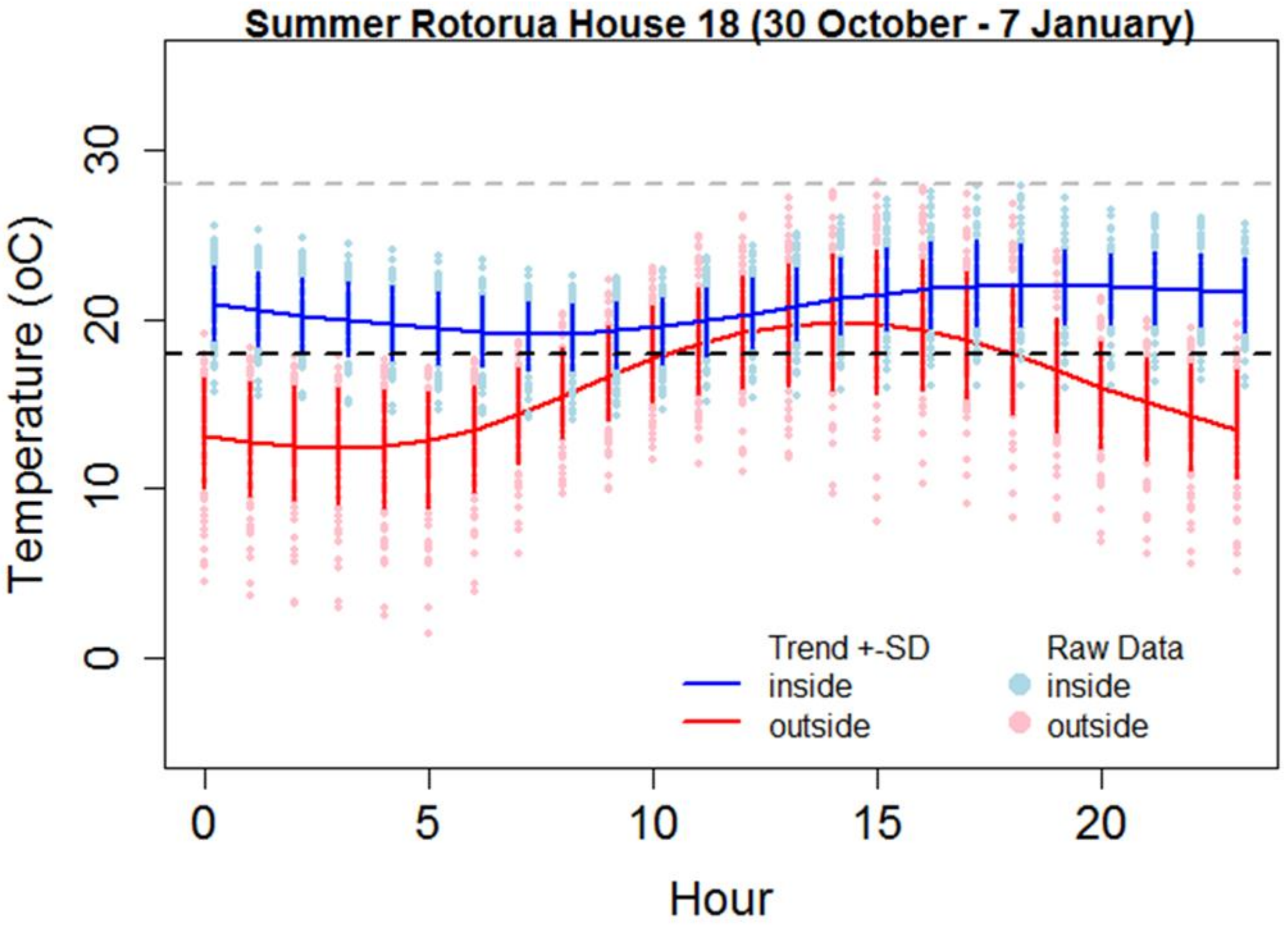
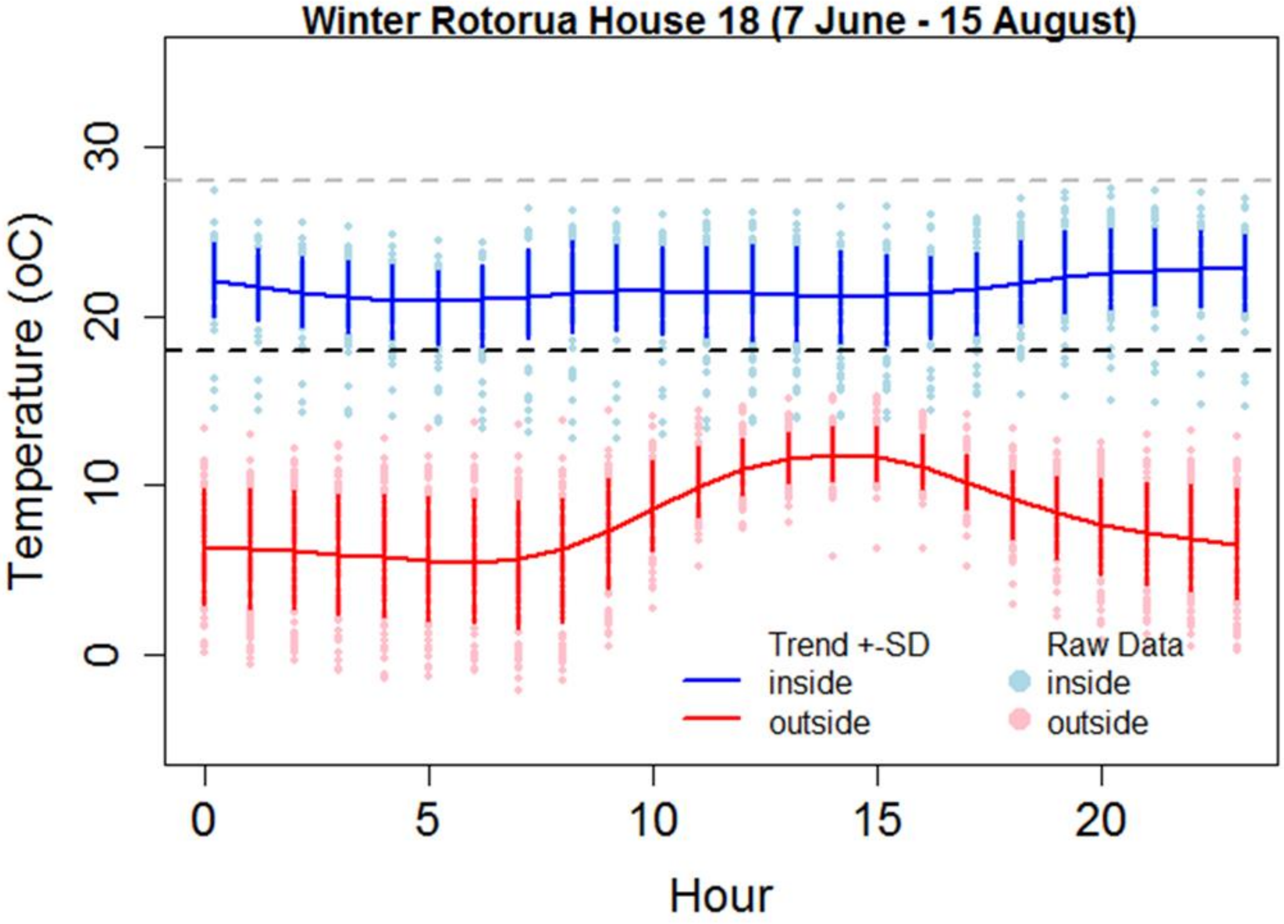

Winter Murupara House 16 (7 June - 15 August)

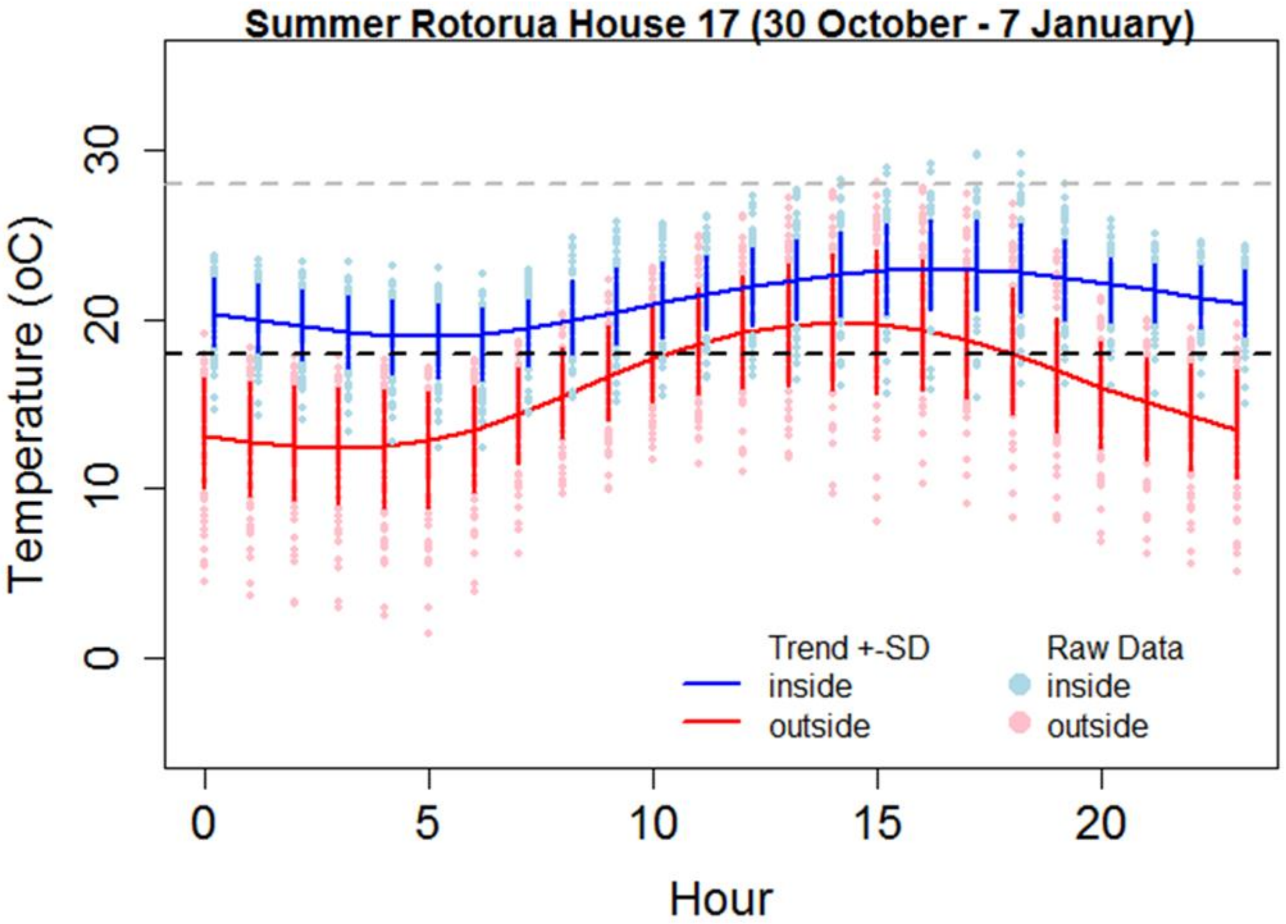
Table 4. Summary of outcomes for individual houses in Rotorua (see graphs on following pages)

House	Quality Index	**Summary of outcome** (Sum=summer, Win=winter; *In*=inside, *Am*=outside)
18	20.5	Sum: *In* held consistently at about 20°C with low variability. *Am* much more variable. Good buffering of hot summer temperatures. Win: *In* held consistently at about 20°C with relatively low variability.
17	24	Sum: *In* maintained close to 20°C, although with **occasional overheating***. Variability less than *Am*. Some buffering of hot afternoon conditions. Win: *In* maintained close to 18°C, although a little cooler in the early morning. **Occasional overheating**.
20	29	Sum: *In* maintained at 23-25°C. Variability lower than *Am*, but **regular overheating** and relatively poor buffering of high *Am* temps (for a modern house). Win: *In* consistently well below 18°C with lower variability than *Am*. Data suggest that heating is only used for a short period in the evenings.

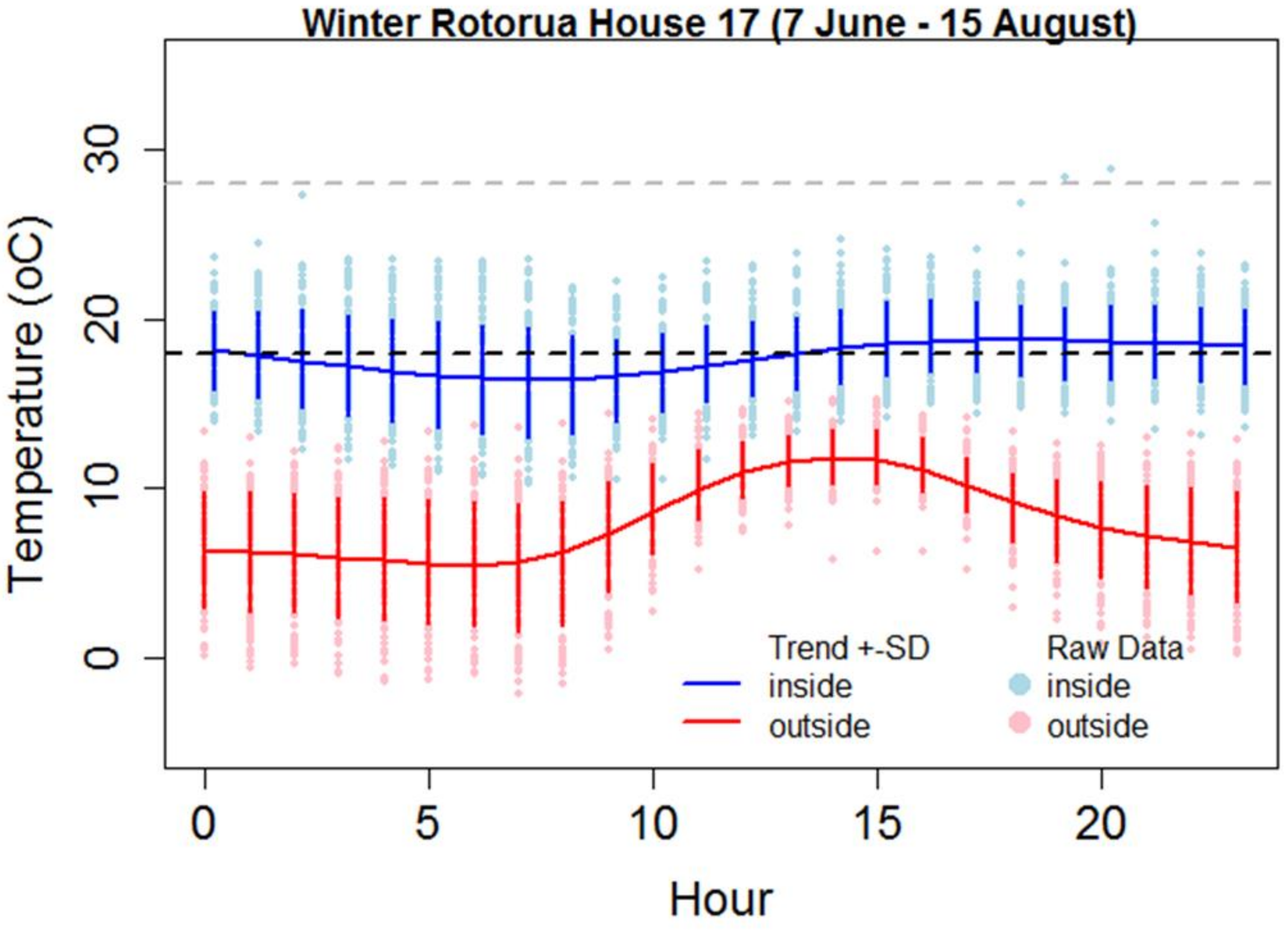
*"Overheating" is defined as temperature exceeding the UN guideline of 28°C.


Summer Rotorua House 18 (30 October - 7 January)
Temperature (oC)
30
20
10
0
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside

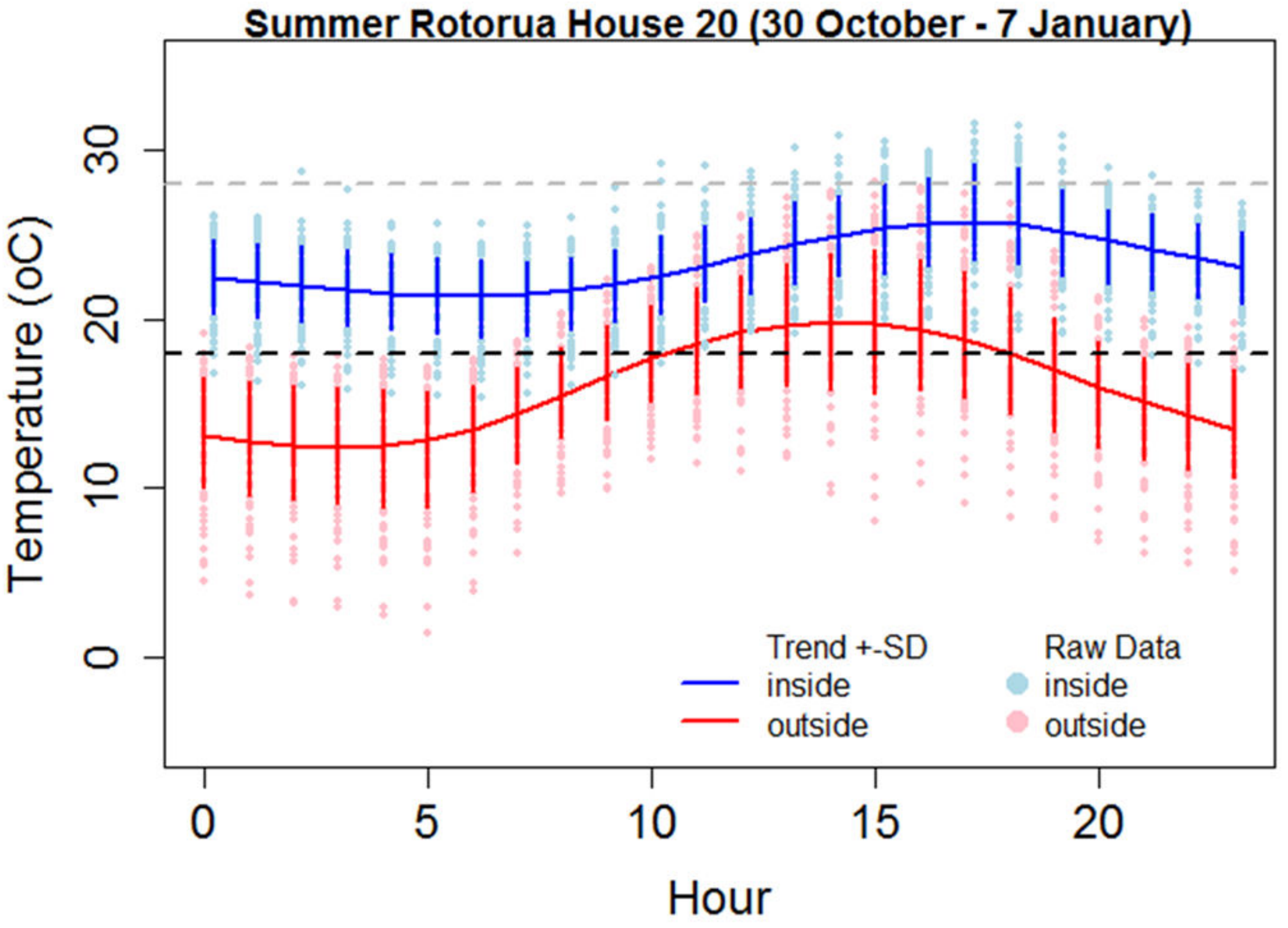

Winter Rotorua House 18 (7 June - 15 August)
Temperature (oC)
30
20
10
0
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside

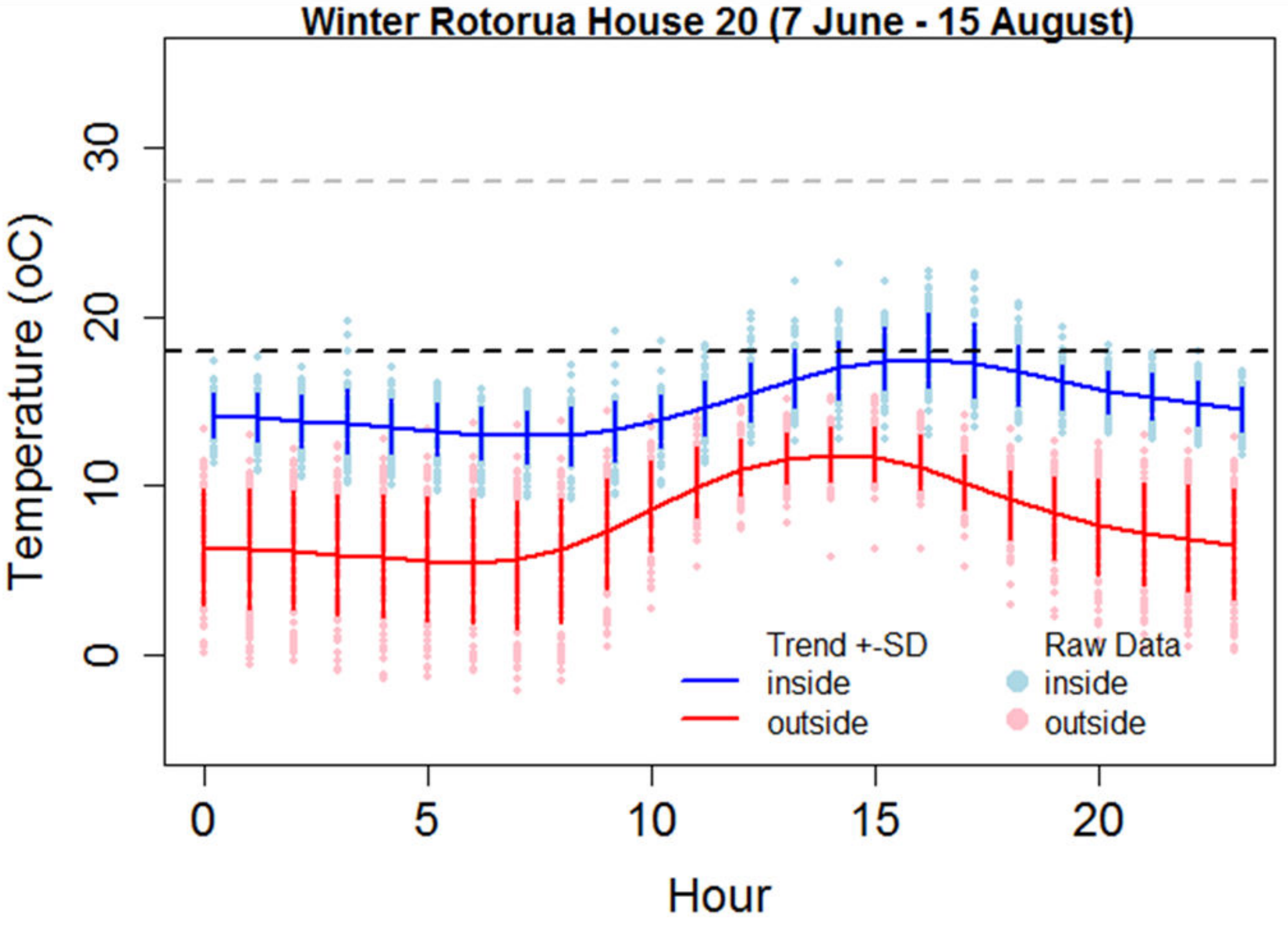


Summer Rotorua House 17 (30 October - 7 January)



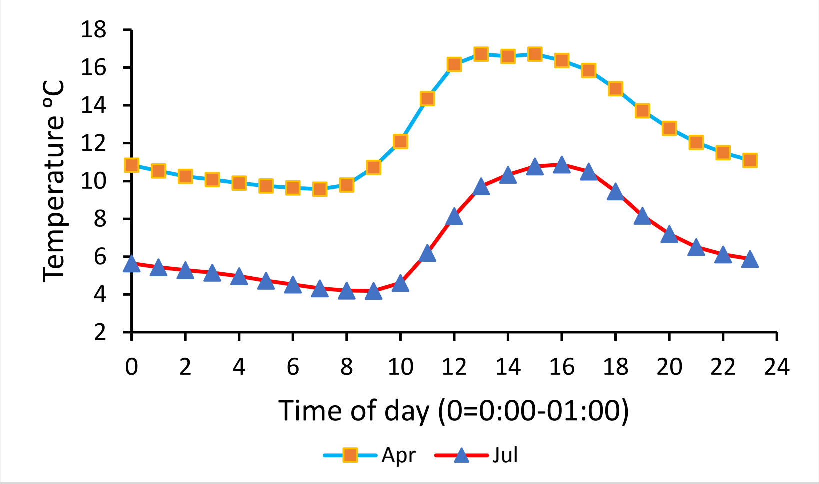
Winter Rotorua House 17 (7 June - 15 August)


Summer Rotorua House 20 (30 October - 7 January)
Temperature (oC)
0
10
20
30
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside

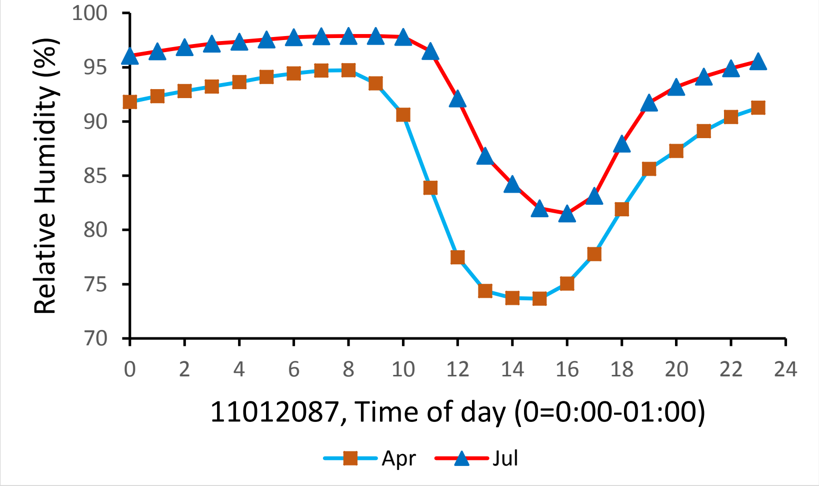

Winter Rotorua House 20 (7 June - 15 August)
Temperature (oC)
0
10
20
30
Hour
0
5
10
15
20
Trend +-SD
inside
outside
Raw Data
inside
outside

How to read the graphs (Reference to Chapter Three)

- Temperature and humidity data were used to create a graphed profile through time inside a room, or outside.
- The graph is constructed from 24 points, each representing the average temperature or relative humidity (RH) in the room every hour through the 24-hr day.
- All data were averaged across the same hour for all days in a month.
- Thus, one line shows the average pattern through the 24-hr cycle for each month.



Average 24-hr Temperature profiles for April and July, showing the 24 points used to draw the graph. 0 hr = midnight. The day began warming at 0800 (April) or 1000 (July), with peak temperatures from 1200-1600 (April) or 1400-1700 (July).



Average 24-hr Relative Humidity profiles for April and July, showing the 24 points used to draw the graph. RH remained above 80% throughout July, and was very high at night in both months.

For simplicity, the points are removed from the graphs in this report.

Variation

- As expected, the two graphs above show variation in temperature through the day, and overall higher temperatures in April than in July. For variation or variability, the technical term is *variance*. In order to understand the variability in a set of data, the difference between *each* measurement and the average is added into a simple mathematical formula. That formula gives one value for the variance that captures all of the variability in the data.

- The calculated measure of variance used here is the standard deviation.
- Sets of data in which there is a lot of variability will have a high value for the calculated variance; sets of data with little variability will have a low calculated variance. E.g. the two sets of values: 1,3,5,7,9 and 3,4,5,6,7 both have the same average (5), but the first set has higher variance (3.16) than the second set (1.58) because it contains more variability.
- Once the average and the variance are both calculated, they can be combined to produce a single value enabling comparison of variability in different data sets. E.g., the data here can be used to investigate weather variability in July by comparing the average:variance relationship for the two July data (inside and outside the house). If the calculated value is high, then variability is low; if the calculated value is low, then variability is high.
- A higher value for the calculated relationship is predicted for inside the house because temperature is expected to vary less in a protected environment.

Temperature and Relative Humidity (RH)

- On the Celsius scale (used here), the United Nations recommends that comfortable internal house temperatures suitable for human habitation should lie within the range 18-28 °C.
- Internal temperatures consistently below 18 °C are considered to be health- and even life-threatening, particularly for children and the elderly.
- RH (humidity) is a measure of the amount of moisture in the air at a particular temperature. It is reported as a % value, which is a measurement of the moisture concentration in the air *relative to* the amount that the air could hold at the measurement temperature.
- Temperature and RH are related. At higher temperatures, the air can hold more moisture; thus (e.g.) at 80% RH, there is more moisture in a room at 25 °C than at 15 °C. The water vapour is denser at the higher temperature.
- The relationship between temperature and RH is negative: as temperature goes up, RH tends to come down, and vice versa. That relationship can be seen in the graphs. However, the relationship is not exact, and RH can be (e.g.) high even when temperature is high.

Consequences

- The most likely health effects are skin and respiratory problems.
- High RH at any temperature can promote the growth of mould in a house. Mould grows more slowly at lower temperatures, but it will still grow if humidity is high.
- Management of humidity in houses is normally achieved using ventilation. Older houses in New Zealand tend to be closed up when temperatures are cold (in order to retain heat and minimise draughts). However, a consequence is that internal moisture remains trapped inside the house. Wetter air (higher humidity) is uncomfortable (= feels cold), resulting in people closing up the house even more, and/or adding more heat.
- A positive feedback process can therefore develop, whereby trapped moisture inside the house creates more active heating, which then creates more moisture (e.g. through unflued gas burners, or cooking). Health consequences have a higher probability under such conditions.

- Air trapped inside a house also accumulates contaminants, such as chemical fumes, odours, and carbon dioxide or monoxide.
- Ventilation is only part of the solution to high internal RH. If RH is high outside, then moving “fresh” air from outside to inside may have little drying effect on the internal environment. However, ventilation may inhibit mould growth and will reduce contaminant loads. The notions of humidity and air quality management received little attention in NZ when older housing was being designed. Retrospective insulation of older houses has reduced passive ventilation due to draughts and leaks, and in some cases created a new suite of problems with moisture accumulation, rot, and mould growth.

Appendix 3: Whole of building simulation report

Andrea Stocchero
Scion

Introduction

This report builds on previous activities and recommendations of the Project Design Team. Taking account of whole of building energy performance, it compares the key parameters for healthy homes (as identified by the Project Team) - between a base-line, standard-building-code building (known as M1) and a similar building with higher specifications (M4). M4 was optimised by the Project Design Team to include an opaque building envelope.

The comparison was conducted by running and analysing whole-building dynamic simulations. The analysis allowed for a high-level assessment (simulation assumptions were made) of the whole M4 building energy demand in relation to the in-use performance delivered by the two building envelopes, and different ventilation strategies.

The findings of this work can be used, in conjunction with a construction cost comparison, to assess the life-time affordability of the proposed M4 building in comparison to M1 standard-building-code building. The work can also inform the development of the "Te Whaiti Prototype, Tallwood Designed Building" to be constructed by the Matekuare Whanau Trust (out of scope of this work).

Methods

Two simulations activities were conducted to assess the performance of the final M4 building opaque building envelope (wall, ceiling, floor), and the performance of the M1 standard building code envelope.

The simulation results were used for two purposes. First, to assess the performance of the opaque building envelope proposed by the Project Design Team, and second, to compare the results with the standard building code M1 building which is already built and in use at Toi Ohomai Campus, Rotorua. The whole-building simulations were used to conduct a high-level assessment and comparison of the performance and energy demand of the two buildings (M4 proposed, M1 existing).

Three building models have been simulated using WUFI® Plus software: M4 Building with natural ventilation, M4 Building using a mechanical ventilation with heat recovery (MVHR) system, and M1 Building.

Model preparation and simulation

The whole-building indoor environment simulation entailed the preparation of whole building 3D models using WUFI® Plus software, including opaque and transparent building envelope components (walls, floor, roof and windows), and heating, ventilation and air conditioning (HVAC) systems, for M4 and M1 buildings.

Simulation variables and assumptions

Assumptions were made in order to define the full building envelope, including windows and doors, and simulation conditions, particularly in relation to user-defined ventilation and HVAC settings, and internal loads.

The simulation design variables and relative assumptions that have been used within the simulation set are presented in the Table 1 below.

Table 1. Variables and assumptions used within the simulation set.

Building **Variables**	**M1**	**M4**
Opaque building envelope	Standard building code	Optimised M4 building envelope
Airtightness (air infiltration rate ACH)	3.5 ACH*	0.9 ACH**
Indoor air temperature (T) *Target levels***	Constant across models** Min: 20 °C Max: 25 °C	
Indoor Relative Humidity (R.H.) *Target levels***	Constant across models** Min: 30 % Max: 65%	
Indoor CO_2 concentration *Target level***	Constant across models** Max: 1000 ppm	
Outdoor climate and unheated attic climate	Constant across models	
Building Volume	Constant across models	
Building Form factor	Constant across models	
Building orientation and shading	Constant across models	
Transparent building envelope (Windows: glazing and frames)	Constant across models	
Occupancy levels	Constant across models Family of 4 people (from WUFI® Plus Database)	
Ventilation	Constant across models Manual, (window opening schedule) [A simulation of M4 building with a mechanical ventilation with heat recovery (MVHR) system with 95% heat recovery performance and a ventilation flow of 0.35 air changes per hour (1/h) was run and results compared in the results and discussion section of this report.]	
Heating system	Constant across models 1 Heat Pump and 2 Radiant panel heaters	

*assumed from Rupp & McNeil (2018).
**assumed from the Toitū te Kainga, Toitū te Ora, Toitū te Tangata project team proposed key parameters and target performance for healthy homes (see Appendix 5).

Both buildings are similar enough in terms of size (surfaces and volumetric parameters) and layout to be directly comparable (Chapter 7). The 3D model for both was developed using WUFI® Plus software built-in Building Wizard. Figure 1 shows the 3D model developed from the existing M1 building. Minor differences between the two building designs (specifically roof pitch direction and shape of North windows) are considered to be neglectable in relation to both the definition of the 3D model for simulations and their influence on simulation results.

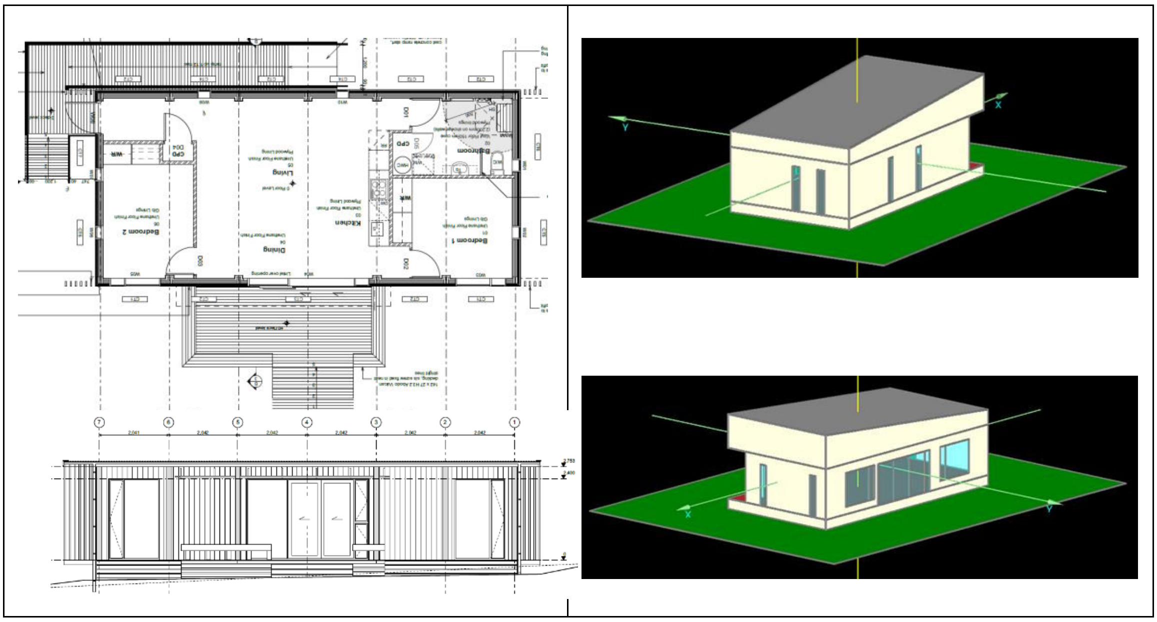


Figure 1. Layout and North-elevation of M-type cabin (left) and, South-West and North-East views of 3-D model in WUFI® Plus software (right).

Simulation use

The comparative whole-building dynamic simulation results were used to assess the necessary effort in terms of energy consumption for heating, cooling, ventilation and humidifying and dehumidifying to achieve the target levels for healthy indoor living conditions. The simulation also included the one-dimensional hygrothermal simulation (equivalent to simulation using WUFI® Pro software) of the final opaque building envelope proposed for the M4 building in comparison to the existing M1 building envelope, which was used as a base-line (100%).

The comparison of different simulation results was used to assess the influence of the proposed opaque building envelope, in terms of variation of performance (%) and in relation to the energy required to achieve and maintain the target indoor environment conditions.

The comparison of manual and mechanical heat recovery ventilation systems for the M4 building enabled the assessment of the energy demand implications related to the implementation of the mechanical ventilation with heat recovery system (MHRV). While recommended, installation of this system will add energy demand and construction costs relative to manual ventilation only.

The subsequent results can also be used, in combination with the construction costs, to inform on the whole-of-life affordability of the building. However, due to the number and nature of assumptions necessary to develop the 3D models and run the dynamic simulations, the affordability figures are expressed in percentage (%) of saving rather than economical ($) value.

Results and Discussion

Whole-building indoor environment simulation

When comparing the results between the M1 and M4 buildings, M1 building components were used as the base-line (100%) to assess improvements in performance. The energy performance in the form of an increase or decrease of energy losses and energy demand between buildings can be directly correlated with a decrease in running cost for active heating, ventilation and air conditioning necessary to achieve and maintain the target conditions for healthy indoor environments.

Thermal performance of walls

The whole-building simulations included the one-dimensional hygrothermal simulation (equivalent to simulation using WUFI® Pro software) of the opaque building envelopes for M1 and M4 buildings. Table 2 summarises the thermal resistance (R-value), and its reciprocal thermal transmittance (U-value), between M1 wall and M4 wall components. The comparison of these values shows that the M4 Insulated wall section component has 2 times more thermal resistance (100% improvement) compared to the M1 insulated section (base line value).

The comparison of the wall sections where the timber structural elements are present shows the M4 wall component to have 2.6 times more thermal resistance (160% improvement) compared to M1. Notably, the R-value of M4 wall structural section is double the M1 insulated section, which explains the overall improvement in energy performance of the proposed wall system for M4 compared to M1.

Table 2. Comparison of opaque building envelope elements (walls) thermal performance.

Building & Position Values	**M1 Wall**		**M4 Wall**	
	Insulation	**Structure**	**Insulation**	**Structure**
R-Value	3.04	1.27	6.08	3.29

Opaque building envelope heat loss

The whole-building dynamic simulation results in relation to heat losses through the opaque building envelope are used to compare the thermal performance of the M1 and M4 building envelopes. Table 3 shows the heat losses over a period of one year.

Heat losses from M4 exterior walls are 3 times lower (66% reduction) compared to M1 exterior walls. Heat losses from M4 floor are 5 times lower (80% reduction) compared to M1 exterior walls. Heat losses from M4 ceiling are 2.1 times lower (52% reduction) compared to M1 exterior walls.

Lower heat losses from the opaque building envelope will translate to lower energy demand and cost for heating to maintain indoor air temperature at the target levels (Table 1).

Table 3. Comparison of heat loss through opaque building envelope elements.

Value & Building Values	**Heat loss (kWh)**	
	M1	**M4**
Exterior walls	100% (base-line)	33.3% (66.7% reduction)
Floor to unconditioned space	100% (base-line)	19.8% (80.2% reduction)

Ceiling to unconditioned space	100% (base-line)	46.2% (53.8% reduction)

Energy demand

Table 4 summarises the heating and cooling energy demand variations (%) for M4 with natural ventilation, and M4 using a mechanical ventilation with a heat recovery (MVHR) system, in comparison with M1, the base-line (100%).

The heating demand results show a reduction of 66% in heating energy for M4 with manual ventilation and 65.9% for M4 with MVHR, compared to M1. These energy savings represent savings in running cost during the heating period for achieving and maintaining the indoor conditions at the target levels (Table 1).

The cooling demand results show an increase of 39.9% in cooling energy for M4 with manual ventilation and 44.2% for M4 with MVHR, compared to M1. These energy demand increases are due to the higher insulation levels of the M4 opaque building envelope, and can be related to running costs during the cooling period for achieving and maintaining the indoor conditions at the target levels (Table 1). However, the cooling period simulation assumed a worst-case scenario where natural ventilation through windows opened during occupational periods was limited (e.g. due to safety, outdoor air pollution or noise). Different natural ventilation schedules during the cooling period should reduce the cooling energy demand of all buildings, mitigating the variation between M1 and M4 buildings.

It is noted that M-type building layout is designed to maximise cross-ventilation. It is also noted that a MVHR system with heat recovery by-pass would allow an increase in the ventilation rate to mitigate indoor overheating, with limited need to open windows (worst case scenario) and low-energy demand. Lastly, it is recognised that in the specific context of the Matekuare whānau, heating is the main issue to contend with. Demand for cooling is limited to a small part of the year (Chapter 3) and is likely to be met mostly or entirely using natural ventilation.

The total energy demand (heating and cooling) results shows an overall decrease of 45.9% in heating energy for M4 with manual ventilation and a reduction of 45.7% for M4 with MVHR, compared to M1. These values are higher if most cooling is through natural ventilation.

Table 4. Comparison of energy demand of M1 and M4 building cases.

Value & Building Values	**Energy demand variation**		
	M1	**M4** with manual ventilation	**M4** with MVHR
Heating demand	100% (base-line)	34% (66% reduction)	34.1% (65.9% reduction)
Cooling demand	100% (base-line)	139.9% (39.9% increase)	144.2% (44.2% increase)
Total energy demand	100% (base-line)	54.1% (45.9% reduction)	54.3% (45.7% reduction)

The negligible difference in heating and cooling demands between M4 cases with different ventilation strategies depends on the specific ventilation setting used in the simulations. In particular, the manual ventilation simulation setting (windows opening schedules) applied, has been designed to optimise indoor air change efficacy while minimising energy loss. However, in real life, manual ventilation strategies depend on building-user management and are therefore subject to uncontrolled variations and inefficiencies that would impact on both indoor air quality, energy conservation and heating and cooling costs. Being automated, mechanical ventilation strategies using MVHR systems are less subject to variation from user schedules, are more reliable in terms of indoor air quality management, and can be more energy efficient compared to manual ventilation.

Recommendations

- The findings of this work can be used, in conjunction with a construction cost comparison, to assess the life-time affordability of the proposed M4 building in comparison to M1 standard building code building.
- This work can also inform the development of the “Te Whaiti Prototype, Tallwood Designed Building” to be constructed by the Matekuare Whānau Trust (out of scope of this work).

Conclusions

- The energy performance in terms of increase or decrease of energy losses and energy demand between buildings can be directly linked to running costs for active heating, ventilation and air conditioning necessary to achieve and maintain target conditions for healthy indoor environments
- The findings can be used, in combination with the construction cost, to inform on the whole-of-life affordability of the building

The analysis of dynamic simulation results showed that:

- The proposed M4 opaque building envelope (walls, floor, roof) provides overall lower heat losses that will translate to lower energy demand and cost for heating and maintaining the indoor air temperature at the target levels. In particular:
    - Heat losses from M4 exterior walls are 66% lower than M1 exterior walls
    - Heat losses from M4 floor are 80% lower than M1 floor
    - Heat losses from M4 ceiling are 52% lower than M1 ceiling
- The proposed M4 opaque building envelope enables overall lower energy demand compared to M1, which will translate to lower costs for heating and maintaining the indoor environment conditions at the target levels. In particular:
    - Total energy demand for M4 is 54% (both cases) lower compared to M1
    - Heating demand for M4 is 66% (both cases) lower compared to M1
    - Cooling demand (worst case scenario) for M4 Building is 40% (manual ventilation) to 44% (MVHR) higher compared to M1
    - Cooling demand costs can be reduced by using different ventilation schedules for both natural and mechanical ventilation
- The negligible difference in energy demands between M4 cases with different ventilation strategies depends on the specific ventilation setting used in the simulations.
- M-type buildings are designed to maximise natural cross-ventilation efficiency; however, a MVHR system with heat recovery by-pass is recommended as it would provide an overall more reliable ventilation with negligible increase in energy demand compared to manual ventilation.

Appendix 4: Healthy Homes: Key Parameters and their target performance

Andrea Stocchero
Scion

Dr Kara Rosemeier (PHINZ)
PHINZ

Introduction

The design and construction of houses (and buildings) that protect and nurture the health of their inhabitants, at low operating and maintenance costs, requires the setting (and pursuit) of realistic and achievable building performance targets that are based on robust scientific and technical foundations. To this end, the research project team set about identifying the key parameters and desirable performance levels (targets) to be delivered by a healthy and life-time affordable home.

Methods

The Passive House Institute New Zealand, an Incorporated Charitable Trust, identified strong alignment between its mandate and the Toitū te Kainga, Toitū te Ora, Toitū te Tangata project end goals. That is, the creation of houses that are warm and comfortable, have low operating and maintenance costs, are easily constructed and protect and nurture the health of inhabitants.

Desiring to support the project, PHINZ Board offered the in-kind support and expertise of Dr Kara Rosemeier, Board member and Director of Passive House Academy New Zealand (PHANZ). Through a series of face to face and virtual wānanga, Dr Rosemeier worked with the project team to define the parameters and performance targets to enable the creation of houses that meet the project goals.

To achieve the performance targets that were set, it was deemed necessary to implement design, construction and operational strategies, as well as verify and measure performance levels (to assess whether targets are met or not). Therefore, options for assessing the performance of the design during the design phase, and measuring and monitoring the delivered performance during construction and post-occupancy of the building, were also deliberated and proposed.

Discussion

The following key parameters were identified as having a direct correlation to the health, comfort and operating and maintenance costs in houses and buildings.

Indoor Air Temperature

The World Health Organization (1987), identified 18°C as the minimum air temperature for healthy, sedentary adults. They also identified 20°C as the minimum air temperature for ill and impaired people and for children and the elderly. Importantly, these air temperatures apply when other comfort criteria, such as sufficiently high radiant temperatures, are met (WHO, 1987).

Temperature variations within a building can cause thermal stress on the respiratory and circulatory systems. Indoor temperatures below 16°C increases the risk of respiratory infections, and below 12°C stress the cardiovascular system (Braubach, et al., 2011; EHINZ, 2018).

Cold temperatures also contribute to excess winter deaths in comparison to other times of the year.

Indoor Air Relative Humidity

Indoor air relative humidity (RH) influences materials and surfaces water activity (A_w) and moisture content (MC), which are correlated with the formation of mildew and mould on surfaces (Nielsen, et al., 2004). High RH also supports the proliferation of bacteria and dust mites in indoor environments. Mildew, mould, bacteria and dust mites all contribute to aggravating allergies and asthma.

Excessively high RH levels also contribute to thermal discomfort, while low RH (below 20%) can cause eyes, respiratory tract and skin dryness and irritation.

Indoor air RH levels are influenced by a variety of factors, including outdoor RH levels, occupants' activities, and heating, cooling and ventilation behaviours (Sharmin, et al., 2014). Managing indoor water vapour sources, effective ventilation strategies, and indoor environment heating, are important to control indoor air RH levels. However, as indoor air RH levels depend on air temperature, management of indoor air temperature is the key factor ensuring RH levels are maintained within acceptable ranges even when ventilating.

Indoor Surface Temperature

The surface temperature of all surfaces and objects in the space (wall, ceilings, floors, windows and even furniture) influences occupants' perception of comfort, due to radiant heat transfers from the environment to the skin (in both indoor and outdoor environments). When the mean radiant temperature (MRT) of an environment is lower than the skin temperature, heat transfers from the skin to the environment (Bean, 2010; Havenith, 2004; Stanton et al., 2004) and the person may feel cold.

Surface temperatures also influence air stratification and temperature asymmetries that are perceived as draughts and reduce occupants' thermal comfort.

Moisture

Low surface temperatures increase Aw, which facilitates mould growth and decay. It is important to note that A_w and MC are strongly correlated with air RH levels. A_w and dampness can occur on surfaces and materials in indoor environments and/or within building envelope cavities, affecting occupant health and building performance and durability.

Indoor Air Quality (Concentrations of gaseous air pollutants)

The New Zealand Standard NZS 4303:1990 "Ventilation for Acceptable Indoor Air Quality" which is aligned with and adapted from other international standards (e.g. ASHRAE 62-1989 Standard) suggests an indoor CO_2 concentration higher than 1,000 ppm as a threshold indicator for inadequate ventilation. International literature commonly references ASHRAE when using the 1,000 ppm as a threshold level for assessing acceptable/not-acceptable indoor CO_2 concentration. (ASHRAE, 1989; NZS, 1990; Bassett, 2001; OSHA, 2018; Sharmin et al., 2014).

While CO_2 levels above 1000 ppm are not threatening in isolation, they can be viewed as an indication of poor ventilation effectiveness, which may entail elevated concentrations of other, more difficult to measure, indoor air pollutants.

Energy Efficiency

There is no current international agreement on the minimum level of energy efficiency buildings should provide in order to deliver healthy and comfortable living conditions. However, there is increasing agreement and efforts that minimising energy demand and greenhouse gas emissions of buildings is desirable. These outcomes are generally achieved by optimising the building envelope and using efficient building services.

For example, **t**he Paris Agreement on Climate Change suggests that the building sector should avoid at least 50% of projected growth in energy consumption through mainstreaming of highly energy-efficient, near or net-zero energy or energy-plus new buildings, and renovation of the existing stock of buildings by 2030 (Otto, 2016). In response, the World Green Building Council developed a Coordinated Action towards meeting the Paris Agreement commitments, identifying the need for all new buildings to operate at net zero carbon from 2030 and 100% of buildings to operate at net zero carbon by 2050. Thus, net zero carbon buildings should become standard business practice as soon as possible to avoid the need for future major retrofits; and prevent the lock-in of carbon emitting systems for decades to come (WorldGBC, 2017).

To achieve achieve the EU's 2020 Targets, and the objectives set by the Low Carbon Economy Roadmap 2050, the European Union deliberated the EU Directive Energy Performance of Buildings (EPBD) that recommends implementing strategies for achieving Nearly Zero Energy Buildings (NZEBs). NZEBs address the responsiveness towards the intermittent availability of renewables while still providing healthy and comfortable living conditions by minimising their energy demand through efficient building envelopes and systems. The Intergovernmental Panel on Climate Change 5th assessment report singled out the Passive House Standard as one of the key climate change mitigation options for buildings (Lucon, 2014). That standard is already a mandatory requirement for some international city councils (e.g. Dún Laoghaire-Rathdown County Council in Ireland, Bruxelles in Belgium, Luxemburg, Nuremberg in Germany) and is fostered and supported by local authorities and financing groups worldwide (e.g. Austria, Belgium, Canada, Germany, Ireland, Italy, Norway, Spain, U.S.A.) (iPHA, 2018; Passive House+, 2016; Lucon, et al., 2014).

In 2006 the New Zealand Ministry of Social Development suggested that the low values for New Zealand residential energy use reflects low levels of space heating. Houses in New Zealand are “energy efficient” in the respect that they use little energy, but are poorly heated (Lloyd, 2006). However, NZ building electricity use per capita increased by 120% within the period 2000-2012, the highest increase rate among the 2014 G20 members (OECD/IEA and IPEEC, 2015).

Despite this energy demand increase, research found that low-income homes in New Zealand were colder than WHO guidelines: with 16–17°C in living areas and 14°C in bedrooms on average (EHINZ, 2018a, Braubach, et al., 2006), suggesting minimal space heating compared to other developed countries. In addition, EHINZ (2018b) suggests that in 2013, 44,800 (3%) households did not have a source of home heating, which is an increasing percentage compared to 2006. Furthermore BRANZ 5th House Condition Survey highlighted that 46% of New Zealand households do not heat bedrooms in winter and that without such heat, it is unlikely that indoor temperature would always achieve the World Health Organisation (WHO) minimum recommended level (BRANZ, 2018).

This effects fir NZ houses have a range of causes, including lack of regulation, user behaviour, fuel poverty in relation to both financial situation and building envelope, and/or building system energy efficiency. Due to the high social costs of living below WHO levels, space heating behaviour should be expected to change in the foreseeable future.

According to UNICEF New Zealand (2018) "The poor standard of New Zealand housing exists largely because of a lack of regulation around acceptable housing standards. The cost to the New Zealand healthcare system, as a result of kids living in unhealthy homes, is immense. Over 40,000 New Zealand children are admitted to hospital every year due to income poverty and inadequate housing, and the cost of this hospitalisation to the tax system is around $1,500 per patient, per day. When these children go back home to the same cold houses, they get sick over and over again, the cycle repeats itself." (UNICEF New Zealand, 2018).

An example of the implementation of NZEBs in New Zealand derives from the Certified Passive Houses that have been designed, built and certified under the international Passive House Standard.

Achieving the Passive House standard currently incurs significant additional expenditure in New Zealand due to an immature market for highly energy-efficient building components. Following the standard requirements while targeting a less-stringent energy requirement threshold (e.g. doubling the primary energy demand target) will make compliance achievable with minimal additional cost under careful planning, while the benefits outlined in the health and comfort sections are achievable with manageable operating cost. The primary energy renewable (PER) threshold is the amount of renewable energy that needs to be generated to operate a building throughout the year. To achieve the threshold with renewable energy alone, it is necessary to holistically optimise the use of renewable energy in the operation of buildings. This takes account of the synchronicity of renewable energy generation and consumption demand at the location. For example, the summer cooling in New Zealand has a lesser PER factor than heating in winter, as peak photovoltaic generation coincides with peak heating demand – but not with peak cooling demand.

Recommendations

As a result of the discussions between the project team and PHINZ, Table 1 gives the target performance for each key parameter. Suggested procedures for measuring outcomes are recommended for achieving the goal of healthier, more comfortable homes with lower operating and maintenance costs.

Table 1. Recommended Key Parameters and their target performance for NZ houses

Indoor Air temperature

Minimum air temperature: Houses can maintain a minimum air temperature of 20°C at a height of 1.1 m in all rooms throughout the year while the design energy requirement is met. This does not require the houses to be heated to this temperature.

Measuring outcomes

- off-site assessment: PHPP modelling;
- on-site measurement: inexpensive data logger, such as i-button at 0.1 m and 1.1 m in representative rooms (away from heat sources or solar impact) during the heating season.

Maximum air temperature: Houses maintain a maximum air temperature of 25°C at a height of 1.1 m in all rooms 90% of the year (7884 hours) while the design energy requirement is met.

Measuring outcomes

- off-site assessment: PHPP modelling;
- on-site measurement: inexpensive data logger, such as i-button at 1.1 m in representative rooms (away from heat sources or solar impact) from October to April.

Indoor Air Relative Humidity:

Indoor air relative humidity of representative rooms (e.g. kitchen, bathroom and bedrooms) stays within a range of 30-65% for 90% of the year (7884 hours).

Measuring outcomes

- on-site measurement: inexpensive data logger, such as for example “i-button”, in representative rooms (away from heat sources or solar impact) throughout the year.

Indoor Surface Temperature:

Floors surface temperature: The interior surface temperature of floors 1 m inwards from a wall does not drop below 19°C during typical usage. This is of particular importance to the health of infants who play on the floor.

Measuring outcomes:

- off-site assessment: 2-D modelling using actual construction, design outdoor temperature for the location and 20°C indoor air temperature;
- on-site measurement: spot tests with infrared-thermometer.

Other surfaces temperature: The interior surface temperature of outdoor facing walls, windows, doors and roofs does not drop below 17.8°C during typical usage. This is to avoid stratification and temperature asymmetries that are perceived as draught, and impact on thermal comfort; they can also make parts of the house (e.g. the space in front of a window) unusable during cold periods.

Measuring outcomes:

- off-site assessment: PHPP modelling using actual construction, design outdoor temperature for the location and 22°C indoor air temperature;
- on-site measurement: spot tests with infrared-thermometer mid-winter.

Moisture:

Indoor surface moisture: Surface temperatures everywhere are high enough to prevent high water activity (A_w) and material dampness leading to mould growth on surfaces and material decay.

Measuring outcomes:

- off-site assessment: modelling of surfaces with PHPP or WUFI Pro® and WUFI Bio® ; additionally, 2D modelling for corners, using actual construction, design outdoor temperature for the location, 20°C indoor air temperature at 65% relative humidity, and increased interior surface resistance to account for curtains, furniture etc.;
- on-site measurement: spot tests with infrared-thermometer.

Interstitial moisture: Interstitial moisture build-up and mould growth is prevented.

Measuring outcomes:

- off-site assessment: Design for airtightness performance and verify that the design achieves a continuous uninterrupted airtight building envelope; WUFI® optional;
- on-site measurement: blower-door test results of either qe50 ($m^3/(hm^2)$) or n50 (h-1) of less than 1, measured to AS/NZ ISO 9972:2015

Indoor Air Quality (Concentrations of gaseous air pollutants):

Carbon dioxide (CO_2) concentrations are used as a proxy for concentrations of gaseous air pollutants. At a height of 1.1 m in the living room and 0.3-0.5 m in bedrooms (breathing zone), CO_2-concentration does not exceed 1,000 ppm 90% of the year (7884 hours), and never exceeds 1,500 ppm.

Measuring outcomes:

- off-site assessment: modelling to demonstrate that 30 m^3 per person per hour of fresh, outdoor air can continuously be provided to living and bedrooms whenever these are occupied, and that a corresponding amount of stale air is continuously extracted from kitchen and bathrooms;
- on-site measurement: logging of CO_2 concentrations for one winter week in living and bedrooms at appropriate heights.

Energy-efficiency:

Heating energy demand: The energy demand for heating to achieve the health and comfort outcomes above must not exceed 30 kWh/(m^2a) where the ‘a’ denotes per annum (year).

Operational primary energy demand: The overall primary energy renewable requirement for the operation of the building (including all services, lights, appliances) must not exceed 75 kWh/(m^2a).

Measuring outcomes:

- off-site assessment: PHPP model;
- on-site: log of non-grid energy use (e.g. wood, bottled gas, PV), invoices for grid connected power use (consumption normalised by degree day data)

Acknowledgements

The Toitū te Kainga, Toitū te Ora, Toitū te Tangata project team acknowledges the Passive House Institute New Zealand (PHINZ) for their in-kind contribution to this report and for funding the contribution of PHINZ Board member Dr Kara Rosemeier. The project team thanks Dr Rosemeier for her expert advice, guidance and support in the development and writing of this report.

http://www.euro.who.int/__data/assets/pdf_file/0003/142077/e95004.pdf

Appendix 5: About PHINZ

The Passive House Institute New Zealand is an Incorporated Charitable Trust with the following aims to benefit the community by improving public health and well-being and relieving fuel poverty of the people of New Zealand through the promotion of healthy and highly energy efficient homes and public buildings; and by working with the public sector of New Zealand to improve the energy efficiency of New Zealand homes and public buildings.

PHINZ aims also to advance education of the building industry and members of the public about improved energy efficiency in New Zealand buildings. This by providing a platform for the building sector to gain knowledge of highly energy efficient buildings; educating building professionals and lay persons about Certified Passive Houses; promoting the Passive House Standard in New Zealand; Researching the performance of built Certified Passive Houses in New Zealand and making such research publicly available; and Researching the New Zealand housing industry in general and the New Zealand climate and making such research publicly available to promote energy efficient building options.

Information about PHINZ, members and activities are available at

PASSIVEHOUSEINSTITUTE
NEW ZEALAND

http://passivehouse.nz/

Everything you always wanted to know about Passive Houses in New Zealand

The new brochure “Everything you always wanted to know about Passive Houses in New Zealand” can be downloaded at: http://phinz.org.nz/wp-content/uploads/2017/03/PHINZ-Brochure-March17.pdf

About the Passive House Standard

Adapted from passivehouse.com:

The international Passive House Standard is a building standard that has been developed by the Passive House Institute (PHI), an independent research institute. The Passive House Standard is the only internationally recognised, performance-based energy standard in construction that allows for the delivery of energy efficient, comfortable and affordable buildings.

The Passive House concept is based on the goal of reducing heat losses to an absolute minimum, thus rendering large heating systems unnecessary. With peak heating loads below 10 W per square meter of living area, the low remaining heat demand can be delivered by making efficient use of the sun, internal heat sources and heat recovery, rendering conventional heating systems unnecessary throughout even the coldest of winters. During warmer months, Passive Houses make use of passive cooling techniques such as strategic shading to keep comfortably cool.

Passive Houses are praised for the high level of comfort they offer. Internal surface temperatures vary little from indoor air temperatures, even in the face of extreme outdoor temperatures.

While the Passive House concept and principles remain the same across the world since the fundamental physics laws related to building performance are universally valid, the design and construction details will adapt according to the local climate and specific site conditions. For this reason, buildings fulfilling the Passive House Standard are very diverse in different climate conditions.

Information about the international Passive House Standard can be retrieved at

Passive House
Institute

Passipedia PASSIPEDIA
The Passive House Resource

https://passivehouse.com/index.html https://passipedia.org/