Living House – CLT Affordable, fast to build and Carbon Zero House

Richard Naish

ABSTRACT: The scope of the project was to develop an affordable 3-bedroom house that could be built in 6 weeks and achieve negative carbon whole of life certification. The proposal develops a 36 CLT panel 'flat pack' mass timber house that has been optimized to become an ultra-low labour, fast to build house. The average New Zealand traditional timber frame house cost is 40% labour, 60% materials, Living House accounts for only 10% labour. The average cost of a government built 3 bedroom house in NZ is $585,000 NZD, Living House is $335,000 NZD. In April 2025 we completed building a prototype house in Rotorua, NZ. It was proven that it could be completed in just 31 days for $335,000 NZD and has been certified negative 140 kgCO_2e per m2.

KEYWORDS: CLT, Carbon Zero, Affordable, House

1 – INTRODUCTION

There are currently 21,000 people on the NZ emergency housing register. Over 2000 children wake up every morning in in some kind of emergency housing accommodation. There are a record number of people sleeping in cars while waiting for some form of emergency accommodation. The current average cost for a government built 3-bedroom house is $585,000 NZD, excluding land. The Living House project started as a reaction to these statistics.

Figure 1. Living House Prototype, Rotorua, NZ

2 – BACKGROUND

The NZ construction industry has been building houses out of stick timber and linings for almost 200 years with little innovation and limited adoption of innovative practices. So, this project started as a research project within RTA Studio's in-house design lab. We have taken the single unit 3-bedroom house and undertaken a complete rethink of how a house can be built in the 21st century utilizing the most innovative materials and practices.

3 – PROJECT DESCRIPTION

The house is 86m2 with three bedrooms, a combined bathroom / laundry and an open plan living, dining and kitchen. It is constructed of 36 pre-cut Cross Laminated Timber (CLT) mass timber panels forming the roof, walls and floor. These are wrapped in PIR insulation and corrugated metal cladding. Fig.1.

There are no internal linings, all electrical and plumbing fittings and reticulation is designed to be fitted with minimal labour. The house is founded on timber driven piles using no concrete, creating a suspended floor. There is a heat-pump driven HWC and air-conditioning systems powered by a PV solar array and inverter system.

[1] Author - Richard Naish, Director, RTA Studio, Auckland, New Zealand, rich@rtastudio.co.nz

https://doi.org/10.52202/080513-0490

4 – RESEARCH PROCESS

4.1 UNDERSTANDING THE CHALLENGES

Housing affordability in NZ is becoming increasingly challenging. In 2024, house price to income ratio in NZ was the seventh highest in the world with the average mortgage payment representing almost half of income.

From the outset, it was determined that there are a limited number of ways to dramatically reduce the cost of building a house in NZ. This project could not expect to alter land/infrastructure costs or taxes. The cost of materials in NZ is disproportionality high largely due to its remote geography.

Though the NZ construction industry is heavily reliant on imports, the forestry industry contributes significantly to the national economy. Radiata pine (Pinus Radiata) makes up 90% of the planted forest estate [1].

RTA Studio have championed the use of mass timber construction in NZ. Award winning commercial projects Te Whare Nui o Tuteata (completed), Fisher & Paykel Appliances HOME Building (under construction) both feature LVL diagrid and CLT slab structure. Prior to this project, RTA Studio were yet to complete a mass timber residential project.

The design process began with a comprehensive research period to arrive at the optimal combination of structure and envelope to allow a fast build. Cost-benefit analysis was carried out in-house to understand the comparative cost of traditional timber frame construction, against CLT. A test area of a house was modelled to compare cost ($NZD/m2) and potential biogenic carbon (kg/CO2e/m2). The CLT model contained three times more timber volume than a timber frame version and the CLT was found to be more than four times as expensive.

Further analysis identified that of a typical NZ house costing $558,000 NZD, the cost of labour accounts for approximately 40%. Fig.2.

This presented the first design challenge, how could re-thinking traditional NZ construction reduce the labour component of a build?

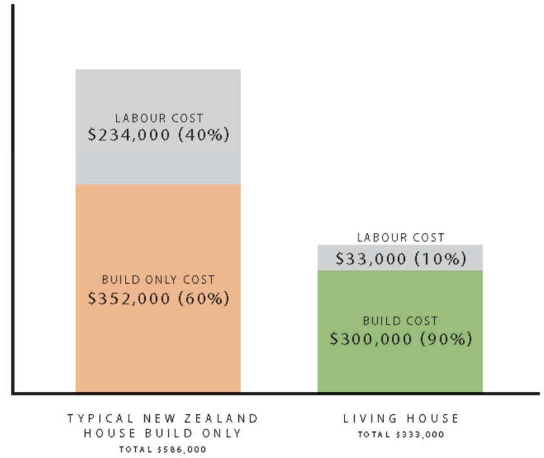


Figure 2. Designing out labour costs

4.2 PROOF OF CONCEPT

The construction methodology would need to be replicated around the country; this meant a reliance on utilising the skills of the existing workforce rather than construction companies specialising in mass timber.

Often new thinking and technologies are considered a risk which in turn, adds cost. We needed to not only design an affordable house but also build one. The decision was made to build a prototype as proof of concept. Thus showing the construction industry, government agencies and those looking to get on the property ladder that a sustainable home could be affordable.

While the overall goal was to have many homes built around the country, by building a prototype to test affordability, it was not possible to rely on economies of scale to reduce cost. Similarly, while many countries have factories producing pre-fabricated building elements to reduce labour costs- those are not available at scale in NZ.

4.3 MARKET PRECONCEPTIONS

Statistics show Gross Floor Area (GFA) of new houses has been trending downward in recent years [2]. This has largely been driven by the increase in multi-unit housing. Ten years ago, more homes were being consented with a floor area above 200m2 than below. This has shifted in recent years, with more homes being consented with a floor area below 200m2.

https://doi.org/10.52202/080513-0490

New multi-unit homes have exceeded new standalone houses since 2022 indicating that the housing market has become more accepting of homes with a compact footprint.

This presented another opportunity, how can a three bedroom, one bathroom home be reduced in size to provide no more than is necessary. We asked a fundamental question- what is essential for a house to live in? The Living House sought to provide an answer.

4.4 ENVIRONMENTAL RESPONSIBILITY

RTA recognise that with the NZ Construction industry contributes 20% of total greenhouses gas emissions in NZ. We have a responsibility to design every building to be as sustainable as possible within the design parameters. In this instance, we were not designing for a client – so it was clear that the goal for the project should be a certified carbon zero home.

RTA's experience from the commercial sector has proven that mass timber can be achieved at a comparative cost against traditional concrete and steel structures. Key to this success was a high degree of repetition of structural elements.

To mitigate the comparatively high cost of CLT, the Living House also needed to not only a high degree of repetition in the structure but in all other materials. The design team considered every material selection to ensure it was entirely appropriate.

The design was developed through a process of optimisation, aiming to minimise materials, fittings and labour. The plan area, volume and surface area have been optimised to reduce material volume while maximizing space, natural light and ventilation for best practice healthy home design.

5 – DESIGN PROCESS

5.1 DESIGN AS PRODUCT

The RTA team described the goal as providing an efficiently repeatable house as 'Product'. The starting point was that product needed to be absolutely fit for purpose in every respect whilst stripping out anything non-essential. Internally dubbed as the 'Toyota Corolla of houses', each space was refined to be no larger than absolutely necessary.

By maximising the ceiling height with a gable form roof, it was possible to make each space feel much larger than its footprint. The floor plan references traditional Pasifika living arrangements ensuring it provides culturally appropriate housing. Fig.3

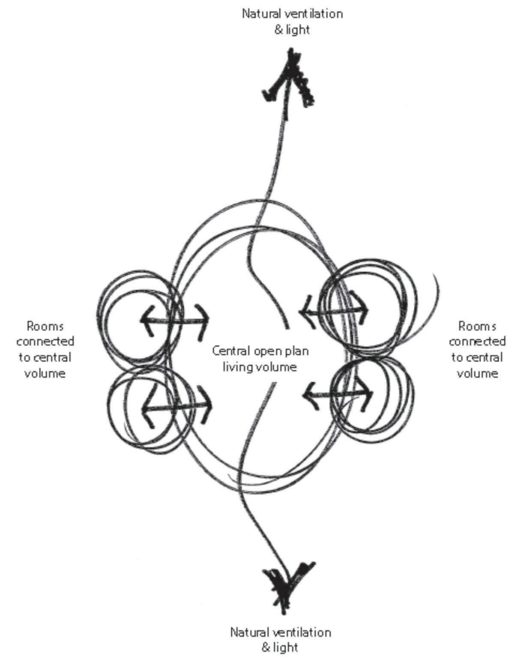


Figure 3. Adjacencies diagram.

The simple gable form and large volume references both traditional Maori Whare and the modern-day NZ vernacular. Fig.4

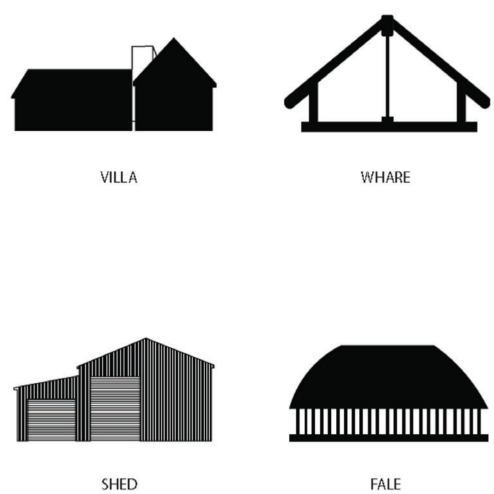


Figure 4. New Zealand and Pasifika references.

This plan in combination with the high ceilings and placement of openings in the façade also promotes natural ventilation.

5.2 FLEXIBILITY

The single-house typology is not suited to dense urban areas however the Living House offers a single-house solution for suburban settings, infill to subdivided sections or remote rural locations. Equally, the Living House is well suited to co-housing. Social housing trusts and multi-house community trusts have shown interest in the co-housing model, noting the opportunity for multi-generational living. The floor plan is designed for maximum flexibility. The three bedrooms have identical dimensions, storage and amenities. Each of these rooms could be suited to a couple, a child, an elder family member or a work-from-home office.

5.3 OFF-SITE OPTIMISATION

The house mirrors in plan with the CLT panels repeating to ensure CNC time off-site is reduced and wastage minimised. The house is made up of 36 CLT panels with a high degree of repetition. Fig.5

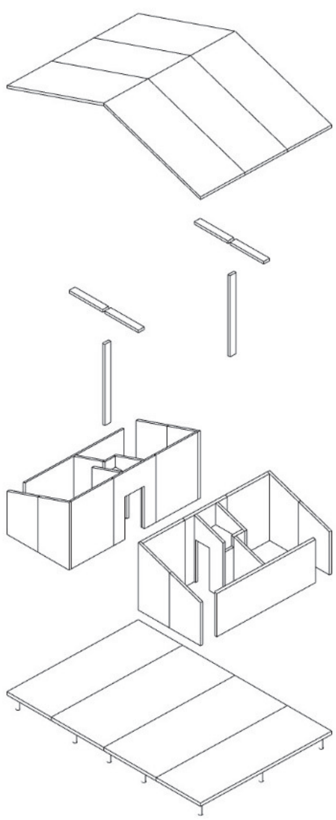


Figure 5. CLT panel axonometric

Figure 6. Interior volume

5.4 REDUCING ON-SITE LABOUR

To remove labour costs, the house has been designed with no internal wall or ceiling linings. This has been achieved by exposing services throughout. Fig.6

Plumbing, electrical outlets and lighting are surface-mounted reducing the necessity for the traditional first-fix, second-fix by sub trades. This removed the associated inefficiency of coordination with other building trades. Services then reticulate horizontally under the floor slab, allowing easy installation and a high degree of future proofing.

There is an inherent honesty in the simplicity of the design. The structure is expressed in its purest form throughout the interior with timber being the hero. The legibility of the design is easy to understand with the CLT lamellas on show and visible screws.

Much like a Tesla or iPhone, personalisation is limited to selection of five colourways for the exterior cladding (all standard NZ stock). Every other detail in the house, including a plug-in Kitchen and a Laundry designed in collaboration with Fisher & Paykel Appliances is identical for each house.

A rigorous approach was applied to all material and product selections to find a balance between budget and sustainability.

To simplify the build process, each component part of the house has been added to a schedule. Based on the structural engineer's specification, the schedule shows 1928 screws (all readily available on the market). An alternative schedule is also provided to the builder in the event that a particular screw type is out of stock.

https://doi.org/10.52202/080513-0490

This detailed knowledge of the componentry that makes up the house simplifies the ordering process for the builder, aiding cost-control and reducing wastage.

This approach was applied to all material and product selections. By specifying these pre-determined elements, the builder would, for example, know to the millimetre what lengths of conduit would be required.

The elevations are also mirrored allowing the repetition of elements to include windows, doors, downpipes and flashings, cladding and insulation panels. Four identical operable windows, four identical ranch slider doors and the clerestory windows are also mirrored at either end of the house.

Following analysis against timber joinery, aluminium joinery was selected with thermally broken profiles and a naturally automated trickle ventilator which opens and closes in response to external air temperatures. Aluminium joinery reduced the need for maintenance. The manufacturer, APL, recycles 99% of waste aluminium at a NZ smelter.

The solid timber walls and floors are robust to the wear and tear that could be expected of social housing or workers accommodation on a dairy farm. Fig.7

Figure 7. Exposed timber structure and services

5.5 FIT FOR PURPOSE

Using experience from RTA's high-end residential, large-scale commercial and cost-efficient education projects, product selections needed to meet the following criteria;

- Low-embodied carbon
- Recyclable materials
- Cost effective
- Durable, minimal maintenance requirements
- Readily available in NZ

Wherever possible, materials serve a dual-purpose. The CLT structure doubles as useful thermal mass but careful consideration was also given to shading, passive ventilation and the specification of mechanical cooling. The living area opens out onto an external 12m2 timber deck with and a fully covered roof, featuring operable aluminium louvres. Both items are included in the costing so each Living House has a covered outdoor space that can be adapted to different weather conditions. Shading studies showed the external louvre roof also serves as an operable shading device to the living room. In summer, the external louvres can protect the living room from direct solar gain while the clerestory windows still offer natural light deep into the plan.

5.6 NON-SITE SPECIFIC

In contrast to all other buildings designed by RTA Studio, the Living House was designed to be entirely non-site specific. The intention for the Living House was that the exact house design and specification is to be used anywhere in the country.

As such, the Living House has been designed for the worst-case environmental constraints; wind zone, corrosion and climate. The structure has been designed for the majority of seismic conditions in NZ (Zones 1, 2 & 3). Specific engineering would be required for a Living House situated in seismic Zone 4 (approximately 10% of land mass).

With all sites presenting unique topographic and geological conditions, it was decided that the design would suit pile foundations. Timber driven piles were used for the prototype house. It was therefore possible to produce a house using no concrete, the only steel elements are the structural screws.

Fisher & Paykel Home Solutions carried out thermal analysis for various NZ climate zones to ensure the mechanical heating/cooling was suitable for all scenarios. They also tested multiple photovoltaic arrangements to ensure the optimal layout, taking into account that the house could have any solar orientation.

It is to be expected that the house orientation will vary due to other opportunities and constraints such as views and privacy. With such an efficient thermal envelope, F&P Home Solutions also analysed cooling load to ensure the house would not overheat.

https://doi.org/10.52202/080513-0490

6 – STRUCTURAL DESIGN

6.1 EXPRESSING STRUCTURE

CLT construction of homes is not common in New Zealand so it was important that the average residential builder would be able to quickly and safely erect the panels with no specialist training. The assembly process has been optimised to dramatically reduce labour hours. Panels have been engineered to use either butt or lap joins, screw fixed together with no complicated CNC milled joints or complex bracketry. Fig.8

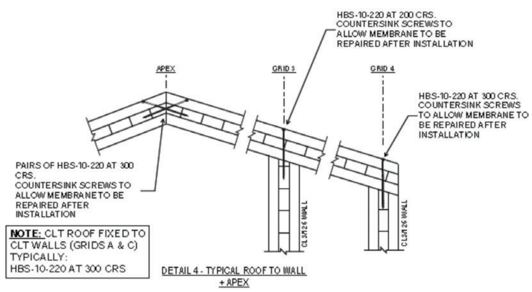


Figure 8.. Simple CLT fixing details

Dunning Thornton Consultants engineered a series of panels using only 126mm thick CLT for both the roof and walls, floor panels are all 166mm CLT. Parameters imposed on the design included CLT panels that could be laid on a single flat-bed truck and be no wider than New Zealand Transport Authority rules for transport without the use of a pilot vehicle: Fig. 9

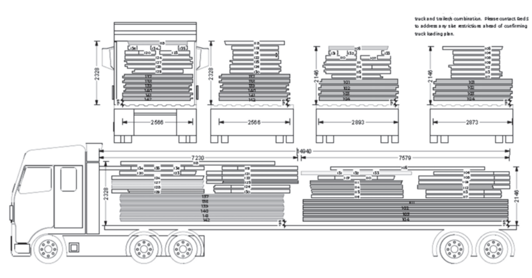


Figure 9. Single-truck loading diagram for CLT panels.

Panel sizes have also been limited by weight such that they can all be lifted by a truck mounted HIAB crane parked in a single location.

All lifting eyes to CLT panels are non-visual within the finished house to the top edge of wall panels. Thoughtful sequencing enables the structural panels to prop one another during the erection sequence. Fig.10

Figure 10. Simple CLT junctions

The only temporary propping required is designed to use basic lightweight ‘chippy stick’ builders props which can be readily hired at low cost.

6.2 CLIMATE RESILIANCE

Using a suspended CLT slab on pile foundations makes the house resilient to potential flood damage and rising sea levels. In recent memory, flooding and earthquakes have contributed to dramatic accommodation shortages in NZ. The rapid build-time using readily available materials makes the Living House an appropriate housing solution for natural-disaster relief.

6.3 HIGH PERFORMING ENVELOPE

Timber framed buildings make up more than 90% of houses in NZ. The main drawback inherent in traditional timber framed building relates to the location of flexible glass wool insulation infilled between the sticks of timber. [3] BRANZ research also shows that insulation typically accounts for only 66% of a timber framed wall. With the insulation layer non-continuous, the timber frame then acts as a cold bridge compromising thermal performance and increasing the risk of interstitial condensation.

https://doi.org/10.52202/080513-0490

The Living House addresses this shortcoming by wrapping the entire CLT structure with a layer of high-performing PIR insulation. The combination of the continuous insulation and thermally broken joinery allows the window to wall ratio to be increased while maintaining a highly insulated internal environment.

The use of consistent rigid PIR insulation rather than flexible glass wool products allows for a simple taping process to give a high-degree of airtightness. This decision alone serves to reduce the operational heating/cooling load.

Working with Fisher & Paykel Home Solutions, the energy and water systems have been selected to reduce energy use and enable excess renewable energy to be supplied back to the national grid.

7 – RESULTS

7.1 AFFORDABLE

A prototype house has now been built, April 2025 in Rotorua, NZ. The house was successfully completed within 31 days.

This construction included running all site services, driving piles, erection of CLT panels, insulation, building wrap, cladding, glazing, roofing, electrical and plumbing fit-out, floor coverings and kitchen and laundry (including appliances).

The construction cost was $335,000 NZD (including GST), not including site-specific items such as the driveway, fences, foundations and site infrastructure (additional $40,000 NZD).

7.2 HEALTHY

A warm, well-ventilated home has proven health benefits for the homeowner's wellbeing [4]. Housing and Health Group, a research collaboration based at the Wellington School of Medicine, have found that when a house is made warmer and drier, the health of occupants improves.

Doing away with the chemicals, dust and wastage associated with plasterboard stopping and painting, exposed timber walls are more durable and give a feeling of warmth. The positive effect of timbers biophilic properties are harder to quantify but humans have a deep-rooted connection to nature.

Timber living and working environments promote wellness, research showing commonly evoked descriptors for 'wood rooms' include "warm," "comfortable," "relaxing," "natural," and "inviting." [5] Fig.11

The timber brings a sense of joy to the home. Anecdotal evidence from those visiting the prototype house has been overwhelmingly positive. People note that the volume of the spaces makes the house feel significantly larger than the GFA suggests. The exposed structural timber evokes a character that is missing from typical plasterboard linings. It also mitigates the negative impact on air quality from VOC emissions associated with paint.

Figure 11. The warmth of Timber

Beyond the home itself, there are social and economic benefits of building this way. Economically disadvantaged groups in society are often disproportionately affected by respiratory and circulatory issues caused by poorly insulated housing. It is more cost effective to have healthy homes than the downstream costs to the public health system [6].

On completion, a member of staff from RTA Studio spent a short period living in the prototype house to identify potential refinements that could be made to the design.

https://doi.org/10.52202/080513-0490

7.3 TRANSPARENCY

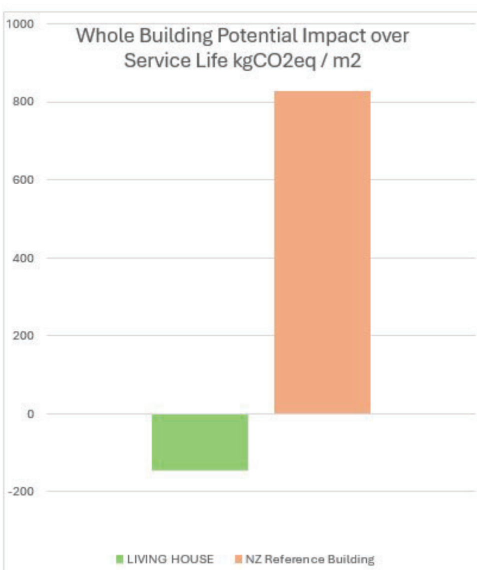
The prototype has been built by a typical small-scale residential builder who had never built with CLT panels before, testing the simplicity of the build methodology.

The business model is for the sale of documents only with pre-consented plans, specifications, supply agreements and assembly handbook such that any customer can purchase and build with any qualified building practitioner.

The prototype build has been recorded and documented to identify further efficiencies in the construction process. A time-lapse video of the construction and full breakdown of all costs has been published on the Living House website giving full transparency to prospective owners and builders.

7.4 SUSTAINABILITY

The Lever Room, a leading science-based consulting and technology company comprehensively measured embodied and operational carbon emissions for the Living House. Their analysis certified that the Living House draws down more carbon than it emits. This compares favourably to an average NZ Reference Building with the same GFA. Fig. 12



Whole Building Potential Impact over Service Life per m2

-140 kgCO2eq / m2	Living House
826 kgCO2eq / m2	NZ Reference Building

Figure 12. Whole of life GWP: Living House vs. Reference Building

Figure 13. Photovoltaic array to Living House roof

The Living House results in a net negative carbon balance of -12,056 kgCO_2e, meaning the CO_2e the building stores in its materials, and saves through exports of clean energy to the grid, is more than it emits across its lifecycle. The life cycle analysis was carried out for 50 years (industry standard) however the selection of durable, low-maintenance materials and products ensures this lifespan would be exceeded.

Though the photovoltaic panels have associated embodied carbon emissions from manufacturing, installation, and eventual replacement after 30 years; the combined benefits of material sequestration and renewable energy generation more than offset these impacts, making the Living House climate positive overall.

The thermally efficient envelope has dual advantages of reducing heating bills for the homeowner and less operational carbon emissions. Along with the PV payback, the contribution to the circular economy is built into each Living House lifecycle. Fig.13

https://doi.org/10.52202/080513-0490

8 – CONCLUSION

This project has successfully proven a new concept for small footprint, fast-to-build, affordable houses. The build cost, almost half that of the government built equivalent, is negative carbon embodied and operational over a 50 year whole of life analysis. It has innovated a simple to use CLT construction methodology as a superior alternative to last century's stick timber construction.

There is a common theory that sustainable buildings are more expensive, with items like solar panels considered a 'nice to have'. The Living House goes a step further proving that an architecturally designed, affordable home can be certified carbon negative.

We acknowledge that Living House does not provide a silver bullet to the challenges facing the housing shortage in NZ. However, the prototype shows that a small affordable home, can also be sustainable. The repeatability of elements that have made the prototype Living House a possibility, can be replicated over and over.

Dr Henri Bailleres, GM for Forests to Timber Products at Scion (Crown Research Institute for Timber) visited the prototype and calculated that under average growth conditions, the 35m3 volume of timber used in the Living House is grown by NZ forests in less than two minutes.

The Living House sequesters carbon, utilises sustainably grown NZ pine and slashes cost through labour reduction. It is a prototype for the future of single unit affordable houses not only in NZ but Australia and world-wide.

9 – REFERENCES

[1] New Zealand Ministry of Primary Industries data.

[2] Stats NZ Tatauranga Aotearoa, national data agency

[3] Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2021). "Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand". Final Report – Building Levy Project LR11092. Build Issue 182

[4] Malcolm Cunningham, BRANZ Principal Scientist. "Warm, dry houses are healthier." Build issue 156, (2018), pp. 59

[5] Rice, J., Kozak, R., Meitner, M., Cohen, D (2007). "Appearance wood products and psychological well-being" - Wood and Fiber Science issue 4.

[6] Dr Kate Bryson, BRANZ Senior Social Scientist. "Healthy homes, healthy people." Build issue 156, (2016), pp. 57

https://doi.org/10.52202/080513-0490