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A DIFFERENT SPIN ON INSULATION

Illustrated ideas on sustainable retrofitting in New Zealand

MASTER'S THESIS
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AFFIDAVIT

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THANKS TO
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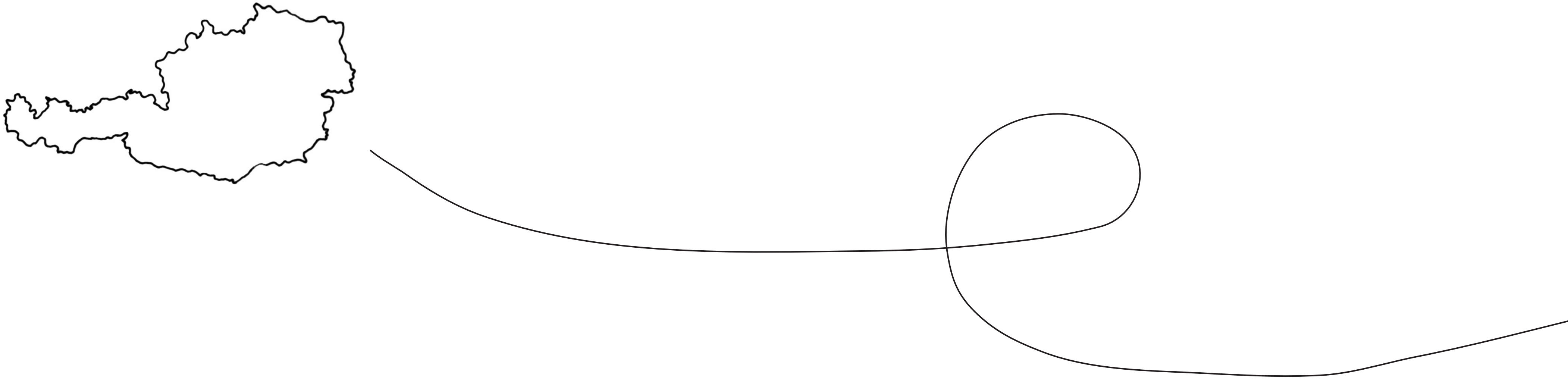
My partner Tom, my parents and friends for for patience and support.

My supervisors Petra and Ferdinand.

Everyone who generously shared their knowledge and ideas to make this thesis happen.



FOREWORD

This book aims to be a display of my work and experiences in New Zealand expressed, both in words and drawings.

A trip for the Research Abroad Program to work on my master thesis turned into a journey to the roots of sheep wool, sustainable building materials and beyond. The approach of my research was to learn from conversations with locals, books, and through my sketchbook. My stay was extended due to Covid19 travel restrictions and has led to an even deeper confrontation with the topic. Furthermore, I had the chance to meet many people involved either in the building or the sheep industry here in New Zealand and share my thoughts and vision with them.

Figure 1: Devon Street, New Plymouth © Artwork (Laura Feller. 2020a)

KURZFASSUNG

»Um eine gute Mahlzeit zubereiten
zu können braucht es zu allererst gute
Zutaten«

Die Bauindustrie trägt in großem Maße zum globalen Ausstoß von Treibhausgas-Emissionen (ca 40%) bei, welcher den Klimawandel stark vorantreiben. Folglich haben wir ArchitektenInnen damit in unserer täglichen Arbeit große Verantwortung, aber auch das Potenzial, schon bei der Planung auf einen möglichst geringen Endenergieverbrauch zu achten und jene Baustoffe und Konstruktionen auszuwählen, die möglichst wenig Herstellungsenergie („Graue Energie") benötigen. Somit können die CO2-Emissionen zukünftiger Gebäude stark reduziert oder sogar gänzlich vermieden werden. Die Verfügbarkeit von CO2-neutralen Baumaterialien und -lösungen ist jedoch noch oft begrenzt und unterscheidet sich von Land zu Land merklich. Als junge Architektin vertrete ich die Meinung, dass der gesamte Bausektor weltweit schnellstmöglich einen Wandel hin zu möglichst CO2-neutralem Bauen machen muss!

Auch in Neuseeland hat das klimagerechte Bauen große Priorität und es bedarf vielfältiger Lösungsansätze. Eine der landesspezifischen Herausforderungen stellen die - für mitteleuropäische Verhältnisse - recht einfach gebauten und damit oft „kalten" und „feuchten" Einfamilienhäuser und Wohnbauten dar.
Um hier die Wohnqualität zu verbessern und die Gebäude energie- und kosteneffizienter zu machen, braucht es weitreichende Renovierungsmaßnahmen - unter anderem in Form von thermischer Sanierung.

Damit steigert man die Behaglichkeit und spart Heizenergie. Aber um die Energie- und CO2-Einsparung ehrlich beurteilen zu können, muss man die Gesamtenergiebilanz über den Lebenszyklus des Gebäudes betrachten und auch die Herstellungsenergie („graue Energie") der Baumaterialien, sowie den Energieaufwand des Bauprozesses mit einbeziehen. Üblicherweise wird aber nur die mögliche Heizenergieeinsparung gesehen und die Gesamtbilanz ausser Acht gelassen! Gerade bei Dämmstoffen gibt es welche, die so viel Energie in der Herstellung verbrauchen, wie sie danach in ihrer durchschnittlichen Nutzungsdauer gerade wieder einsparen können - das bedeutet, dass es in manchen Fällen für die Umwelt keinerlei Verbesserung darstellt, ob man das Gebäude dämmt oder nicht!

Im Rahmen meiner Arbeit untersuche ich Schafwolle als Dämmmaterial, die über hervorragende Dämmeigenschaften verfügt, ohne dabei großen negativen Einfluss auf die Umwelt auszuüben. Schafwolle ist als eines der wenigen natürlichen Baumaterialien auch in Neuseeland bereits in Verwendung, im Vergleich zu gängigen Dämmmaterialien jedoch sehr limitiert. Rohe Schafwolle ist in Neuseeland als Nebenprodukt der Tierhaltung für Schaffleisch in großen Mengen verfügbar - die grobe Qualität ist aber nicht für die Textilindustrie geeignet und wird aktuell fast gänzlich exportiert. Nur ein geringer Teil davon wird innerhalb des Landes zu Dämmprodukten oder Teppichboden verarbeitet. Die Produkte sind derzeit auch vergleichsweise hochpreisig.

Meine Thesis untersucht, mit Hilfe von Informationen aus wissenschaftlichen Dokumenten, Studienreporten und Umweltdeklarationen, das Treibhausgaspotenzial (Global Warming Potential kurz GWP) und die Leistungsfähigkeit des Materials im Vergleich zu anderen gängigen Bauprodukten. Weiters werden, anhand einer Case Study, Konstruktionsdetails und Renovierungsmethoden aufgezeigt, welche beispielhaft zur Berechnung der gesamten CO2-Einsparungen von Häusern mit ähnlicher Bausubstanz in ganz Neuseeland herangezogen werden können. Außerdem wird die energetische Rücklaufzeit von Schafwolle im Vergleich zu anderen Dämmmaterialien, wie zum Beispiel Glaswolle, berechnet. Das Ergebnis zeigt, dass Schafwolldämmung alle Bauvorschriften erfüllt und in gewissen Bereichen sogar besser abschneidet als vergleichbare Dämmmaterialien. Gleichzeitig beträgt das GWP von Schafwolle nur ca. 20% von Mineralwolle, 18% von Polyesterfasern und 13% von EPS Dämmung. Neben den hervorragenden Dämmeigenschaften verfügen Schafwollfasern auch über eine einzigartige hygroskopische Eigenschaft, welche potenziell ideal für den Einsatz in Neuseelands älteren und feuchten Bauten wäre - spezielle Untersuchungen dazu sind aber noch dringend nötig.

Zusammenfassend bräuchte das Thema CO2-neutrales Bauen, vermehrte Aufmerksamkeit sowie weitergehende Forschungsarbeit, speziell auch zum Thema Schafwolle in Neuseeland. Oberstes Ziel des Bausektors muss es sein, Emissionen am Bausektor zukünftig in allen Bereichen weitestgehend zu vermindern, so dass unsere Gebäude nicht nur Menschen vor Umwelteinflüssen schützen sondern umgekehrt, diese auch zum Klimaschutz beitragen.

ABSTRACT

» To cook a good meal,
you first need good ingredients«

Global carbon emissions are a huge driver of climate change and the building industry contributes largely to that, therefore architects can play a key role in reducing these emissions from the start. However, access to low carbon building materials and solutions are still limited and vary notably from country to country. As a young architect, I advocate that the current mainstream practices which architects follow, along with the whole building sector, need an acceleration of change towards a zero-carbon built environment.

New Zealand has made its climate goals priority which includes the built environment. One issue that the country specifically deals with are large numbers of inefficient, cold, damp houses. Improvements require thermal retrofitting to make them more: comfortable, energy-efficient, and cost-effective. These improvements are important for reducing future emissions through energy loss. However, when looking at the whole life cycle of the building, it is also important to consider the embodied emissions within the materials and build process. Currently, this is either overlooked or made difficult due to the lack of access to environmentally sound materials ,such as insulation.

I propose using sheep wool as an excellent insulation material with a minor environmental impact that is readily available in large amounts within New Zealand. This study examines the Global Warming Potential (GWP) and building performance of sheep wool in comparison with other insulation materials using Information gathered from scientific papers, study reports, and environmental product declarations. Additionally, practical construction methods are proposed and presented as a case study which can be used as a model for calculating total carbon savings in similar New Zealand houses. It also highlights the different energy payback times of sheep wool compared to other insulation materials such as glass wool.

The results suggest that sheep wool insulation meets and exceeds building requirements and at the same time, its GWP is only about 20% of mineral wool. Furthermore, the GWP of sheep wool is only 18% of polyester fibre or 13% of expanded polystyrene insulation. However, current availability of sheep wool insulation in New Zealand is limited and the material is expensive due to low demand.

In addition to its insulation performance, sheep wool also presents unique hygroscopic properties which could potentially be ideal for resolving many of NZs older damp constructions.

When taking all of these findings into account I propose that more research and awareness into alternative low carbon materials, such as sheep wool is needed in order to reduce building emissions and have a greater impact on climate change.

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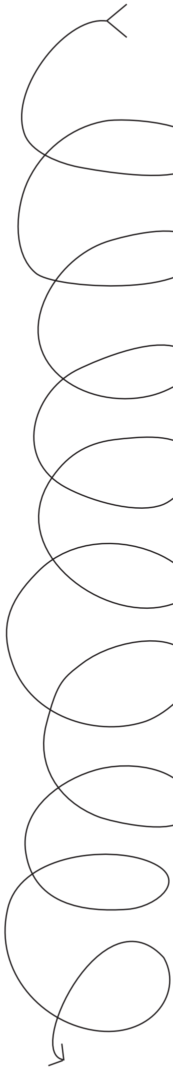

GLOSSARY & ABBREVIATIONS

CARBON [CO_2] “Carbon” generally is used to indicate all greenhouse gases, not just carbon dioxide (CO2). Sometimes other greenhouse gases are also related by the term CO2-equivalent emissions like methan (CH4), Nitrous oxide (N2O also known als laughing gas) or Sulfur hexafluoride (SF6).4 Their global warming potential (GWP) is quantified in units of carbon dioxide equivalence. A kilogram of carbon dioxide therefore has a GWP of 1 kgCO2e (WGBC.2019).

CARBON FOOTPRINT This term might be the most familiar one for a lot of people, however not used in the building sector a lot. Carbon footprint means embodied carbon, but rather related to a person than a building. It describes the carbon emissions caused directly and indirectly by a person, event or organisation.

CARBON HANDPRINT Unlike the carbon footprint it describes the positiv impact a institution, product or building has on the global emissions. Simply said, if your carbon balance is positive, you can give it away to others to achieve »net zero carbon« on a total scheme. Companies can for example handprint with large solar PV facilities by producing more renewable energy then they need (Stora Enso. 2018).

EMBODIED CARBON [EC] Carbon emissions associated with materials and construction processes throughout the whole life cycle of a building or infrastructure. Embodied carbon therefore includes: material extraction (module A1), transport to manufacturer (A2), manufacturing (A3), transport to site (A4), construction (A5), use phase (B1, eg concrete carbonation but excluding operational carbon), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5), deconstruction (C1), transport to end of life facilities (C2), processing (C3), disposal (C4). Benefits beyond the system boundary (D) should also be reported separately to modules A-C (WGBC.2019).

OPERATIONAL CARBON [OC] The emissions associated with energy used (B6) to operate the building or in the operation of infrastructure.

UPFRONT CARBON Carbon emissions released before the building or infrastructure begins to be used, sometimes called upfront carbon, will be responsible for half of the entire carbon footprint of new construction between now and 2050, threatening to consume a large part of our remaining carbon budget (WGBC.2019).

END OF LIFE CARBON The carbon emissions associated with deconstruction/demolition (C1), transport from site (C2), waste processing (C3) and disposal (C4) phases of a building or infrastructure’s life cycle which occur after its use.

NET CARBON ZERO This term implies that the total sum of emissions is zero. We will not extinguish all use of fossil fuels by 2050. Fortunately, there is ways to sequester carbon and get it out of our atmossphere. If the amount of stored carbon outweighs the total emissions or even exceeds them we have succesfully combated global warming.

GLOBAL WARMING POTENTIAL [GWP]

Greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming. The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years (EPA. n.d.).

WHOLE BUILDING LIFE-CYCLE ASSESSMENT [LCA]

Life cycle assessments calculate the potential enviromental impacts of materials, products and services across a defined life cycle. This process looks at multiple impacts, including the global warming potential, over the entire life cycle—from extraction and manufacturing through the landfill or recycling plant. Knowing about LCA and how it works can help designers and specifiers to select building products and services that have a lower environmental impact.

Software is designed to be used by building professionals and there is a range of products - from open source to established ones for example Tally (for Revit®), Athena Impact Estimator or One Click which also supports other CAD software like ArchiCad or SketchUp.

ENVIRONMENTAL PRODUCT DECLARATIONS [EPD]

This is an independently verified document that gives information about the life-cycle environmental impact of a product. It is defined by the ISO 14025 and officially registered to provide a transparent way to compare products for a project. Yet the availability of an EPD document, does not necessarily mean the product has a positive impact on the environment, there is no requirements of the performance of a product.

ABBREVIATIONS

EC..........Embodied Carbon
EPD.........Environmental Product Declaration
GWP........Global Warming Potential
LCA.........Life Cycle Assesment
NZ..........New Zealand
NZGBC.....New Zealand Green Building Council
OC.........Operational Carbon
WGBC......World Green Building Council

FIGURE 2: 'It is in our hands' © Artwork (Laura Feller. 2020b)

> ***"We must radically increase the pace and scope of decarbonisation efforts, collaborating across the whole construction value chain to achieve the scale of change needed."***
>
> (World Green Building Council. 2019: p. 9)

THIS IS NOT JUST
A MASTER THESIS.

THIS IS AN IMMEDIATE CALL FOR ACTION FOR ARCHITECTS AND EVERYONE INVOLVED WITH THE BUILDING SECTOR TO TACKLE CLIMATE CHANGE.

1 CONTENT

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1 ARCHITECTURE & GLOBAL WARMING = A WARNING

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FORM FOLLOWS FUTURE

This is an urgent call to educate all sectors on a low carbon built environment and create awareness amongst policymakers and investors. We must strive to create a public dialogue around overlooked fundamentals in the building industry. Knowledge is key and can create the overall movement we need.

Who is to make the transition to a 'new environmental era' if not the next generation? Architects Towards A Net Zero Carbon Built Environment could be the equivalent of the Fridays For Future movement for our sector.
Let's take action now!

»I believe future architects have to act as communicators enabling the right connections throughout the whole development.«

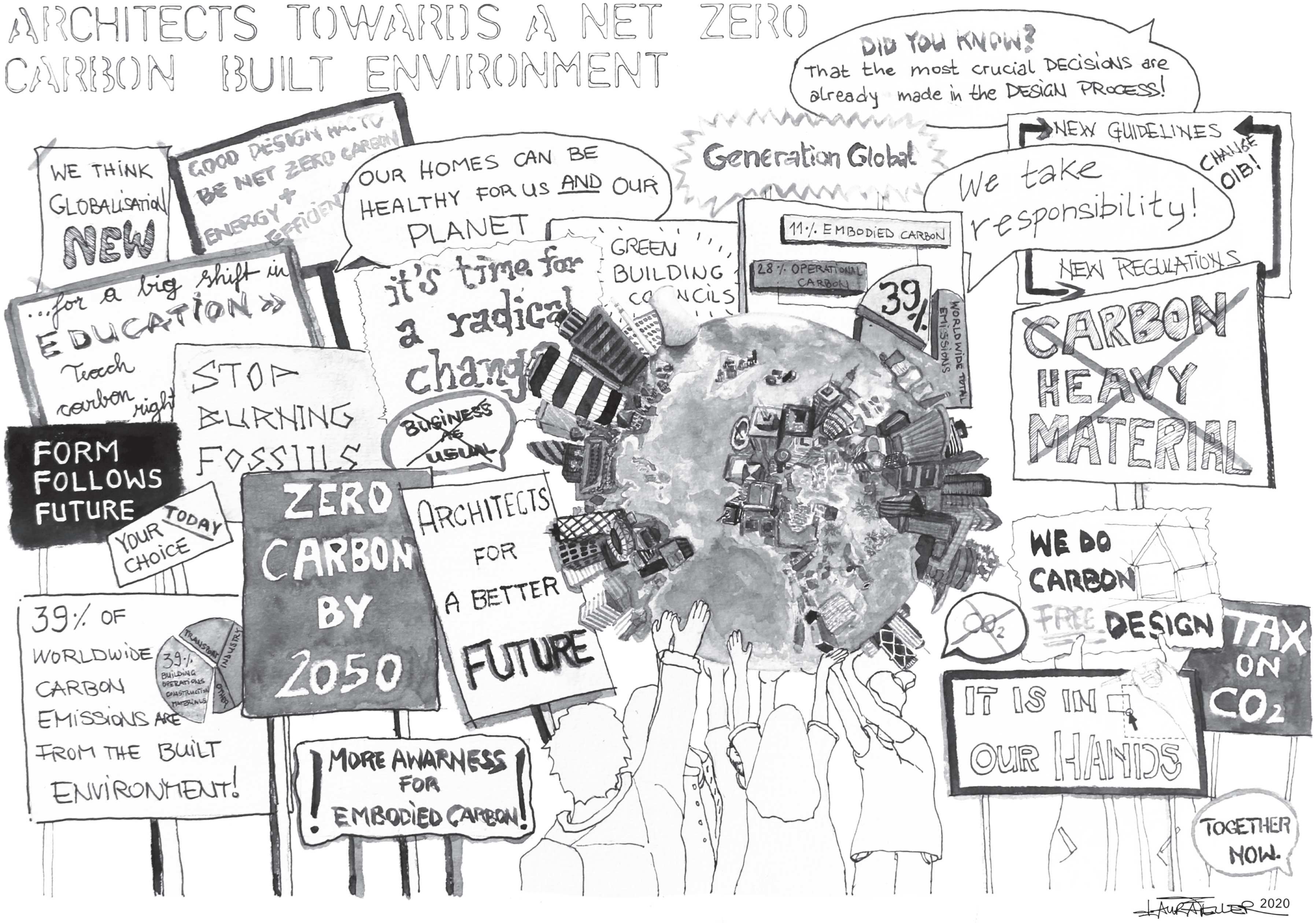


FIGURE 3: 'Architects For A Better Future' © Artwork (Laura Feller. 2020c)

1.1 MOTIVATION

Climate change is the biggest challenge of our time. Every country faces different challenges tackling global warming, but we share a common vision. In 2016 the United Nations Framework Convention on Climate Change (UNFCCC) conference took place where the Paris Agreement was signed and ratified by 189 parties. Its main goal is to keep the global temperature rise well below 2°C above pre-industrial levels with the ambitious pursue to limit it even to 1.5°C in this century (UNFCCC. 2020). To achieve this goal and secure a habitable earth, we have to cut our greenhouse gas emissions radically.

This, alongside with the fact of a fast-growing world population - which is expected to reach almost 10 billion by mid-century (United Nations. 2019: p 5) - and the rapid urbanization that comes with it, has to be great motivation to all of us.

» We can not longer do business as usual. It’s time for a radical change! «

1.2 ARCHITECTURES IMPACT ON CLIMATE CHANGE

Looking at the carbon footprint of the building sector we find that the percentage of global carbon emissions is 39%. That is the largest share and more than industry or transportation each. The emissions of the building industry come from 28% operational carbon, which is all the energy needed to heat, cool and power, and 11% of embodied carbon, emitted by materials, transport and construction.

This presents a huge opportunity to reduce greenhouse gas emissions within the building industry. All architects must accept the challenge and take on responsibility in their future projects. This task can broadly be divided into two parts:

A) Construct new buildings net carbon zero and plan to have houses with a large lifespan up to 120 years or longer.

B) Bring all existing buildings up to a state-of-the-art efficiency level and make their energy performance zero carbon.

An increasing population demands new buildings, thus makes part A fundamental. With our knowledge and technology today, it is achievable to build low-carbon and zero-carbon buildings and cities. Reducing their environmental impact, with factors such as a responsible choice of site, accessibility, smart orientation and efficient energy use as well as material decisions, is fairly easy. For new buildings the possibilities are countless. Even though it is not yet practised enough by architects, we experience a progressive change and increasing awareness.

Part B on the other hand, is taking care of existing buildings, because 90% of houses, we live in now, will still be occupied in 2050. These houses need our attention and have to be renovated to meet current standards, while only releasing minimal carbon emissions. This thesis is going to discuss methods to achieve these goals for existing houses and specifically give examples for retrofitting buildings in New Zealand.

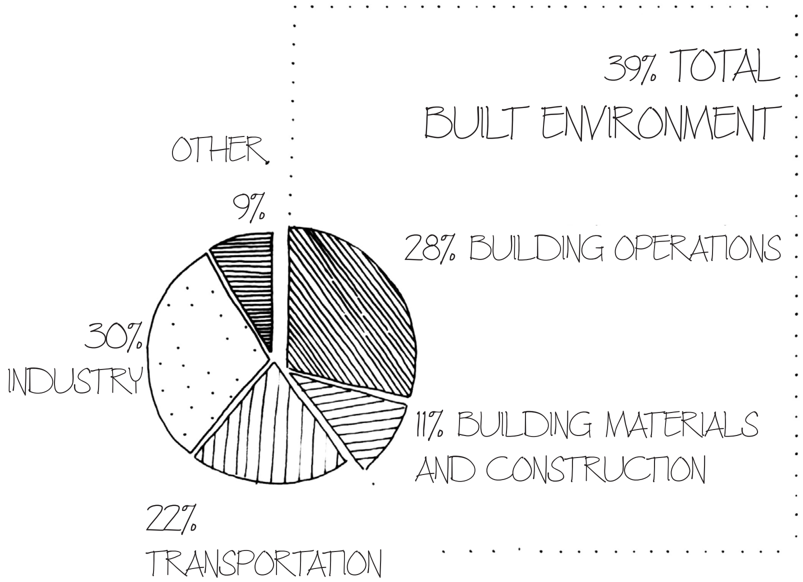
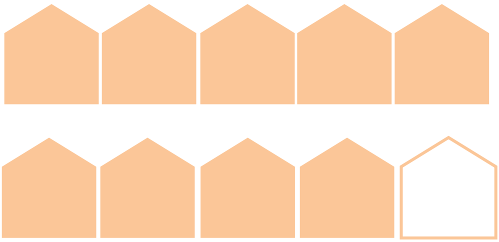


FIGURE 4: Total global greenhouse gas emissions per sector
© Laura Feller adapted from (Architecture 2030.2018)



9 / 10 buildings that exist now, will still be standing and occupied in 2050*

(Renovate Europe. n.d.)

WORLD GREEN BUILDING COUNCIL VISION:

By 2030, all new buildings, infrastructure and renovations will have at least 40% less embodied carbon with significant upfront carbon reduction, and all new buildings must be net zero operational carbon.

By 2050, new buildings, infrastructure and renovations will have net zero embodied carbon, and all buildings, including existing buildings, must be net zero operational carbon. (WGBC.2019)

> ***"Very few people are aware of the fact that buildings are currently responsible for 39% of global energy related carbon emissions: 28% from operational emissions, from energy needed to heat, cool and power them, and the remaining 11% from materials and construction."***

(WGBC. 2019)

Talking about CO_2 emissions must always mean addressing both, embodied and operational carbon. Misconceptions about the term "net zero carbon building", often causes conversations and projects to go down a pathway, that is only half the deal. Whereas, common sense today by saying zero carbon building means just "highly energy-efficient", there are two major components to be considered. Definition after the United Kingdom Green Building Council (UKGBC. 2019):

NET ZERO CARBON: CONSTRUCTION

»When the amount of carbon emissions associated with a building's product and construction stages up to practical completion is zero or negative, through the use of offsets or the net export of on-site renewable energy.«

NET ZERO CARBON: OPERATIONAL ENERGY

»When the amount of carbon emissions associated with the building's operational energy on an annual basis is zero or negative. A net zero carbon building is highly energy-efficient and powered from on-site and/or off-site renewable energy sources, with any remaining carbon balance offset.«

Consciousness about both of the above is key for successful net-zero carbon building practises. Reaching a high level of energy efficiency while having a high amount of embodied carbon means failing the ultimate goal and vice versa. Even though 11% might sound small compared to the 28% of operational carbon, the embodied carbon matters just the same and will receive increased relevance in the upcoming 30 years.

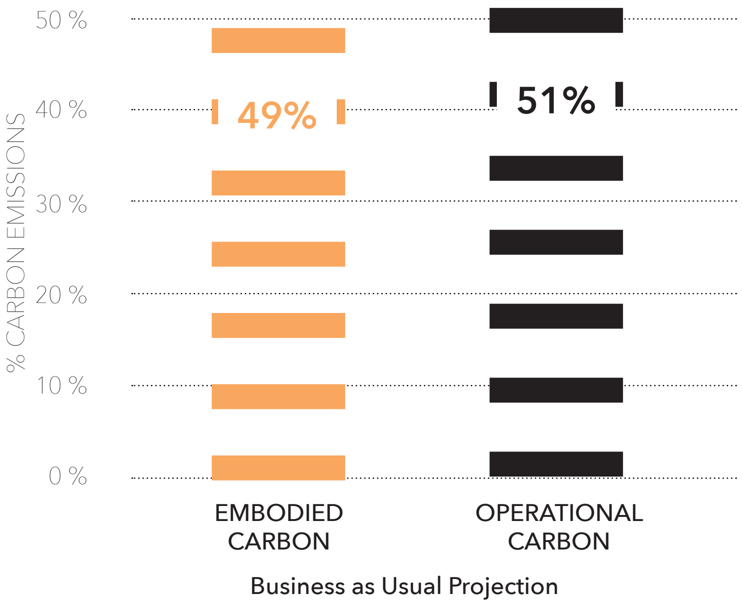
Current efforts to make buildings more efficient to operate and to provide a green energy grid can be seen in many countries, including New Zealand. Though, the missing link to the »Whole Life Cycle Approach« has to be made urgently.

> ***»Embodied carbon will be responsible for almost half of total new construction emissions between now and 2050«***
>
> (Architecture 2030.2018)

The importance of embodied carbon in buildings is a fact, yet largely underestimated by architects, builders, manufacturers and governments. Once a building is finished, no further reduction of embodied carbon is possible. Operational carbon impacts, on the other hand, can be decreased over time, e.g. using more renewable energy or a change of heat source. Projections show (Figure 5), that only half the total global construction emissions until 2050 will be coming from operating our houses. The other half comes from producing and transporting material and construction (UN Energy Outlook. 2017).

Some materials have large amounts of embodied carbon while others can store CO2 and therefore even carbon negative. If being looked at as a country, cement, would be third-largest emitter in the world behind China and the US. It is accountable for 7% of worlds anthropogenic carbon dioxide emissions alone (Architecture 2030. n.d.). Together with the steel and aluminium industry, it makes over 20% of total emissions. Furthermore, cement production has increased by 400% since 1990.

FIGURE 5: Total carbon emissions of global construction from 2020- 2050 © Laura Feller adapted from (UN Energy Outlook. 2017)



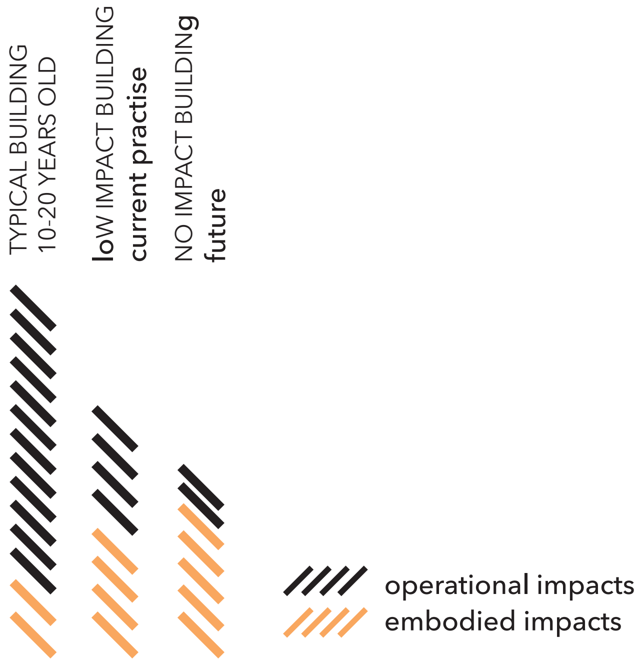


FIGURE 6: Share of embodied and operational impacts for different building practises © Laura Feller adapted from (Working Group Sustainable Construction.2020)

We have experienced an ongoing trend in architecture, that favours concrete, as an aesthetic material for surfaces, as well as the structural advantages of building with it for several centuries. Today, we have a choice between multiple options to achieve the same advantages. We can replace concrete with other high-tech construction materials like CLT, or look into available low cement mixes and upcoming composite materials like hempcrete. Considering alternatives wherever possible as soon as during the design process, is a very important step towards zero carbon buildings. Whenever concrete is only chosen for aesthetic reasons, it should be questioned in general.

Positive to mention is that we are moving towards a time you could call a post-concrete era, where architects, designers or building engineers who care about climate change, progressively build with timber. It is praiseworthy, that a lot of effort goes into new timber constructions and building products and in recent years timber technology has leapt. Timber does not only have a negative carbon balance but can also reduce the weight of a building by up to 80% which results in minimal foundations (Walsh N. 2020).

Through the natural process of photosynthesis, 1 cubic meter of wood can sequester 1 t CO$_2$. It is crucial to highlight, that a lot of common wood panel products have a larger carbon footprint than solid timber. This is due to the manufacture of the building product and additives like glue. Again, there are multiple options and big differences between producers, that need to be considered. Stora Enso, for example, a leading CLT manufacturer from Scandinavia, has committed to renewable and natural timber panel products. Unlike others, they use environmental friendly adhesives, to connect their wood layers. Stora Enso has been a partner of the World Green Building Council's Europe Regional Network since 2017. The company aims to replace fossil fuel-based materials by innovating and new products based on wood and other renewable materials (Stora Enso. 2017).

INSULATION MATERIAL VS. OTHER BUILDING MATERIALS

Whereas construction materials are receiving increased attention, in the embodied carbon conversation, there's currently only a minor focus on the topic of insulation. Nonetheless, if we imagine an average house structure, insulation materials represent a big part of the total volume. Since houses are designed to be more and more efficient the amount of insulation used is on a constant rise too. Another factor to be considered is, that the material for the primary structure of a house is only needed for new construction, whereas insulation is added or replaced in almost all refurbishments.

Most of today's insulation products are made out of crude oils and/or have a very energy-intensive manufacturing process. That means, they emit a large amount of greenhouse gas into the atmosphere before even being installed. This applies for example to XPS, EPS, Glass Wool and Rock Wool. Also, at the end of their life, they go to landfill and continue to pollute our planet (= end of life carbon).

approx.
3729 mio. t
CO$_2$ embodied
from 6.13 billion m^2
annual new construction
(Architecture 2030.2018)

The whole life cycle of a house shows that we have to consider the energy payback time, which describes how many years it takes to offset the embodied energy. In some scenarios, the amortization can be up to 30 years or even more than a materials lifetime (Wind G. et. al. n.d.). This makes it pointless to be insulating with that material particular material at the first place from a carbon emission point of view.

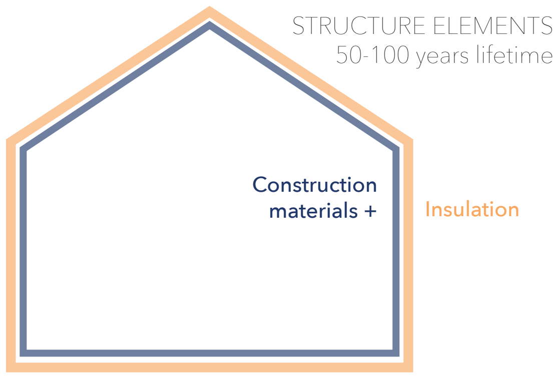


FIGURE 7: Attention on insulation © Laura Feller adapted from (World Green Building Council.2019: p. 28)

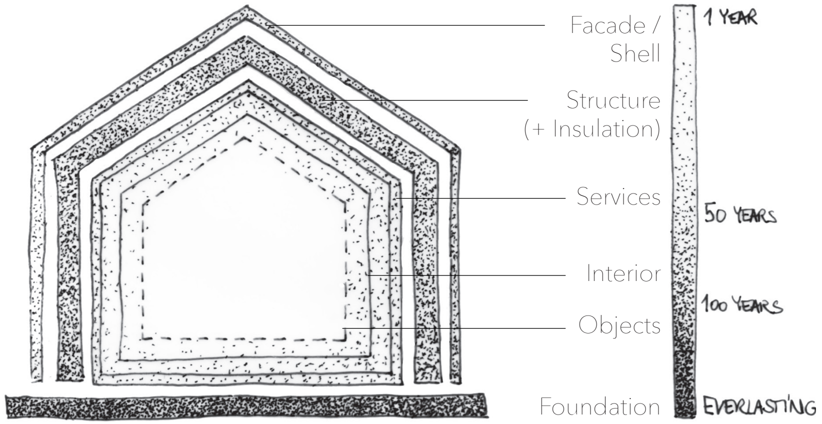


FIGURE 8: Elements of a building and their typical lifetime, before replacement is needed © Laura Feller adapted from (World Green Building Council.2019: p. 28)

Embodied carbon emissions are especially relevant when we are looking to reduce a lot CO_2 in a short amount of time e.g. until 2030, 2050. There is no point, in building and retrofitting buildings up to a high energy efficiency standard, when the amount of carbon emissions released, from the renovation, was bigger than the potential carbon savings. This is a huge call for a change to low or zero carbon insulation products, and this thesis aims to provide ideas towards a successful shift in the insulation sector.

Does it need to be new?

Differing typical lifetimes of building elements, before replacement, should also be weighed. (Figure 6) How long is the material going to be in use, can the performance also be done by an environmental friendly material? Where does it make sense to use a carbon-intensive material and why? How and when does it need to replaced and what is going to happen at the end of its life?

The answers to these questions will vary depending on the type of project and also the region and climate it is built-in. Nevertheless, the very first question we should be asking for any project is, whether new construction is actually needed. It is a fact that when avoiding the use of virgin materials, we avoid their impacts altogether (Melton P. 2018).

To succeed in our vision for every whole building life cycle to be net carbon zero by 2050, we will have to change our approach as early as in the design process. The following four points can guide you through a project.

»Prevent« embodied carbon emissions by looking at the whole life cycle either for a single product or a whole project. Use carbon calculating tools throughout the whole design process. Deliver reduction strategies through exploring alternative methods to deliver the desired function e.g. increase utilization or adaptation of existing assets (renovation/ reuse). Optimise construction with zero or low carbon solutions providing maximum efficiency which leads to a reduction of overall new material demand. Think through building processes and eliminate waste on-site, providing strategies and guidance. Be sure you also consider »future« scenarios and plan for the end of life. First, maximise the potential for maintenance, repair and renovation, and ensure flexibility for future adaptation.

Second, design every detail in a way, that building components can easily be separated in case of renovation or deconstruction. Work with a range of products that can be reused or recycled. Like every other industry, we have to strive towards a circular economy instead of a linear one. Lastly, examine to offset any remaining carbon emissions either through verified offset schemes (approved by local GBC or relevant industry body) or within the project.

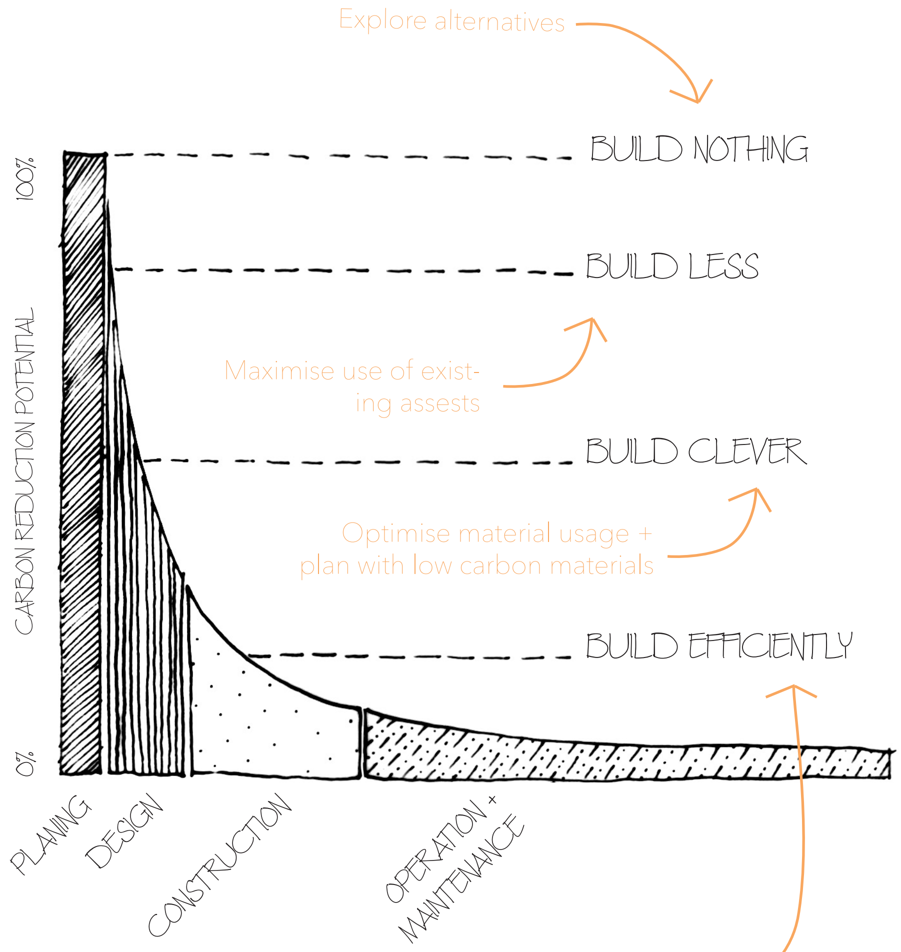


FIGURE 9: Carbon reduction potential © Laura Feller adapted from (World Green Building Council.2019: p.11)

1.3 OPPORTUNITIES TO REDUCE EMBODIED CARBON

'Carbon Handprint'?

One way to draw carbon down from the atmosphere is called 'carbon handprinting'. The term receives increasing attention in the embodied carbon talk. Unlike the carbon footprint, it describes the positive impact an institution, product or building has on the global emissions. Simply said if your carbon balance is positive, you can give it away to others, to achieve »net zero carbon« on a total scheme. Companies, for example, could be hand printing having large solar photovoltaic facilities that produce more renewable energy than they need (Stora Enso. 2018).

Large corporations, like the United Nations or Microsoft, are leading the way to reduce embodied carbon. In 2007 a study, for the of the United Headquarters in New York City, has shown that, if the building was demolished and reconstructed, it would take 35-70 years before the operational efficiencies gained by the new construction would offset the initial outlay of embodied carbon (WGBC. 2019). Therefore, the decision to renovate was clear.

In the Redmond modernization project, Microsoft is building a sustainable campus. They are committed to reducing embodied carbon by at least 15%, aiming for a total reduction by 30%. To achieve their goal, they are reusing and recycling as many materials as possible. Construction materials like concrete, steel and wood, general interior materials, carpets and furnishing but also security and IT equipment were secured (Microsoft. 2019). Acquired emission savings from recycling or reusing material, fall into the group of »beyond life cycle«. So do GHG emissions that are avoided as a result of exporting renewable energy, or using waste as a fuel source for other processes.(WGBC 2019: p 18) In other words, everything beyond all 'life cycle emissions', which is described as your footprint(negative carbon balance), adds to earlier mentioned handprint (positive carbon balance).

WHAT MAKES A NET ZERO CARBON BUILDING

1.4 WHOLE LIFE CYCLE BUILDING APPROACH

Knowing about the total carbon impact of your building at every stage and being aware where emissions come from, allows you to alter accordingly. This process is happening simultaneously with planning, design and construction, it requires carbon calculating tools like the Life Cycle Assessment (LCA). Some available software offers a plug-in to common CAD programmes. Connected to BIM it can be very easy to exchange building materials, or run scenarios for reusing parts of existing structures, while comparing the total amount of CO2 emissions.

Only when thinking of different versions of your project, implying carbon saving scenarios and looking at the whole picture, carbon-smart decisions become possible. It can not be stressed enough that the greatest savings can be achieved in the very early design stages and lay therefore in the hands of architects. As a project progresses, it becomes more challenging and more costly to make design changes to reduce embodied carbon. (WGBC 2019:p19)

The LCA relies heavily on detailed and honest data concerning raw material supply, from manufacturers or freight forwarders. Currently, it can be difficult to receive comprehensive information and big differences in available facts, depending on the country.

There are labels like the »Environmental product declaration«(EPD), that communicates transparent and comparable data and other relevant information about the life-cycle environmental impact of a product (EPD Australasia. 2018). EPDs exist in most countries but are not mandatory for manufacturers yet. It is important to note that an EPD does not judge products - »That judgement or comparison is left to the EPD user in the context of their design project or usage.« - therefore gives no guarantee a product is environmentally friendly. Architects must be pushing policymakers to put legal regulations in place and generalise EPD declarations all over the world.

A whole life cycle assessment collects carbon emissions, by looking at the following stages:

PRODUCT STAGE [A1- A3]
(Figure 10) The product stage consists of all emissions coming from the origin and harvest of raw materials (A1), their transport to manufacturers (A2) and the manufacturing process (A3) itself. This information can be found on product declarations, for example, the Environmental Product Declaration (EPD).

CONSTRUCTION STAGE [A4- A5]
For the construction phase, the actual construction process and installation plus the necessary transportation is considered. Important factors are, possible prefabrication, how far away are construction firms or plumbers based. Plan well to maximise the outcome of each time a firm or worker travels to the site.

»Whole life cycle building approach must be standard < 2020 onwards!«

USE STAGE [B1-5]
Next, is the so-called use stage and talking about embodied carbon, this describes any predictable repair or maintenance, that has to be done after a certain amount of years. This can include weatherboard, roofing, paint, lights, parts of the heating system and other items with a lifetime shorter than 100-120 years. The simultaneously measured operational carbon goes towards a separate unit, the operational energy and water use [B6-7]..

END OF LIFE STAGE [C1-C4]
The last stage requests planning and foresight about everything that happens at the end of the buildings life and how much energy is needed for that as well as related carbon emissions. The process of deconstruction, the amount of waste that goes to landfill, the trucks and other machinery like diggers that will be used for it.

BEYOND THE LIFE CYCLE [D]
All the parts that can be recovered and used for future projects or manufacture plus the material that can be safely separated and recycled, adds positively to the whole balance. This goes even beyond the life cycle and draws greenhouse gas emissions from the atmosphere.

1.5 STAGES OF A LIFE CYCLE

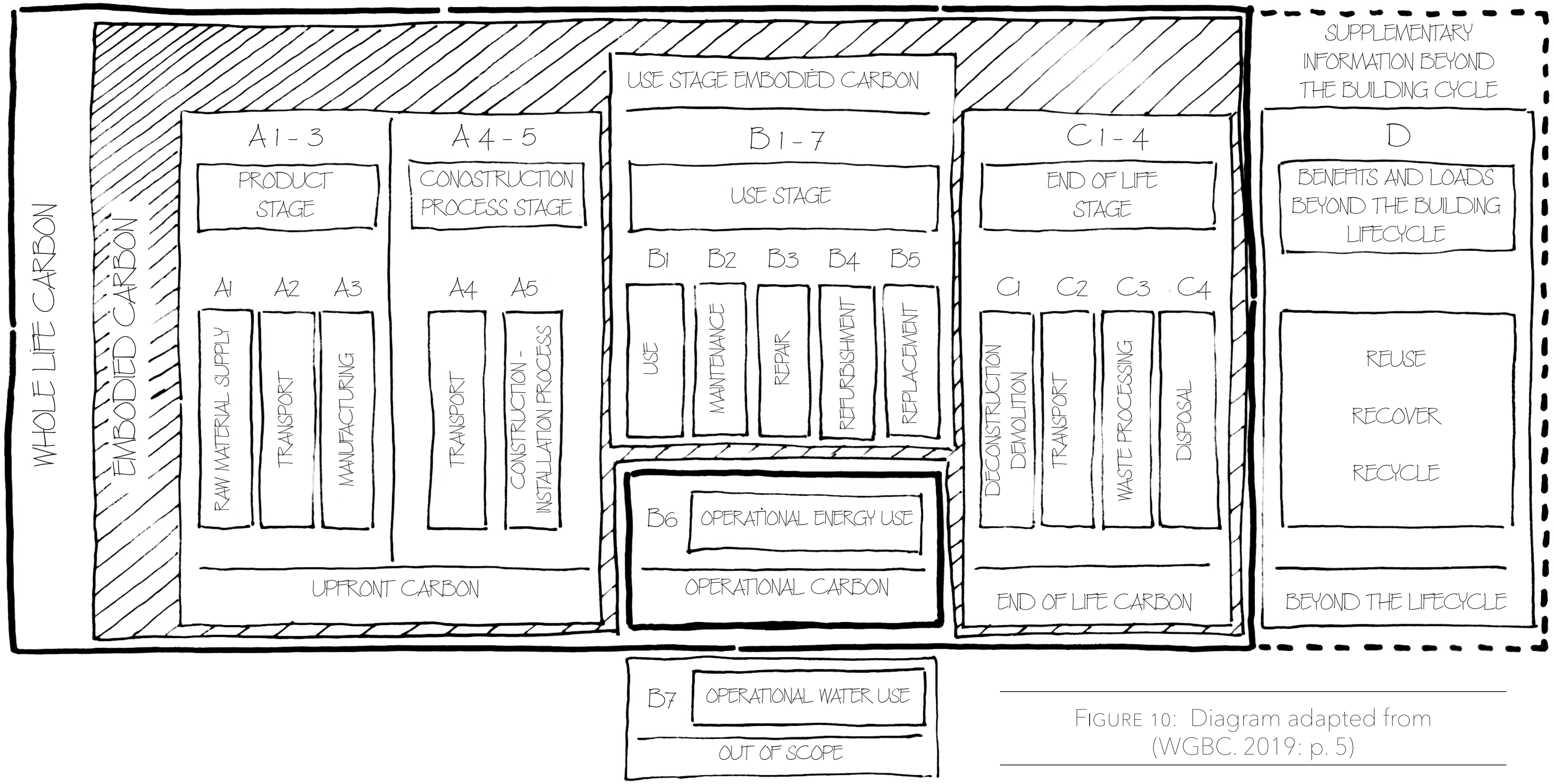
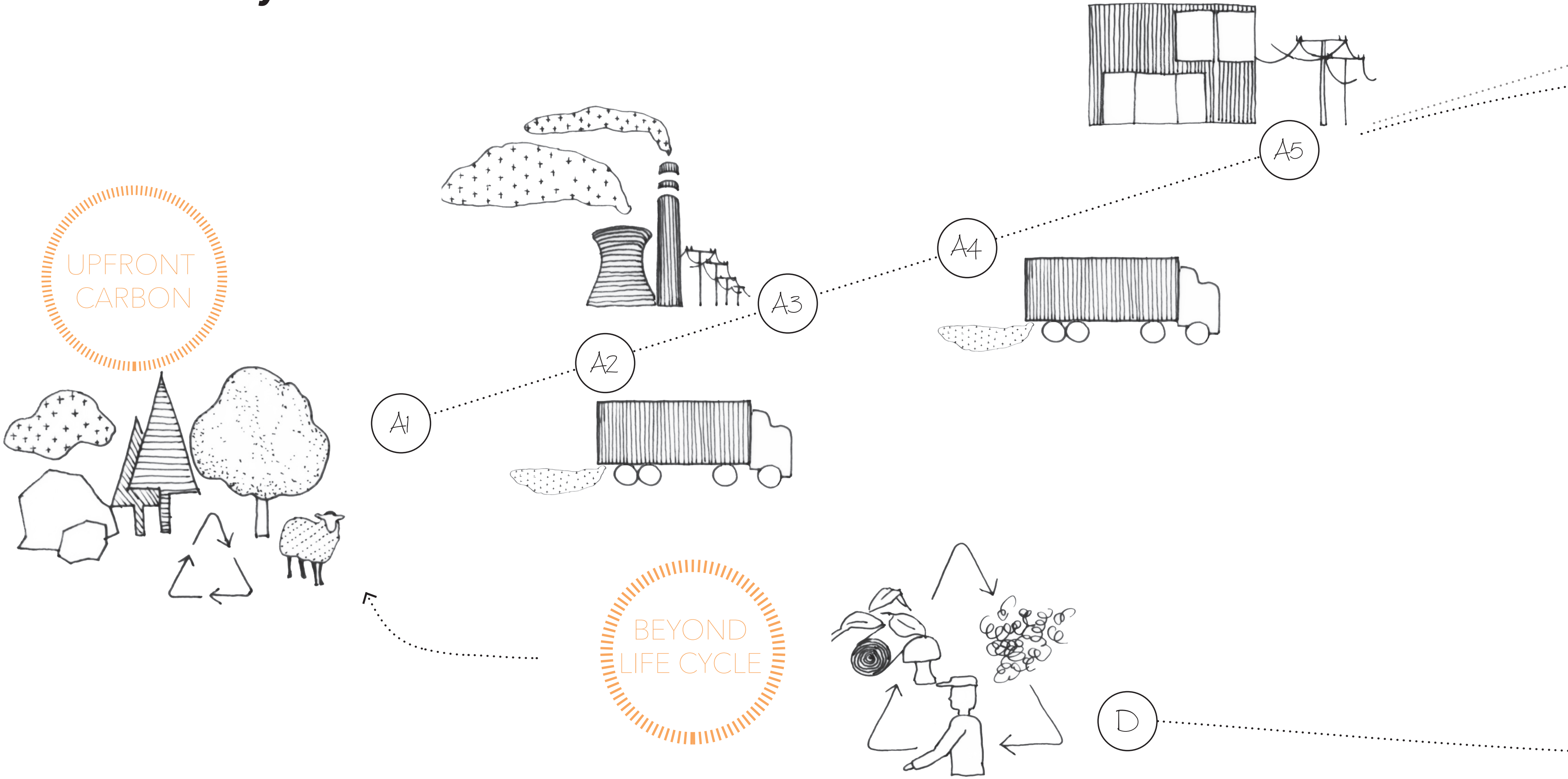
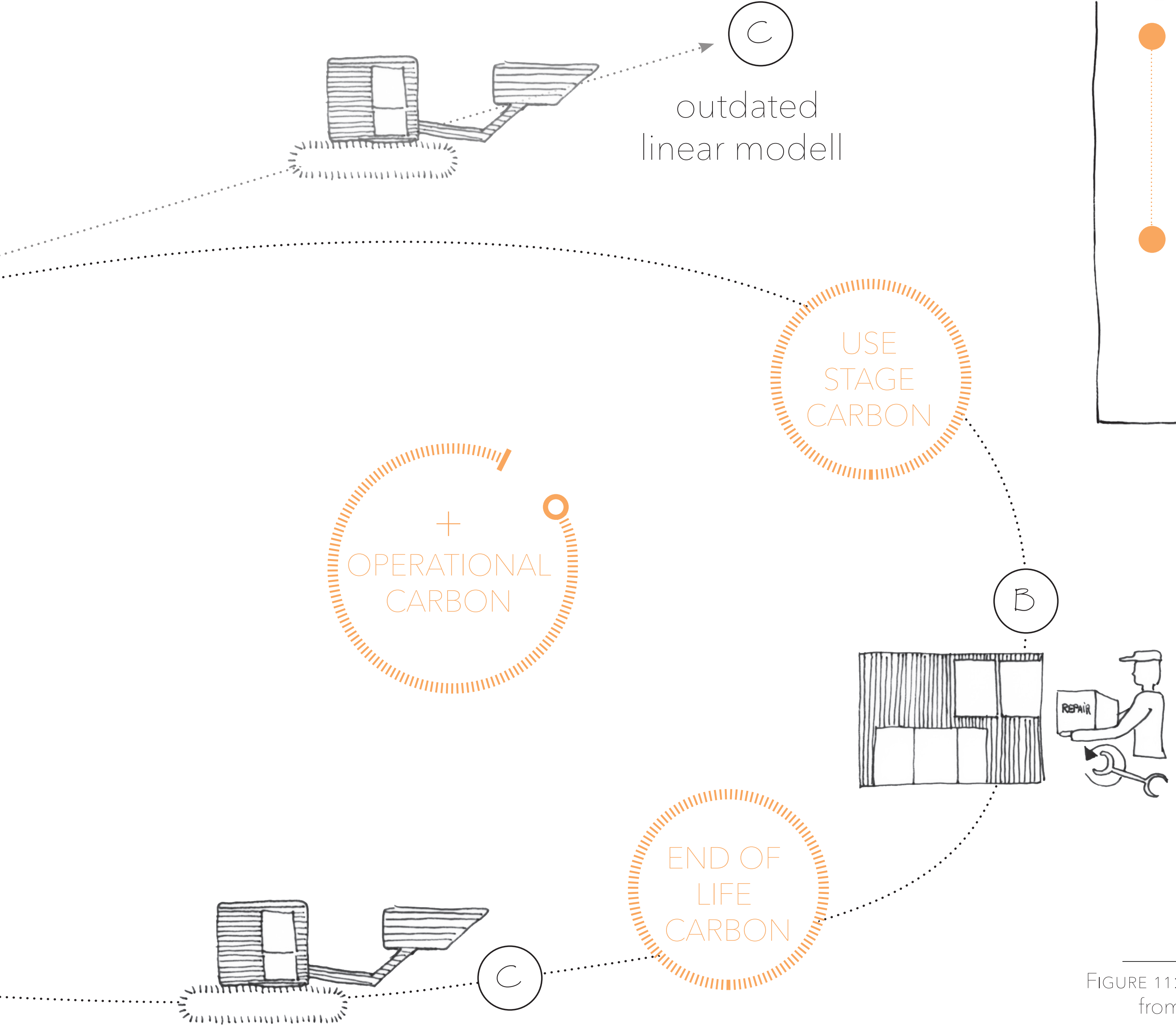


FIGURE 10: Diagram adapted from (WGBC. 2019: p. 5)

»From a linear approach towards a whole building life cycle assessment.«





- PRODUCT STAGE
  A1
  Raw material supply
  A2
  Transport
  A3
  Manufacturing
- CONSTRUCTION
  PROCESS STAGE
  A4
  Transport
  A5
  Construction -
  Installation process
- USE STAGE
  B1-B5
  Maintenance, repair &
  replacement supply
- END OF LIFE STAGE
  C1-C4
  Deconstruction, transport, waste,
  processing &
  disposal
- BEYOND THE LIFE CYCLE
  D
  Recovery, reuse,
  recycling potential

FIGURE 11: Measuring embodied carbon © Laura Feller adapted from (Working Group Sustainable Construction.2020)

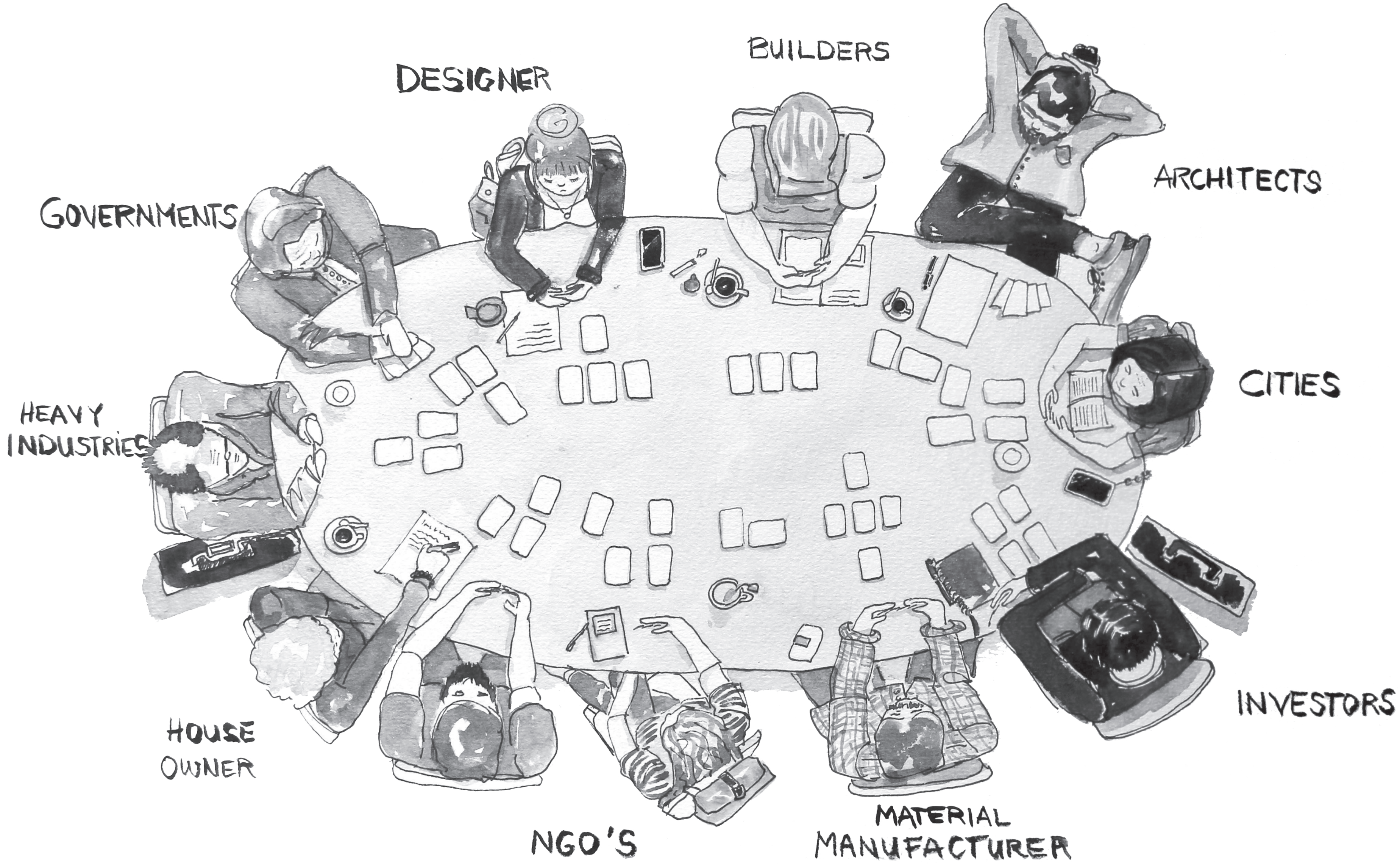


FIGURE 12: 'The Big Game Players' © Artwork (Laura Feller. 2020d)

»IT IS CRUCIAL TO BE ON THE SAME TEAM TO WIN THE GAME«

1.6 CONCLUSION & PROSPECT

With our built environment making up to 40% of total global emissions, there is no doubt that change is needed. Architects play a key role in this shift, acquiring new skills within their field of expertise. There is no uniform solution for a zero carbon project, methods to achieve a small carbon footprint are as individual as the designs themselves. However, with today's knowledge there are plentiful opportunities to achieve zero carbon buildings - both new construction and refurbishments.

What is currently missing, is communication, the right education on the topic across the sectors and standards. We need to set appropriate targets within the building industry so that we will all reach our climate goal.

The shift needs guidance through awareness, new policies and funding, creating the necessary push to generate momentum. Everyone involved has to stop competing against each other and realise that we all have a

2 CONTENT

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2 NEW ZEALAND TOWARDS A NET ZERO CARBON BUILT ENVIRONMENT

//

2.1 INTRODUCTION

Since my research is based in Aotearoa - 'Land of the White Cloud' - I was particularly interested to learn about New Zealand's building industry and future visions. New Zealand's buildings emit 20% of the country's total carbon emissions, which is as much pollution as 1 million cars on the road every year (NZGBC. 2019). New Zealand needs to both reduce operational and embodied carbon emissions.

Reducing operational carbon has generally been the first priority in climate policies for the built environment. It is positive to mention that, the country's energy grid is 84% renewable, striving to be 100% by 2035 (New Zealand Government. 2011). In order to make appropriate use of this green energy, houses have to reduce their consumption and have to be updated to a higher energy efficiency.

The best results in reducing embodied carbon can be achieved when replacing concrete and steel with timber constructions. However, New Zealand's buildings are mostly made of timber frame construction. To further reduce embodied carbon, we need to look beyond materials for the superstructure.

By international comparison New Zealand's building code is weak and being criticised when it comes to it's energy efficiency requirements (NZGBC.2019: p 11). Houses are generally cold, damp and difficult to heat. Living in an older farm house in Taranaki and visiting different homes, throughout all seasons of the year, has allowed me to experience that for myself. This has given me reason to focus on New Zealand's thermal house performance, taking the zero carbon goal for 2050 into account.

»Together, right now, we all have a chance to play key roles in this historical, industry-defining accomplishment.«

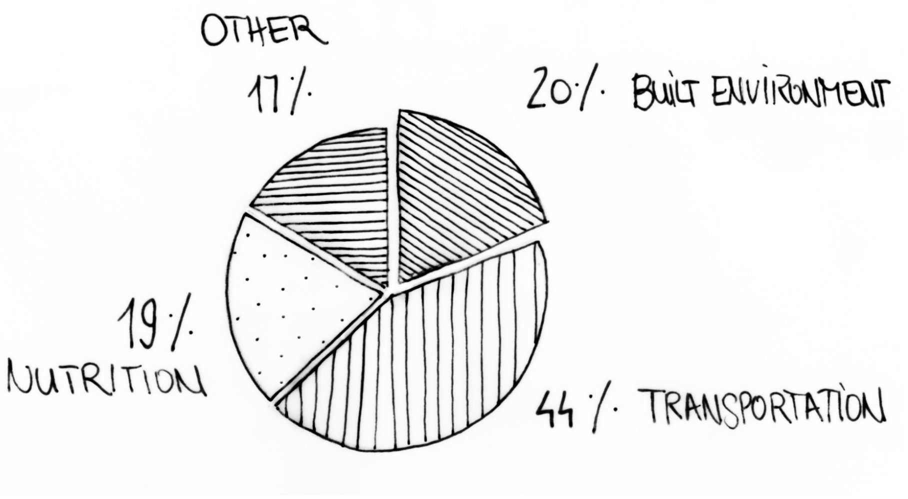
(NZGBC. 2019)

2.2 NEW ZEALAND'S CARBON FOOTPRINT

To get an actual idea of the total carbon emissions of the built environment, a whole life cycle perspective that includes the international trade is needed. (Figure 11). Many diagrams are misleading because only the operational energy use of houses, is considered and material production, transportation and demolition are shifted to other sectors. Furthermore, since agricultural is the biggest part of New Zealand's economy, but most of meat and dairy product are exported, relating emissions are therefore shifting overseas. The diagram on the right shows the internal carbon footprint of the country, the built environment (20%) and nutrition (19%) being second largest share, while transportation accounts for the largest share (40%) and the remaining 17% are other sources. Constructing and renovating New Zealand's buildings emit as much climate-changing pollution as 1 million cars on the road every year (NZGBC. 2019: p 3)

New Zealand needs to both reduce operational and embodied carbon emissions. Overall, it is positive to mention that the country's energy grid is a mix of renewables (hydro and wind) and non-renewables (coal and gas) and has significantly increased green energy production, setting a new record in 2018. Whereas 40% of primary energy supply[1] came from renewable sources, over 84% of electricity was generated by hydro and wind. It is a leading country for renewable energy generation, with the average for the OECD[2] countries being just 25%. (Ministry of Business, Innovation and Employment. 2018). Aiming to provide 90 per cent of electricity generated in New Zealand, derived from renewable energy sources, and striving for 100% in 2035 (New Zealand Government. 2011). While continuing that journey, it is important to focus on the energy efficiency of buildings, to reduce energy consumption, and embodied carbon emissions in construction of new buildings and thermal retrofits.

Most of us, are familiar with the term of a carbon footprint, which can for example, tell us how much our personal lifestyle effects global warming.



60.000 kt CO_2e
NZ's total footprint

13 t CO_2e
per person

consumption oriented view (incl. international trade)

FIGURE 13: New Zealand's total carbon emissions
© Laura Feller adapted from (Thinkstep Ltd. 2018)

[1] Total primary energy supply is the amount of energy available for use in New Zealand accounting for imports and exports.

[2] Organisation for Economic Co-operation and Development

Or it can show when a specific country reaches it's 'Earth Overshoot Day', the date all resources, that can be regenareted from earth in the given year, are used up. Some of us might check how much carbon our last international flight emitted and even offset that amount. In fact, we all have to do the same for our buildings, architects, homeowners and everyone else involved in the building process. We need to consider the carbon budget of a project from the very early steps onwards. We have to urgently raise awareness about it and make information more accessible.

»Our buildings carbon footprint is way too big«

Assuming we aim to keep anthropogenic global temperature rise within 1.5°C, the carbon budget for a typical stand alone house in New Zealand, is 39t CO_2e (Dowdell.2020: p 35). For comparison, the CO_2 emissions per capita for New Zealand, was 17 t CO_2e in 2018 (thinkstep Ltd. 2018: p 4).

The footprint of an average standalone house, with a gross area about 200m², is currently about 273t CO_2 eq. This is seven times bigger than the available carbon budget. To legally set a budget, that is regulated by policies, can be a stepping stone to New Zealand's targets.

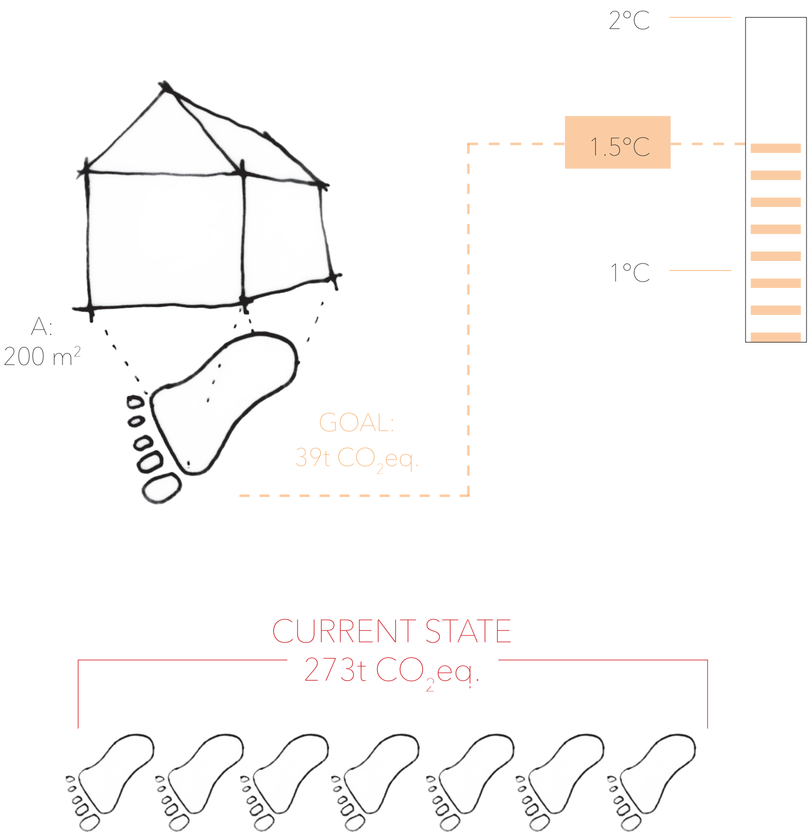


FIGURE 14: Average footprint of a New Zealand House © Laura Feller adapted from (Dowdell.2020: p 35)

»The footprint of an average stand-alone house, with a gross area about 200m², is currently about 273t CO_2 eq. - that is 7 x the carbon budget!«

(Dowdell.2020: p 35)

2.3 NEW ZEALAND'S ROAD MAP TOWARDS 2050 GOAL

TODAY

Building upon the Paris Agreement, the year of 2019 has seen a lot of important work on de-carbonising the built environment in New Zealand. It is important to note that the UNFCCC did not actually include specific national or international targets to reduce greenhouse gas emissions. (MacGregor, C., Dowdell, D., Jaques, R., Bint, L. & Berg, B. 2018: p 14). New Zealand has set a number of CO_2 emissions targets in the past years and is one of the few countries to have zero carbon emissions enshrined in law (ClimateActionTracker.2020). Still the Climate Action Tracker rates New Zealand's ambitions currently as »insufficient« and not consistent with holding warming below 2°C. If all countries were in this range, temperatures would reach up to 3°C. It is further noteworthy that it has excluded methan emissions from agriculture and waste (over 40% of New Zealand's emissions) from the Zero Carbon Act. (Climate Action Tracker.2020) Even more important becomes our work in the building sector, to reduce as much green house gas emissions as possible.

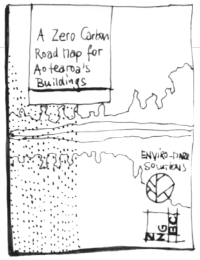
The New Zealand Green Building Council (NZGBC) has released 'A Zero Carbon Road Map for Aotearoa's Building, addressing all the goals the country has to reach within the building sector until 2050. It was followed by the Climate Change Response Amendment Act adopted by the New Zealand government and the Building for Climate Change programme initiated by the Ministry of Business, Innovation & Employment.

2030

Those documents set a constructive foundation for the the sector, aiming for all new buildings be net carbon zero by 2030. NZGBC's road map outlines major pathways the country has to go down, making a healthier zero carbon future happen. These proposals include an improved Building Code, significantly increased transparency around the energy-efficiency of buildings, and a call for government ministries and departments to lead a revolutionary shift in green buildings. (WGBC, 2019: p 3). The NZGBC proposes a focus on

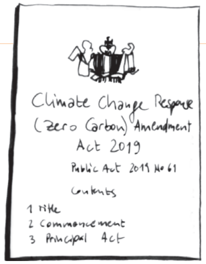
UNFCC
PARIS AGREEMENT

UNITED NATIONS FRAMEWORK
CONVENTION ON CLIMATE CHANGE
OCTOBER 2016
(UNFCCC. 2020)



A ZERO CARBON ROAD MAP
FOR AOTEAROA'S BUILDINGS

NEW ZEALAND
BUILDING COUNCIL
SEPTEMBER 2019



CLIMATE CHANGE RESPONSE
(ZERO CARBON) AMENDMENT ACT

NEW ZEALAND MINISTRY
FOR THE ENVIRONMENT
NOVEMBER 2019

Are policies meeting the 2050 carbon goal?

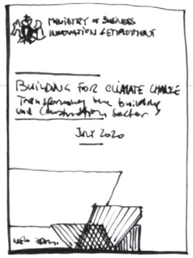
new construction for the next 10 years. Houses have to be built zero carbon from the start to avoid any significant future changes and to prevent the lock-in of carbon-emitting systems for decades to come. To achieve this, NZGBC proposes three updates to the Building Code in 2022, 2026 and 2030, including restricting fossil fuel combustion in new buildings by 2026 and eliminating their use all together by 2030. (WGBC 2019: p. 2)

2050

At the same time existing buildings need to be continually updated to net zero carbon standards, the vision for 2050 is: all buildings operate 100% net zero carbon. The government's target is '50 by 2050, which means net emissions 50% below 1990 gross emission (MacGregor, C., Dowdell, D., Jaques, R., Bint, L. & Berg, B. 2018: p 15).

Green Star, Homestar and NABERSNZ (commercial office buildings) are labels that, already enable measurement and reduction of greenhouse gas emissions, but more certifications, especially relating to net carbon embodied energy seem necessary. In New Zealand green building certificates are widely voluntarily, thus currently there is only a low coverage throughout the country.(IEA. 2020). It is in this context that NZGBC has developed two tools that allow building owners to measure, manage and offset their emissions.

The first one 'Zero Carbon Commitment' is for home owners that just want to start their journey, it enables to publish and compare a building's energy consumption and carbon emissions transparently online. In a next step the 'carboNZero building certification' allows to measure current carbon emissions more formally, manage your carbon footprint, will allow for offset where there are unavoidable emissions (NZGBC. 2019: p 8). When successfully completed, house-owners will also receive a certificate that will raise the value of properties in the upcoming years.



BUILDING FOR CLIMATE CHANGE

NZ MINISTRY OF BUSINESS,
INNOVATION & EMPLOYMENT
JULY 2020

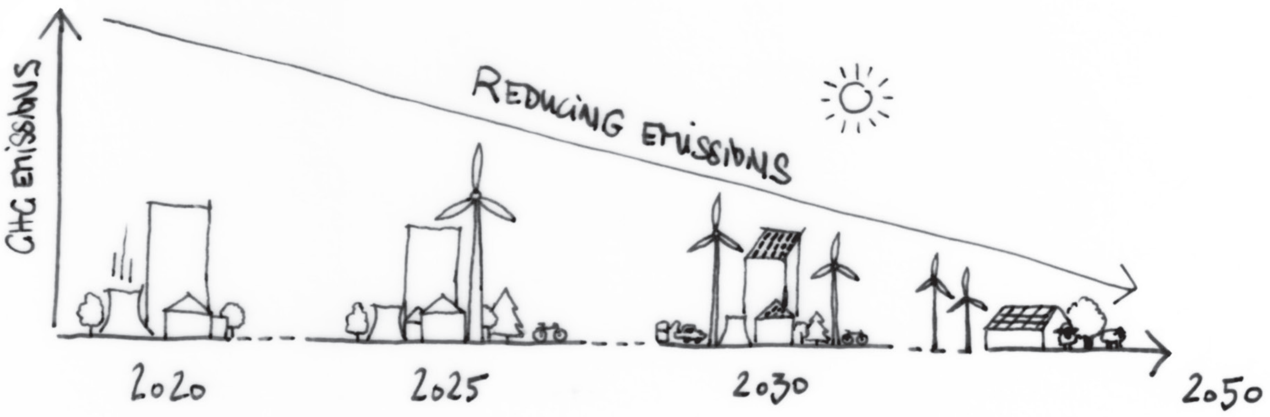


FIGURE 15: New Zealand's pathway towards 2050 © Laura Feller adapted from (New Zealand Green Building Council.2019)

2.4 NEW ZEALAND'S HOUSING STOCK

2.4.1 OVERVIEW

New Zealand's urbanization rate has been on a moderate rise in the last ten years, from 86,22% in 2009 to 86,62% in 2019 (Statista. 2020). Still very little people live in joined dwellings, the number of two or more flats/units/townhouses/apartments/houses joined together was 266,748. About 8 out of 10 private dwellings are separate houses according to the 2013 census. This makes 1,193,358 separate houses from a total of 1,561,956 dwellings in the country. Looking at home ownership by households, data shows that 64.8 percent (down from 66.9 percent in 2006) of households owned their home or held it in a family trust in 2013 (StatsNZ.2014).

A recently published research article by BRANZ (an independent research organisation aimed to improve the performance of the New Zealand building system), surveyed 560 houses, to be broadly representative of the national housing stock and included both owner-occupied and rental houses. It was done approximately every five years since 1994, with the latest one published in 2015. Findings show, that there is an enormous potential to make houses warmer, drier and more cost effective to heat. (BRANZ.2015)

2.4.2 HEATING

Poor insulation makes a very insufficient building when it comes to heating. A lot of heat will be transmitted through all surrounding surface and get lost. In addition to low insulation levels, the heating system largely effects the performance of a house. Central heating is in still in its infancy in New Zealand and has only slowly began to make its way into homes. Only 5 % of houses have central heating (French, L.J. , Camilleri, M.J.T., Isaacs, N.P. A.R. and Pollard. 2006: p 14), while portable electric heaters are the most common type of heating appliance, used in over 50% of all houses. In owner occupied houses solid fuel heaters (typically wood burners) were the second most common, found in almost half the houses, followed by heat pumps (46%).

2.4.3 INDOOR TEMPERATURES

The combination of poor insulation and inefficient heating causes energy bills to go through the roof and many families are forced to leave their heaters off. It is very common that, the living room is the only room heated over the winter months (June-August) and only during the hours spent there in the evenings. The World Health Organisation recommends a minimum indoor temperature of 18°C in order to live a healthy lifestyle. On average, rooms are below 20°C 83% of the time, with the living rooms being the warmest. (Figure 16). The national average shows that only 10.9% households are heating the living area constantly and 5.9% not heating at all. (French, L.J. , Camilleri, M.J.T., Isaacs, N.P. A.R. and Pollard. 2006: p 2). Just half the households heat their bedrooms, same as the children's rooms (BRANZ.2019).

ROOM	MORNING	DAY	EVENING	NIGHT
Living room	13.5	15.8	17.8	14.8
Bedroom	12.6	14.2	15.	13.6
Ambient	7.8	12.0	9.4	7.6

FIGURE 16: Mean indoor temperatures (°C) © Laura Feller adapted from (French, L.J. , Camilleri, M.J.T., Isaacs, N.P. A.R. and Pollard. 2006: p 2)

2.4.4 LEAKY HOMES

The 'Leaky Homes Crisis' describes an ongoing construction crisis in New Zealand concerning timber-frame houses built between the late 1980s and mid-2000s. Large numbers of houses have structural damaged because of weathertightness issues, with an estimated 42.000 houses that could need repair. The financial damage is approx. $11.3 billion. To provide consistent procedures for resolving leaky home disputes across the country, the government established the Weathertight Homes Resolution Services Act 2006. (Stewart, P. 2014).
Buildings identified to be most likely to leak, are built in Mediterranean style (without eaves and flat roofs). They usually have plaster-style monolithic cladding systems, made out of plaster over polystyrene or fibre-cement sheet. Moisture gets trapped in the construction due to a lack of ventilation and drainage. The walls are likely to rot and grow dangerous fungus, causing structural problems for the building and health problems for those who live there (Settled.n.d.). Several factors may play a role, including issues with the introduction of new Building Code, design issues and problems around installing materials. However, the major problem was that from the early 1990s a range of alternative timber framing treatment options were available. Up to 1992, most timber used for house framing in New Zealand was radiata pine (Pinus Radiata) treated with boron. From 1998 to April 2004, homes were often built with untreated kiln-dried radiata pine framing (Department of Building and Housing.2004).

Although my thesis focuses on homes built before 1980 (= before thermal insulation was required), it is necessary to be aware of this existing problem and to learn from it. It can be noticed, that New Zealand's building industry is very cautious about moisture in buildings and does not want to repeat the same mistakes again.

2.5 CLIMATE & INSULATION REQUIREMENTS

2.5.1 CLIMATE

New Zealand is long and narrow thus the far north is much warmer than the far south. With an average 24h winter temperature of 11.9°C in Kaikohe compared to 6.2° in Invercargill (Figure 17) the heating period varies between 5.5 and 8.6 months. Despite having a more moderate climate houses in the North have generally less efficient and less powerful heaters, which explains the low indoor temperatures throughout whole the country. (French, L. et al. 2006: p 3,10).

Insulation became first mandatory in 1978, with the NZS 4218P Minimal thermal insulation requirements for residential buildings (Elkink 2011: p 17). These thermal insulation requirements have slightly increased over the years, whereas most change can be seen on Zone 3. (Figure 18).

In 2009 latest standard for *Thermal Insulation for Housing and Small Buildings (NZS 4218:2009)* was published under the Building Act . Construction R-values are specified for three different climate zones on the North and South Island of New Zealand (Figure 17). These zones exist since the building code NZS 4218 in 1996, before that R-values were the same all over the country, despite having a different climate. The building code clause *H Energy efficiency* states that: Buildings must be constructed that their building performance index (BPI) does not exceed 1.55. Two compliance methods (schedule or modelling method) to calculate the BPI are described in NZS 4218:2009 standard. Alternatively, BRANZ provides a free online tool Annual Loss Factor (ALF), to calculate the BPI for projects. (Building Performance.2009)
However, owner-occupied houses do not have to be upgraded to latest standards to this date. This means most houses built before 2009 have insufficient insulation levels, and their energy performance should be improved (Elkink 2011: p 22).

2.5.2 REGULATIONS FOR RENTAL HOUSES

Along with rental homes, new regulations were issued in the Healthy Home Standards in July, 2019. Due to the new law it is compulsory for all landlords, to retrofit ceiling and underfloor insulation, where it is reasonably practical to install. This applies to all rental properties, covered by The Residential Tenancies Act, to make them more energy efficient and provide a better quality of life. Walls are not included in the document and being not compulsory, will probably be left out in most retrofits. All private rentals must comply with the healthy homes standards by latest 2024 (TenancyService.2019: p 2).

BUILDING ELEMENT	**ZONE 1**	**ZONE 2**	**ZONE 3**
Roof	R 2.9	R 2.9	R 3.3
Wall	R 1.9	R 1.9	R 3.0
Floor	R 1.3	R 1.3	R 1.3
Windows & glazing	R 0.26	R 0.26	R 0.26
Skylights	R 0.26	R 0.26	R 0.31

FIGURE 17: Construction r-values (m2 . °C/W) © Laura Feller adapted from (New Zealand Standards.2009)

		R-values (m² °C/W)		
STANDARD: YEAR	COVERAGE	Ceiling	Wall	Floor
NZS 4218P:1978	New Zealand	R 1.9	R 1.5	R 0.9
NZS 4218:1996	Zones 1 and 2	R 1.9	R 1.5	R 1.3
	Zone 3	R 2.5	R 1.9	R 1.3

FIGURE 18: Historic standard R-Values © Laura Feller adapted from (Elkink 2011: p 17)

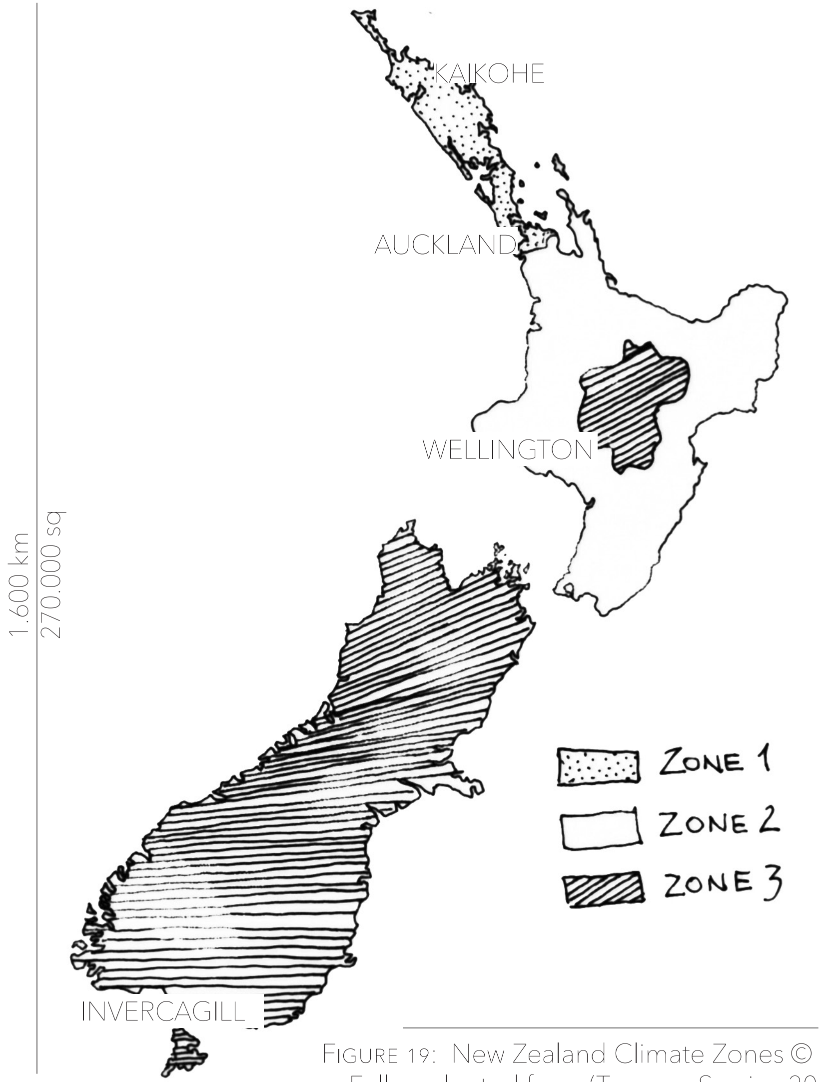


FIGURE 19: New Zealand Climate Zones © Laura Feller adapted from (Tenancy Service.2020)

2.6 THERMAL PERFORMANCE

2.6.1 INSULATION LEVELS

The BRANZ House Condition Survey 2015 #1 suggests that over half of existing dwellings (53%, representing 830,000 houses), could benefit from retrofitted insulation. Many houses were found to have at least one defect, such as gaps in insulation (31%) or insulation settling (22%), insulation not fitted properly (16%) or displaced (11%). With insufficient coverage of subfloor (19% representing 290,000 dwellings) and poor roof insulation (47% representing 740,000 dwellings) most houses are hardly passing the minimum building code requirements. A minimum depth of 120 mm across at least 80% of the accessible roof space, recommended by the Energy Efficiency and Conservation Authority (EECA) was only found in 39% of all houses (Figure 19).

New Zealand houses are generally considered low thermal mass, because of the common light timber construction. (French, L.J. , Camilleri, M.J.T., Isaacs, N.P. A.R. and Pollard. 2006: p 9). Single glazed windows, currently being used in 81% of all houses (this figure was 90% for rentals), add to a poor thermal performance. Only in 10% of houses double-glazed windows were used throughout the houses, with the rest having a mix of single and double glazing.

2.6.2 HEAT LOSS

A typical uninsulated timber frame house with pile-foundation experiences the largest heat loss through the roof (30-35%) followed by the walls (18-25%) and glazing (21-23%). Floor heat losses are usually the smallest with 12- 14 %. Considering that London and Christchurch have similar heating degree days, the insulation levels and air tightness in the UK (Figure 19) are at least double, or in case of floor insulation five times higher. (NZGBC. 2019: p 11)

2.6.3 HEALTH ISSUES: MOISTURE AND MOLD

Cold and moist rooms, as a result of inefficient heating and low insulation levels, as well as poor orientation, are very likely to build mold. In almost 50% of houses, viewed in the BRANZ survey, mold was visible. (BRANZ. 2019). These conditions cause respiratory problems and other illnesses and lower the quality and value of the property.

2.6.4 GOVERNMENT FUNDING

The government is currently running the Warmer Kiwi Homes Programme, a grant covering most costs, of new ceiling or underfloor insulation as well as one heater per household. Home-

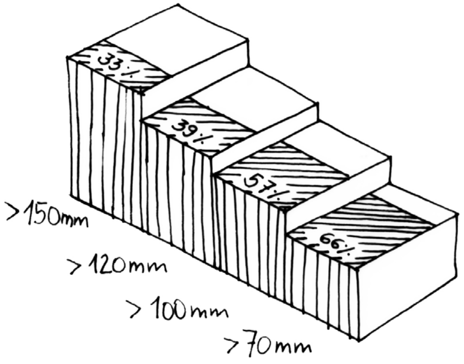


FIGURE 20: Proportion of houses where ceiling insulation meets a particular requirement © Laura Feller adapted from (BRANZ.2019)

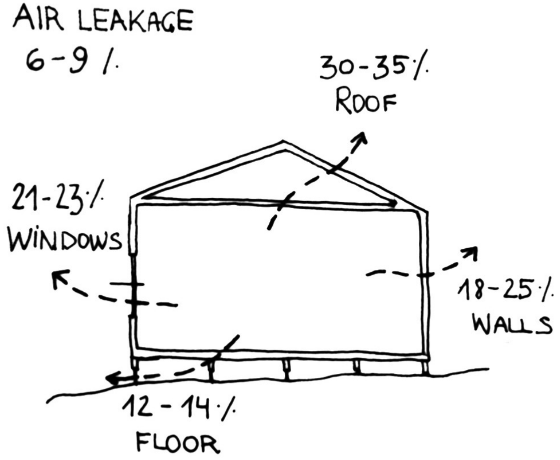


FIGURE 21: Heat loss from an uninsulated house © Laura Feller adapted from (Camilleri, M.J.T.2010)

47%
of all NZ houses had insufficient coverage of roof insulation

ONLY
10%
of houses had double-glazed windows througout

49%
of all NZ houses showed visible mold

2/3
of New Zealand houses are owned vs. 1/3 rented

50%
of all NZ houses heat with a portable electric heater

(BRANZ. 2019)

owners are given the grant when meeting low income requirements.

2.6.5 CURRENT PRACTICE

Thermal retrofitting in New Zealand usually include installation of roof and underfloor insulation but spare the walls. This is commonly explained by the work intensity and cost through both builders and homeowners. It can be assumed that the government funding plays a noticeable role, and therefore including wall insulation in the Warmer Kiwi Homes Program, could regulate this problem.

2.6.6 BENEFITS FROM INSULATION

A well insulated house makes it easy to achieve a comfortable indoor temperature throughout the year. Although insulation is mostly talked about in the context of keeping a home warm, it will conversely keep the house from overheating in summer. This is an existing problem in some areas, expected to increase in the following years, due to a predicted higher number of days with uncomfortable indoor temperatures, due to global warming. (Camilleri. 2000: p 20)

The higher energy efficiency of a house, gained through adequate insulation levels, results in a less energy intensive house to run. Consequently, the house is more cost effective to operate and uses less operational carbon. In addition it can be said, that an energy efficient home effects the household budget positively, also from a health point of view. Families will suffer less from illnesses caused by cold and damp houses, resulting in less sick days from work and lower medical bills, which again means saving money that can be spend on heating. Overall the cost and effort of insulation is outweighed by its advantages.

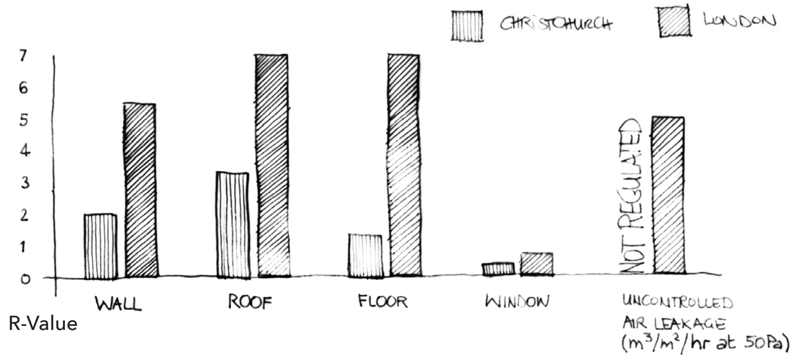


FIGURE 22: Comparison of Insulation & Air-tightness requirements: Christchurch - London © Laura Feller adapted from (NZGBC. 2019: p 11)

FIGURE 23: 'Lyttelton' ©Artwork (Laura Feller.2020e)

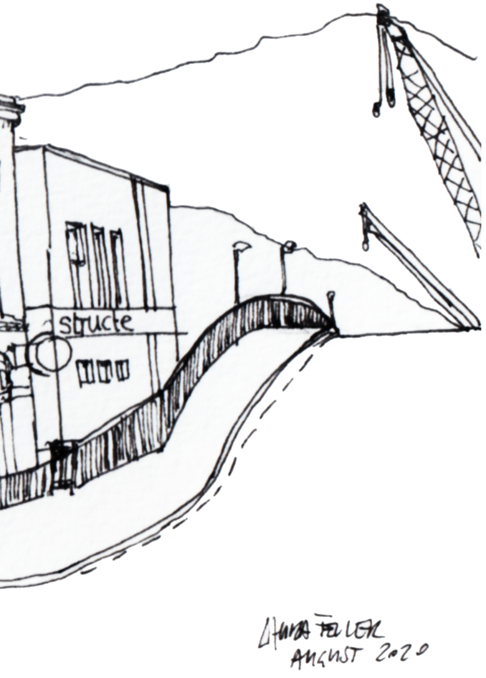
2.7 CONCLUSION & PROSPECT

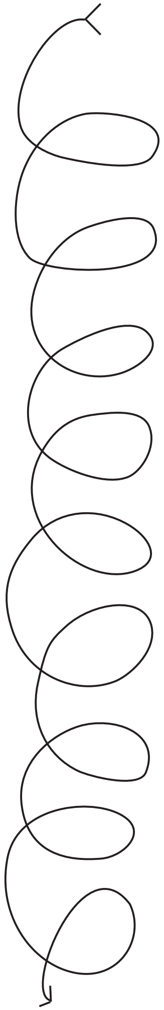
New Zealand has set stepping stones towards Zero Carbon Buildings by 2050 with different official documents.The coming years will show if these goals will be reinforced enough by adapted regulations and government programs.

The large percentage of existing occupied private dwellings with low standard of living, due to insufficiency, is a challenge that New Zealand will continue facing for many years. In awareness of many factors being part of the problem, I have identified thermal insulation to be one of the most crucial building tasks at the time. Together with high performance glazing and sustainable heat sources, insulation represents the foundation of a modern home.

Considering the limited carbon budget of future building projects, it is necessary to examine sustainable ways to retrofit and pass on the knowledge, to everyone involved in the building industry. We can not carry on wasting time, money and material on solutions that are not meeting long term CO_2 emission goals. In the following chapter I will propose a local low carbon insulation material and analyse it's properties and advantages compared to commonly used insulation products. To do so I will look at the whole life cycle of the material which is the only way to find out about the true impact of any material, product or service we use.

»Understanding carbon is probably the biggest challenge of our time«





3 CONTENT

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3 SHEEP WOOL: A SUSTAINABLE INSULATION MATERIAL

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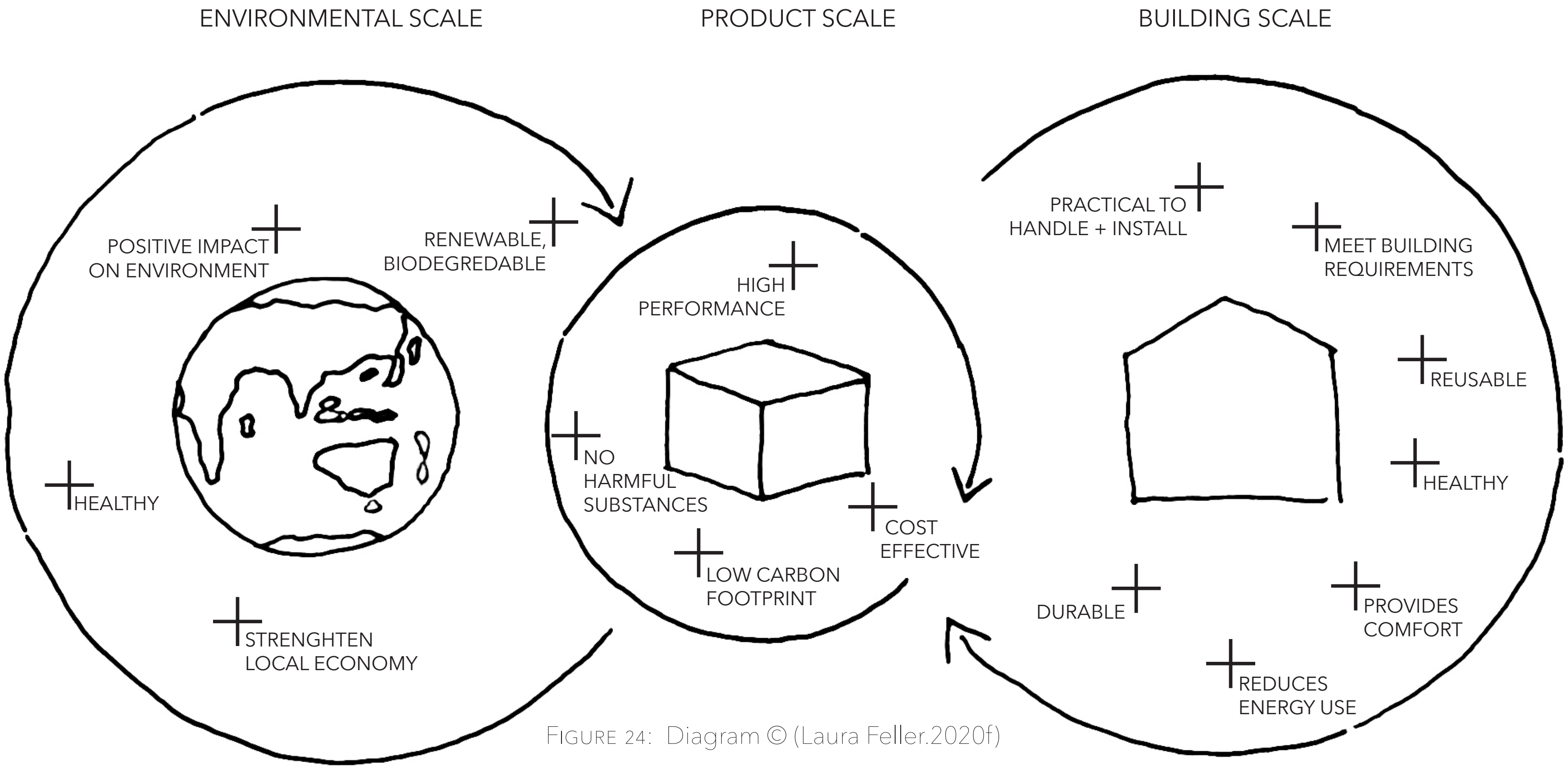


FIGURE 24: Diagram © (Laura Feller.2020f)

3.1 INTRODUCTION

The building industry is pushed by innovation, with high performance being the ultimate goal. High tech materials and solutions make sophisticated ideas possible and let building projects go beyond limits. Most of those technologies have been driven by money and oil in the past without considering the impact on the environment.

Yet, today we know that the global warming potential of natural building materials is only a fraction of common products. They act as a replacement in most areas without a negative impact on performance, while creating a positive effect on the climate.

'Performance' does not start with the building operating, but with the harvest of all the virgin materials needed to build it - and 'Performance' does not end, with the building not being used anymore, but with the final use of construction materials - reuse, recycling or disposal. More and more voices of the industry like the Green Building Councils or The Living Future Institute see our houses as part of a whole life cycle.

The environmental impact of materials and health issues related to building products are as important as building performance, practicality and cost effectiveness. It is desirable that all those factors are implied in every production line and design.

»Thinking sustainable does not stop with environmental impacts, truly sustainable is only a product that creates added value to everything involved in the life cycle, so is the economy, people and culture.«

Seeking a low carbon insulation material to improve thermal performance in New Zealand, it's not farfetched to think of sheep wool. In the following part, I will look at the basic requirements sheep wool meets from a building point of view. More importantly I will examine sheep wool's opportunities beyond common criteria. This means viewing environmental, health, cultural and economic factors that speak for a great insulation product in general and especially in New Zealand.

3.2 SHEEP WOOL

Sheep wool is a natural renewable fibre that is composed of protein just like the human hair. Sheep are domestic animals raised for their meat, milk and wool. They grow their fleece from a simple mixture of grass, water, air and sunshine. Regardless of their breed and purpose, their wool grows rapidly and sheep are usually shorn once per year, producing approximately 4.5 kg (IWTO. 2020) of wool annually.

It is one of the oldest known fibres in human history and has been used since 10,000 BCE. People made clothing to keep warm but wool was already used in construction to seal early timber constructions (Korjenic A. et al. 2014). Today, wool is considered a high quality fibre in the textile industry and favoured to knit jumpers, hats, scarfs and gloves. But the area of use goes far beyond fashion, it is also used to produce protective garments worn by firefighters and soldiers. The natural fibre also appears in houses, where it is converted into interior textiles such as carpets, bedding, upholstery or used inside construction as insulation. It provides excellent properties for thermal, acoustic insulation, fire resistance and handles moisture very well.

Wool comes in a variety of colours and qualities. The quality of wool fibre depends on the diameter (microns µ) and length (mm). Based on the grade/ micron it can be divided in 5 groups: Extra fine, fine, medium, broad and coarse. (IWTO. 2020 p: 9) The well known merino sheep give the finest wool (>14.5 µ) used by fashion designers and made into soft garments and high quality fabric. Coarse wool on the other end of the spectrum, with micron 26-32 µ, is best used for rugs, upholstery and insulation. The finer the wool the higher the price, New Zealand wool export data from July 2019 - February 2020 show that Fine Wool (US$20.702/ per tonne FOB) was about five times more expensive than medium coarse wool (US$4.097 per tonne FOB) (Andrew Burtt. 2020). Wool prices are very low at the moment and farmers struggle. At current prices, the farmer sells the wool for 12 US$ per kg (on average; the fleece's value also depends on what part of the sheep it comes from). (Australian Wool Exchange market reports).

TECHNICAL PROPERTIES

Thermal conductivity **λ**: 0,035 - 0,046 W/(mK)
Density **ρ**: 18 - 30 kg/m³
Resistance to water vapour transmission µ: 1 - 2
Fire performance: flame retardant (B2)
(Baunetzwissen.n.d)

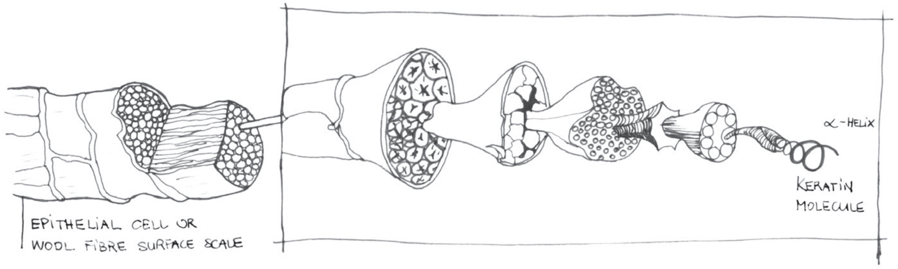


FIGURE 25: Structure of a sheep wool fibre © Laura Feller adapted from (ResearchGate.n.d)

3.2.1 PROPERTIES OF SHEEP WOOL REGARDING BUILDING PERFORMANCE

THE STRUCTURE OF WOOL

Sheep can cope with any weather and their fleece is a natural insulator. The superior properties of sheep wool are a result of the unique structure of its fibres. They are composed of proteins, called Keratin that create millions of tiny air pockets which create the insulating effect that allows sheep to either stay warm in winter or cool in summer (Figure 24).

THERMAL CONDUCTIVITY

Sheep wool insulation has a good thermal conductivity of between 0.035 – 0.045 W/mK. In comparison mineral wool performs between 0.035 - 0,040 W/mK. It's heat capacity value is comparably high and it offers a better thermal heat protection in summer than common mineral wool (Figure 26).

FIRE RESISTANCY

Sheep wool is a superior fibre when it comes to fire safety. Unlike most alternatives it self-extinguishes after the flame is removed, simply because it requires more oxygen to burn than is available in air. (Kufner, H. 2012: p 184) It does not maintain a flame below 570°C-600°C and is difficult to ignite due to its high nitrogen and water content. Furthermore, it will not melt, drip or exhaust any toxic fumes like comparable synthetic products. (IWTO. 2020)

SOUND ABSORBTION

Wool fibre is composed of micro-cavities which contributes to enhanced sound absorption. Wool insulation is an excellent sound absorber, with a noise reduction coefficient of 0.90 from 800 Hz to 2 kHz. (Berardi et al. 2015: p 849)

MOISTURE MANAGEMENT

Confronting moisture and condensation in buildings is one of the biggest challenges we face in the building industry. Sheep wool is hygroscopic and can adsorb a third of its weight in moisture before you can see significant changes in the thermal conductivity coefficient. Comparably, synthetic fibres can only absorb 3% and cotton about 8% (Korjenic et al. 2014: p 250). In fact, wool generates heat when it gets wet. The explanation lays in the physical behaviour of wool, adsorption is an exothermic process and energy is released as the fibre adsorbs moisture. Temperature can be reduced with the opposite effect: energy is adsorbed when wool releases moisture into a dry atmosphere, therefore cools the environment. (Woolmark Company. 2019: p 106). Moreover wool, as a protein, is biologically resistant against the growth of mold which is crucial for any insulation material (Korjenic et al. 2014: p 251).

DURABILITY

The coiled springs of wool molecular chains makes it a resilient fibre. Tests have shown, wool can bend 20,000 times without breaking and even has the power to recover (Korjenic et al. 2014: p 250) Sheep wool insulation lasts the life time of a building structure. There is no decrease of insulation ability due to humidity or other circumstances. Producers like Havelock Wool or Terra Lana give a 50-year warranty.

> ***»Sheep wool fibre can handle moisture like no other insulation material»***

AREA OF APPLICATION

Sheep wool insulation comes in soft matts or loose fill and is a suitable for thermal and sound insulation in all areas, expect for perimeter insulation due to the high pressure impact. Sheep can be torn apart or cut and is easy to install. Due to its flexibility it fits in every shape and is especially suitable for renovations where not everything is square angled.

INDOOR AIR QUALITY & HEALTH

Wool fibres are a complex structure, each fibres consists of 18 amino acids chains to be precise. 60% of those have a reactive side chain and therefore can filter air from harmful chemicals and other odorous substances. This process, where the fibre and the chemicals undergo an irreversible bond is called chemisorption. Sheep wool purifies air, travelling through walls, ceiling and floor cavities, from the most common gaseous indoor air pollutants with known adverse health effects. These are following: Nitrogen Dioxide, Sulphur Dioxide and Formaldehyde. (Hegyi et al. 2020). Formaldehyde is especially harmful and has been classified as a human carcinogen (cancer-causing substance). It is for example found in fibreglass and other common building products like plywood and glues (National Cancer Insitute. 2011).

The treatment of wool with Borax against moths and other insects has to

3.4 ENVIRONMENTAL IMPACT OF SHEEP WOOL INSULATION

be looked at critically, however there are substitutes on the market. Previously used Borax is being banned in some countries including the EU, instead Thorlan IW is used. The inoffensive substance is applied during a process that is similar to dying wool and undergoes a permanent chemical bonding. Products that are treated with Thorlan have received eco certificates like natureplus (Korjenic et al. 2014: p 251). Alternatively, a plasma ionic treatment has been invented, called Ionic Protect® (Brosch.2019: p 5) that functions without additional chemicals. Where Borax is still used, it appears in low concentration such as 0,73% (Sustainable Minds.2020) It has to be mentioned that other insulation materials consist of Borax as well, e.g. glass wool batts contain of 6-7% borax (EPD Australasia.2017).

The low carbon footprint is arguably the biggest argument for natural materials like sheep wool in times of a common effort to limit global warming. It is important to be aware, that a 100% wool product and one where polyester or other fibres are added, can not be put into one pot. The lack of broad data on embodied carbon data is a big barrier comparing specific products and the research often fails to distinguish. Firstly, polyester fibre is produced out of mineral oil (non renewable) and the large amount of primary energy and emissions (Cherrett et al. 2005: p 13) coming add negatively (this is currently improved by using recycled PET bottles) Secondly, common knowledge can make sense of the fact that one material is fully biodegradable and the other one is not. This clearly makes a difference in the whole life cycle approach, no matter if the PE came from a recycled source.

In the following text, wool fibre always implies meaning 100% raw wool. Wool fibre is not only low in carbon, it can even sequester atmospheric carbon. This means wool stores carbon and only releases it in case of biolog-

> ***»The GWP of sheep wool is only about 20% of glass wool, so from a sustainable point of view there is only one winner!«***
> (COMPARE FIGURE 26)

PRODUCT	Thermal conductivity λ [W/mk]	GWP* kg CO_2 eq. / funct. unit	Density ρ kg/m³	Material class DIN 4102-1	Vapour resistancy μ	Heat capacity c J /(kg*K)
Sheep wool	0,035 - 0,045	0,54	20 - 80	B2	1-2	1.800
Glass wool	0,035 - 0,050	2,45	25- 220	A1, A2, B2	1-2	1.030
Polyester	0,035 - 0,040	2,86	15-20	B1	1-2	1.600
Rock wool	0,035 - 0,050	1,93	20-150	A1, A2, B2	1-2	1.030
EPS	0,035 – 0,040	4,17	15-30	B1, B2	20 - 100	1.500
XPS	0,030 - 0,040	4,2	20-50	B,B2	80 - 250	1.500
SPRAYFOAM	0,025 - 0,040	4,3	30-80	B,B2	30 - 100	1.400

FIGURE 26: Properties of insulation available in New Zealand © Laura Feller: Data source from (Baubook Info.n.d)

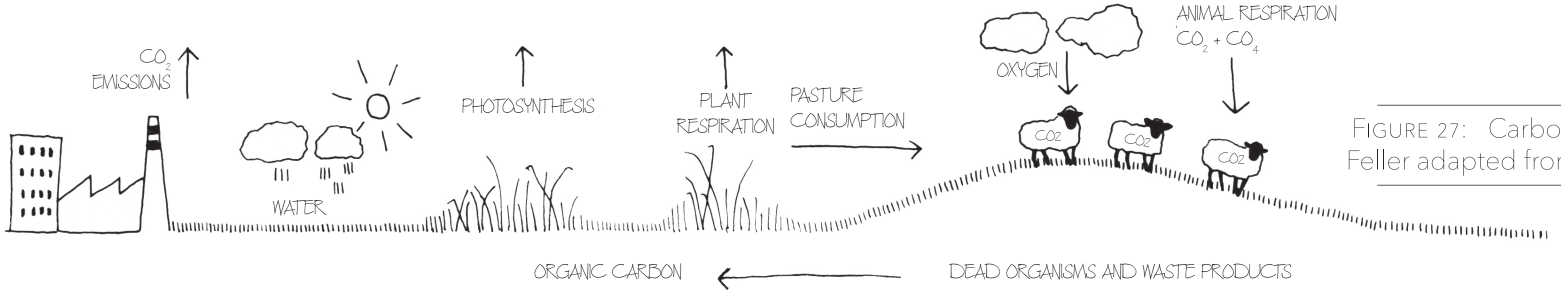
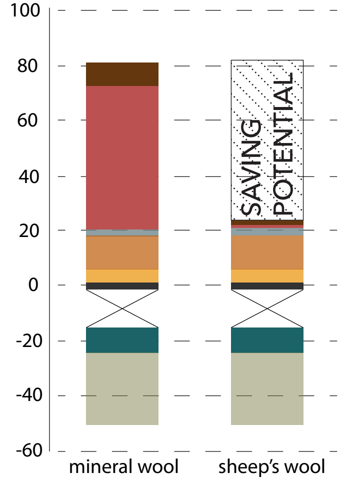
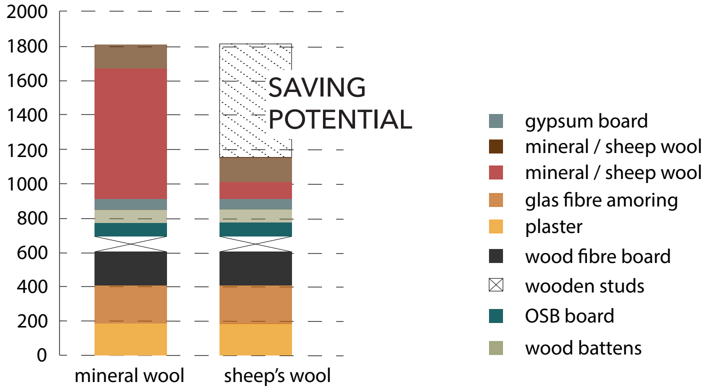


FIGURE 27: Carbon storage in sheep wool © Laura Feller adapted from (TheWoolmarkCompany.2019)



GRAPH 1: CO_2 equivalents in kg of wood frame construction with mineral wool and sheep wool, respectively



GRAPH 2: Primary energy in MJ/m^2 of wood frame construction with mineral wool and sheep wool, respectively

FIGURE 28: Comparison of mineral wool and sheep wool impacts in a standard timber frame wall © Laura Feller adapted from (Korjenic et al. 2014: p 254)

3.4.1 COMPARISON OF SHEEP WOOL AND MINERAL WOOL

ical degradation. Like this houses can work as a carbon storage for a century or more. Carbon makes up 50% of the weight of wool (compared to 40% for cotton and 24% for cellulose).It is stored, through the process of photosynthesis, in the grasses and other plants that sheep eat (Figure 27).

»1 kg of clean wool equates to 1.8 kg of CO_2 stored«

which is roughly the same as stored in solid timber (Architecture 2030.2020). While sheep wool sequesters CO_2, sheep being living creatures, produce methane. Methane (CH4) is a green house gas with a 20 times higher GWP than CO_2. To take account of the main purpose of a sheep meat production, the methane emission has to be shared and will create lower individual footprints (Korjenic et al. 2014: p 254). Furthermore, research has shown that even with the emitted Methane gas sheep wool has a significant lower impact than synthetic insulation (Figure 26). An interdisciplinary research project between the Vienna University of Technology and the Brno University of Technology suggests that CO_2 equivalents of mineral wool are 75% higher than of sheep wool [Graph 1 (Figure 28)]. Graph 2 (Figure 28), indicates that sheep wool needs just over a quarter of the primary energy mineral wool needs to be produced. I was able to prove these numbers in my case study, comparing sheep wool and glass wool.

Glass wool is a mineral wool out of glass fibre that is non combustible and provides good R-values. The high GWP comes from manufacturing process that requires very high temperatures. The raw materials - window glass (up to 78-84% recycled), Borax /6-7%), Feldspar sand (5-6%), Limestone and soda ash(1-2%) - are melted at 1.300-1500°C and the droplets of melt exiting the furnace are spun into fibres (Eurima.2018). Phenolic binder (2.5-10%), which is a phenol formaldehyde resin (carcinogen), is added and the glass wool is then hardened by 200°C (EPDAustralasia.2017). At the end of its life it can theoretically be put back in the manufacturing process. In most cases the material goes to waste into landfill because it is not dismantled correctly.

3.5 WHOLE A LIFE CYCLE APPROACH FOR SHEEP WOOL INSULATION IN NZ

PRODUCT STAGE

A1 RAW MATERIAL SUPPLY

In New Zealand coarse wool is mostly grown as a side product of sheep meat production with no purpose in the textile industry. Currently to over 70% exported and processed by other countries.

A2 TRANSPORT

The small size of the New Zealand naturally requires short trips (Figure 17), this saves both CO2 and money for the business. Independent collection points for wool and manufacturing processes, for each the North and the South Island, seem logical (at present Auckland and Christchurch) to keep transportation even shorter. Freight is currently transported by trucks and also using a local train system connecting most of the country. Development in electric trucks or other low carbon solutions are welcome.

A3 MANUFACTURING

Manufacturing sheep wool requires no energy intensive processing or high temperatures . First, the fleece is washed and cleaned from vegetable matter (sticks, grass),dirt (sand, oil) and grease (Lanolin). This happens at about 50°C using soap and soda as a detergent (A. Korjenic/J. Zach/J. Hroudová. 2014: p 249). The natural grease Lanolin can be easily sperarated during this process and is made into healthy personal care products e.g. lip balm or cream or shoe polish and gives the process additional value (IWTO.2020). A treatment against moths is needed and the means of protection are constantly reviewed and tested to be environmental friendly. Alternative to biocides there is development on a plamsa ionic treatment called Ionic Protect®, which is proved to permanently protect against insects. (Brosch.2019: p 5)

CONSTRUCTION/ INSTALLATION STAGE

A4 TRANSPORT

Once the product is packed, it will be distributed to local shops or directly to the site. Regarding the transport phase A2 applies also to A4. The bigger the network of small manufactures in every region the shorter are individual transports.

A5 CONSTRUCTION

The batts come in a variety of widths and can be simply torn by hand or cut into the right lenght using big scissors or a special saw. Loose fill is blown in by a machine, this needs electricity and the use of green energy is highly recommended to reduce the overall foot print. Studies show that there is no known concern about potential health risks from working with sheep wool (Mansour E. , Loxton C. , Elias R.M. , Ormondroyd G.A. 2014). Unlike other insulation materials e.g. glass wool there is no need to wear a face mask to protect airways.

USE STAGE

B1-B5 MAINTENANCE, REPAIR & REPLACEMENT SUPPLY

Without being exposed to extreme water damage (moisture content > 30%), sheep wool will last the lifetime of a building. If needed sheep wool can easily be topped up or replaced, as it is permanently connected to the buildings structure.

END OF LIFE STAGE

C1-C4 DECONSTRUCTION, TRANSPORT, WASTE, PROCESSING & DISPOSAl

No hazardous waste comes out of wool insulation and easy the material can be easily gained for further processing. Further opportunities showed in Figure 29 and explained on the next page.

> ***»The mix of a natural and a synthetic fibre should generally be revised in the industry, ultimately the advantage of a biodegradable material is lost.«***

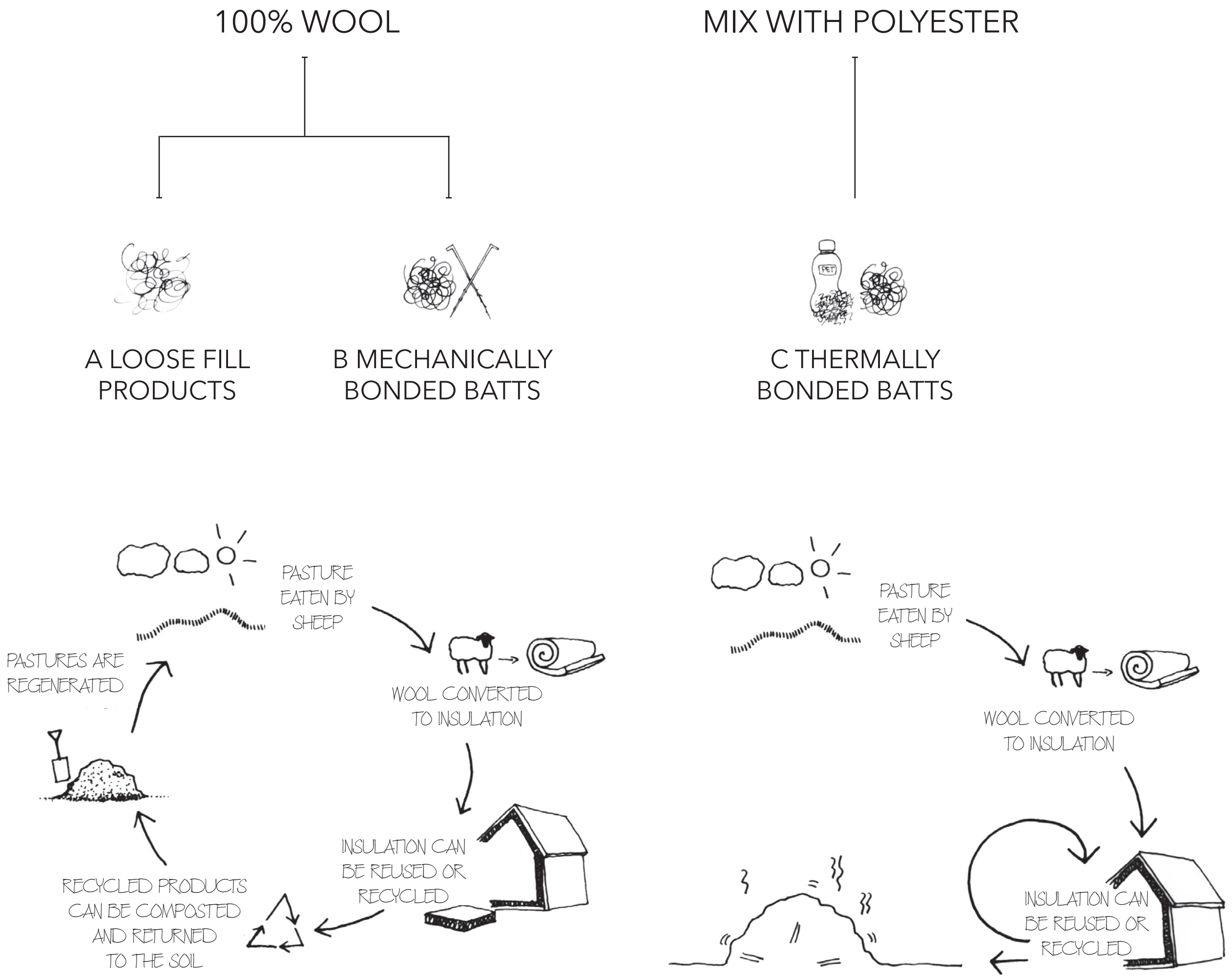


FIGURE 29: Methods of manufacturing © (Laura Feller.2020g)

BEYOND THE LIFE CYCLE D

[A+B]
Pure wool can either be 100% reused for insulation material or other wool products, or de-composted.

Biodegradation (A+B)
Depending on the environment the fibre will be broken down by specific bacteria and fungi within 3-6 months and goes fully back to the soil (Hodgson A., Collie S. 2014).

[C]
Products that contain a percentage of polyester or other fibre for binding can only be reused in the same production line. Otherwise landfill is the only option and it ends up there together with non natural products like glass wool, EPS or XPS and adds to our waste and pollution problem.

3.6 HISTORY OF SHEEP & IMPORTANCE FOR NEW ZEALAND'S ECONOMY

3.6.1 HISTORIC BACKGROUND

Thinking sustainable does not stop with environmental impacts, truly sustainable is only a product that creates added value to everything involved in the life cycle, so is the economy, people and culture. Sheep wool is a locally produced renewable fibre. Sheep farming has played a very important role in New Zealand's industry for over 130 years. James Cook released the first two sheep in 1773 nonetheless sheep farming wasn't established before the 1950s. Initially there was mostly South Island farmers, however as more and more Europeans settled on the North Island the trade was quickly spread over the whole country (Stringleman H., Peden R. 2015).

»Bring back the Golden Years of Sheep wool in New Zealand!«

The export of wool has played a crucial part of the economy since the 1850s. It accounted more than a third of the country's exports for several decades. With the first ever shipment of frozen sheep meat to Great Britain in 1982 a milestone was set. A noticeable shift toward meat production appeared. It was in the same year when the sheep population peaked at just over 70 million. That would have been around 20 sheep per inhabitant, so roughly four times more sheep than New Zealand has now.

Between the mid-1880s until the late 1980s income from sheep wool and meat dominated the market. With increasing production for the overseas market everyone - agronomists, plant breeders, soil scientists, geneticists and animal breeders - worked together to improve sheep farming. In "the grassland revolution" new science was applied to agriculture and the countryside was turned over to grow more and better grass. Another turning point was the successful spreading of fertiliser from aeroplanes which happened around 20 years after the second world war. The so called "Golden Years" happened in post-war times, when Great Britain took all the meat and wool New Zealand could produce. The first oil-shock in the early 1970s occurred and costs of production started raising significantly. Furthermore the invention of synthetic fibres would change the history of fashion forever. The wool price has never recovered from that. (New Zealand History. 2019)

3.6.3 SHEEP FARMING TODAY

After the mid-1980s agriculture moved to dairy farming and returns from the dairy industry overtook those of sheep production. Nonetheless, New Zealand is the second largest exporter of sheep meat globally, Figure 30 shows the shift from wool production towards meat production in New Zealand. (Workman D. 2020). It also remains the second largest exporter of sheep wool world wide, with 20% of the world's exports by volume, after Australia with 52%.

Most of New Zealand's wool is processed outside the country. About a third of the total volume is handled in New Zealand where it is made into carpets, rugs or other finished products locally. A percentage also goes through various stages of wool processing, including combing, spinning and being made into yarn. All the other 70% of wool is exported raw or scoured, where grease, dirt and other contamination is removed to be woven and spun overseas (Nicol A., Saunders C. 2008).

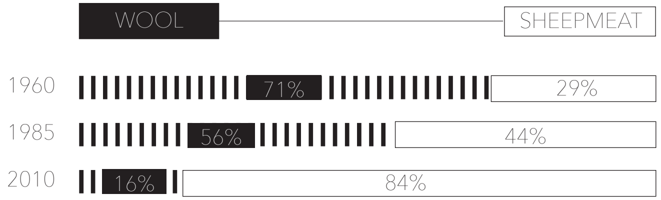


FIGURE 30: Sheep wool and meat export in New Zealand © Laura Feller adapted from (ArchiveStats.2011)

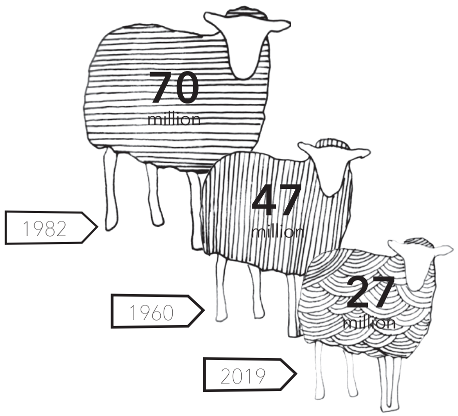
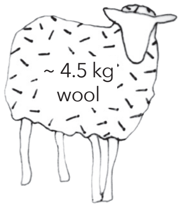


FIGURE 31: Number of sheep in New Zealand © Laura Feller adapted from (New Zealand History. 2019)



TOTAL WOOL IN 2019
121.500 t

FIGURE 32: Sheep per region in 2018 © Laura Feller adapted from Andrew Burtt (2020)

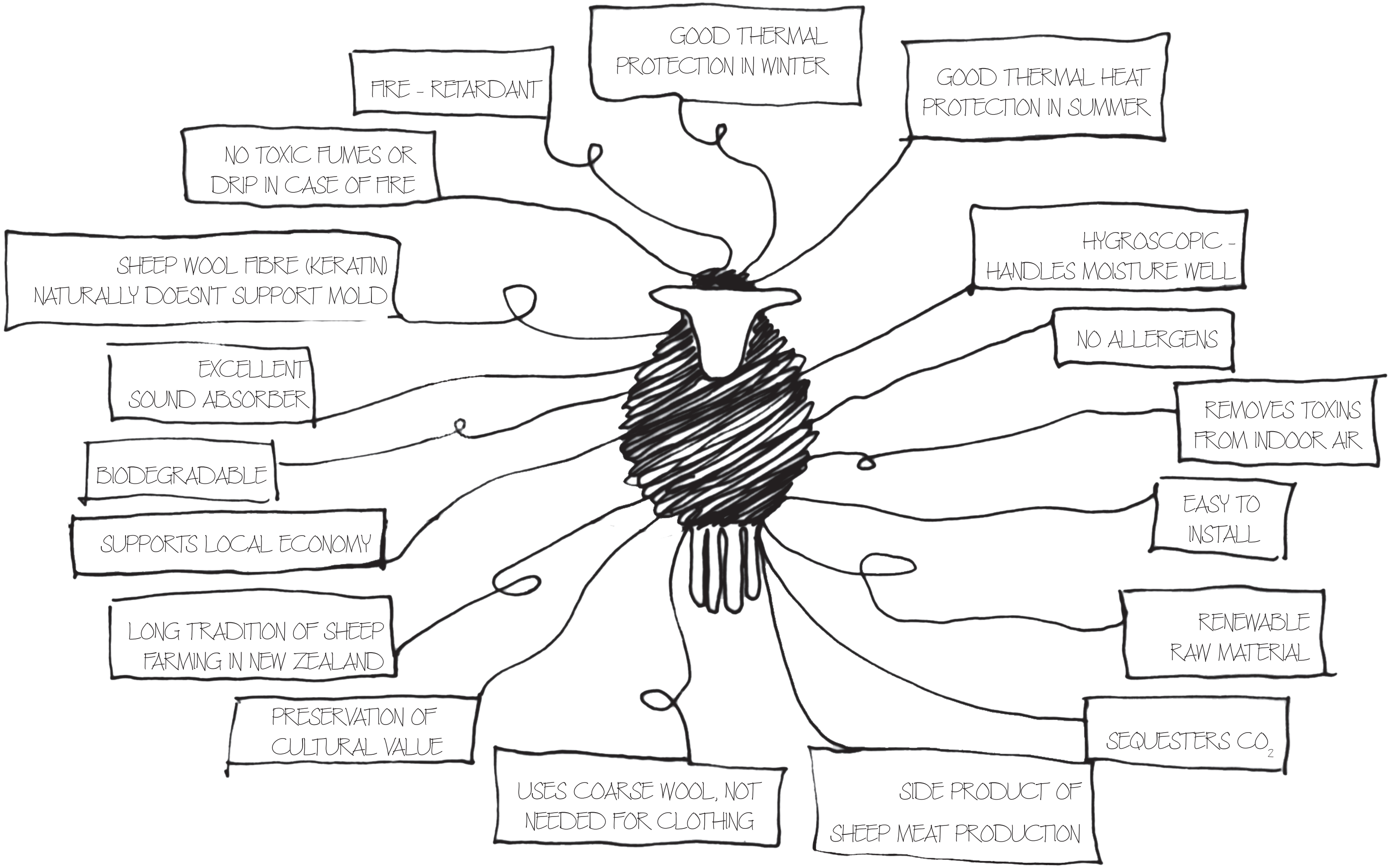
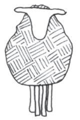


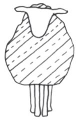
FIGURE 33: Properties of sheep wool at a glance © (Laura Feller.2020h)

3.7 COMPETITION ON THE MARKET

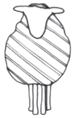
eco insulation systems
www.ecoinsulation.co.nz/ecofleece



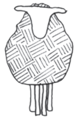
INSULWOOL®
www.insulwool.com



Natural Wool Products
www.naturalwoolproducts.co.nz



Terra Lana
www.terralana.co.nz



Manufactures in New Zealand

Sheep wool insulation products show excellent properties and meet and/ or exceed building product standards. After all, the most common argument against sheep wool insulation is simply the price. Sheep wool products are currently not available in wholesale and a valid statement about the cost is not possible. A rough comparison shows that sheep wool products are 2-3 times more expensive than glass wool or rock wool (Healthbasedbuildings.2020). On the other hand e.g. polyester insulation, which is, an alternative to mineral wool offered in New Zealand's hardware stores, appears slightly more expensive (4% on average) (Mitre10.2020).

Understandably, the average homeowner can not take on the extra cost. I assume, currently only people with an increased awareness of global warming or with the right budget choose sheep wool for their home. Therefore, the shift towards a fair price has to be initiated by policymakers acting towards the goals in the Zero Carbon Act.

HOW TO INITIATE CHANGE

- awareness
- compensate carbon emissions
- funding through grants
- certificates
- eco labels

A cap for CO_2 emissions and uniform carbon labels will be motivation for manufacturers to invest in sustainable building solutions. The much discussed 'carbon tax' will be an effective tool, to even out the price difference between glass wool and sheep wool. It only seems logical that the emitter of emissions has to stand up for them. Only when the whole life cycle is taken into account, the customer can see the real price of a product.

Tools the government can control to support homeowners, are grants for building projects that are bound to low carbon construction, as well as mandatory certificates with carbon ratings for real estate, that creates in-market creased value.

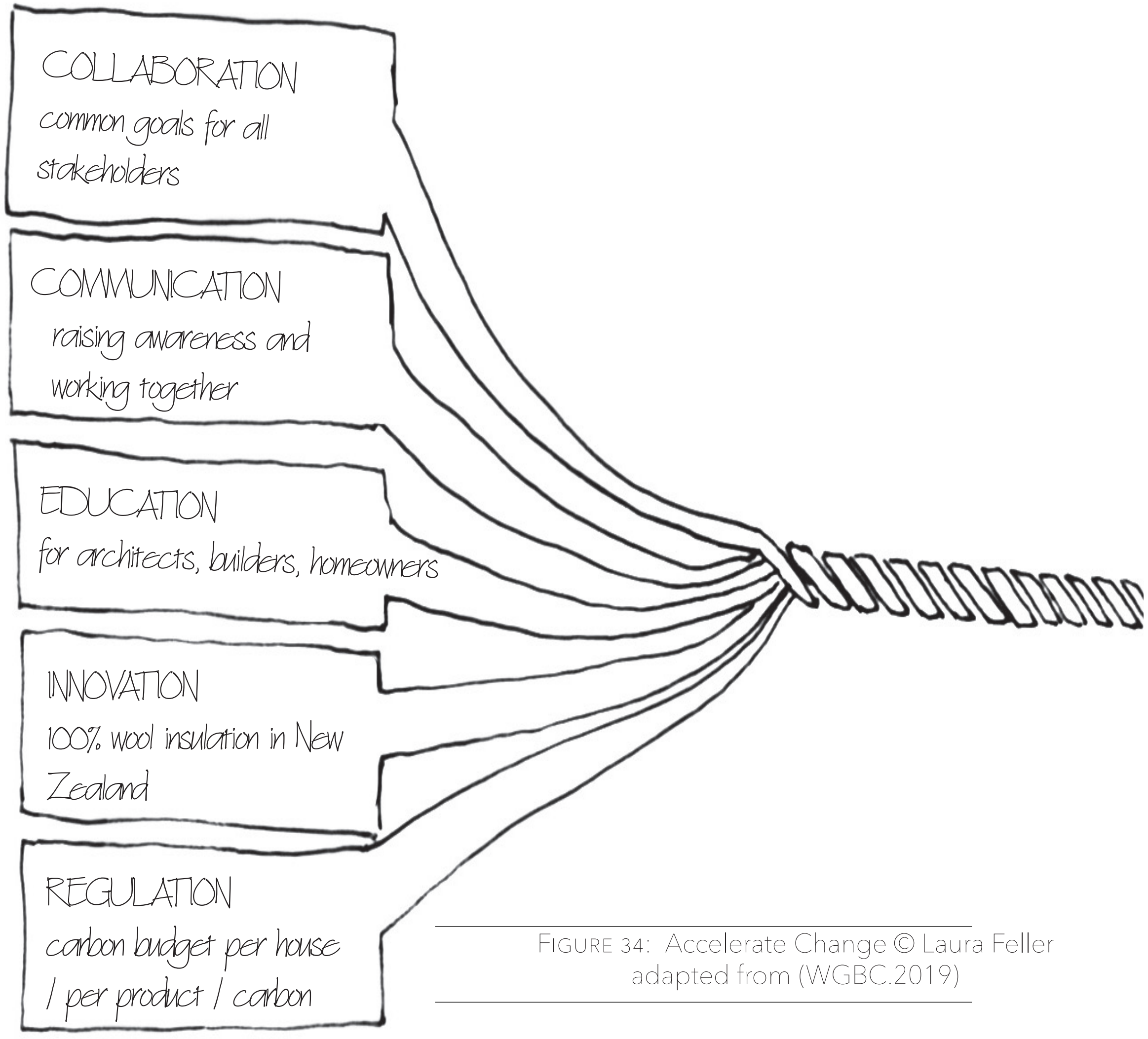


FIGURE 34: Accelerate Change © Laura Feller adapted from (WGBC.2019)

»Sheep wool in action«

Recent public action and a petition in favour of wool insulation shines light on the future of sheep wool in the building sector of New Zealand. This implicates a much welcomed rising awareness and demand on sheep wool insulation, the country has to prepare for.

The interest of all stakeholders must share the common vision of reaching climate targets. The government is liable to the Climate Change Amendment Act and will have to support alternative solutions in the building sector to reduce enough emissions. Certificates and lables can be great motivation for both manufacturer and consumer and should be further developed in the country. Also funding can initiate a change in current practice, like the petition of Amy Blaikie suggests: 'New Zealand wool products used in public-funded buildings and KiwiBuild home. (Amy Blaikie. 2020).

3.8 CONCLUSION & PROSPECT

> ***»We need an acceleration of renovations, with the knowledge of low carbon solutions.«***

Wool insulation products have been used for centuries and are available in many countries of the world and have a wide field of application. There are batts or loose fill products available on the market. For walls, roofs and ceiling both batts and loose fill are suitable. For underfloor installation the batts version is the most practical. Furthermore, wool fleece can also be used to insulate air or heating pipes and for foot step sound insulation. Only for perimeter insulation sheep wool, like other fibres, can not perform due to the high pressure impact.

Currently, there are two major factories, one in Auckland to supply the North Island, and one in Christchurch to supply the South Island. Existing products are either a 100% wool loose fill or batts bond with polyester. The needle felting method, that can produce batts without additional synthetic fibre, is not yet practised (Havelock Wool US, Isolena, AUT). Urgent development in the industry is needed and New Zealand's manufacturer have to learn from other countries. Moreover, architects and builder have to be educated in order to make the right choice of insulation material for their building projects.

My research about sheep wool concluded, that it is superior to common insulation materials - e.g. glass wool, PU foam, mineral wool, and EPS - in many ways. In New Zealand, the comparison with glass wool (PinkBatts®), which is currently the most used insulation product, is particularly meaningful. PinkBatts® does not compete with sheep wool, in any category I have reviewed, except the price of the product. The money issue comes back to the end-consumer and explains the lower popularity of existing sheep wool products. A lower demand leaves sheep wool manufacturers with smaller budgets and less possibilities to stand up against heavy industries at the time.

Finally, long overdue compulsory compensation for factories carbon emissions, would automatically regulate the price of insulation products, and put sheep wool in a competitive position on the market.

4 CONTENT

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4 A BRIEF HISTORY OF HOUSING IN NEW ZEALAND

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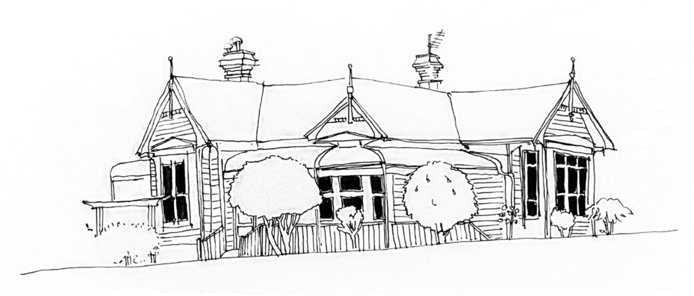
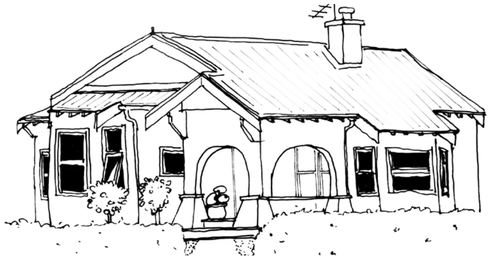


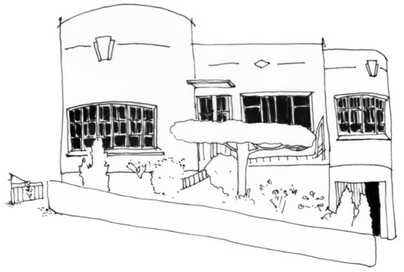
VILLA

1880 - through to WW 1



BUNGALOW

1920 - dominant style in WW 1



ART DECO

1930s

1950s State Housing

1940s - 1960s

1950s Private Housing

1940s - 1960s

1970s Housing

1970s

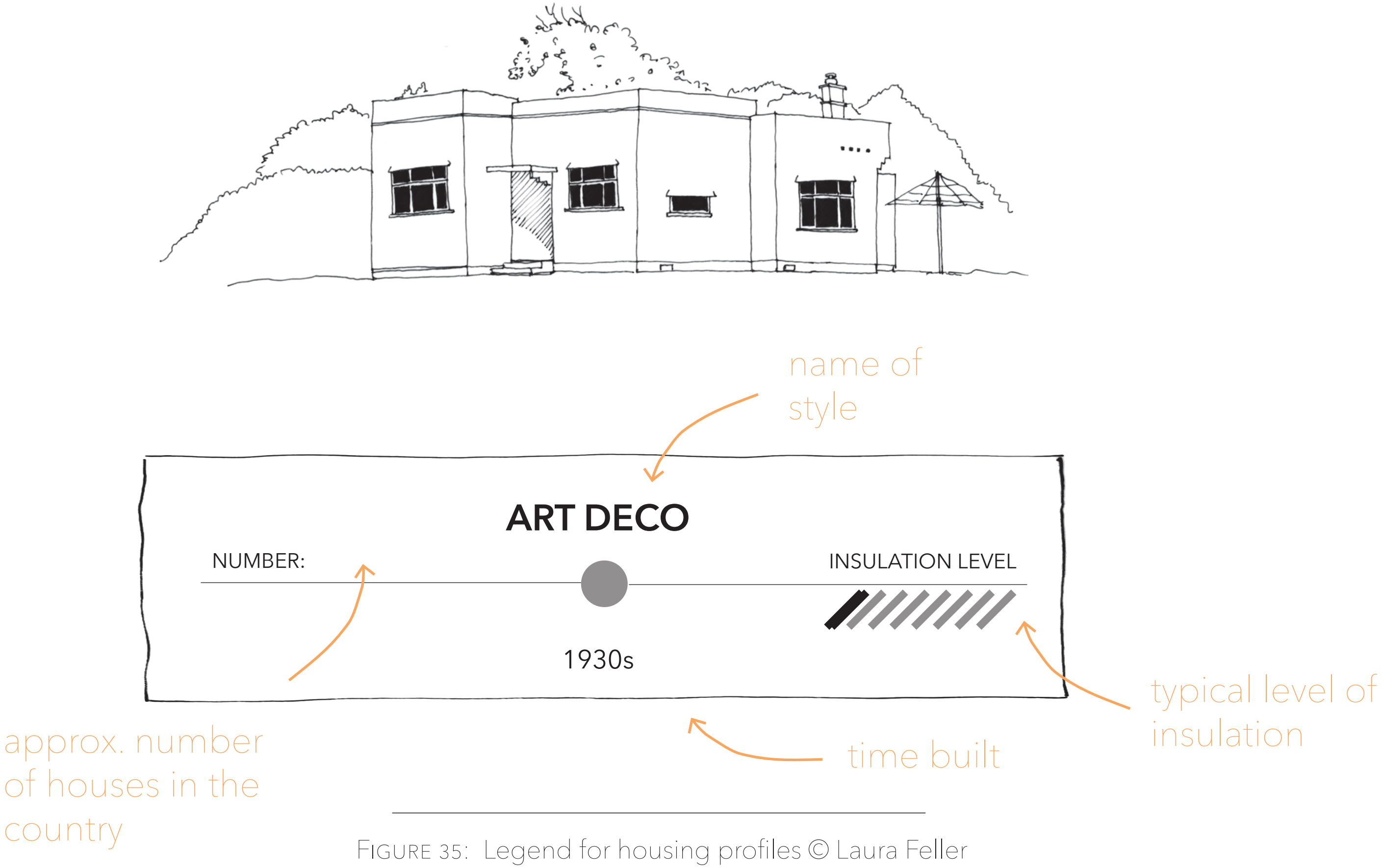


FIGURE 35: Legend for housing profiles © Laura Feller

4.1 NEW ZEALAND'S PRIVATE HOUSING STYLES *SIGNIFICANT FOR RENOVATION*

New Zealand's history of western houses is relatively young compared to the rest of the world. Abel Tasman was the first European to discover the South Pacific Island group in 1642, but the first settlers would not arrive until almost 200 years later (History. 2010) The oldest surviving dwelling is the 'Kemp house' in Keri Keri dated back to 1821. It was only certain regions in the far North where traders and settlers built permanently, the majority lived in traditional Maori 'whare' or in simple tents or other shelters (Stacpoole. 1976). From the late 19th century different housing styles started to develope, with plenty of land available the majority of dwellings were detached or semi-detached and usually single-floored.

New Zealand's architecture has formed five significant groups of housing styles between the years 1880-1980. In 1978 thermal insulation was introduced to the building code for the first time. Consequentially, many of those early houses still have very little or no insulation. This brief study on historic housing stock aims to provide an overview of exisiting New Zealand houses that are important for renovation today. Furthermore, key findings of different housing types help to define a case study project, that is representative for a large group of dwellings.

For each style the following key features are indicated as shown in Figure 34:

- approx. number of houses in New Zealand
- name of style
- time built
- typical level of insulation

FIGURE 36: Villa 135 Lemonstreet, New Plymouth © (Laura Feller.2020i)

4.1.1 VILLA

NUMBER: 85.000

INSULATION LEVEL

1880 - through to World War 1

The villa design was developed when urban population in colonial towns and villages increased drastically in the 1880s. Most of these were single-storey houses with a hip roof sloping about 30–45°.
Often found is a decorated veranda or porch and one or more bay windows facing the street. A typical layout would have a central corridor with the living area (known as the 'parlour'), three bedrooms, a kitchen and pantry. Indoor washing facilities and toilets were only incorporated later on. The construction was almost entirely built out of timber with metal roofs. Weather board was the most common facade, nevertheless there are villas made of brick masonry. (Salmond, J. 1986: p 110-180).

The villa style is still very popular and renovating of these houses is a significant part of the building industry. Originally, they had no insulation and although, some are retrofitted already, many have yet to be renovated (BRANZ Renovate. n.d.)

FIGURE 37: Bungalow 111 Liardetstreet, New Plymouth © (Laura Feller.2020j)

4.1.2 BUNGALOW

INSULATION LEVEL

STOCK: UNKNOWN

1920 - dominant style in World War 1

International trends started to have a big influence on New Zealand. During this time buildings and villas gradually transformed to a bungalow style house. Typical features are a low-pitch roof sloping about 15–25°, horizontal weatherboard and one large, deep, projecting verandah or porch, sometimes two.

The bungalow layout was less formal than villas, it shares the central corridor as well as the living area located in the front. Houses of that time had services like bathroom, toilet and laundry inside.

Bungalows were single-storey houses constructed with timber, some exemptions made out of brick. The roof are usually clad in steel, shingles or Marseille tiles. (Salmond, J. 1986: p 186-211) At the time of their construction no insulation was installed, however in some cases underfloor insulation has been added. Major retrofitting is needed to meet current standards and increasing energy efficiency (BRANZ Renovate. n.d.)

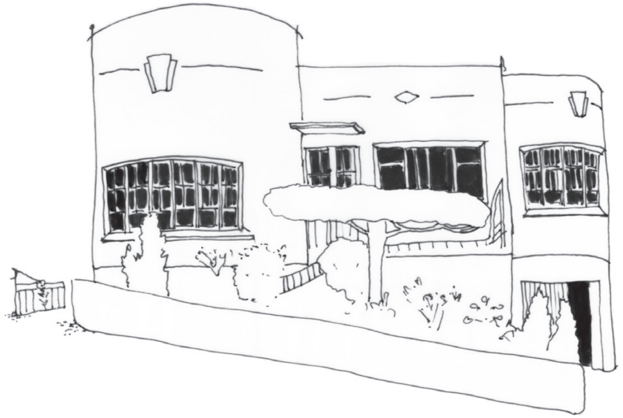


FIGURE 38: Art Deco House © Laura Feller adapted from (BRANZ Renovate (n.d.)

4.1.3 ART DECO

NUMBER: UNKNOWN

INSULATION LEVEL

▨

1930s

In the 1930s the modern style appeared and marked the arrival of art deco houses in New Zealand. The International style remained an architect's style and never reached the mass-housing market here.

Based on European influences, building design were very functional, most decorating elements disappeared and so did the pitched roofs. Common themes were parapet walls with rounded corners, flat roofs invisible from the street view and doors and windows without external facing boards. The verandah from ealier times gave way to a shallow recessed porch. To meet the clean look, international modern buildings were made from steel and concrete and the wall cladding was typically stucco - a cement plaster applied onto a timber construction. Adaptations with bevel-back weatherboard, brick and concrete were used occassionally. Art deco houses were built without insulation and widely still lack it, due to the difficult access to ceiling, wall and floor space (BRANZ Renovate. n.d.).

FIGURE 39: State housing Cook Street, New Plymouth © (Laura Feller.2020k)

4.1.4 1950s STATE HOUSING

INSULATION LEVEL

NUMBER: 30.000

1940s -1960s

The biggest influence on New Zealand houses, in the 1940s until the 60s, was state housing. Addressing the shortage of both skilled workers and building materials the Government built high quality economical homes, 80% stand-alone and the remaining 20% semi-detached. Houses used standardised components and a range of standard plans, following newly introduced building regulations.

There was an ambition to give those state houses and individual look.

The governments brief required different floor plans and elevations in every group of 10 buildings on a street. Key features were a rectangular floor plan consisting of 2- 5 bedrooms with simple hip or gable roofs and no decoration. The doors were set back shallow and windows were rather small and multi-paned.

Houses built during that time, originally had no insulation. Despite that many buildings have been altered over time, very few have reached today's standard. (Elkink A. . 2011)

FIGURE 40: 1950s house 56 Mid Puniho Road, Warea © (Laura Feller.2020m)

4.1.5 1950s PRIVATE HOUSING

NUMBER: 262.000

INSULATION LEVEL

1940s -1960s

In the early 1940s very few houses were built privately and financing rules heavily influenced the look, tleading to private homes closely resembling state houses. Two key differences make it possible to distinguish: In private houses it was popular to use corrugated steel for roofing and stucco for walls, both never appeared in state housing.

Layout and form had more variation than earlier styles, yet common features include a fairly small, efficient layout that was oriented for sun and a roof with 30° pitch. Windows got larger and a family space was often included. In the 1960s there was a period of brick and tile houses but timber had already gained popularity again by the end of the decade. During that time architects explored 'the New Zealand' style, that represented local values and environment. Typical were hipped or gabled roofs topped with finials and long verandas that extended the full length of the house and exposed brick fireplaces."(Elkink A. . 2011: p 22-26)

Houses built during that time, originally had no insulation. Many of these buildings have been altered over time, however very few have reached today's standard.

FIGURE 41: 1970s house © Laura Feller adapted from (BRANZ Renovate.n.d.)

4.1.6 1970s HOUSES

NUMBER: 279.000

INSULATION LEVEL

1970s

The 1970s were a period of expanding suburban developement. Common designs were characterised by the architectural styles that have developed in the last century. Many were built by developers, as so called 'spec' houses. Those were usually rectangular or L-shaped and built with lower-cost materials. A lot of them were just built from generic plans and are not particularly suitable for the site and/ or poorly orientated. Open plan living reached high popularity and you can see increased presence of garages, often with internal access.

Most constructions were still timber frame, with a higher grade of prefabrication, nevertheless alternative constructions methods e.g. concrete block constructions were pioneered by architects.

Houses started to have some insulation after 1978, after the first insulation requirements were introduced (Figure 18). A large proportion of 1970s houses has never been updated to current standards and need renovation (Elkink A. . 2011).

4.2 TYPICAL CONSTRUCTION

Common properties in pre-1980 houses give an idea of a typical New Zealand home. There were very little two-storey houses and most of them were stand-alone. Still today is estimated that 80% of housing nationally is stand-alone and another 19% is multi-unit but the majority is low-rise ((Bengtsson J. et al 2007: p 31). Approximately 70% of houses are in the 100 to 200 m^2 floor area range, representing two- or three-bedroom houses.

The majority of dwellings have a timber frame construction. Studs at 400 or 600 mm centre were originally just braced with outside cladding, from the 1950s dwangs were added to the structure. The most popular foundation was suspended timber floor (73%).

Houses had typically either a hip (Figure 42)or gabled roof. The most used material for roofing was sheet steel, followed by pressed metal and concrete tiles. (Bengtsson J. et al 2007: p 4)

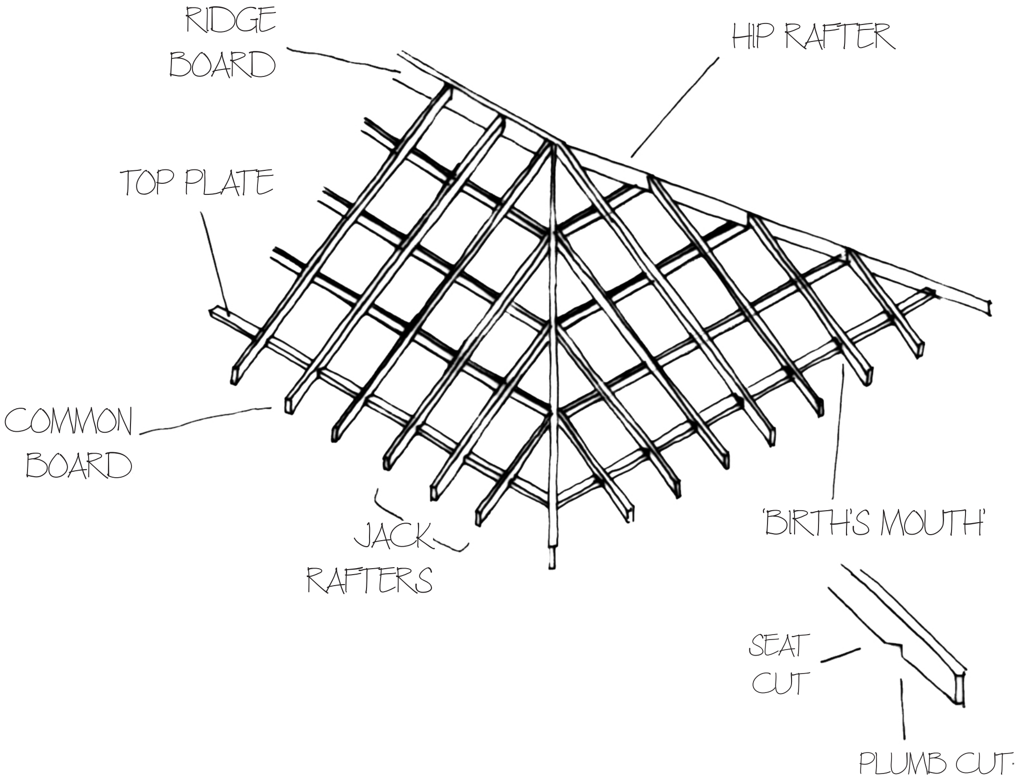


FIGURE 42: Typical roof construction 1940s-60s © Laura Feller adapted from (BRANZ Renovate.n.d.)

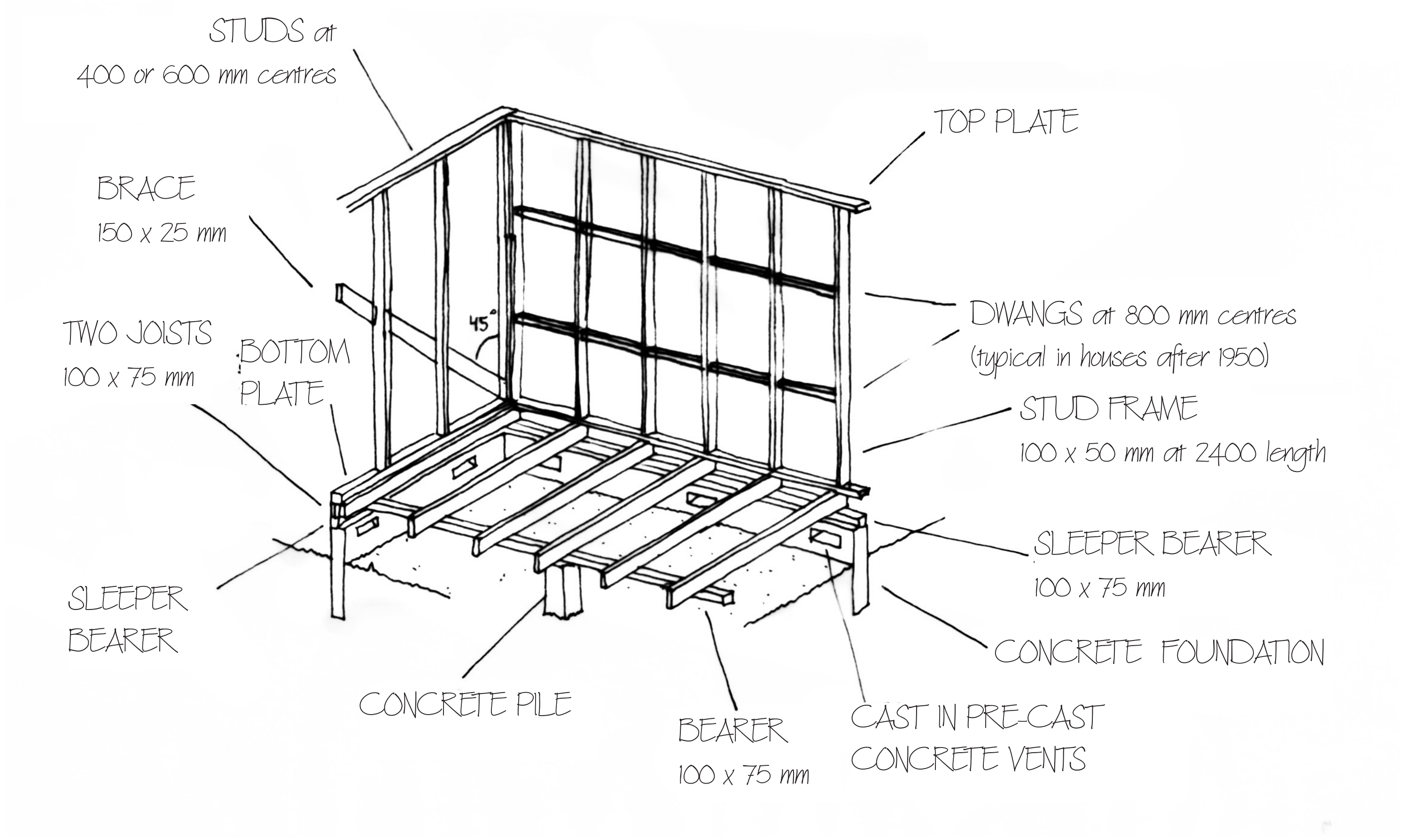


FIGURE 43: Typical timber frame construction © Laura Feller adapted from (BRANZ Renovate.n.d.)

4.2.1 TYPICAL WALLS

Timber wall claddings are predominant for pre-1970 housing. Stucco, brick veneer as well as asbestos-cement façades becoming more and more popular (Figure 44 - Figure 47). Inside linings were commonly plaster board or softboard, with either wall paper or a paint finish.

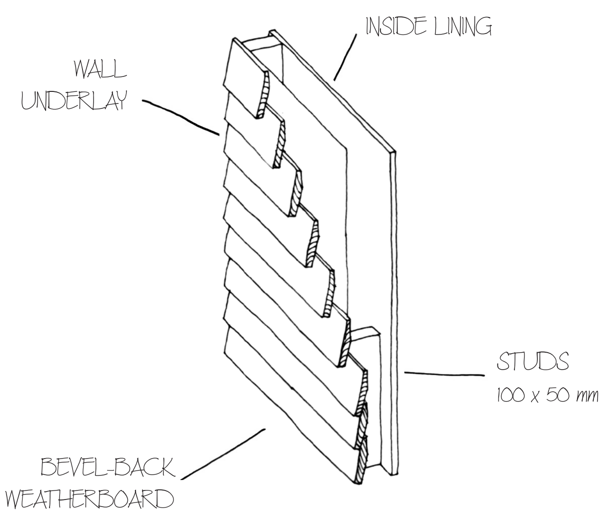


Figure 44: Bevel-Back weatherboard © Laura Feller adapted from (BRANZ Renovate.n.d.)

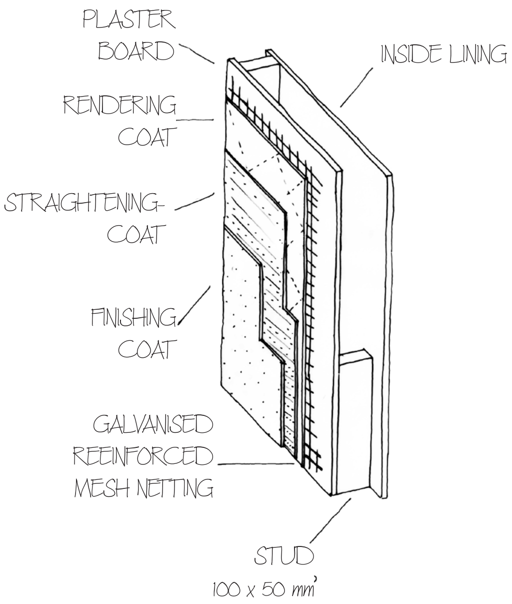


Figure 45: Stucco © Laura Feller adapted from (BRANZ Renovate.n.d.)

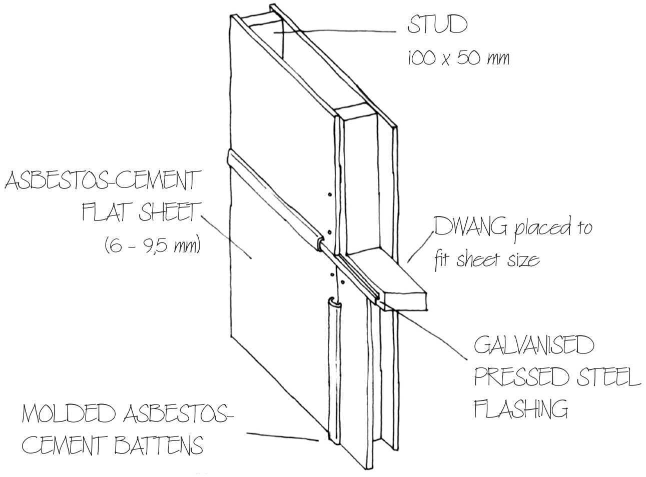


FIGURE 46: Asbestos-cement flat sheet © Laura Feller adapted from (BRANZ Renovate.n.d.)

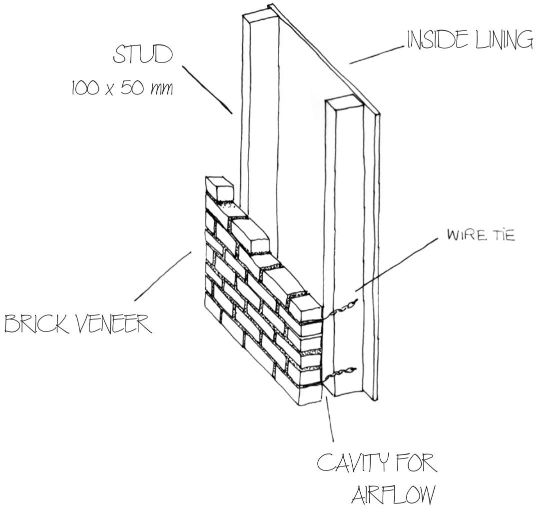


FIGURE 47: Brick veneer © Laura Feller adapted from (BRANZ Renovate.n.d.)

4.2.2 TYPICAL INSULATION LEVEL AND GLAZING

All residential houses built in the late 19th century up to the late 1970s had very little or no insulation. A BRANZ report suggests that the number of existing houses from that period reaches about 800.000. Further analysis suggests that about half of them had not been retrofitted with any or sufficient insulation (including retrofitted buildings.) Currently there are over 390,000 homes with no insulation or insufficient insulation levels. Comparable the 2018 Census counted 1.886.517 total dwellings in New Zealand (StatsNZ. 2018).

Windows were originally timber frame with single glazing, over the years many of them have been replaced by aluminium frames. Unlike European windows, the majority is hinged at the top (awning) rather than on the side.

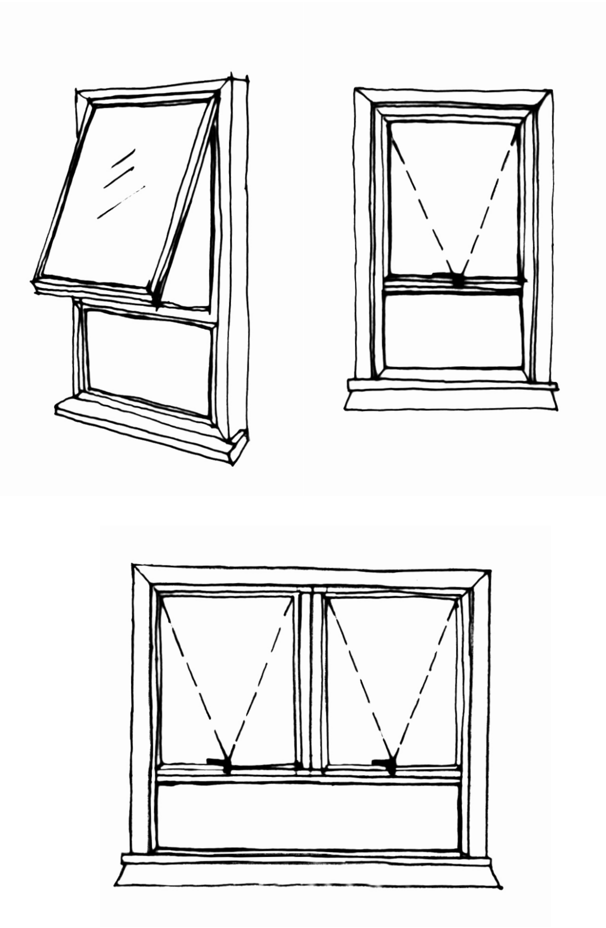


Figure 48: Typical windows © Laura Feller adapted from (BRANZ Renovate.n.d.)

4.3 BENEFITS OF RETROFITTING

The benefits for retrofitting thermal insulation can be various and can be broadly categorised as follows:

- Reduced energy costs (heating in winter / cooling in summer)
- Reduced health problems
- Improved living comfort
- Improved noise mitigation
- Improved house value/resale value
- Improved quality of building stock
- Improved impact on environment through energy savings

R-values (m^2 °C/W)

COVERAGE	Ceiling	Wall	Floor	Windows*
Auckland + Wellington	R 2.6	R 2.2	R 1.4	R 0.26
Christchurch	R 3.2	R 2.2	R 1.4	R 0.31

*Double glazing with aluminium frame

FIGURE 49: Recommended 3rd level Insulation © Laura Feller adapted from (Bengtsson J. et al 2007)

4.3.1 FINANCIAL FACTOR

Not only the concerns about the living condition and the building substance, but also the economic factor suggest urgent action. The net present value (NPV) decreases over time, which means the longer we wait to start retrofitting, the lower the lifetime benefit for the building (resulting in a lower NPV). (Bengtsson J. et al 2007: p 9)

For a maximum NPV it is recommended to upgrade to a 3rd insulation level (Figure 49), with no awnings installed and no upgrade from single glazing to double glazing. However, where it is possible, double glazing retrofit is recommended. It still provides positive NPV, for about 2/3rds of maximum NPV for most cases (Bengtsson J. et al 2007: p 67). The same report has created models with different retrofitting scenarios, and all agree on an estimated 10 years to retrofit existing houses with insufficient insulation.

FIGURE 50: A villa on Grafton Road, Auckland © (Laura Feller.2020n)

Typical features of a villa can be seen: bay windows, the verandah, weather-board cladding and decorative elements on the porch.

4.4 CONCLUSION

Thermal retrofitting is a major challenge concerning almost a quarter of New Zealand's housing stock. Over 390,000 homes built between 1880 and 1970 need insulation and/ or other modifications.

In addition to the need of insulation, large numbers of homes (constructed before the 1970s) may be due for major maintenance within the next the next few years. If this is the case the replacement of cladding and/or windows give opportunity to install insulation in walls and hard-to-access roof spaces. Underfloor spaces provide commonly access and enough space to fit underfloor insulation.

Nevertheless, many houses have intact outside cladding and the cost of replacing single-glazed windows is not feasible for the homeowner. More so in favour of reducing embodied carbon, possible repairs have to be chosen over replacement.

In conclusion, a large 'wave' of thermal retrofitting has to arrive and it should be done promptly both considering embodied and operational carbon emissions.

5 CONTENT

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5 CASE STUDY

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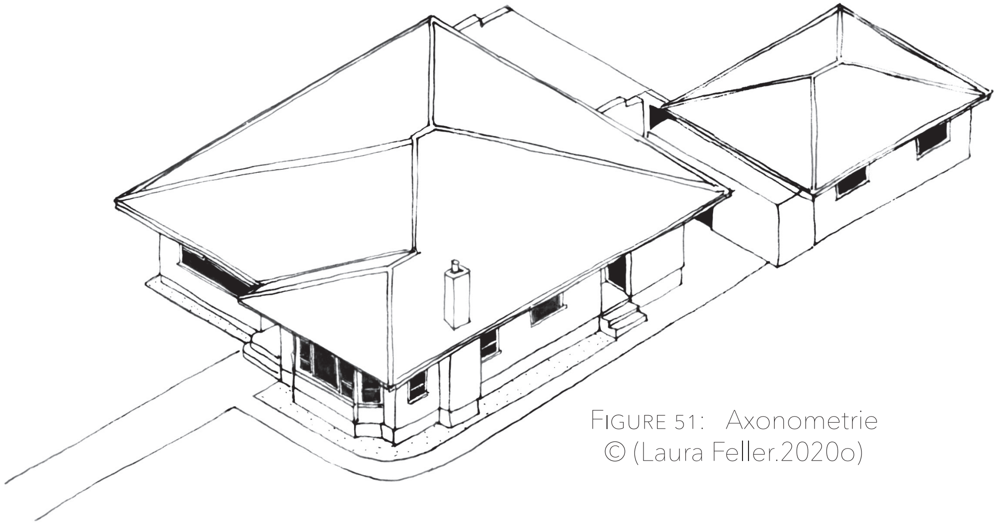


FIGURE 51: Axonometrie
© (Laura Feller.2020o)

MID PUNIHO ROAD
SINGLE-FAMILY HOUSE

1950

The following case study looks at a typical 1950s dwelling and seeks to be representative for a large group of houses. The aim is to have insulation in ceiling, underfloor and walls, creating minimal impact on the environment and the existing structure. Both ceiling and underfloor have been insulated in 2017. The wall was not part of the retrofitting, because cladding in lining are still in good condition. The lack of building solutions for similar building tasks all over the country makes it impossible to bring all housing stock up to current standards. Different approaches to install wall, insulation are investigated and weighed against each other.

The focus is on total energy savings in the whole life cycle. Given that thermal insulation levels reach required standard, the embodied carbon of sheep wool in comparison to common glass wool is examined. Ultimately, the energy payback time of retrofitting and the amount of CO_2 saved by using sheep wool are calculated.

The results are projected on a nation wide scale and suggest the potential total carbon savings.

5.1 EXISTING BUILDING ANALYSIS

year: 1950
floor space: 90,5 m^2
stand-alone, single floor
family house
timber frame construction
with stucco cladding
hip roof
single-glazed aluminium windows
heating: open fire place / no central heating

A three-bedroom house built in the 1950s , with typical timber frame constructio and a hip roof. The native timber commonly used back then is very durable and walls and roof are still in very good condition. Also the stucco cladding, shows no damage.

The roof was originally finished with steel sheets but was later no adapted to the popular pressed sheet shingles on a layer of battens nailed onto the steel sheet.

We can find existing roof insulation, which is a 60 mm layer of pinkbatts, fitted between the beams (bottom chords). Underfloor insulation was installed in recent years, sitting between the joists. To protect insulation against dampness from the soil a foil or vapour barrier was layed our on the ground.

The walls are in excellent condition, inside and outside but have no insulation. All windows are single-gazed with aluminium frames. The inside lining was done with plasterboard and the ceilings show the typical softboard decorations.

Like most 1940s-60s houses, the living room has an open fireplace that provides the only source of heating in the house. The fire surround is tiled with a timber shelf above, which was very common in that time. It sits in an outside wall, where the chimney was constructed from reinforced concrete (BRANZ. n.d.). There was a ventilation system installed, that can distribute heat from living room to the three bedrooms. In my own testing this system failed to heat all the connecting rooms to a moderate temperature and it is mainly the living room that is warm.

PERSONAL LIVING EXPERIENCE
within a 12- month period

The indoor temperatures of all rooms except living room with connected kitchen, is consistantly below a moderate and comfortable temperature in most months of the year except during summer (Dec - Feb). During this period the living room and kitchen tend to easily overheat and most windows have to be open all day to regulate the temperature. Over the colder months we experienced many mornings with a temperature below 14°C in the bedrooms, when no additional electric heater was used. Condensation inside the glazing is very common in the mornings and growth of mold on walls and even on the wooden doors started developing over the winter. When indicvidual rooms where heated it takes a long time to reach a comfortable temperature and the heat disappear within a short amount of time, as soon as the heating source stops. This is obvisoulsy explained by the missing wall insulation and insufficient layers in roof and underfloor as well as the general low thermal capacity of timber frame construction.

5.1.1 CLIMATE OF BUILDING SITE

New Zealands has generally indicated a temperate oceanic climate. New Plymouth in Taranaki is 29 m above sea level and the climate here is mild, temperate and generally warm. The temperatures averages 13.6°C with highest month being February (high of 23°C) which is also the driest. July is rated the coldest (low of 5 °C) and wettest month of the year. Annual rainfall is 1609 mm (Climate-Data. n.d)

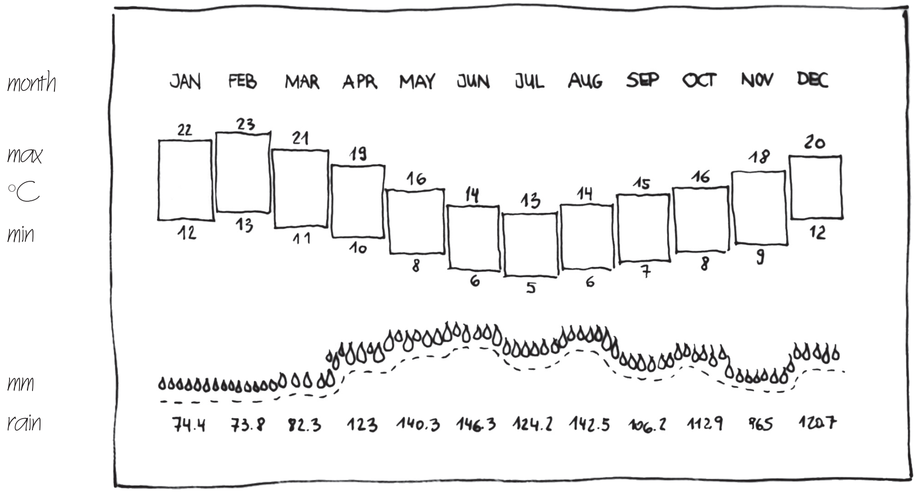
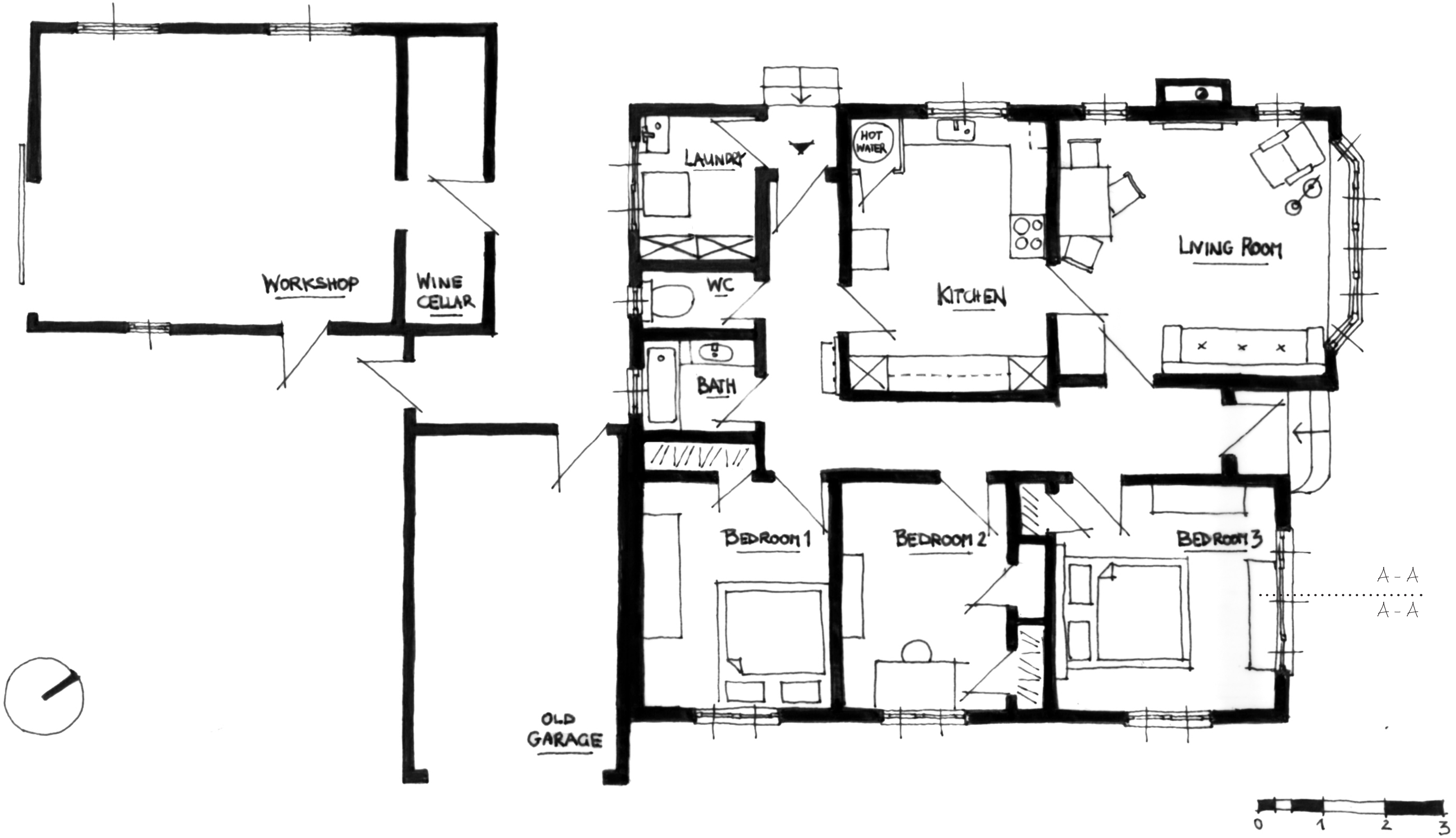


FIGURE 52: Climate diagram New Plymouth © Laura Feller adapted from Climate-Data (n.d.)

Figure 53: Site plan © (Laura Feller.2020o)

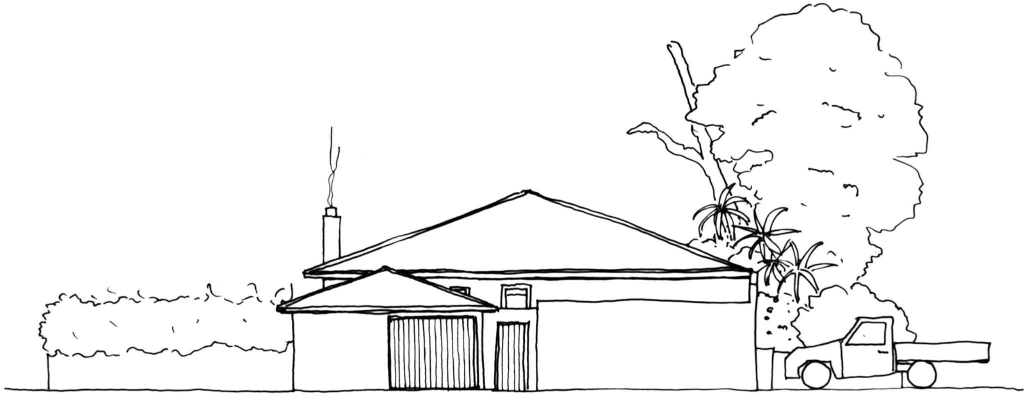
SITE PLAN



FLOOR PLAN

FIGURE 54: Floor plan © (Laura Feller.2020p)

NORTH-WEST

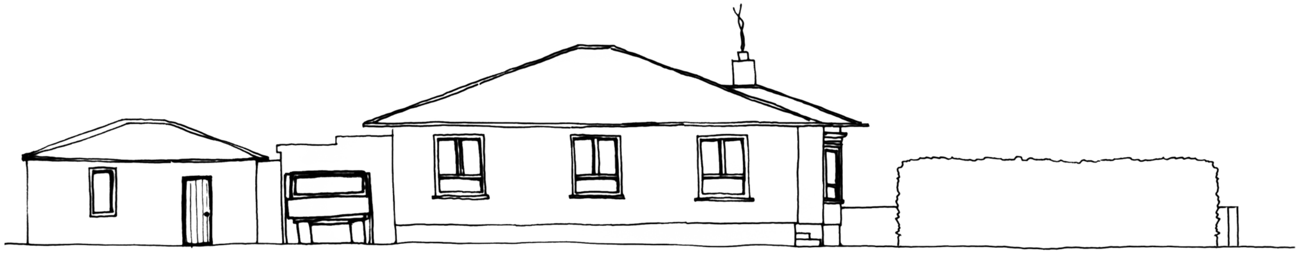


SOUTH-EAST

ELEVATIONS M 1:200

Figure 55: Elevations © (Laura Feller.2020p)

SOUTH-WEST ELEVATION



NORTH-EAST

ELEVATIONS M 1:200

5.2 ANALYSIS APPROACH

Factors that improve thermal performance but can not be influenced by an existing building, such as location and orientation of the house, are disregarded in this study. After analysing the key problems of the existing construction, ceiling, underfloor and in particular the walls are shown in detail. Each structure is evaluated individually from both a building performance and environmental point of view.

For the wall structure different methods and options are weighed against each other, to find the most practical solution.

Finally, the positive changes resulting from the thermal retrofitting is explained throught the following:

- heat demand
- CO$_2$ emissions
- energy payback time

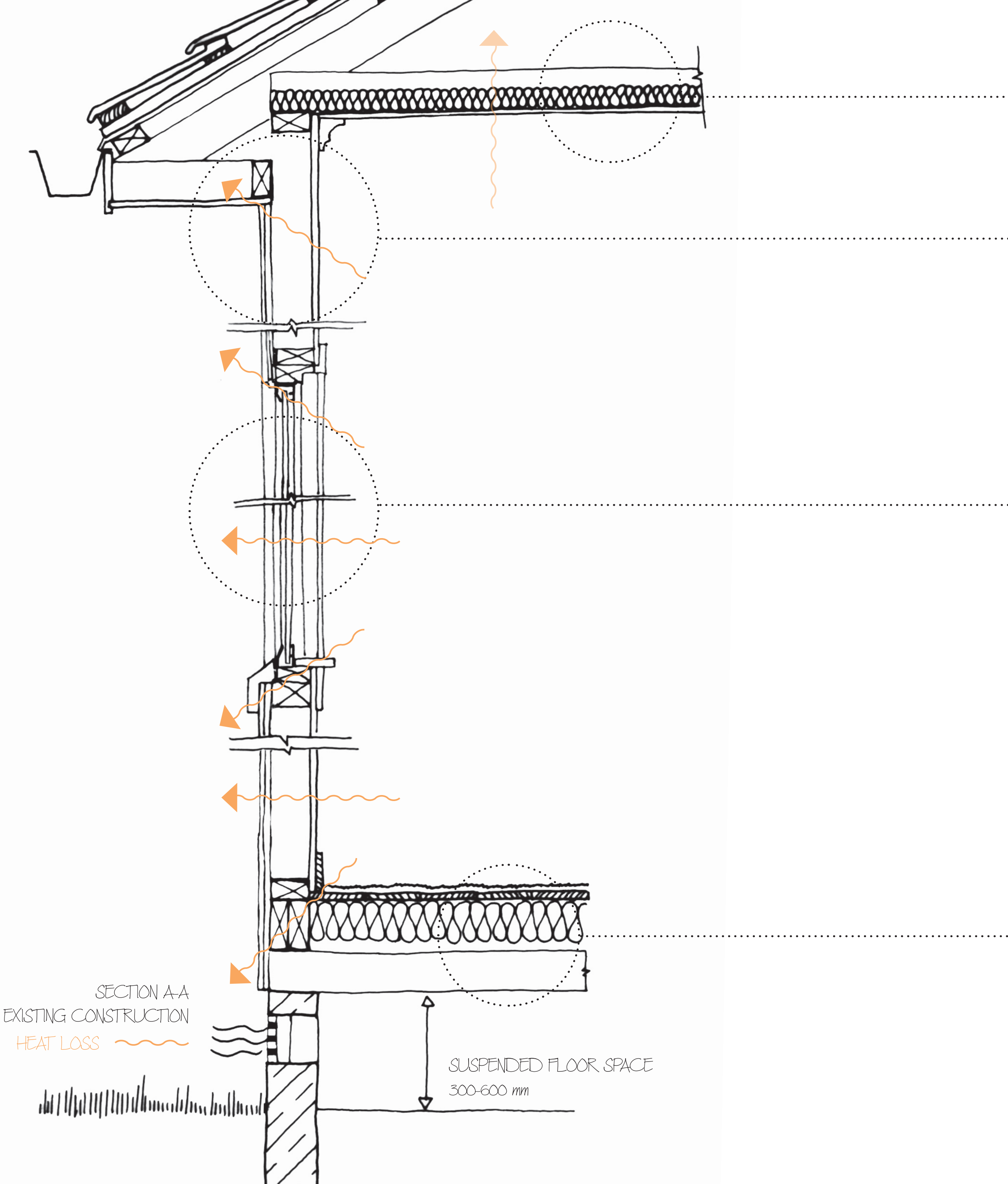


FIGURE 56: Cross section A-A © (Laura Feller.2020q)

5.3 KEY PROBLEMS

CEILING

EXISTING INSULATION IN CEILING
APPROX. 60 MM GLASS WOOL
= insufficient ✗

WALL

NO EXISTING INSULATION IN WALL
= highly insufficient ✗

WINDOWS

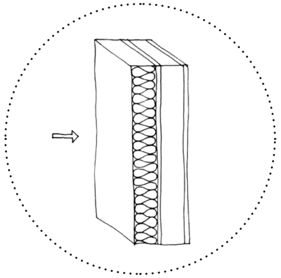
SINGLE-GLAZED WINDOWS WITH ALUMINIUM FRAMES
= highly insufficient ✗

The original wooden windows were replaced by aluminium profiles, with single-glazing. The original frame is still in place and the aluminium frame installed inside of it. The frame is not insulated and creates thermal bridges. Especially after the walls are insulated, the windows will have the biggest heat loss. Furthermore, condensation will most likely appear and can create damage in the construction. The sometimes practiced, inexpensive method to only replace the glazing is problematic for the frame and the connection detail. It is recommended to change all windows including frames to a current standard. To reach a BPI, below 1.55, according to current building standard double-glazed windows are inevitable.

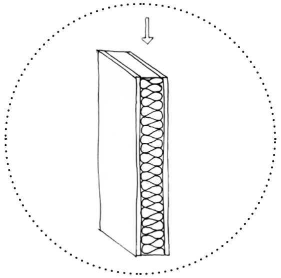
FLOOR

EXISTING INSULATION IN UNDERFLOOR +
POLYTHENE SHEET ON GROUND
RETROFIT IN 2007
= sufficient to current standards ✓

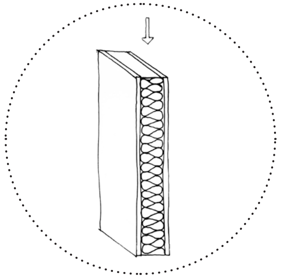
5.4 GENERAL METHODS TO RETROFIT A TIMBER FRAME CONSTRUCTION



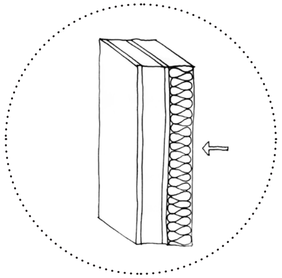
FROM OUTSIDE



IN BETWEEN
1) BLOW-IN



IN BETWEEN
2) BATTS



FROM INSIDE

PRO's

+ inside lining and mouldings obtained
+ damaged cladding can be replaced
+continuous vapour retarder
+ new wall underlay

CON's

- appearance/ width of eaves changes
- new facade (cost + changed look)

PRO's

+ obtain wall thickness
+ minimal impact on inside lining (blow-in -insulation)

CON's

- studs are thermal bridges
- no control over condition of wall underlay
- can not install vapour retardant
- can not ensure cavity drainage for direct-fixed panel claddings
- thermal bridge in floor connection
- only practical for constructions without dwangs (built before 1950)

PRO's

+ obtain wall thickness
+ can replace wall underlay
+ can install vapour retardant

CON's

- studs are thermal bridges
- new inside lining
- fitted kitchen or bathroom facilities
- thermal bridge in floor connection

PRO's

+ installation wall
+ insulation covers studs
+ appearance of eaves is obtained

CON's

- loss of living area
- condensation problem in cavity
- new inside lining
- replace mouldings (corner of wall to ceiling)
- replace skirting
- continuous vapour retarder not possible
- fitted kitchen or bathroom facilities
- thermal bridge in floor connection

All following retrofit suggestions focus mainly on the insulation material. It is suggested to only work with buildings materials that have low embodied carbon, however the currrent availabilty of those is very limited in New Zealand. The ideal solution would look different in another country e.g. Austria due to the product range.

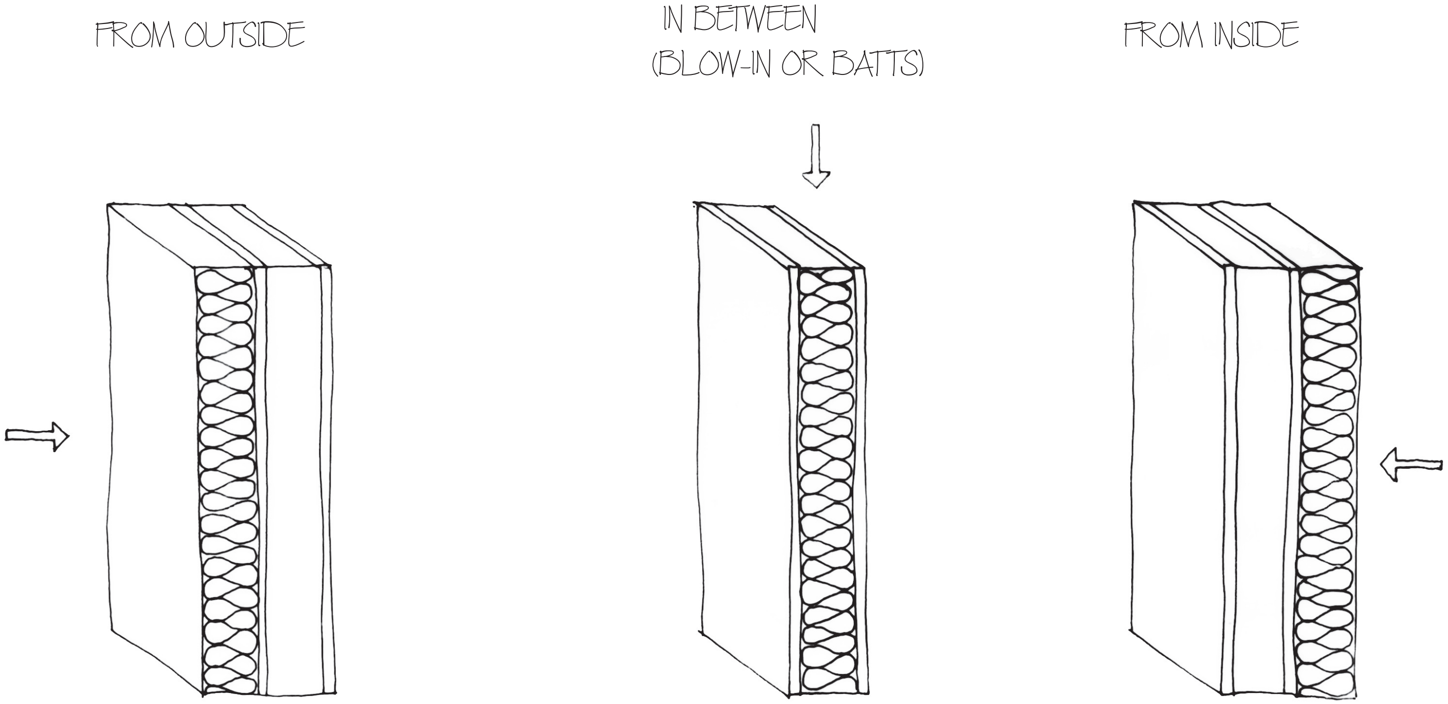


Figure 57: Methods of retrofitting insulation © (Laura Feller.2020r)

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5.5 SUPERSTRUCTURE

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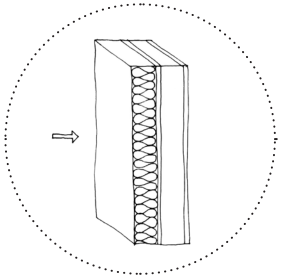
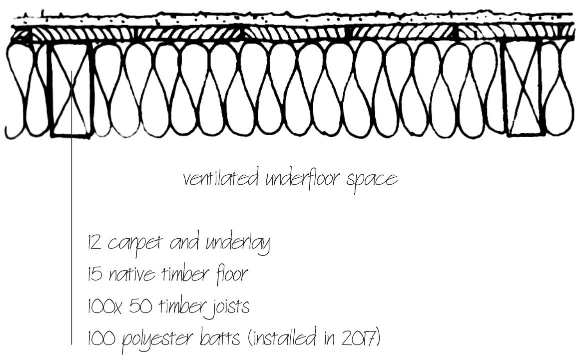


UNDERFLOOR
Polyester Batt Insulation

The suspended timberfloor construction makes the underfloor easily accessible through a manhole in the laundry room. Polyester batts were retrofittet between the joists and a polyethylene sheet keeps moisture coming from the ground. This is current retrofit practice and the R-value is compliant with the standard.

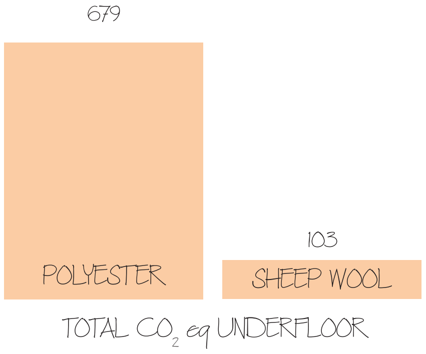
The comparison on the right shows the potential carbon savings if sheep wool was used instead of polyester. Sheep wool insulation only contains about 20% embodied carbon compared to polyester insulation. However, the most carbon can be saved by not using any raw material at all. Given that the polyester batts are in good condition it is not recommended to replace the insulation.

EXISTING RETROFIT DETAIL
WITH POLYESTER BATTS (INSTALLED 2017)

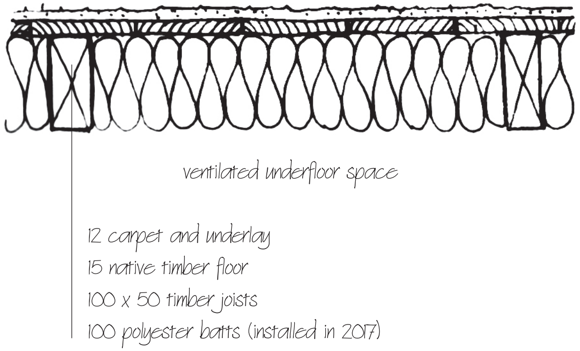


$R=2{,}82\ m^2K/W\ (R_{min}\ 1{,}3)$

No need to retrofit: Insulation is in good condition + sufficient R-value



EXISTING RETROFIT DETAIL
WITH POLYESTER BATTS (INSTALLED 2017)



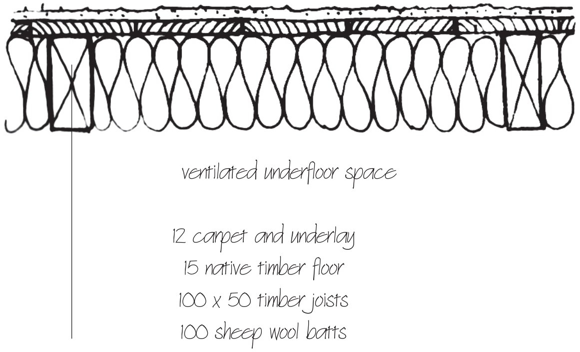
ventilated underfloor space

12 carpet and underlay
15 native timber floor
100 x 50 timber joists
100 polyester batts (installed in 2017)

R=2,82 m^2K/W

- 81 %
kg CO2 equ
total

COMPARISON
WITH SHEEP WOOL

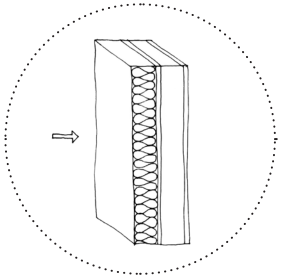


ventilated underfloor space

12 carpet and underlay
15 native timber floor
100 x 50 timber joists
100 sheep wool batts

R= 2,95 m^2K/W

*values from Ubakus.de

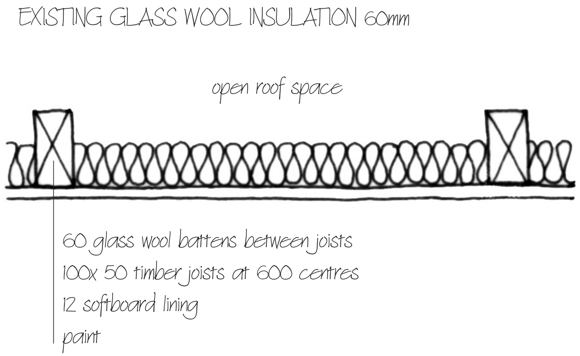


5.5.2 CEILING

EXISTING DETAIL

CEILING
Glass wool batt insulation

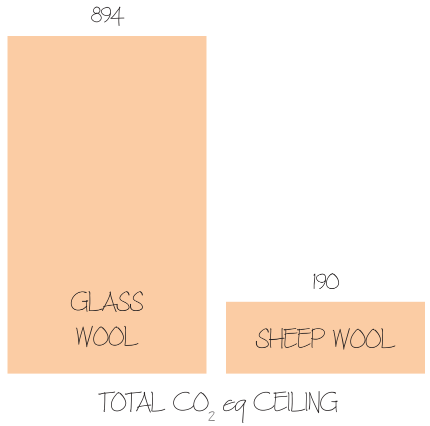
The ceiling is accessible through a manhole and a layer of approx. 60 mm glass wool batts was found. The batts exposed to the open roof space and are not in good condition. The required R-value is 2,9 m^2K/W whereas the estimated R-value of the construction is about 1,7 m^2K/W and therefore insufficient to current standards. It is recommended to replace the batts in between the joists and put a second layer of insulation on top covering the joists. This eliminates thermal bridges in the ceiling construction. The comparison on the right shows the construction detail and how much carbon sheep wool insulation can save compared to common glass wool.



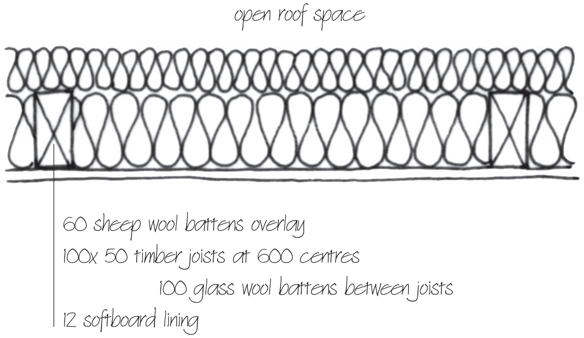
R=1,7 m^2K/W

current R-value is not building code compliant (Zone 2, walls: Rmin = 2.9)

GWP COMPARISON & RETROFIT SUGGESTION



RETROFIT WITH
SHEEP WOOL INSULATION

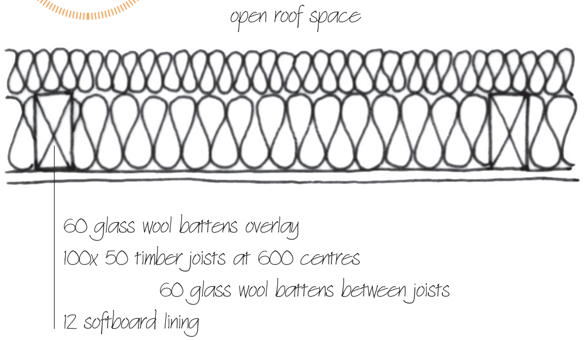


R=4,23 m^2K/W
($R_{STANDARD}$ = 2.9)

Thermal capacity inside: 11.5 kJ/m^2K
Drying reserve: 34686 g/m^2a
No condensate*

+78 %
kg CO2 equ
total

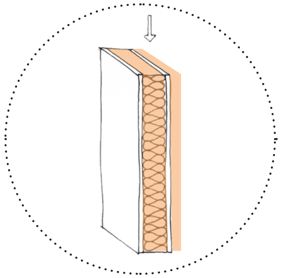
RETROFIT WITH
GLASS WOOL INSULATION



R=4,44 m^2K/W
($R_{STANDARD}$ = 2.9)

Thermal capacity inside: 12,9 kJ/m2K
Drying reserve: 14124 g/m2a

*values from Ubakus.de



5.5.3 EXTERNAL WALLS

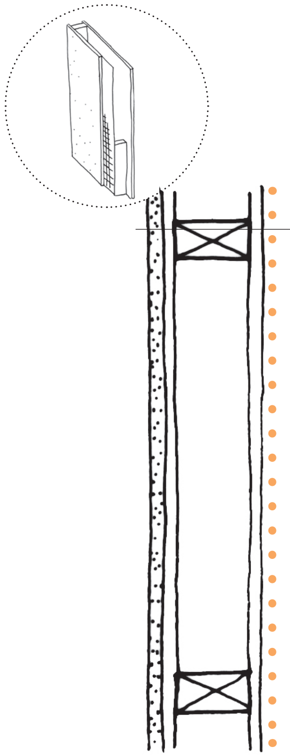
RETROFIT SUGGESTION WALL [1]

IN BETWEEN
A) BLOW-IN + SERVICES CAVITY

WALL
no existing insulation

If the wall construction including the wall underlay is in good condition, loose-fill sheep wool insulation is the ideal solution to retrofit. The inner lining can mostly be obtained and the vapour retarder will be placed on top of it. Ideally, an installation wall is constructed with 30 x 50 mm battens which can be filled with a 30 mm layer of sheep wool battens. The inner lining finishes the wall construction.

This method assumes that mouldings or skirting boards are easy to be replaced.



Condensate
inside! *

EXISTING DETAIL
[a] STUCCO

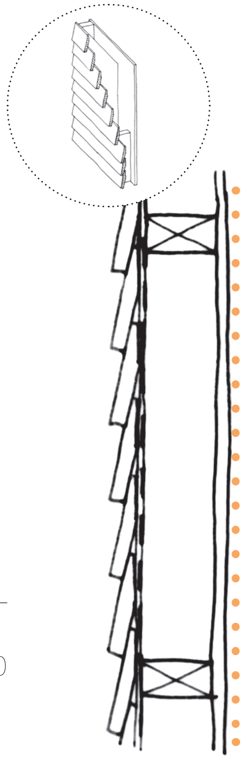
18 cement-mortar plaster over wire netting
15 plaster board
wiall underlay ?
100x 50 timber studs
12 inner lining

R=0,31 m²K/W (R 1,9)

Heat protection
Temperature amplitude damping: 1.0
phase shift: 0.1 h
Thermal capacity inside: 1.6 kJ/m²K

Temperature at inside too low.

Existing building component:
Environmental performance
indicators = not applicable

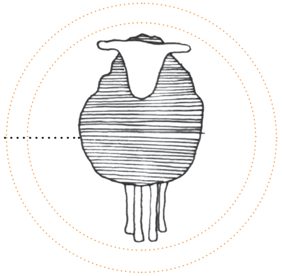


Condensate
inside! *

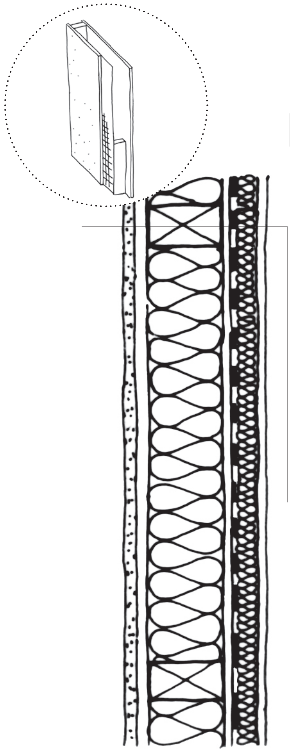
[b] WEATHER BOARD

Comparable structure:

Typical direct-fixed weatherboard cladding early 1900s - mid 1900s.



[1a/2a] STUCCO



18 cement-mortar plaster over wire netting
15 plaster board
wall underlay
100x 50 timber studs
blown in sheep wool insulation
12 gypsum board
vapour retarder
30 x 50 battens (services cavity)
sheep wool batts insulation
12 inner lining

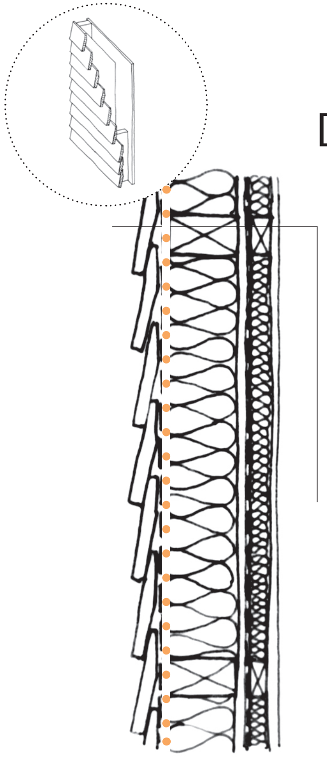
No condensate*

R=3.42 m²K/W
($R_{STANDARD}$=1,9 < $R_{recommended}$ =2.2)

Heat protection
Temperature amplitude damping: 4.3
phase shift: 6.8 h
Thermal capacity inside: 18.6 kJ/m²K

Drying reserve: 1205 g/m²a

[1b /2b] WEATHER BOARD



direct-fixed weatherboard cladding
wall underlay
100x 50 timber studs
blown in sheep wool insulation
12 inner lining
vapour retarder
30 x 50 battens (services cavity)
sheep wool batts insulation
12 inner lining

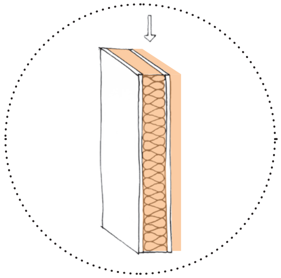
Condensate inside of weather-board cladding!*

R=3.37 m²K/W
($R_{STANDARD}$=1,9 < $R_{recommended}$ =2.2)

Heat protection
Temperature amplitude damping: 4,3
phase shift: 6,8 h
Thermal capacity inside: 19,6 kJ/m2K

Condensate: 1,51 kg/m²
Drying reserve: 76 g/m²a
Dries 56 days

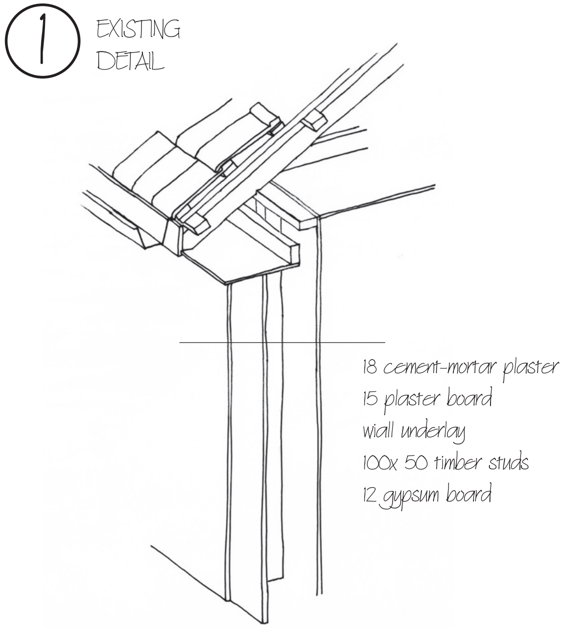
*values from Ubakus.de

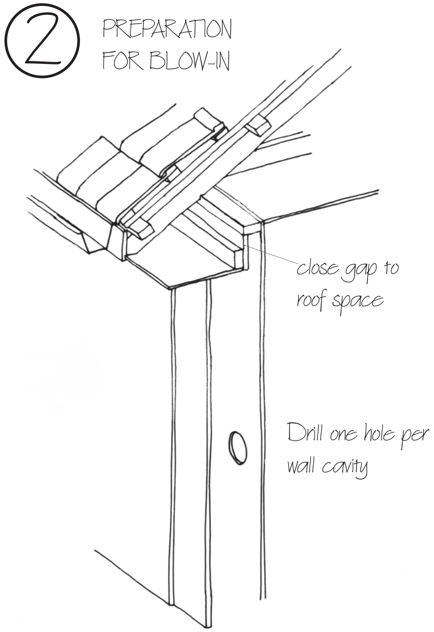


IN BETWEEN
A) BLOW-IN + SERVICES CAVITY

[1a] PROCESS SKETCH

Sheep wool
Loose-fill insulation +
installation wall





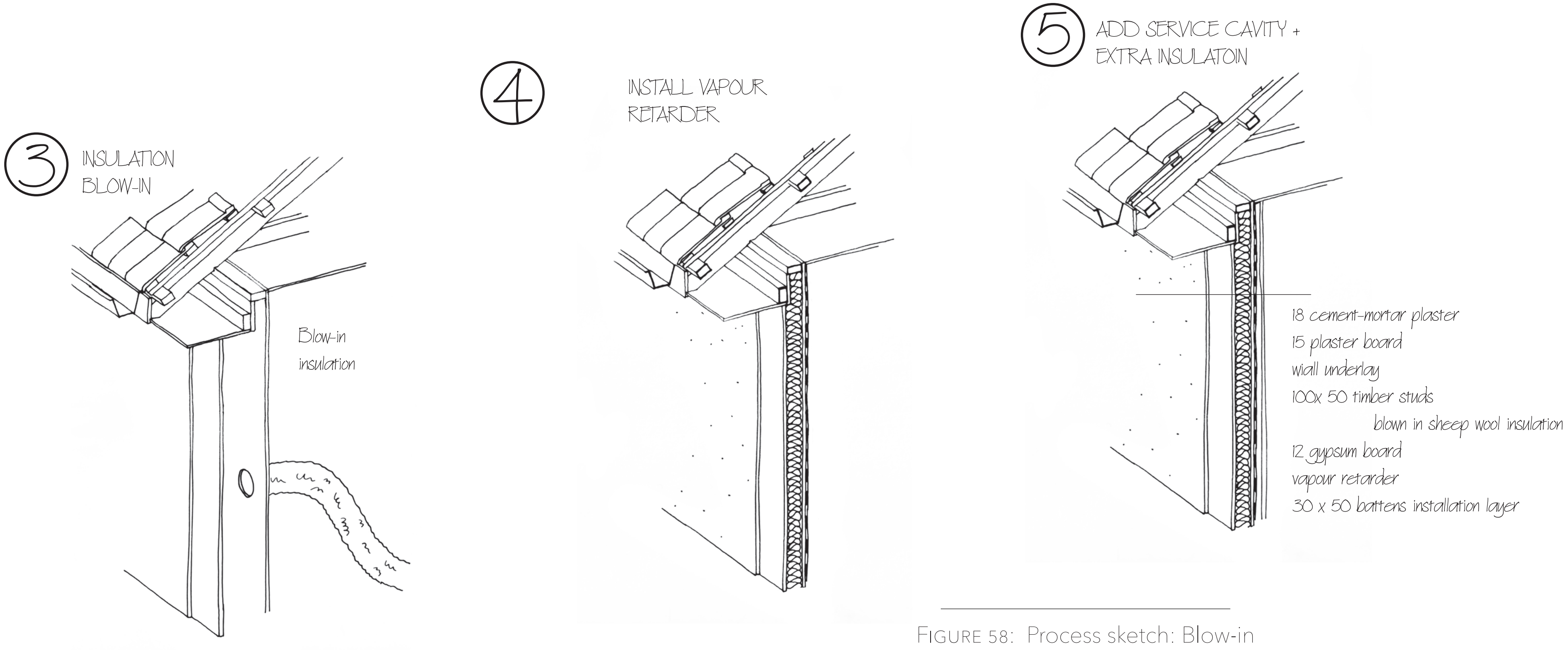
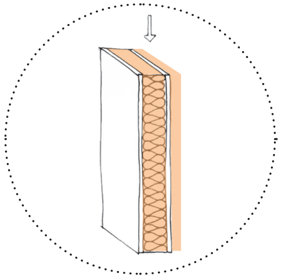


FIGURE 58: Process sketch: Blow-in insulation © (Laura Feller.2020s)



IN BETWEEN
A) BATTS + SERVICES CAVITY

[2a] PROCESS SKETCH

Sheep Wool Batts installation from inside

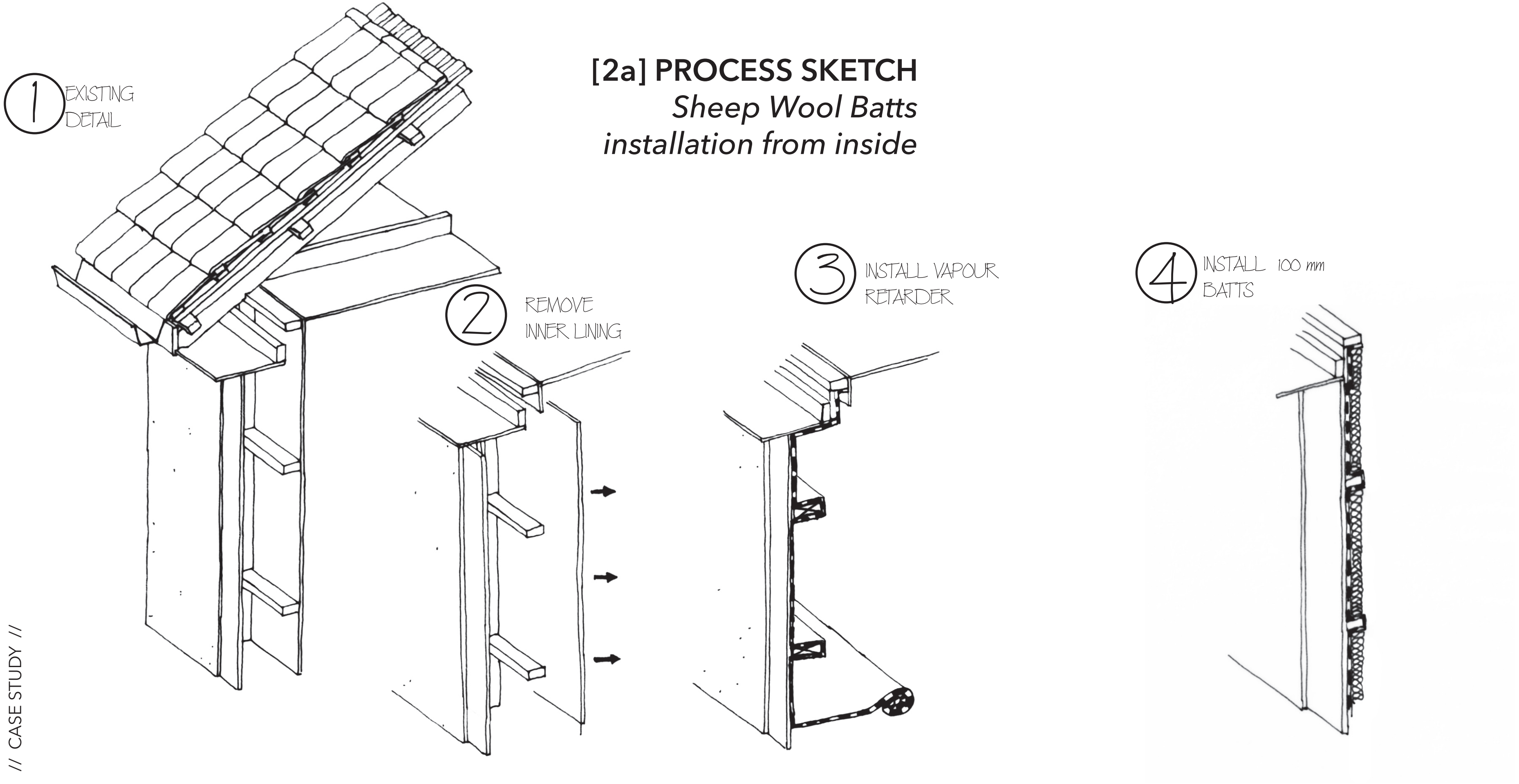
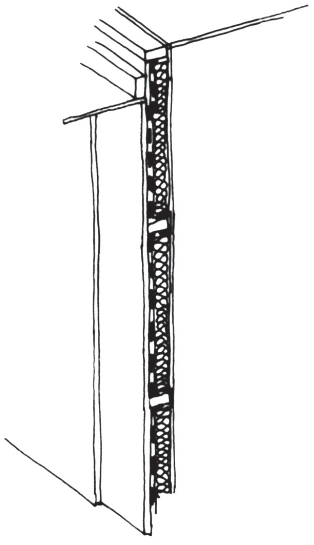
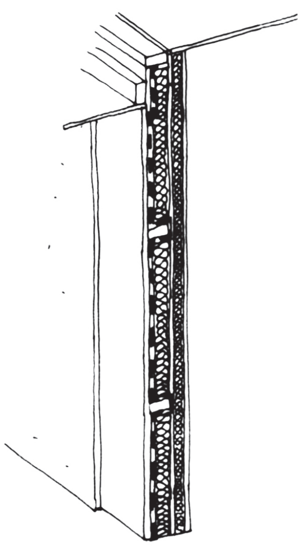


FIGURE 59: Process sketch: Installation from inside © (Laura Feller.2020t)

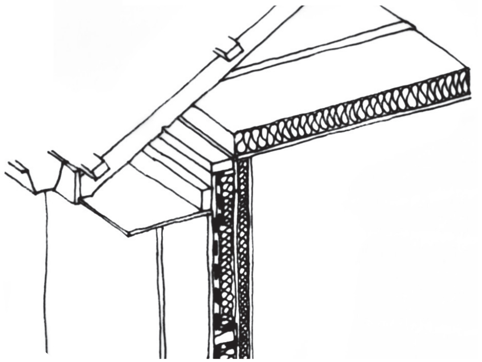
⑤ RE-INSTALL GYPSUM BOARD



⑥ INSTALLATION WALL 30 mm filled with sheep wool battens

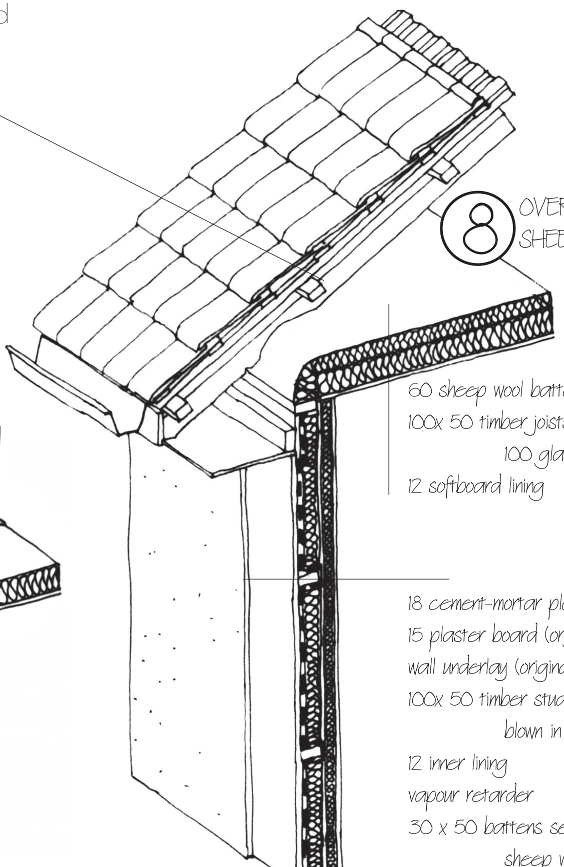


⑦ CEILING TOP UP INSULATION BETWEEN JOISTS



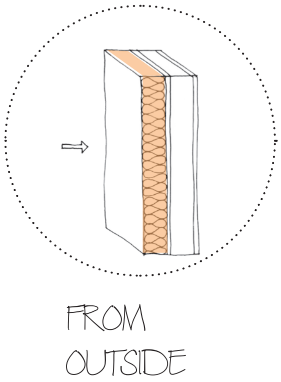
A common skillion roof construction like this is accessable through a man hole and due to the open construction, insulation can easily be topped up, added or replaced.

⑧ OVERLAY WITH 60 mm extra SHEEP WOOL BATTENS



60 sheep wool battens overlay
100x 50 timber joists (local wood) at 600 centres
100 glass wool battens between joists
12 softboard lining

18 cement-mortar plaster (original)
15 plaster board (original)
wall underlay (original)
100x 50 timber studs (original)
blown in sheep wool insulation
12 inner lining
vapour retarder
30 x 50 battens service cavity
sheep wool matt insulation
12 inner lining



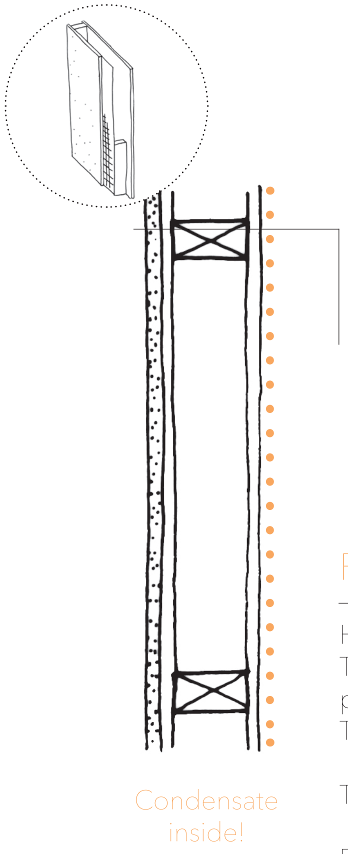
RETROFIT SUGGESTION WALL [3]

[3]
Sheep Wool Batts insulation

Retrofitting from the outside is the best option if:

- the cladding needs to be replaced
- windows have to be replaced
- the inner lining is in good condition
- existing mouldings or skirtings are difficult to replace
- kitchen, bathroom and other facilities hinder the access from insice largely

EXISTING DETAIL
[a] STUCCO

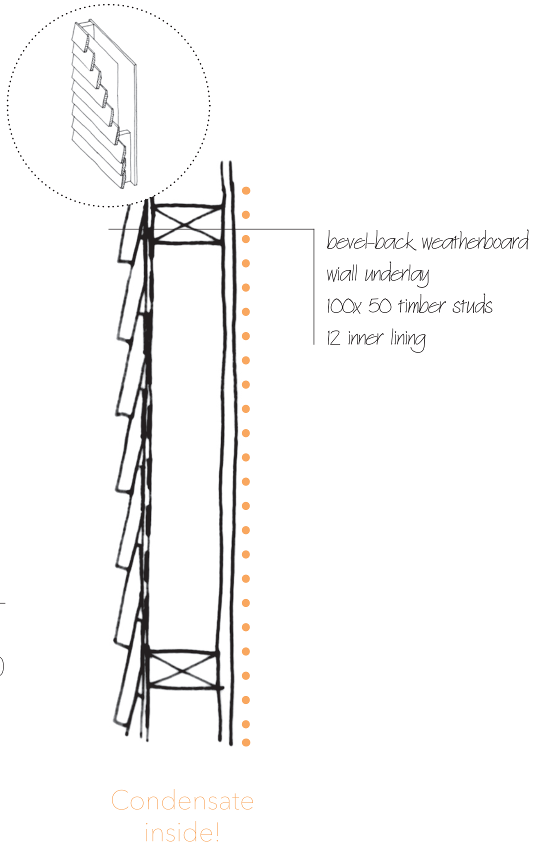


R=0,31 m²K/W (R 1,9)

Heat protection
Temperature amplitude damping: 1.0
phase shift: 0.1 h
Thermal capacity inside: 1.6 kJ/m²K

Temperature at inside too low.

Existing building component:
Environmental performance
indicators = not applicable

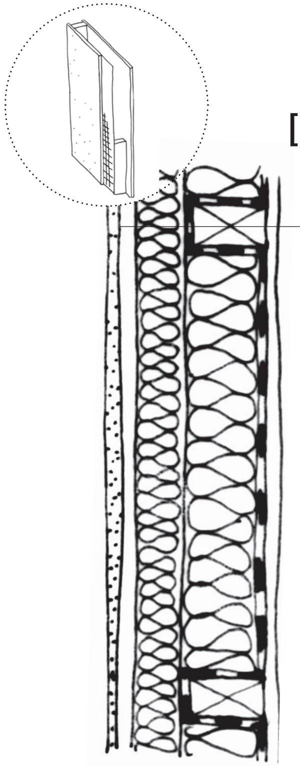


[b] WEATHER BOARD

Comparable structure:

Typical direct-fixed weatherboard cladding early 1900s - mid 1900s.

[3a] STUCCO



8 plaster
25 plaster board
wall underlay
60x 50 timber studs
60 sheep wool insulation
100x 50 timber studs
100 sheep wool insulation
vapour retardant
12 inner lining (existing)

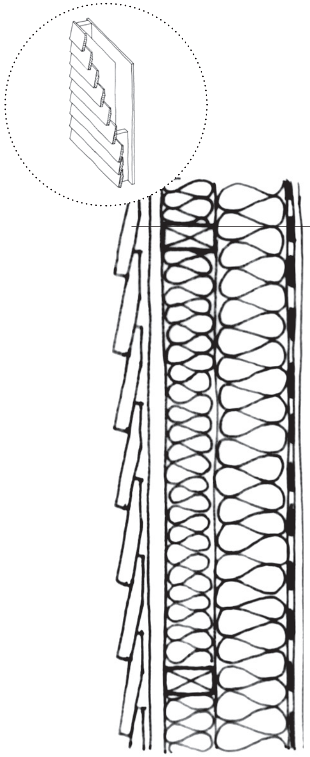
$R=4.16$ m^{2}K/W
$(R_{STANDARD}=1,9 < R_{recommended}=2.2)$

Heat protection
Temperature amplitude damping: 3.6
phase shift: 7.0 h
Thermal capacity inside: 15,6 kJ/m^{2}K

Drying reserve: 1860 g/m^{2}a

No condensate*

[3b] WEATHER BOARD



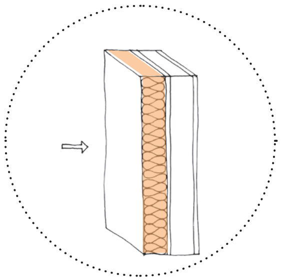
15 plaster
30 plaster board
wall underlay
60x 50 timber studs
60 sheep wool insulation
100x 50 timber studs
100 sheep wool insulation
vapour retardant
12 inner lining (existing)

$R=4.55$ m^{2}K/W
$(R_{STANDARD}=1,9 < R_{recommended}=2.2)$

Heat protection
Temperature amplitude damping: 3.8
phase shift: 6.3 h
Thermal capacity inside: 14,8 kJ/m^{2}K

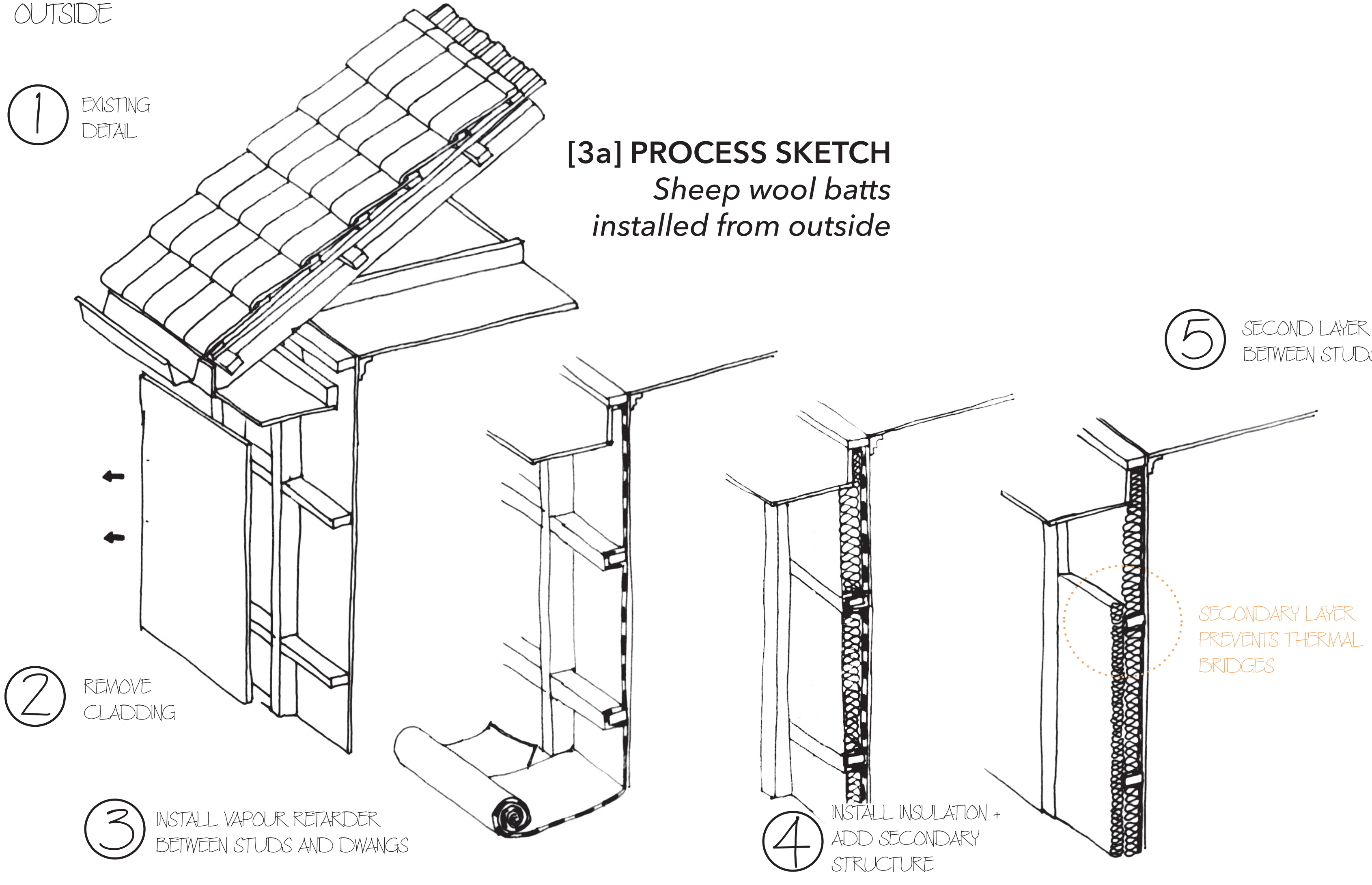
Drying reserve: 2379 g/m^{2}a

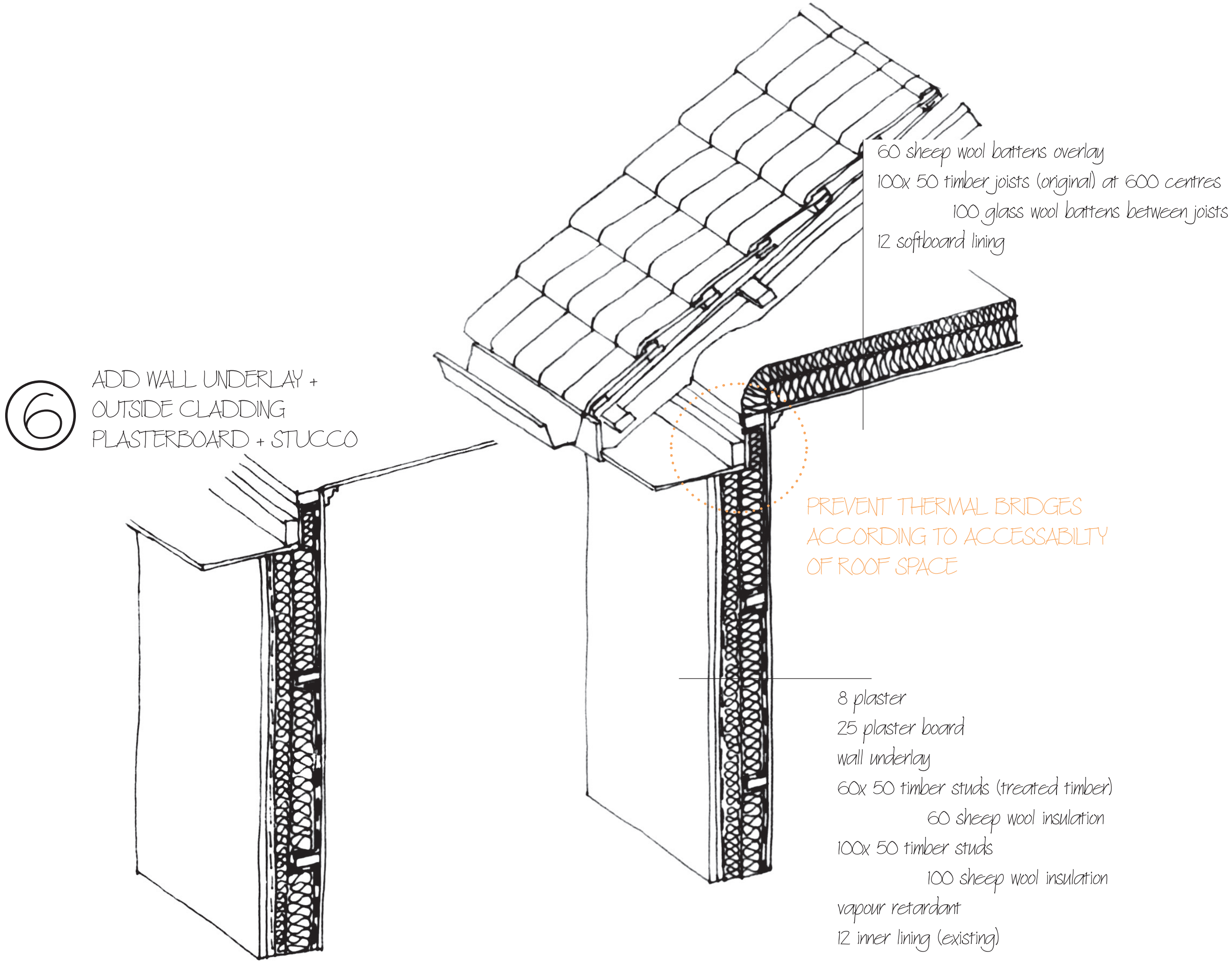
No condensate*



[3a] PROCESS SKETCH

Sheep wool batts installed from outside

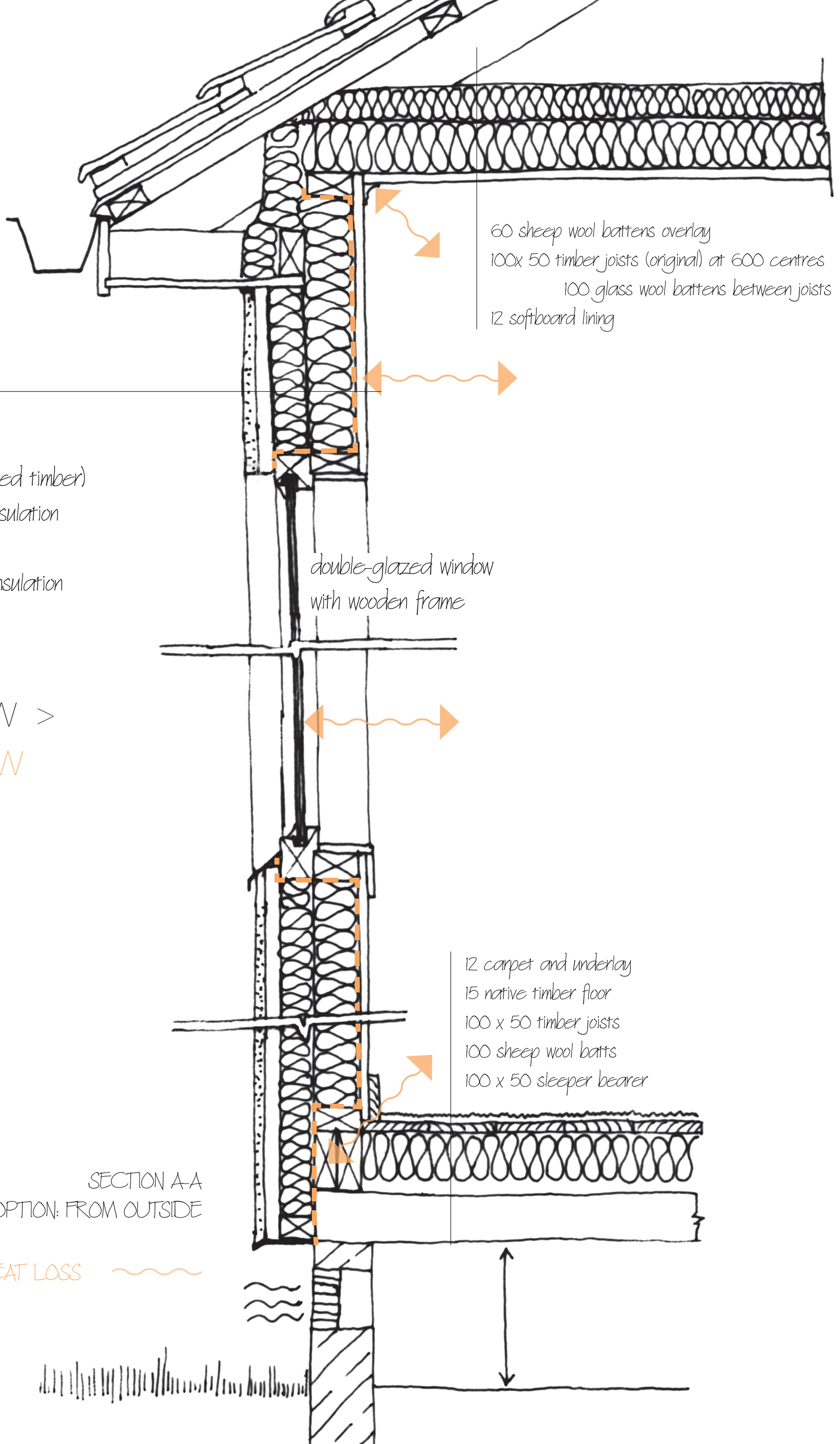




⑥ ADD WALL UNDERLAY +
OUTSIDE CLADDING
PLASTERBOARD + STUCCO

PREVENT THERMAL BRIDGES
ACCORDING TO ACCESSABILTY
OF ROOF SPACE

FIGURE 60: Process sketch: Installation from outside © (Laura Feller.2020u)



60 sheep wool battens overlay
100x 50 timber joists (original) at 600 centres
100 glass wool battens between joists
12 softboard lining

8 plaster
25 plaster board
wall underlay
60x 50 timber studs (treated timber)
60 sheep wool insulation
100x 50 timber studs
100 sheep wool insulation
vapour retardant
12 inner lining (existing)

$R_{exist}=0,31\ m^2K/W\ >$

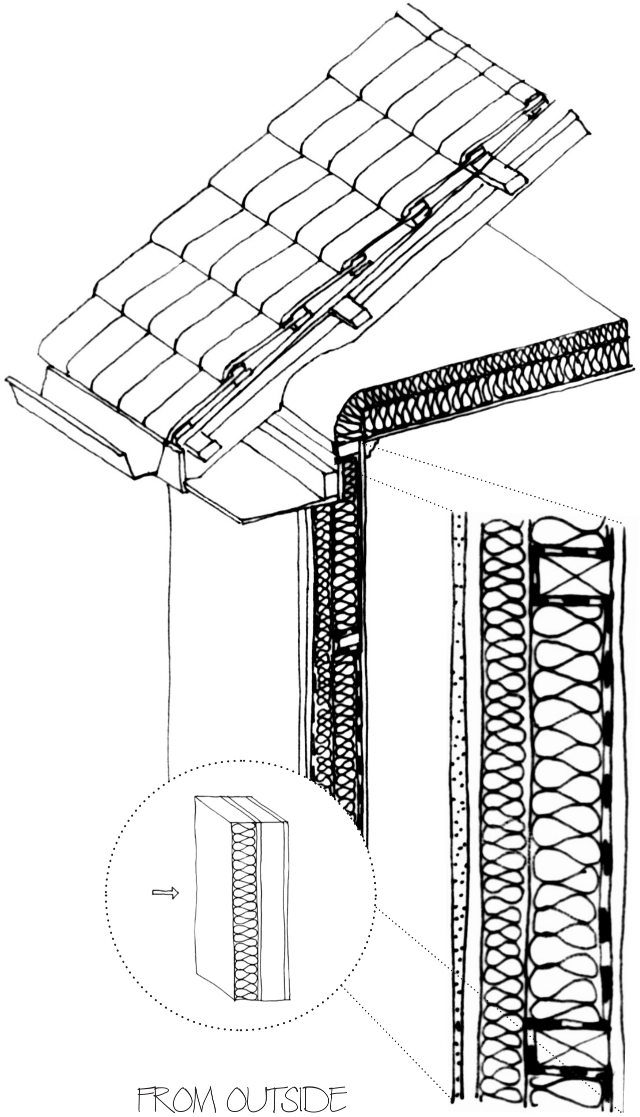
$R_{new}=4.16\ m^2K/W$

double-glazed window
with wooden frame

12 carpet and underlay
15 native timber floor
100 x 50 timber joists
100 sheep wool batts
100 x 50 sleeper bearer

SECTION A-A
RETROFIT OPTION: FROM OUTSIDE

REDUCED HEAT LOSS



5.5.4 RETROFIT OPTION:

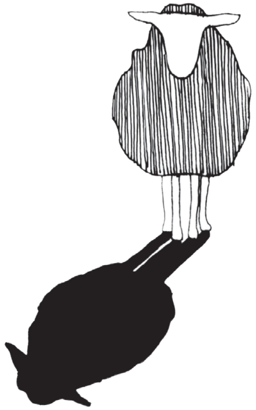
[3a] *Sheep wool batts installed from outside*

Weighing up all advantages and disadvantages of the different retrofitting options, the installation of insulation from outside seems to be the most efficient. The removal of the original facade makes it possible to install a continuous layer of vapour retarder, as well as a replacement of the wall underlay. This eliminates the risk of water entering the insulation layer and condensation within the structure.

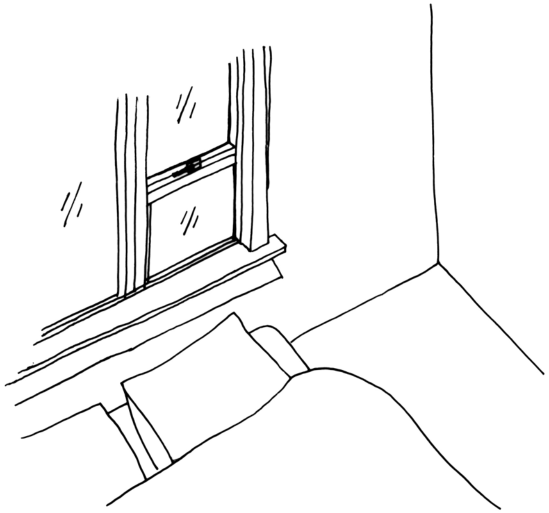
The secondary layer of insulation overlays the 100 x 50 studs, removes thermal bridges in the wall and further increases the R-value. There is no change to the usable floor area and original mouldings inside. Furthermore, in-built kitchen and bathroom facilities can stay in place.

The additional 60 mm do not affect the appearance of the house significantly nor decrease the eaves in a negative way. The gained width of the wall and positioning of windows enables the use of the window sills as a multifunctional space.

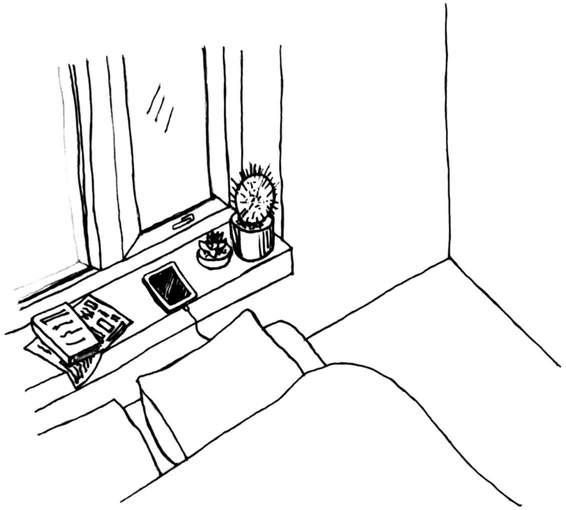
5.5.5 SPATIAL EFFECT OF BUILDING MEASURES



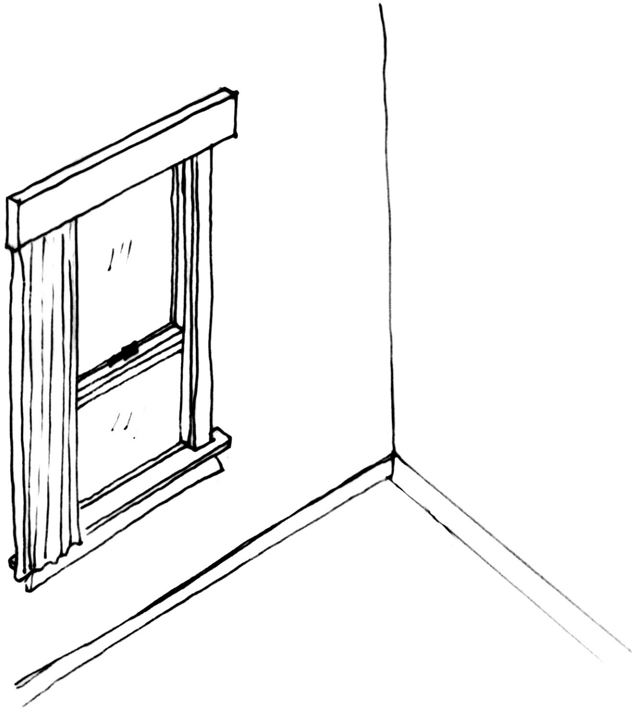
Thermal retrofitting often comes with an alteration of certain parts and elements of a building. Ideally, the necessary changes are designed smart and present an overall improvement for the house. The drawings on the following pages show how the increased thickness, of all outside walls, can effect the living comfort positively.



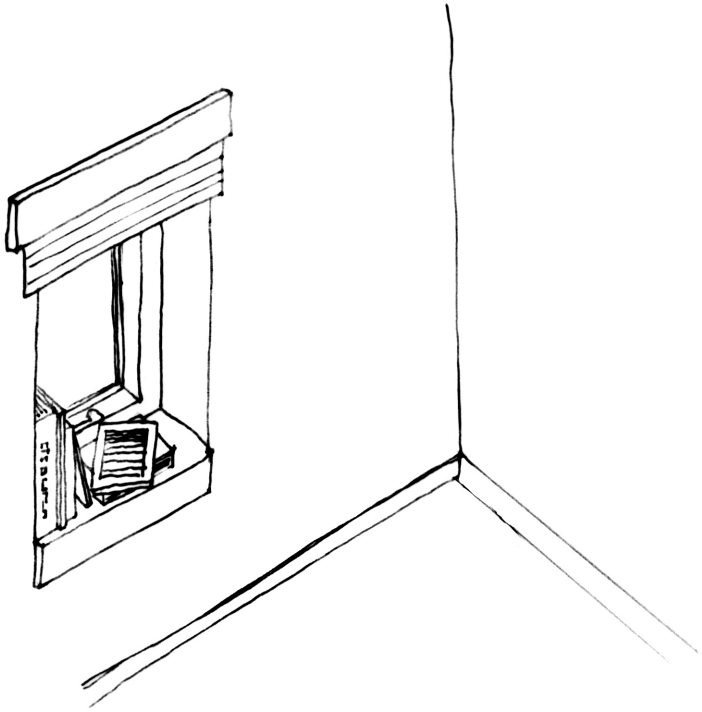
EXISTING WINDOW IN MASTER BEDROOM



BUILT-IN BEDSIDE TABLE

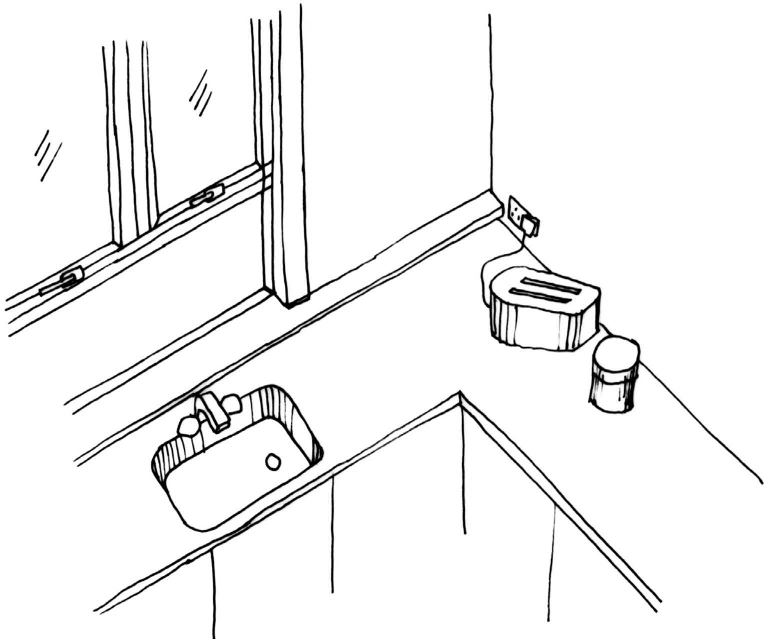


EXISTING WINDOW TYPE



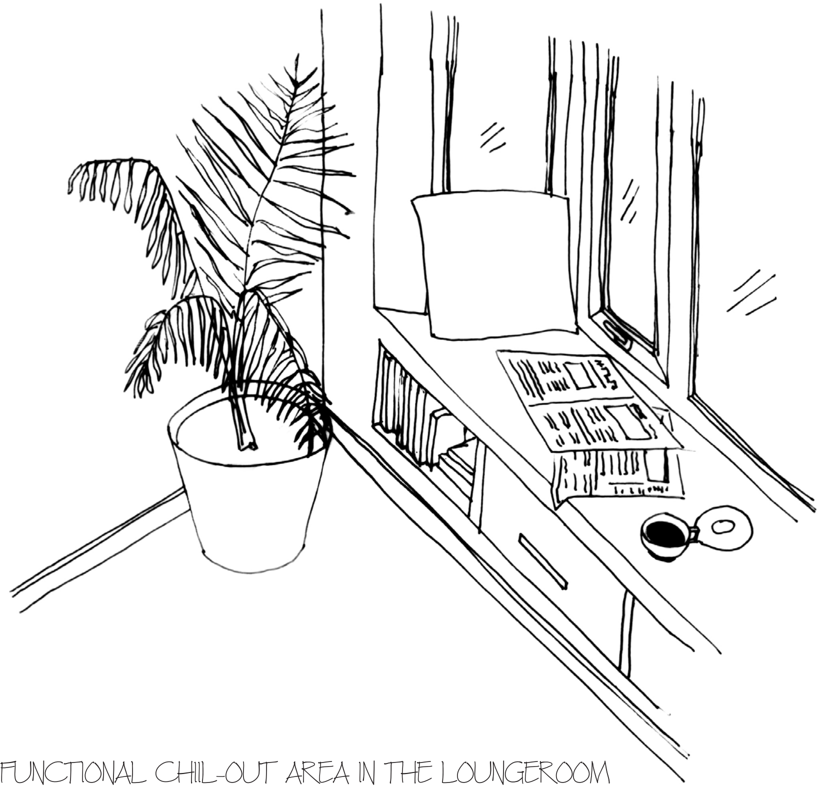
EXTENDED WINDOW SILL CREATES MULTIFUNCTIONAL SHELF

EXISTING WINDOW IN THE KITCHEN



WINDOW SILL & EXTENSION OF WORKBENCH IN THE KITCHEN

EXISTING BAY WINDOW IN THE LOUNGE

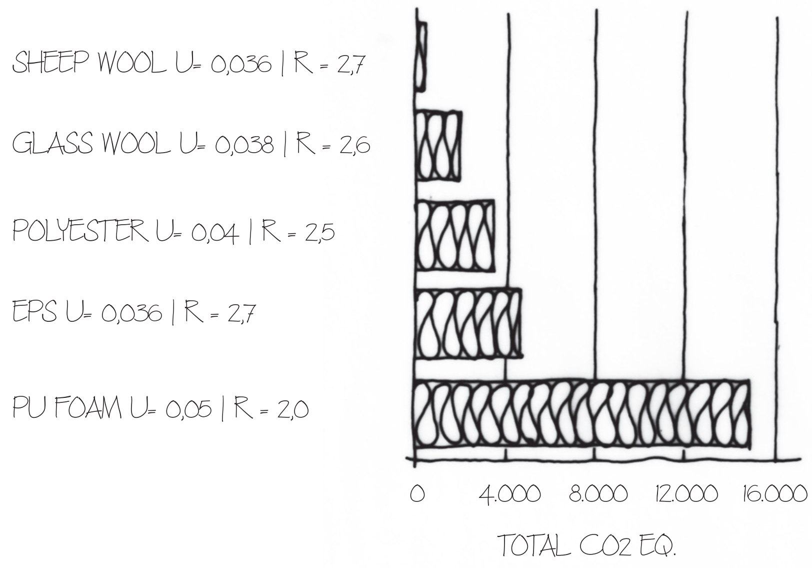


MULTIFUNCTIONAL CHILL-OUT AREA IN THE LOUNGEROOM

5.6 CO$_2$ eq SAVING POTENTIALL

On the basis of the case study and, dependent on the insulation material used, the potential savings of CO$_2$ eq. is calculated. The required amount of glass wool adds five times more embodied carbon to your building process than sheep wool.

Isolena Sheep Wool
20 kg/m$^{3:}$



PinkBatts
20 kg/m$^{3:}$

FIGURE 61: Total CO2 eq. insulation material (Comparison1)
© Graphic&data: (Laura Feller.2020v.1)

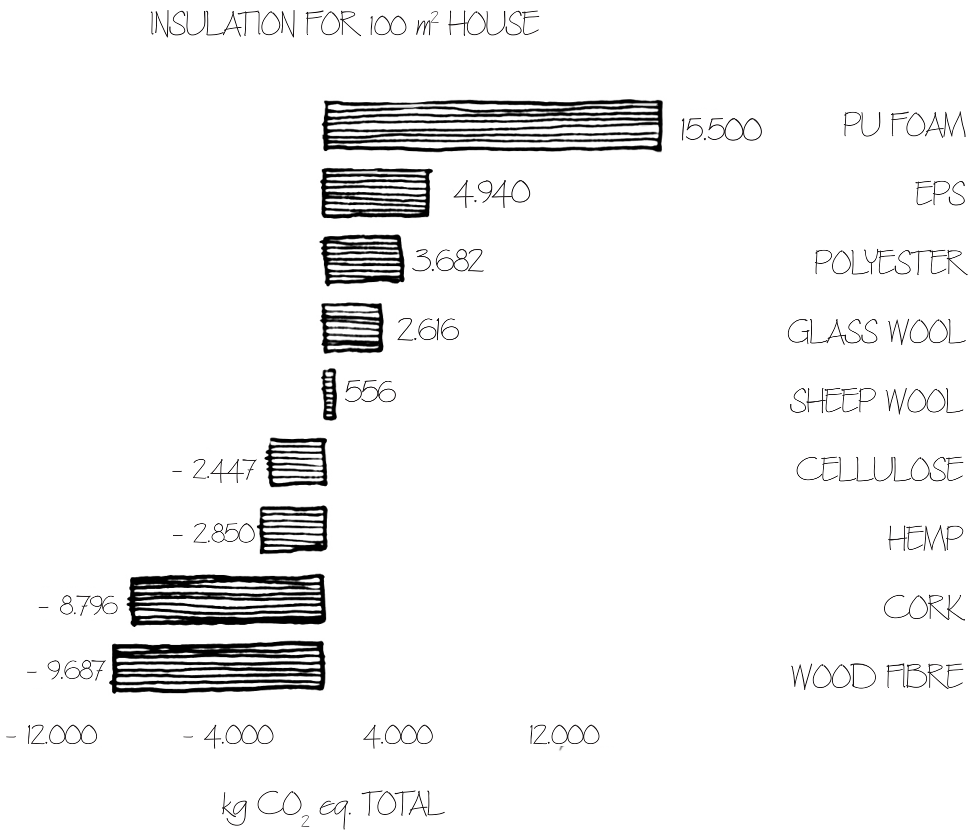


Figure 62: Total CO2 eq. insulation material (Comparison 2)
© Graphic&data: (Laura Feller.2020v2)

5.6.1 GLOBAL WARMING POTENTIAL OF DIFFERENT INSULATION MATERIALS

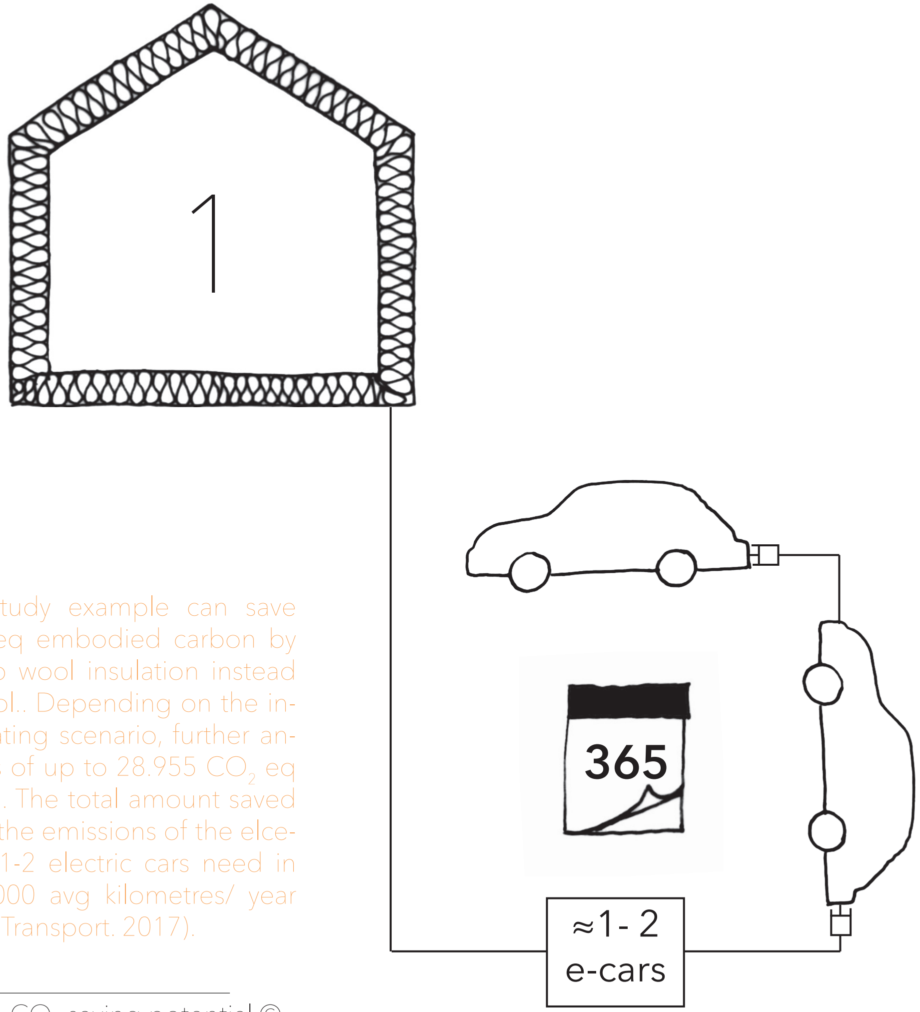
This thesis looked mainly at the material sheep wool compared to glass wool and polyester, seeking to present a meaningful outcome for New Zealand. To widen the scope, the graph on the left shows a wider range of insulation materials and their CO_2 equivalents.

On one end of the spectrum e.g. expanded polystyrol or rigid foam insulation have a much higher number of CO_2 than glass wool. On the other end altenative products like cellulose,hemp, cork or woodfibre can store large amounts of carbon. Currently none of these altenative insulation products is produced in New Zealand, whereas there is a large local supply of sheep wool and a growing sheep wool insulation industry.

While sheep wool insulation is ideal for New Zealand it might not be the first choice in other countries. In Austria sheep wool insulation products are available and have to compete with a list of other alternative products. For example the excellent acoustic insulation properties and the good moisture managment can be a good reason to use sheep wool in Austria.

5.6 $CO_{2\ EQU.}$ SAVING POTENTIAL

Embodied Carbon + Operational Carbon



The case study example can save 2065 CO_2 eq embodied carbon by using sheep wool insulation instead of glass wool.. Depending on the individual heating scenario, further annual savings of up to 28.955 CO_2 eq are possible. The total amount saved equivalates the emissions of the elcetric energy 1-2 electric cars need in a year (14.000 avg kilometres/ year (Ministry Of Transport. 2017).

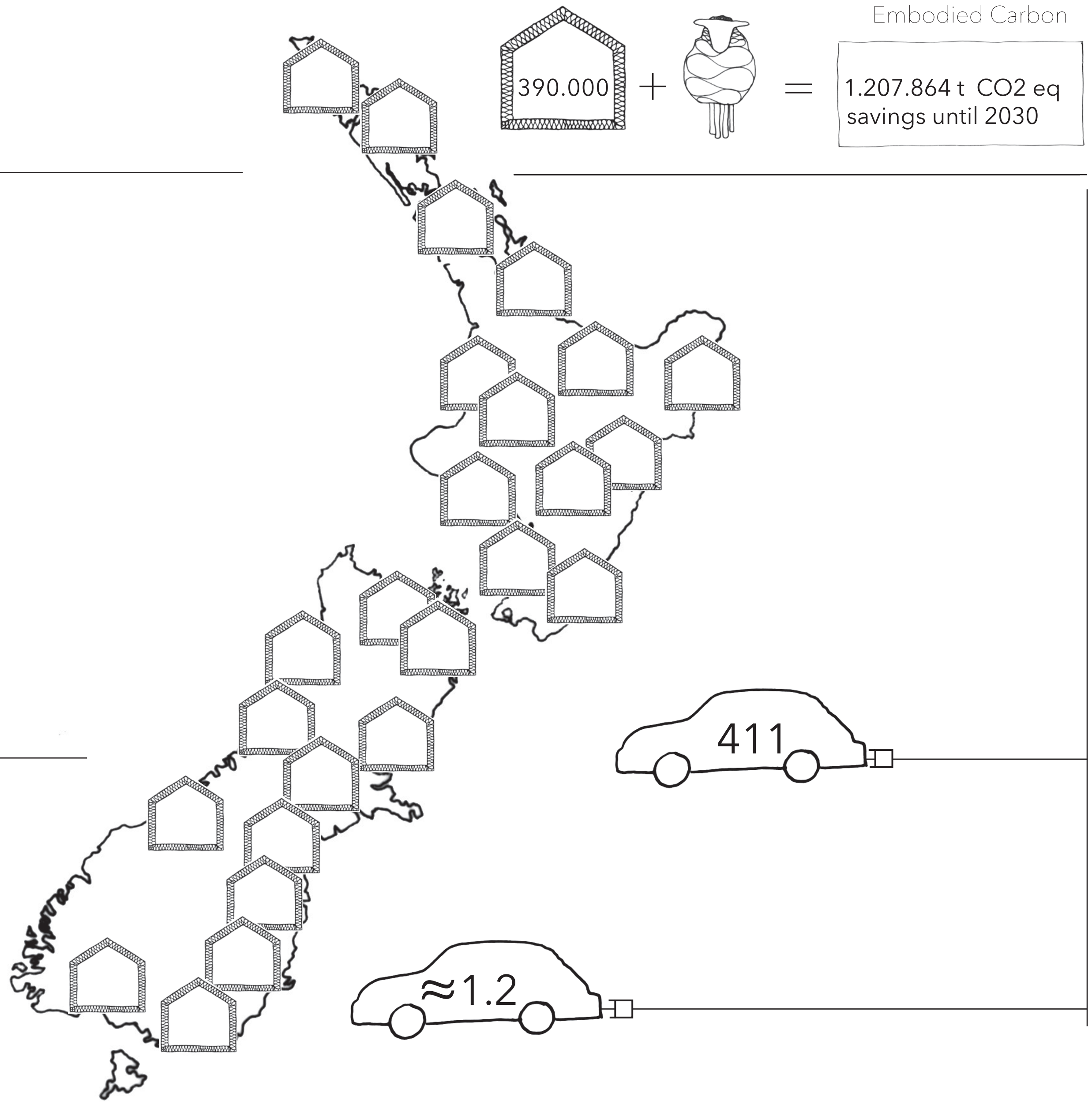
FIGURE 63: CO_2 saving potential © Graphic&data: (Laura Feller.2020w.1)

5.6.1 SINGLE HOUSEHOLD SCALE

It is estimated that all 390.000 houses, with poor thermal performance, across the country could be retrofitted within 10 years (Bengtsson J. et al 2007). By using sheep wool insulation instead of glass wool, New Zealand could save 1.207.864 t CO_2 eq until 2030.

The embodied energy saved alone, could be used to power 411 electric car for a whole year. (14.000 avg kilometres/ year (Ministry Of Transport. 2017).

The embodied energy + operational energy saved with retrofitting, could be used to power between 877.000 -1.2 mio electric car for a whole year.



5.6.2 NATION WIDE SCALE

FIGURE 64: CO_2 saving potential © Graphic&data: (Laura Feller.2020w.2)

5.7 BUILDING PERFORMANCE INDEX AND ANNUAL LOSS FACTOR

The annual heat loss factor was calculated using ALF, the official online tool from BRANZ (ALF.2020), based on the data on the right. In order to comply with the Energy Efficiency Clause H1 of the New Zealand Building Code a building has to have a BPI of less than 1.55 kWh/(m2 . °C . month) in any location throughout New Zealand.

The existing design's BPI is: 2.79 fail

With increased thermal insulation, (walls method [3a]) and all windows replaced by timber frame windows with double-glazing:

The new design's BPI is: 1.38 pass

REQUIRED HEATING ENERGY:

Existing house
Heating Schedule:
(1) 5446.23 kWh/year
(2) 2852.18 kWh/year

Retrofitted house
Heating Schedule:
(1) 2841.12 kWh/year
(2) 1696.37 kWh/year

BUILDING DESIGN

Total Floor Area:	110 m^2
Number of Occupants:	2

CLIMATE

Location: New Plymouth Annual Loss Factor:	12.1
Internal Gain Multiplier:	1.46
Wind Zone Factor:	1.18
NZS 4218:2009 Climate Zone:	2

FLOORS:

Floor area (suspended floor):	110 m^2
Perimeter Length:	10 m
Perimeter Height:	0.5 m
Total Suspended Floor R-value:	1.16 m2°C/W

AIR LEAKAGE:

Basic Airtightness:	Draughty: All pre-1960 houses
Chimneys for open fires:	One chimney
No. of flued heaters:	None
Window Passive Vents:	None
Retrofit airtightening:	Old timber windows replaced
Kitchen vents over hob:	Window mounted extract used 1 hour/day
The location-independent Air Leakage Rate is:	0.90 ac/h
Site Exposure: Exposed (Open spaces with few close buildings or trees)	
Wind Zone Factor:	1.18
Local Air Leakage Rate:	1.20 ac/h
House Volume:	286 m^3

HEATING
Heating Schedule:
(1) All day heating (7am-11pm)
(2) Evening heating (5 pm-11pm)
Heating Level: 20°C

FIGURE 65: Results Building Performance Index
© Laura Feller adapted from (ALF.2020)

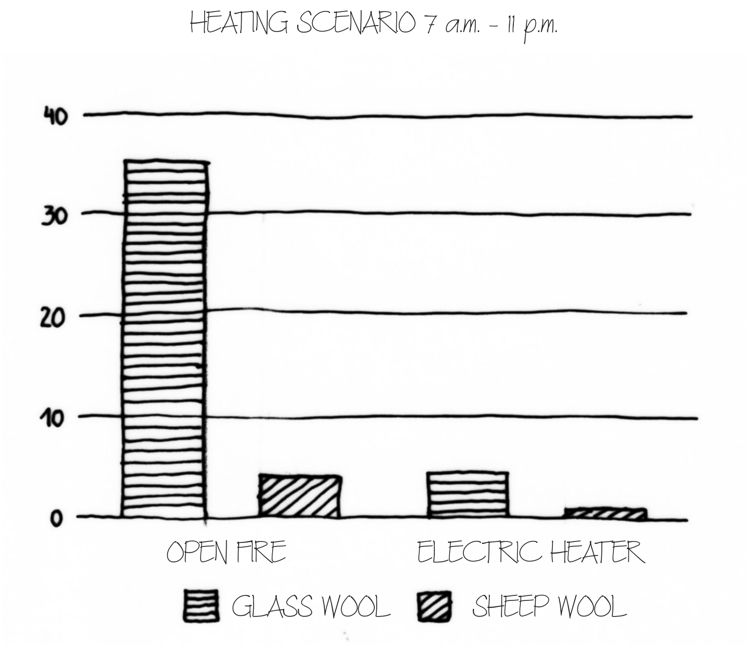


FIGURE 66: Amortisation of rhermal retrofit (regarding CO_2 emissions © Graphic&Data: (Laura Feller.2020x.1)

5.7.1 ENERGY PAYBACK TIME

The annual energy savings for the occupants of the house are depending on the construction R-value and not on the type of insulation material. However, for this thesis the energy payback time (EPT) from a whole life cycle perspective is more expressive.

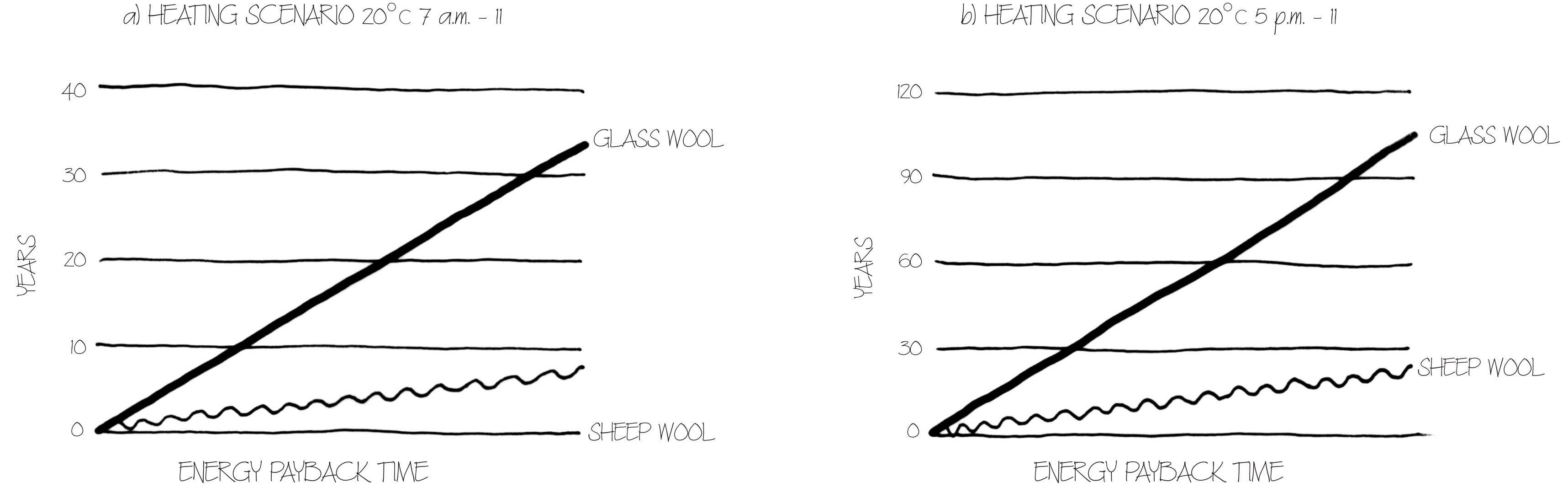
The EPT is representative of the amortisation of a thermal retrofit. It evaluates how many years it takes to offset the amount of embodied carbon from the insulation material. This is the moment when the retrofitting pays off, sole looking at it from an carbon emissions point of view.

The lenght of EPT is dependend on the CO_2 eq of the insulation material used, the annual heating demand and the heat source.

Figures show different heating scenarios and compare different insulation materials, all based on the building details of the case study.

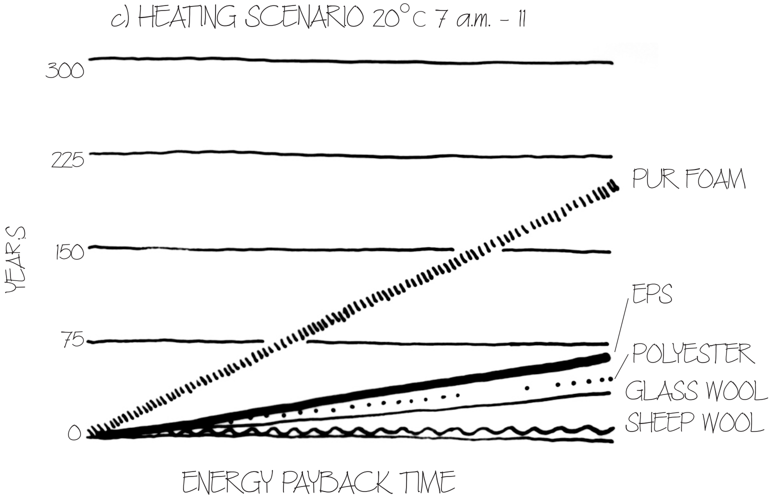
5.7.2 AMORTISATION DIAGRAMS

FIGURE 67: a) b) c) d) Amortisation of thermal retrofit (regarding CO_2 emissions Graphic&data: (Laura Feller.2020x2-5)

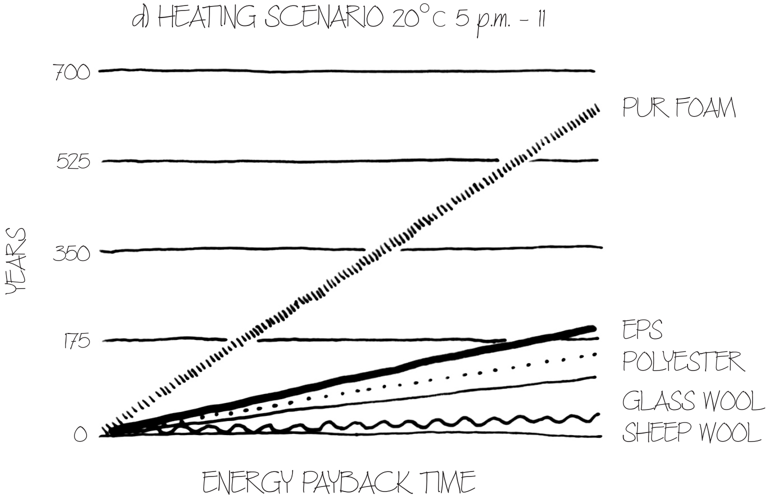


Heat source: Open Wood Fire

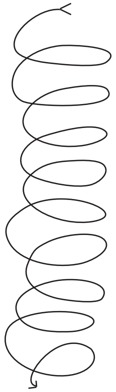
Heat source: Open Wood Fire



Heat source: Open Wood Fire



Heat source: Open Wood Fire



6 CONTENT

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6 SUMMARY & OUTLOOK

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6.1 SUMMARY OF KEY FINDINGS

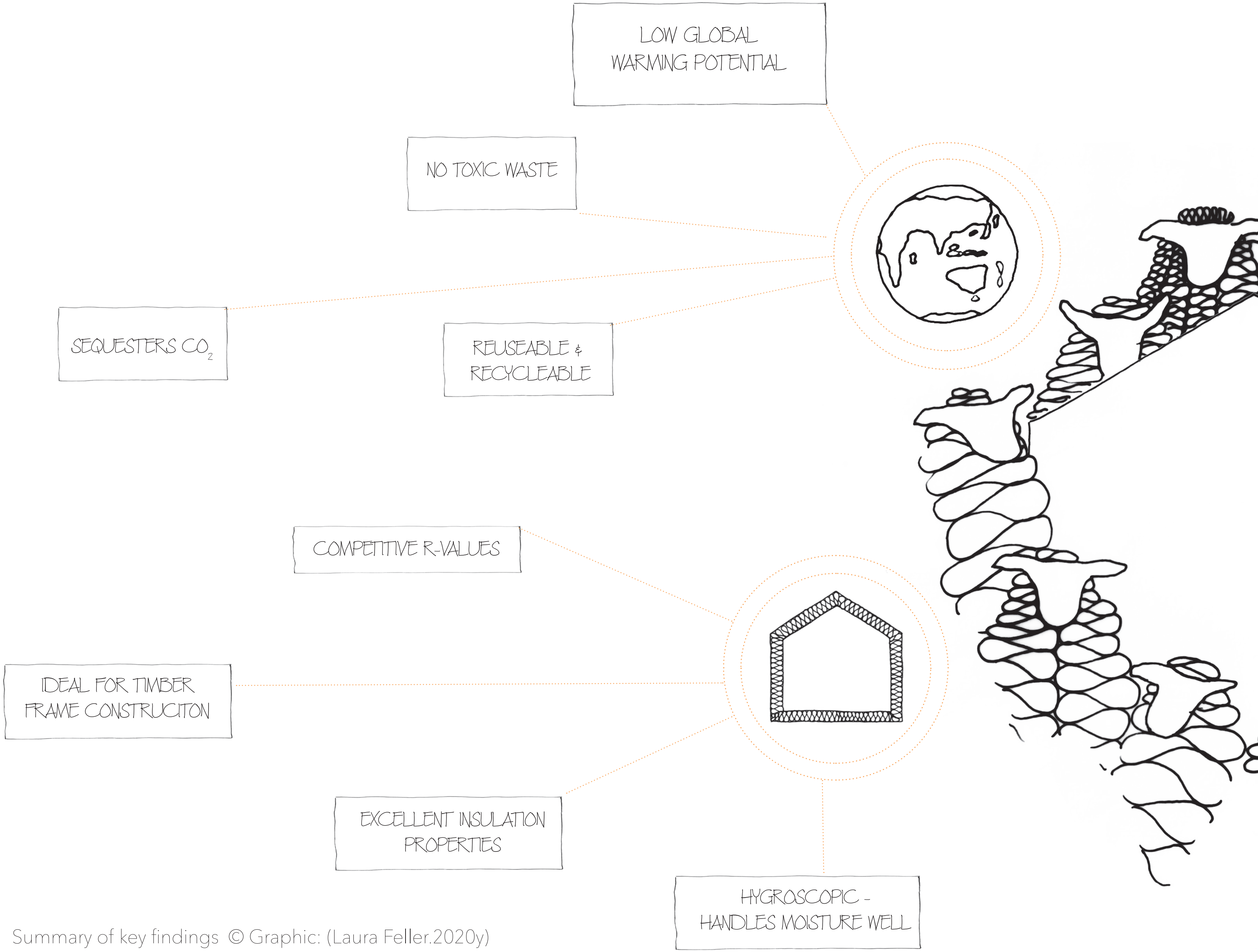
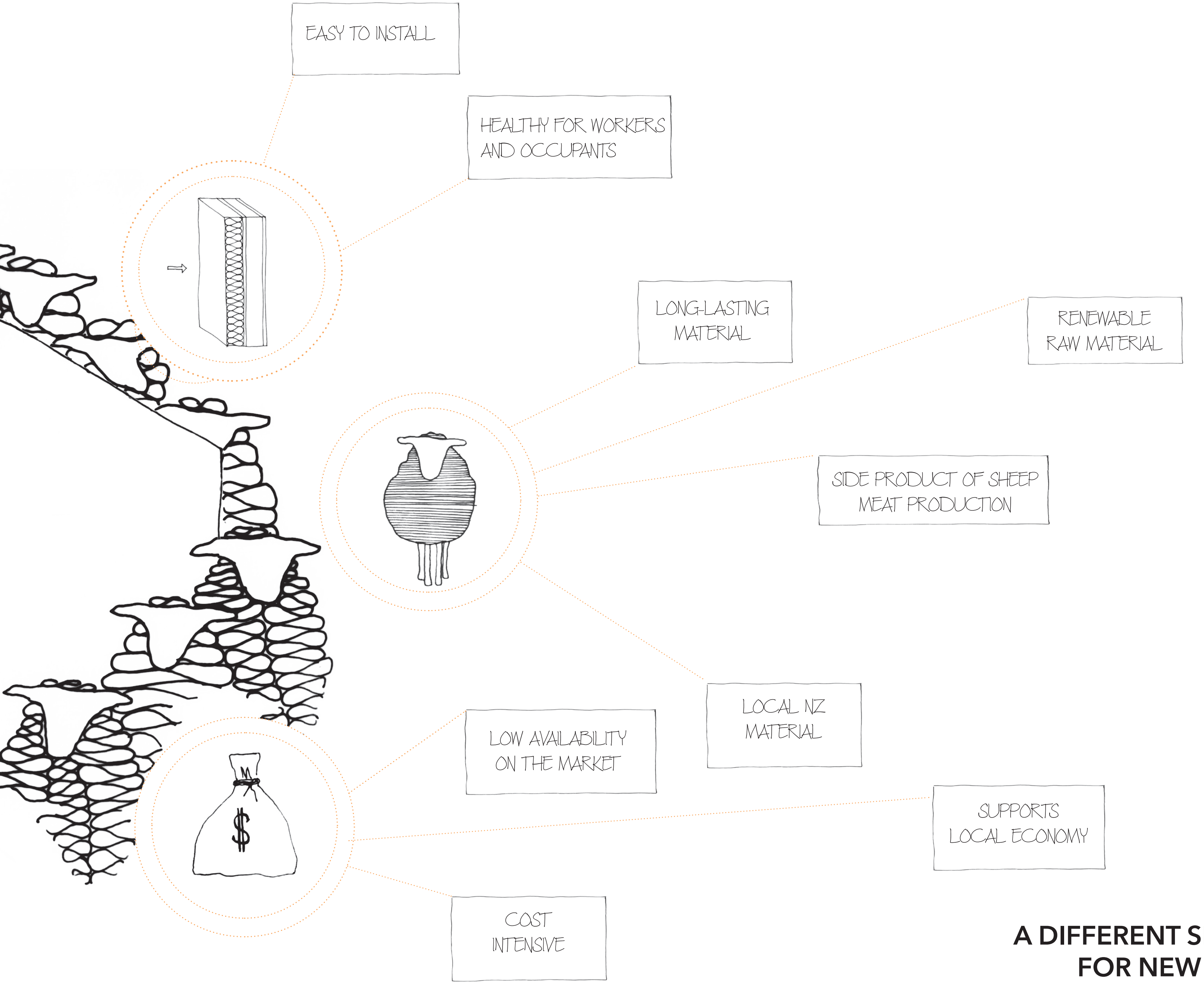


FIGURE 68: Summary of key findings © Graphic: (Laura Feller.2020y)



A DIFFERENT SPIN ON INSULATION FOR NEW ZEALANDS HOUSES

6.2 CONCLUSION

New Zealands built environment contributes to nearly 20% to the countries total carbon emissions, consequently there is great potential to tackle climate change within the building sector. Today's know-how provides many ways of reducing carbon, in both existing and new buildings, and architects find themselves in an important position to apply those solutions. Every country provides specific opportunities due to factors such as varying climates, methods of construction or building regulations. It is further important to differentiate between measures that reduce operational carbon (oc) and embodied carbon (ec).

In New Zealand thermal retrofitting presents a major challenge, concerning about 390.000 houses built between 1880 and 1970, (these may be due for major maintenance within the next few years) in need for renovation. These inefficient houses with little or no insulation bring a low standard of living on the one hand, and avoidable carbon emissions on the other.

Sufficient insulation, together with high standard glazing and a sustainable heat source represent the technical foundation of a modern home. While ultimately aiming to reduce O.C, it is crucial to reduce E.C in the first place. This can be achieved by working with low carbon insulation materials, those which provide the same technical properties as comparable common products. Sheep wool proves to be exactly that, being produced from coarse sheep wool fibre, the wool itself is available in large quantities as a by-product of the sheep meat production in New Zealand.

Sheep wool insulation has been successfully used for many years around the world and also in New Zealand, although it is less common. By looking at a detailed case study of a house built in the 1950s, it has shown that installing sheep wool works well with the commonly used timber frame construction and achieves the required R-values. Different methods of installing the product have been examined and have to be decided on a case-by-case basis depending on the age and condition of the house. For the above mentioned case study it is most efficient to retrofit from outside and replace the cladding as well as the windows.

The total amount of embodied carbon within the insulation, and the total annual energy savings was calculated during the 1950s case study. These numbers could then be compared with other insulation materials such as glass wool. The global warming potential of sheep wool insulation is only 20% of glass wool insulation, hence changing material can save about 2000 kg Co2 eq embodied carbon for an average 100 m2 house alone. While one house is obviously just a drop on the hot stone, projecting that on a nationwide scale could mean savings as much as 1.2 mio t Co2 eq.
Furthermore, in some heating scenarios the energy payback time of glass wool insulation can be more than a lifetime of a house and is not sustainable in any way. Sheep wool insulation has comparable amortisation times that are only a small percentage of glass wool.

All in all, sheep wool insulation is a high performing insulation material that saves a substantial amount of CO2 eq. Despite knowledge around sheep wool and other low carbon products significantly lacking, awareness needs to be increased both within the industry as well as with the broader audience (customer).

New Zealand has set stepping stones towards Zero Carbon Buildings by 2050 with legal documents, it is now time to take action and actively create a shift in the building sector.This change needs guidance through education, new policies and funding, creating the necessary push to generate momentum and awareness.

We can no longer do business as usual. It's time for a radical change!

: Watercolour panoramic view - Mid
Road © Graphic: (Laura Feller.2020y)

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7 REFERENCES & LIST OF FIGURES

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7.2 LIST OF FIGURES