EFFICIENT LIVING SPACES WITH NET ZERO ENERGY CONSUMPTION

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ABSTRACT

To fulfill their agreement on the 'Paris Treaty on Climate Change,' the New Zealand government has taken the initiative to move into zero-carbon houses by 2030. However, the target date of 2030 is not far away, and we need to take relevant actions from now onward.

"Cities are on the front lines of the growing physical risks associated with climate change. They are home to more than half of the world's people, and by 2050, that figure is projected to rise to 68 percent" (Boland et al., 2021). Finding of Boland shows that we need to target urban population and get them to have net-zero energy houses by 2030 to fulfill NZ's commitment towards Paris Treaty. Therefore, this research activity will target net-zero energy urban housing, which could minimize carbon emissions in New Zealand.

For this Project, it was assumed that the client's primary focus is environmentalism and want to live in an efficient house with a net-zero energy consumption which in turn minimize their carbon footprint. It was also assumed that clients would expect comfortable but compact living as their contribution to eco-friendly living. Hung (2010) states that people can experience nature as home and home like experience in nature (Hung, 2010). Therefore, more natural environment around Project houses will be provided to connect people and their homes to nature. The architectural concept of 'Living in Harmony with Nature in a Net-Zero Village within the City' has been introduced to meet clients' expectations. Individuals do not feel that they live in the nature as they did in the past. Apartments have separated from natural environment (Kooshali et al., 2015). Therefore, the Project houses will not consider attached townhouses.

The proposed research is expected to come up with suggestions and designs on how we could develop net-zero energy living spaces that could lead to zero carbon footprint houses. As part of the recommendations of the research, designs will be introduced. These designs can be used by different groups of people such as individuals, couples, and families. The model living spaces will be put up at the proposed site located near Petone beach. People could replicate and adapt the designs given in this research for constructing their living spaces.

In arriving the final design, to let the occupants live with nature, the Project houses had been set up in village like environment surrounded by natural vegetation. Suggestions were made to introduce natural ventilation and use of natural lighting. High R-value materials were recommended for the Project houses to minimize the energy consumption of heating and cooling.

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Chapter 9 describes the features of the proposed design and stages underwent in developing the architectural design.

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CHAPTER 12

This final Chapter will explain the conclusion of the research undertaken and answers to the research question

01

INTRODUCTION

1.1 Research Question

This research will explore answers to two related questions. The first question is how to provide more efficient and compact living spaces. The efficiency aspect will be looked at in two angles namely efficiency of the space utilization and the efficiency of eco-friendliness. They are essential issues in providing futurist living spaces as the land becomes more and more scarce, specifically in the urban context. The second part of the question is connected with having a net-zero energy consumption to minimize negative environmental impact. By combining these two parts of the questions, the research question has been framed as 'How to Provide an Appealing Efficient Living Spaces that Encourages Changes in Environmental Behaviour of Those who Occupy the Dwelling with Net-Zero Energy Consumption'

1.2 Knowledge Gap

Ordinary people misunderstand the meaning of compact housing. The common belief is that small houses are for poor people, and people living in compact houses are only for individuals and not for families. Also, there is a misbelief that people who live in tiny houses cannot have modern facilities (Common Misconceptions About Tiny Home Living, 2020).

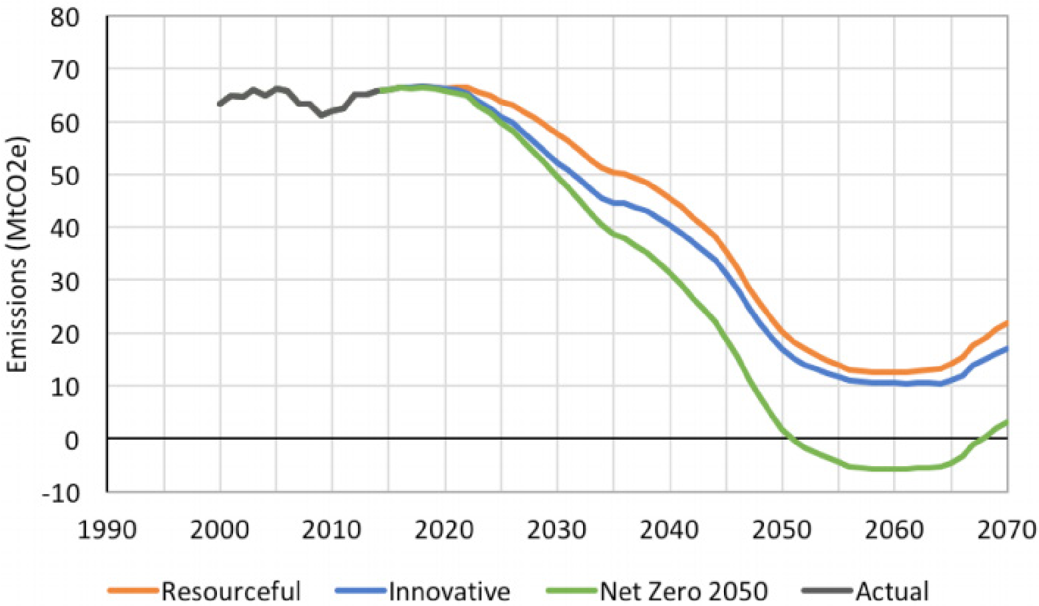
Like in the case of compact housing people misunderstand the meaning of living eco-friendly environment. As detailed out in Chapter 4 below living in eco-friendly environment means reducing, minimizing, and zeroing our carbon footprint. This project aims to provide a contribution to the reduction of carbon emission by using renewable energy generate within the site. Therefore, this research will explore the possibilities of net-zero energy consumption in living spaces.

02 BACKGROUND INFORMATION

2.1 General

To mitigate the climate changes in the world, a large number of countries got together in 2015 and signed an agreement called the 'Paris Treaty on Climate Change' (United Nations Framework Convention on Climate Change, 2016). The objective of the treaty is to limit global warming to 1.5 - 2 degrees Celsius compared to the preindustrial level. At present, 196 parties have signed this agreement, and it is legally binding. New Zealand is a party to the Paris agreement on climate change. In 2017 New Zealand Parliament discussed and agreed to reduce the gross carbon emissions by 30 percent below the 2005 gross emission levels by 2030 (Young, 2017). Furthermore, New Zealand intends to bring the net carbon emission to zero in 2050. The projected carbon emissions in New Zealand are shown in Figure 2.1 below.

Figure 2.1: Net Emissions



Material sourced from Towards a 2050 Pathway for New Zealand

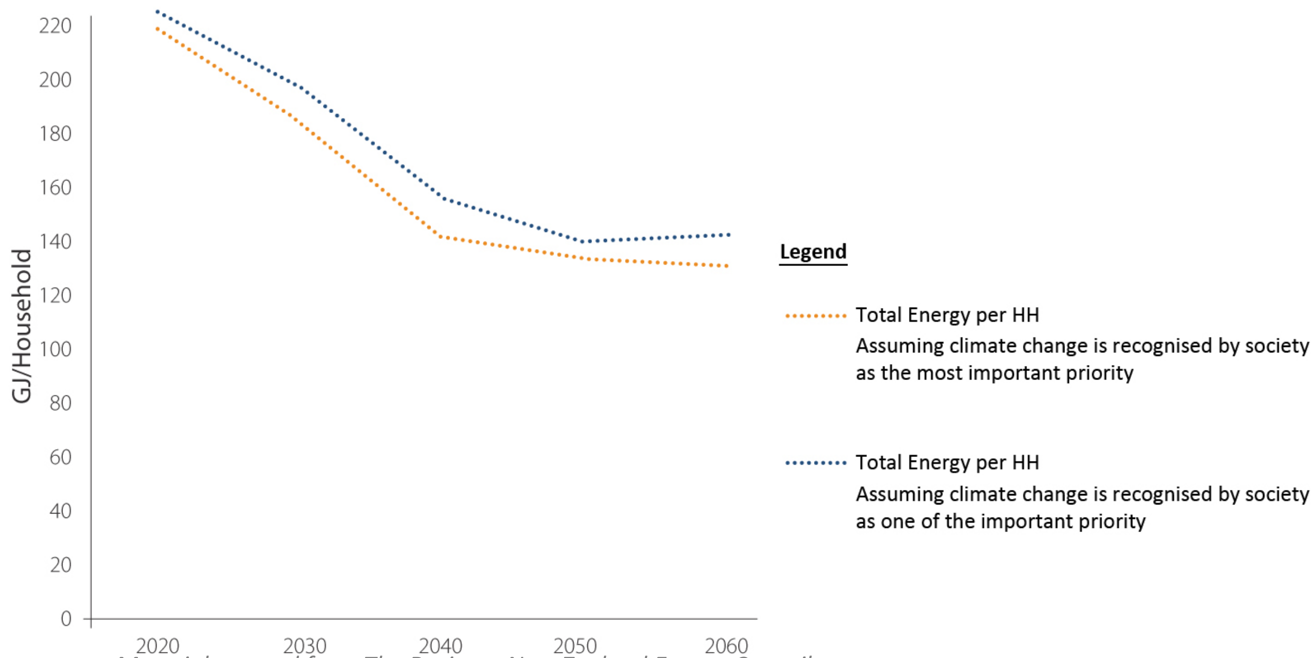
The above chart shows the government's prediction of carbon emissions under different scenarios. For New Zealand to achieve net-zero carbon emission by 2050, it is crucial for all sectors to work towards them. The energy sector, generation of power, is one of the key sectors in this context.

2.2 Net Zero Energy

Net-zero houses or buildings will generate electricity on the site during the day by using renewable energy sources (Electricity Authority Te Mana Hiko, 2018). Part of the energy generated by the households could be consumed by them during the daytime, and the excess energy generated could be either stored or exported to the Grid. The stored electricity can be consumed during the night. If the electricity is exported during the daytime, it can be imported from the Grid during the night (Electricity Authority Te Mana Hiko, 2018). When a building is energy efficient and the actual consumed energy over a period of one year, is less than or equal to energy generated at the site by using renewable sources, then the building is considered as a net-zero energy building (The National Institute of Building Sciences, 2019). Fixsen stated that "A net-zero home will make as much electricity on-site as it will consume over the course of one year. So, in theory, any energy your building is taking from the electrical Grid will be returned"(Fixsen, 2017). More details of energy generation and consumption will be discussed later in this thesis.

The Business New Zealand Energy Council has done a study on The Energy Future of New Zealand Households. The analysis was done under two scenarios, namely, (1) a future where climate change is recognized by society as the most important priority and (2) a future where climate change is recognized as one of many competing priorities (Figure 2.2).

Figure 2.2: Household Energy Consumption



Material sourced from The Business New Zealand Energy Council

As per the above projection of The Business Energy Council, the energy consumption of an average household came down from 2020 onwards and will continue to go down till 2050. However, it will not reach zero by 2050 as required by the 'Paris Treaty on Climate Change' (The Business New Zealand Energy Council, 2021). Significant changes are needed to achieve the 'Paris Treaty Climate Change' targets. The proposed research activity is expected to suggests some solutions to NZ's government goal of achieving net-zero carbon emissions by 2050.

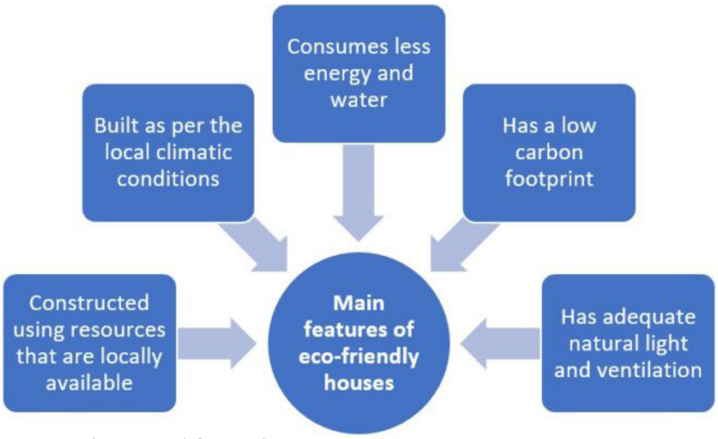
2.3 Eco-Friendly Efficient Housing

Patnaikuni identified housing as a significant sector responsible for about 20-30% of greenhouse gas emissions in developed countries (Patnaikuni, 2009). Patnaikuni's finding suggests that if we can build environmentally friendly houses, it will contribute significantly towards the NZ government's effort to have zero carbon emission by 2050. In order to harness the advantages stated above, the proposed housing design under this research will be an eco-friendly house design in addition to net-zero energy consumption.

In contrary, Gibson believes that "Although New Zealand's overall emissions must shrink by 2050, the researchers assumed housing would maintain its current share of a shrinking emissions pie. They also assumed new housing and existing housing would maintain their respective shares of overall housing emissions" (Gibson, 2020). However, Gibson believes that new homes would be built with eco-friendly features such as natural cooling. We need to counter Gibson's argument by introducing more eco-friendly housing designs, and this research will introduce one such solution.

Furthermore, “the world is facing climatic changes and global warming. To counter this more and more people are moving into eco-friendly homes” (Gupta, 2021). Gupta has come up with a model of eco-friendly houses. The Figure 2.3 below high lights the Gupta's model.

Figure 2.3: Gupta's Model for Eco-friendly Housing



Material sourced from the Houses

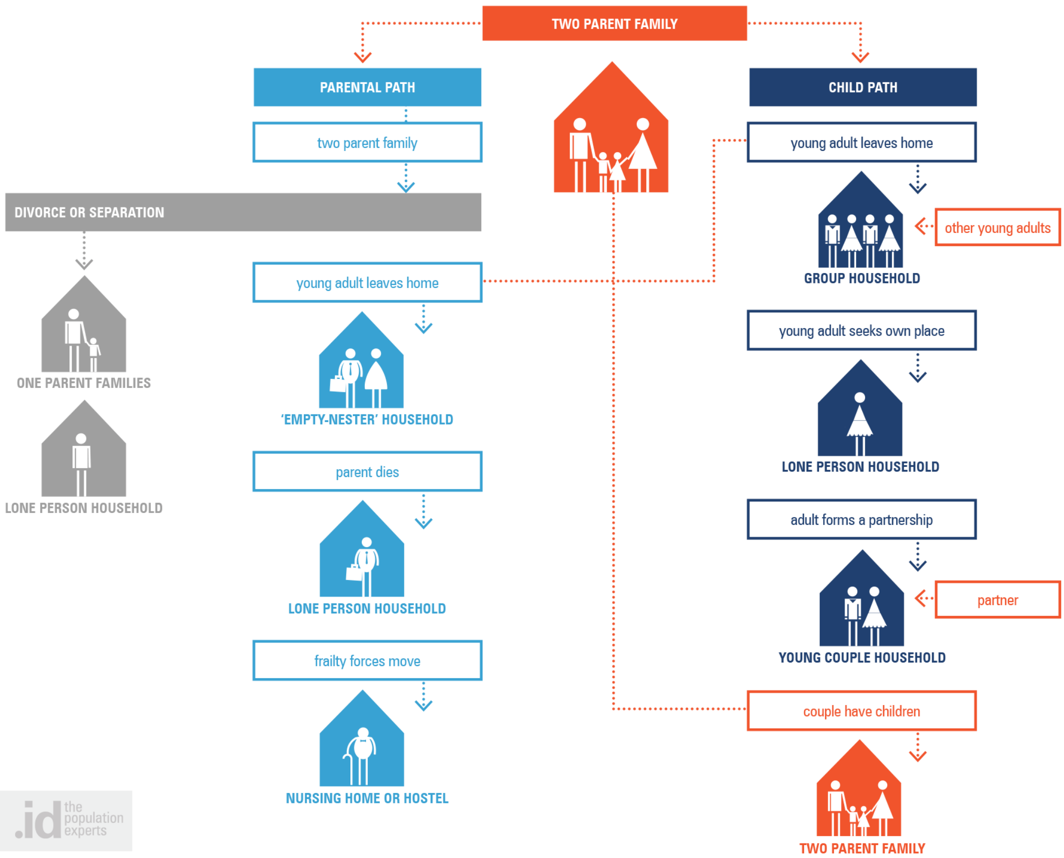
CSR stated that eco-friendly houses are more popular with homeowners because it's a great approach to building design as it enables houses to work better in their environment, use less energy and be more comfortable (CSR, 2020).

2.4 Current Housing Statues in New Zealand

As per the 2018 census carried out by the NZ government, there were 1.6 million private residential units in NZ. 2018 census identify that 1% of the population was severely deprived from adequate housing. The census also identify that home ownership rates have decreased from 73.8% in 1991 to 64.5% in 2018 indicating the need for more housing in New Zealand (Stats NZ, 2020a).

ID community, an evidence base for over 250 local government areas in Australia and New Zealand, has forecasted the household and suburb life cycle in NZ. Figure 2.4 below shows the life stages of the majority of households in the area.

Figure 2.4: The Life Stages of Majority of Household



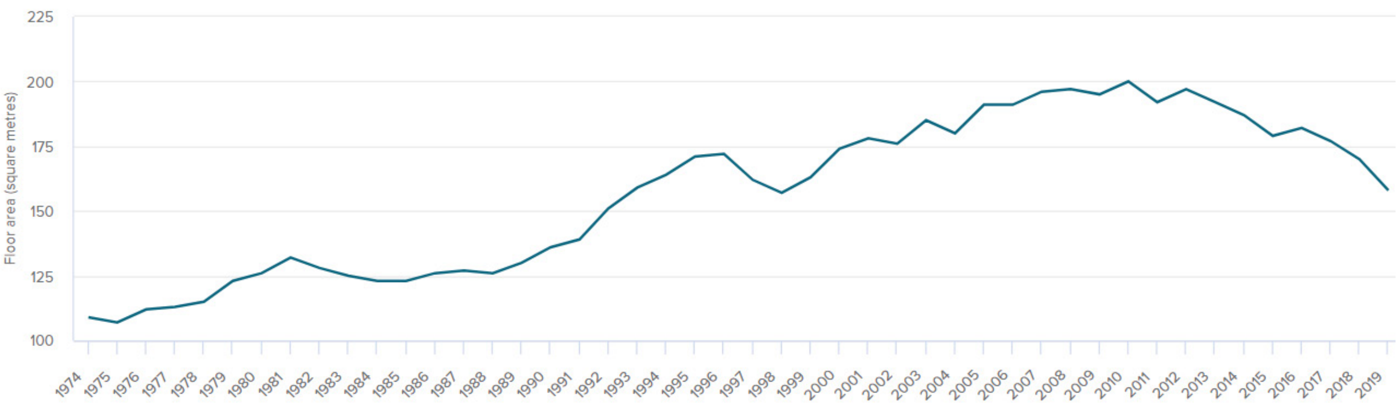
Material sourced from .id Community

The study identifies that "As people grow from children to adults and into old age, they change the type of households that they live in. The traditional path has been to start as a child in a family household, move into a group or lone person household as a youth, becoming a part of a couple relationship within 5-10 years" (.id Community, 2021).

Though this forecast is done in Wellington city, it applies to the entire region. Above life cycle analysis highlight that most people live as individuals or couples. Government statics published as per the 2018 census indicates that 48% of the population in the Petone area where the site is selected for model housing has never married (Stats NZ, 2018). The same source identified that 41% of the female population did not have children. These statistics suggest the need to have many more single and double household units compared to family household units.

A large house, often needs more material, which means more space needs to be heated or cooled. Therefore, it should make sense to evaluate the potential of the smaller dwellings in NZ to bring down the emission levels. New Zealanders used to build unusually big and spaced-apart houses, which had higher emission levels (Stats NZ, 2020a). Gibson (2020) by quoting a study conducted by McLaren and Dowdell identified that the typical Kiwi home is a detached, one-story, three-bedroom dwelling with a 166m^2 floor area, and the size of a typical newly-built house is expected to grow further, to 198m^2 (Gibson, 2020). However, as per Stats NZ, the average floor area of a house in NZ in 1974 was about 109m^2 this has increased to 200m^2 by the year 2010 (Stats NZ, 2020a). Since 2010 the floor area had declined; by the end of 2019, the floor area had dropped to 158m^2. Figure 2.5 shows the average floor area of NZ homes.

Figure 2.5: The Average Floor Area



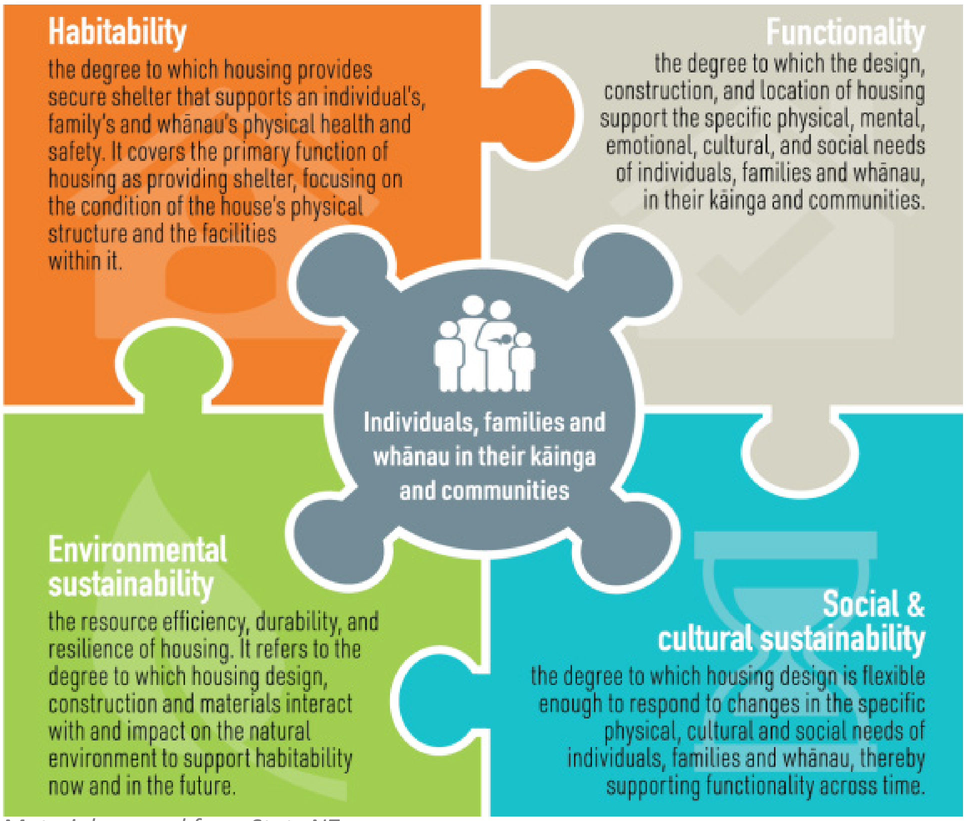
Material sourced from Stats NZ

The above statistics show a 21% drop in the average floor area of a house in NZ over nine years (Stats NZ, 2020b). The new houses that came up in 2019 had an average floor area of 148m^2. This clearly indicates the declining trend of the size of the houses in NZ. To support the NZ government's initiative of zero-carbon housing by 2030, the floor area of the house may need to be much smaller than the average floor area of newly built houses. This study proposes 60% smaller houses than average houses coming up at present. The proposed house size under this study averages around 60m^2.

2.5 Housing Quality

The NZ government has come up with a conceptual framework for housing quality. The framework consists of four interconnected elements: housing habitability, housing functionality, environmental sustainability, and social and cultural sustainability (Stats NZ, 2019). Figure 2.6 below highlights the housing quality framework.

Figure 2.6: The Housing Quality Framework.



Material sourced from Stats NZ

A basic house should provide security to those who occupy it. Likewise, the house should support specific physical, emotional, cultural, and social needs of those who occupy the dwelling. In addition to these essential qualities of a house, the NZ government expects resource efficiency and durability in constructing housing and supporting the natural environment. Furthermore, housing should support social needs such as the connectivity of individuals. The proposed housing design will consider these four factors when finalizing the architectural design.

03

METHODOLOGY

The research methodology consists of a combination of both Qualitative and Quantitative approaches. First, information was gathered using literature reviews and available statistics. Second, information was collected to optimize the utilization of house spaces, lighting and heating, material, and ventilation. Third, the information collected was analyzed by using a qualitative approach. Finally, the observations and conclusions reached were used in coming up with possible designs and models.

The intended research process consists of ten steps. These steps consist of Research Idea, Literature Review, Formulation of the Problem, Empirical Research Questions, Research Planning, Data Collection, Preparation of Models, Answering the Empirical Questions, Comparison with Earlier Research, and Conclusions.

04

LITERATURE REVIEW

As the efficiency aspect will be looked at in two angles namely efficiency of the space utilization and the efficiency of eco-friendliness, literature review will look into two key areas to ascertain efficiency factors of Project houses. In addition to it, net-zero energy part will also be looked at separately under the literature review.

4.1 Compact Housing

Charlie Kilman in his article on 'Small House, Big Impact: The Effect of Tiny Houses on Community and Environment' "argues that the tiny house is a legitimate housing alternative that fosters a strong environmental ethic alongside a greater appreciation for community" (Kilman, 2016, p. 2). Kilman also claims that biggest incentive for living in tiny houses is the saving of money and the average cost of a small house is much less than a cost of a normal house. He also claims that for tiny house owners, less consumption means a smaller environmental footprint and one of the more intangible benefits of living in a tiny house is the constant interaction with the outdoors (Kilman, 2016, p. 6). Finally, he concludes that tiny houses can be a big thing for the economy, the environment, and our communities and it could be just a matter of time before mind set of people changes accepting tiny houses. As Kilman claims the proposed Project houses will have a smaller environmental footprint and occupants of them will have the advantage of better interaction with outdoor.

The Tiny House Movement by Tracey Harris highlights that the tiny house movement is more than a lifestyle choice and that the movement challenges the consumerist lifestyle (Harris, 2020). The book defines a tiny house as a home focus on effective use of space, with a good design to meet needs of residence and a life style. Harris states It is difficult to live an environmentally friendly lifestyle with a large house and a large house means a waste of resources (Harris, 2020, p.22). She also indicates that some people desire to live in community of tiny houses. This argument supports the proposed Project of having a number of tiny houses as a cluster (Harris, 2020, p.25). Furthermore, Harris states that people continue to lose many of their connections to the people in the neighborhood and in the communities by living in bigger spaces. This argument also supports the architectural concept of the Project houses to have a number of small houses as a community.

Riggie of YR Architects have suggested three strategies for compact houses. 1) Creation of small, efficient spaces, 2) Connect with the outdoors, and 3) design simple minimalistic and uncluttered spaces (Riggie, 2016). In order to achieve these strategies, Riggie suggests to consider having multipurpose spaces as far as possible, introduce Multipurpose furniture, use natural daylighting, and outdoor spaces ideas for small efficient spaces. Multipurpose spaces can be planned by combining different functional spaces such as the bedroom and the study room. Furthermore, by having seamless connection between indoor and outdoor, people can feel that they can live in a bigger space. These ideas have been incorporated into the project design.

Tiny house living by Catherine Foster indicates that living in small houses can be exciting as well. Foster confirm this by stating that "two of the smaller urban structures-45m^2 garden studio in Wellington and one at 35m^2 in Auckland are noteworthy examples of how a small footprint can contain a rewarding home, as visually exciting as it is functional" (Foster, 2015). Furthermore, Foster indicated that "the constraints of scale do not lessen the imperatives of good design, where every centimeter is precious, intelligent appreciation of space, resources and materials is even more important than in a conventional build" (Foster, 2015). Foster identified twenty space-efficient features that can be used for a small house. Foster's twenty ideas are more or less similar to the ideas given by Riggie and listed above.

Big Ideas for Small Houses by Catherine Foster identify that people in NZ are adapting to change in time by moving into smaller houses. However, Foster indicates that people who live in tiny houses are not those who want to build assets by investing in houses she confirms by stating, "homes that here range in size from 34m^2 to 100m^2 - the results in terms of home creation (as opposed to asset building) are inspirational" (Foster, 2019).

Various architects have given multiple ideas in designing compact houses. Riggie gives interesting strategies for building compact houses (Riggie, 2016). For a compact house, there is a need to have multipurpose spaces such as combining the bathroom and the laundry room, i.e., hiding laundry appliances behind concealed doors. This strategy not only saves spaces it also minimizes plumbing piping between appliances.

Multifunctional rooms such as office areas can be converted to a guest bedroom with a couch that folds out into a bed is another idea—multipurpose furniture like one piece of built-in furniture instead of having a desk and a table. Hallways could be eliminated or combined with other spaces. For example, a hallway space can be used as a library. Outdoor spaces could be used as living and entertainment spaces.

By eliminating interior walls between the kitchen and dining, people could feel that they are in a bigger space. There is a need to use all wasted spaces, such as wasted space under enclosed stairs to be used for storage or have built-in shelving. Likewise, people in a small space could feel that they are in a bigger space by adding large windows. It will help to get natural daylighting and capturer the views of the surrounding landscape. Skylights, small windows, and the use of glass lites could enhance the use of natural daylight.

New Zealand does not have a standard definition for what constitutes a tiny house (Duxfield, 2020). The Australian Tiny House Association (ATHA) defines that a Tiny House is a moveable dwelling suitable for permanent residential use, with self-contained amenities and services and the option to be grid connected (Australia Tiny House Association, 2021). Appendix Q of 2018 Residential Code published by The Tiny Home Industry Association of USA states that tiny houses are houses with less than 37m^2 (400 square feet) (Thome, 2019). The shelter provided by tiny homes is considered transitional — a temporary fix until people are deemed ready to transition to more permanent, stable housing (Sanchez, 2021). Proposed Project houses are permanent residential spaces, therefore providing tiny houses were not considered as a solution. Hence, the proposed Project will provide more permeant small houses with 60m^2 area.

4.2 Eco-friendly Housing

Different publications identify the key features of, eco-friendly housing slightly differently. For example, Melinda Williams identifies six such features in her publication of Eco Home: Smart Ideas for Sustainable New Zealand homes (Williams, 2018). Features identified by Williams are 1) Respect the site and its community, 2) use renewable natural resources efficiently, 3) choose low-impact materials, 4) move from waste to regeneration, 5) design for a lifetime, 6) integrate a connection with nature (Williams, 2018).

National Self Build and Renovation Center of UK identifies seven critical features of, eco-friendly housing: Insulation, Water conservation, Renewable energy, Smart technology, Energy Star appliances, Reclaimed wood, natural lighting, and ventilation (Common Misconceptions About Tiny Home Living, 2020). For the proposed Project, renewable solar power, natural lighting and heating, conservation of water, and eco-friendly materials will be considered.

Crawford and Stephan on their article on 'Tiny house, tiny footprint? The potential for tiny houses to reduce residential greenhouse gas emissions' states that buildings account for over a third of global energy use and nearly 40% of greenhouse gas emissions (Crawford & Stephan, 2020). Residential building account for over 70% of the energy demand of total buildings. They claim that tiny houses have emerged as a potential solution to the energy demand. They also claim that tiny houses may result in 70% reduction in per capita greenhouse gas emissions. Crawford and Stephan study confirm the importance of tiny houses as one of the key solutions to the greenhouse gas emissions. The proposed Project houses under this research are also considering compact efficient houses which will in turn help to reduce carbon emissions (Crawford & Stephan, 2020).

Ruyu Hung, in her article 'Journeying between Home and Nature: A Geo-Phenomenological Exploration and its Insights for Learning,' argues that" 'Home' and 'Nature' are usually taken as two opposite concepts in relation to the human geographical experience (Hung, 2010). However, drawing on the perspective of geo-phenomenology, that the meanings of nature and home overlap to the extent that it is possible to experience nature as home. Moreover, it can be shown from the paradoxically interwoven senses of nature and of home that there is a dynamic process of a to and from journey between nature and home" (Hung, 2010). Hung questions whether we can experience nature as home, can we have a home like experience in nature and in what sense can these two places be experienced as authentically and significantly related to each other? Hung thinks nature and home are not necessarily experienced as two distinctively different places (Hung, 2010). By taking this idea forward proposed design of Project houses will be blended with the natural environment.

Nikolov Brebbia in his article on 'Use of Environmental Parameters in Building Envelope Design' published under Eco-architecture IV: Harmonisation Between Architecture and Nature states that "Today the architectural profession sees its future in the interplay and balance between the natural and built environments and increasingly seeks to establish a functional interface between them" (Brebbia, 2013, p. 215). Brebbia argue that eco-architecture means use of natural environmental parameters such as sun position and hourly and daily radiation and temperature values into the design (Brebbia, 2013, p. 225). The proposed Project has taken Brebbia's suggestion into consideration and integrated sun position and hourly daily radiation into the Project design details of which are given in Chapter 6, 7 and Para 10.1.

Krista Evans in the article 'Integrating tiny and small homes into the urban landscape: History, land use barriers and potential solutions' states that it is important to integrate small houses in a manner that is perceived as esthetical pleasing (Krista, 2018). This is important because research has indicated that public perception greatly influence the built environment (Krista, 2018). In following this concept propose Project houses will be blended with the nature to have an esthetical pleasing environment.

4.3 Net-Zero Energy Housing

Brimblecombe et al., 2017, on their book on Positive Energy Homes proposes that people should aim for positive energy homes as part of the passive housing. They claim that passive energy homes are a big step towards a journey connecting the home to the environment. Brimblecombe et al. claim that "Positive energy is an attitude about actually contributing, where we 'give back more energy to the common pool than we take out. The Positive Energy Homes concept builds on Passive House in a way that focuses on people, not buildings" (Brimblecombe et al., 2017, p. 181). They believe much of the world is targeting net-zero energy and it doesn't help the community.

Brimblecombe et al., 2017, claim that most reliable way of generating energy is by using solar power. The other renewable energy such as wind, hydro, and geothermal has lot of limitations to use in urban environment. In addition to generating solar power by using PV panels, the book proposes to have power storage systems to ease up the demands from the grid. However, Brimblecombe et al., had not done a cost benefit analysis of adding a power storage system (Brimblecombe et al., 2017, p. 242 - 246).

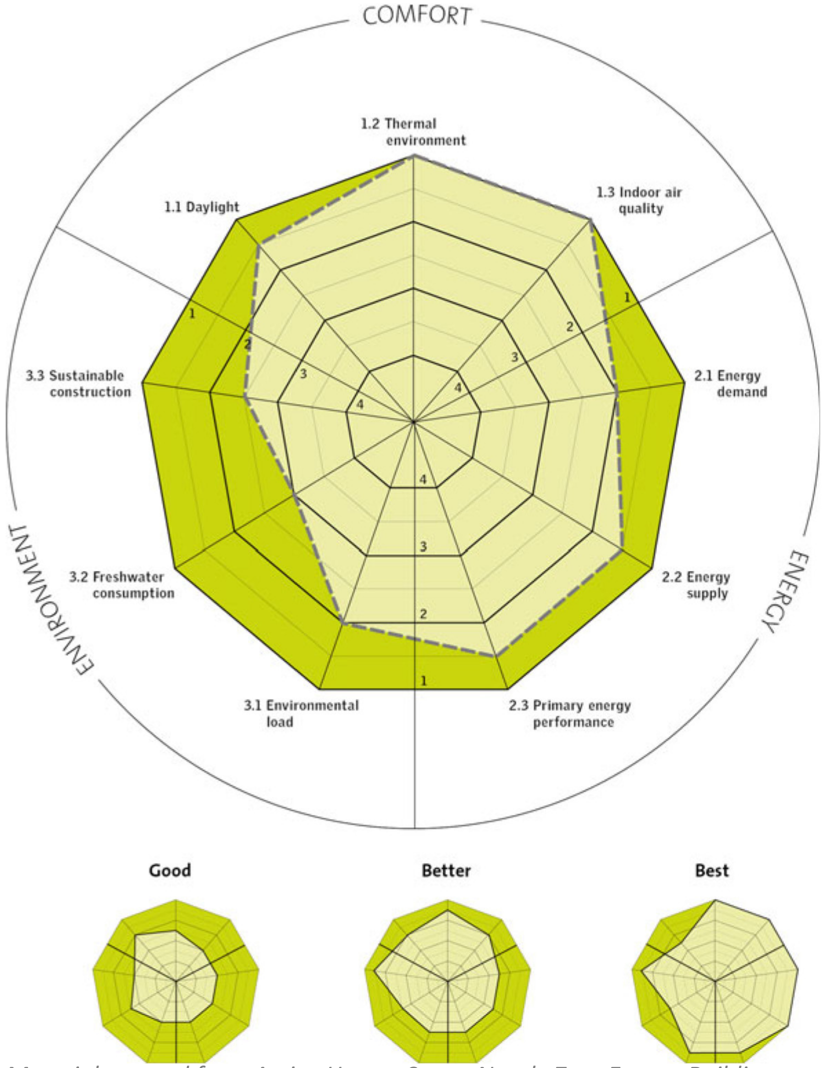
Brimblecombe et al., 2017, raise the question that why don't people share energy in their community. Brimblecombe et al., 2017, claim that people are used to share things for example people share vehicles, tools and equipment such as lawnmowers. Which means communities are already sharing resources. Likewise, sharing energy should not be a problematic issue and proposes community solar power systems. However, creating communal solar power generation system may lead to complications when it comes to managing and sharing the system. Brimblecombe et al., 2017, has not discussed other complications that may arise on community power sharing scheme. Community power sharing is complicated and may need a mini-Grid and a system to identify how much have been generated and consumed by each household. Therefore, the proposed Project will not consider common solar power generation system and will promote individual solar power generating system.

In chapter 6 Brimblecombe et al., 2017, discuss lighting and connections with the environment of a positive energy houses. They claim that "light is the primary way in which we interact with the world. It provides us with a direct connection with the surroundings, allows us to navigate around our environment, appreciate physical beauty, conduct fi ne spatial tasks and helps to regulate our body clock" (Brimblecombe et al., 2017, p. 117). Brimblecombe et al., 2017, also discuss how light could be used for many functions such as light to see, texture and pleasure, direct and high light, create ambience and define space. The chapter 6 also discuss details about how to arrange door and windows to get the maximum benefit of the lighting and connection to the environment. Ideas given in the book such as having high windows and suitable shading have been taken into consideration for the proposed Project houses.

In chapter 5 Brimblecombe et al., 2017, discuss heating arrangement for positive energy house. "Active management of the building envelope, through use of windows to collect solar energy, can eliminate for active heating most of the year. Where additional heat is required, the ventilation system is the ideal method of distributing heat around the home via the heat recovery unit." (Brimblecombe et al., 2017, p. 114). This system of ventilation and heating had been taken into the propose Project houses.

Five authors got together and have done a detail study about active housing. The study has been carried out across 20 countries mainly in Europe, and 75 active houses were selected for detail studies (Feifer et al., 2018). The results of the study have been published under the name 'Active House: Smart Nearly Zero Energy Buildings'. Each house had been analyzed under three principles namely comfort, energy and environment. Under the principle of comfort daylight, thermal environment and indoor air quality was measured. Under the principle of energy, energy demand, energy supply, and primary performance were looked at. Likewise, under environment, environmental load, fresh water consumption and sustainable construction have been looked at. The authors have developed an active house radar to ascertain the level of performance of the houses studied. Figure 4.1 below shows active house radar. Though the results have not been quantified all aspects considered by the above study had been taken into consideration in arriving the final decision of the proposed Project.

Figure 4.1: Active House Radar



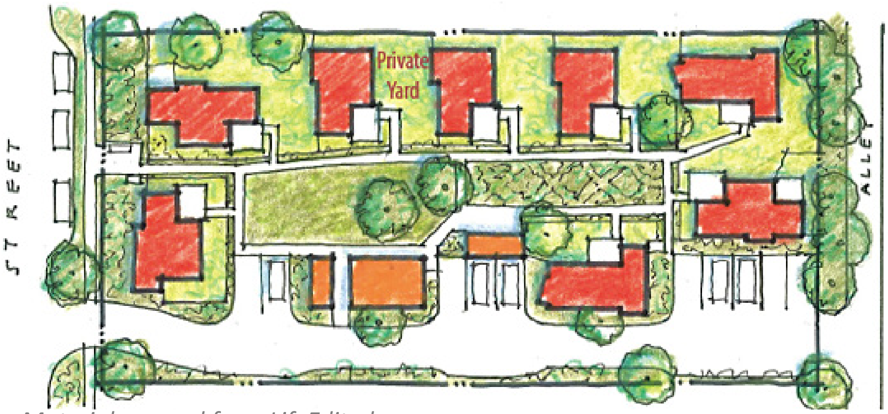
Material sourced from Active House: Smart Nearly Zero Energy Buildings

05

PRECEDENT STUDY

The Project, 'The neighborhood within the neighborhood' by the Ross Chapin Architects, and 'Regen Village', 'Build for Life', and 'Ringkøbing K' by Effekt Architects were selected for precedent studies for the master plan.

Material sourced from LifeEdited



Material sourced from LifeEdited

Material sourced from LifeEdited

THE NEIGHBORHOOD WITHIN THE NEIGHBORHOOD

ROSS CHAPIN ARCHITECTS

The architect Ross Chapin introduced a cluster of houses with shared backyards and alleyways with car-free outdoor areas. Occupants of the houses had outdoor areas like gardens. The idea was to promote tight-knit communities–where neighbors look out for one another, where children can play safely. Ross Chapin architects claim that pocket neighborhoods are designed to promote community but also have enough autonomy and privacy for members to do their own thing, and they see the pocket neighborhood as an excellent option for establishing a strong community while using minimal resources and being adaptable to environments ranging from urban to rural (LifeEdited, 2015). Individual houses did not have a big yard, and low fences were used to divide the space among houses.

MASTER PLAN

Precedent Study

REGEN VILLAGES

EFFEKT ARCHITECTS

Material sourced from Effekt Architects

Regen Village was a development in Almere Netherlands done in 2016 by Effekt Architects. The development is off the Grid that generates its own power. It is considered an Eco Village that generates renewable energy, organic food production, vertical farming, water management, and waste to resource system (Effekt, 2016). The village creates a framework for empowering families and develop a sense of community.

Material sourced from Effekt Architects

Material sourced from Effekt Architects

MASTER PLAN

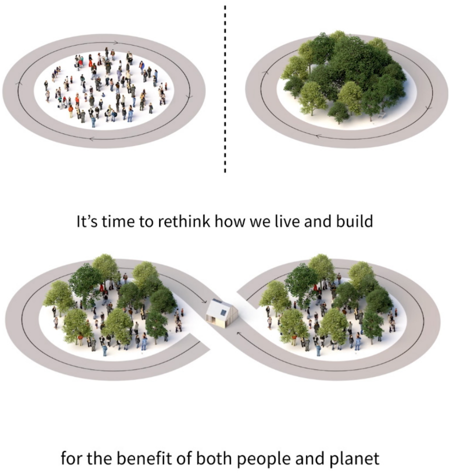
Precedent Study

BUILD FOR LIFE

EFFEKT ARCHITECTS

Build for life is a research project by Effekt architects which has similar features to Regen Village. Effekt claim that "The project will showcase a new way of thinking - one that is centered around building a better living environment that benefits both people and the planet" (Effekt, 2020).

Material sourced from Effekt Architects



Material sourced from Effekt Architects

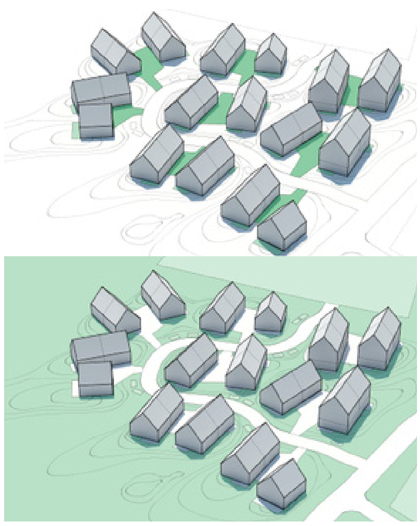
Material sourced from Effekt Architects

Ringkøbing K

EFFEKT ARCHITECTS

Ringkøbing K is another project by Effekt architects which has similar features to Regen Village. Effekt claims that "Ringkøbing K accommodates all aspects of modern way of life while giving residents the unique experience of living in the wild nature" (Effekt, 2015). The Project has various clusters of houses grouped in different orientations.

Material sourced from Effekt Architects



Material sourced from Effekt Architects

Material sourced from Effekt Architects

5.2 NET-ZERO ENERGY

Precedent Study

THE ZERO ENERGY HOUSE

A STUDIO ARCHITECTS

ANNUAL ENERGY USE

Designed/Stimulated	3,217 kWh/yr
Actual	2,361 kWh/yr

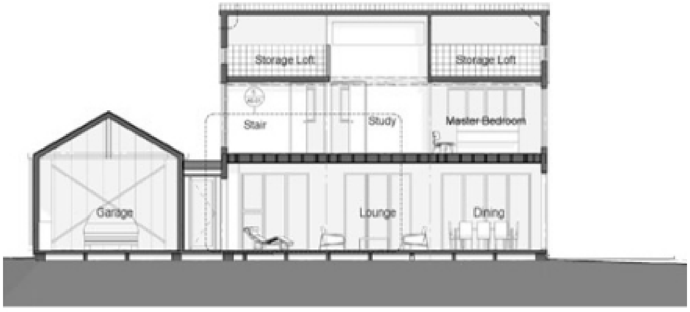
END USE BREAKDOWN

Heating & Cooling	0 kWh/m2/yr
Lighting	0.33 kWh/m2/yr (3%)
Fans/Pumps	1.44 kWh/m2/yr (13%)
Plug Loads & Equipment	4.44 kWh/m2/yr (40%)
Domestic Hot Water	1.11 kWh/m2/yr (10%)
Monitoring & Control	0.89 kWh/m2/yr (8%)
Refrigeration	1.78 kWh/m2/yr (16%)
Oven	1.11 kWh/m2/yr (10%)

Vital Stats

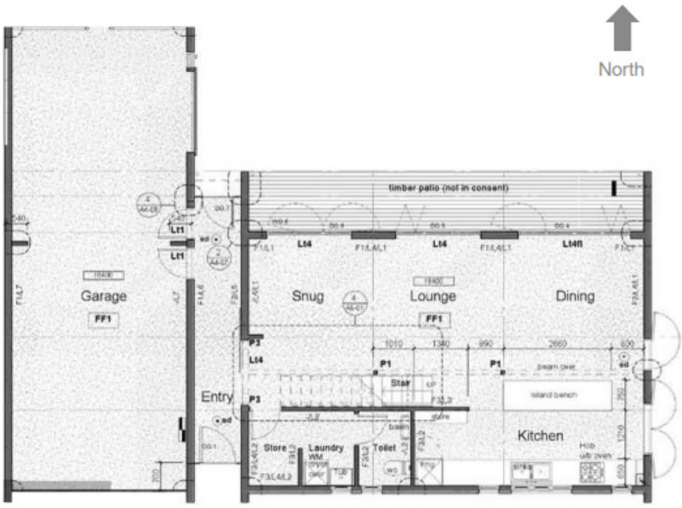
Certification Status	Net Zero Energy Building Certified on April 15th, 2014
Location	Auckland, New Zealand
Bioregion	Auckland
Living Transect	L4
Typology	Building
Project Area	4040 m2
Gross Building Area	200 m2
Building Footprint	130 m2

Material sourced from International Living Future Institute



Material sourced fromAuckland Design Manual

Zero Energy House in Auckland, NZ is powered by solar energy generated by using PV roof slates. Zero Energy House Project is considered to be the first integrated PV roof slates system type in NZ. The house is put up on a 130m^2 land and designed by Studio Architects Auckland. The house is designed for annual power generation of 3217kwh and consumes only 2361kwh (International Living Future Institute, 2016). PV tiles are fixed to 45mm by 45mm roofing battens. Generally, PV slates have 25-year life but are less commonly used. The power generation system is connected to the Grid by using the 'net meted' system. In this system, only excess power generated during the day is exported to the Grid.



Ground level.

Upper level.

Material sourced fromAuckland Design Manual

NET-ZERO ENERGY
Precedent Study

MADRONA PASSIVE HOUSE
SHED ARCHITECTS


Material sourced from International Living Future Institute

Madrona Passive House in Seattle, USA, was designed by SHED architecture & design. Power is generated using a solar panel and net metering system to import and export power to and from the Grid. The house has an airtight envelope and uses low-capacity heat pumps.


Material sourced from International Living Future Institute

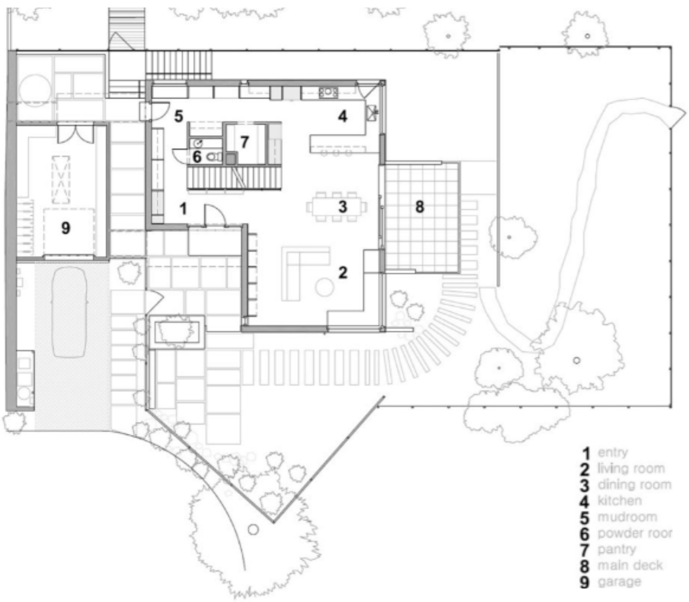
BUILDING SYSTEMS INFORMATION

Roof R-value	72
Floor R-value	24
Wall R-value	34
Window U-value	0.123 - Windows are triple pane Thermoplus
Exterior Shading Devices	Ext blinds
Air Infiltration Testing Conducted, Infiltration rate, Metric	Yes, 0.32, AHC

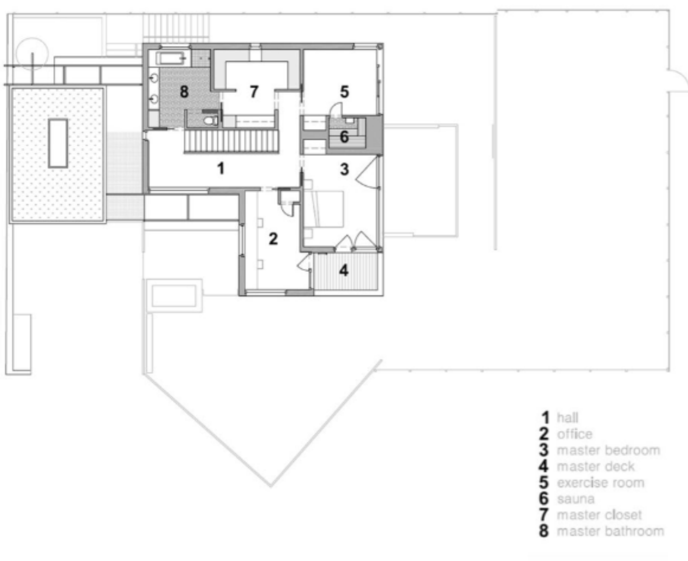
VITAL STATS

Certification Status	Zero Energy Certified
Version of LBC	3.1
Location	Seattle, Washington, USA
Typology	Building
Project Area	3,397 SF
Start of Occupancy	November 2015
Owner Occupied	Yes
Occupancy Type	Residential
Number of Occupants	4

Material sourced from International Living Future Institute



Ground level.



Upper level.

Material sourced from SHED Architecture & Design

TANGLEWOOD

Material sourced from International Living Future Institute

Material sourced from International Living Future Institute

Tanglewood House is located in Auckland, New Zealand, and has an area of 198m^2. Two occupants started occupying the space in 2018. The house has adjustable solar panels at the north side of the house and panels fixed on the flat roof at 5° angles. The adjustable solar panels on the north side can be adjusted between 30° and 50° angles. During the winter, panels are adjusted to 50°, and for the rest of the year, they are adjusted back to 30°. Doing this adjustment power generation during the winter is more efficient. Compared to 5° angle panels on the roof, the 50° angle panels generate 40% more power (International Living Future Institute, 2021).

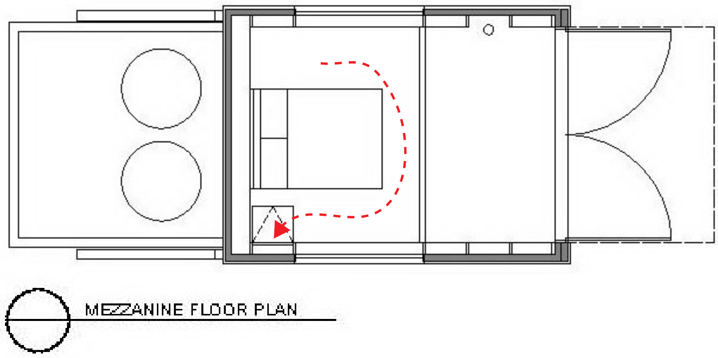
Material sourced from International Living Future Institute

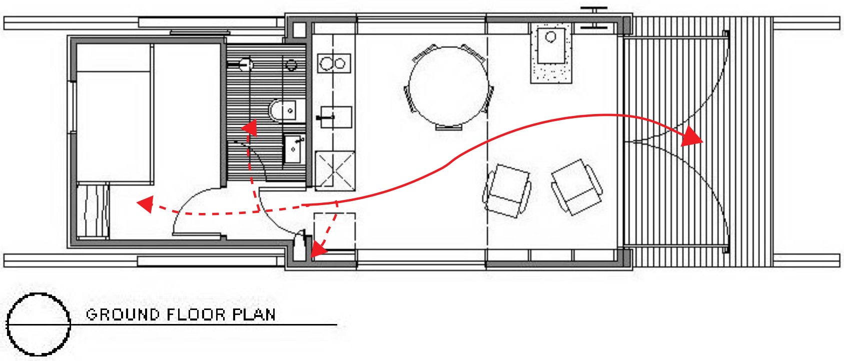
HUT ON SHEDS

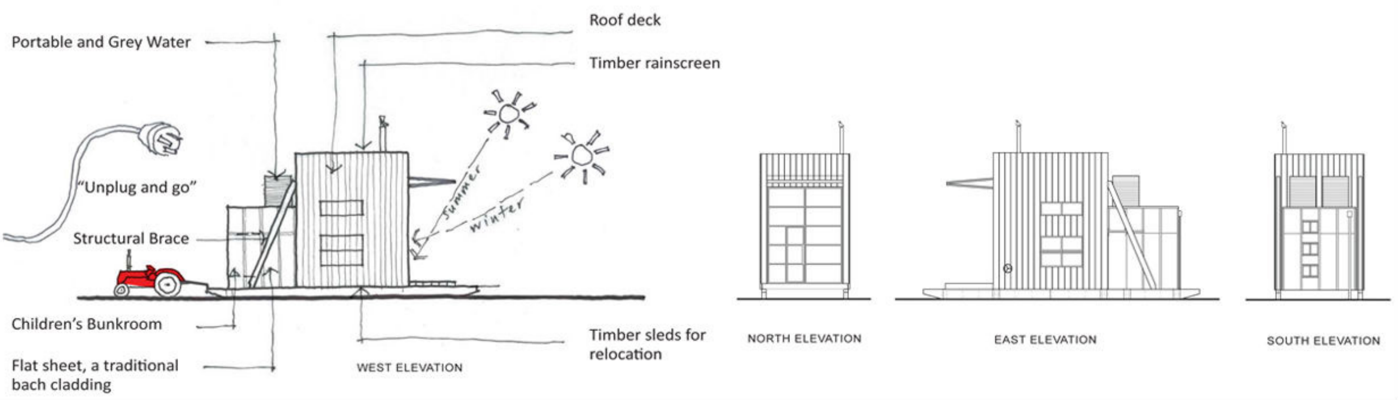
40m^2
2 BEDROOM
CROSSON ARCHITECTS

Material sourced from Crosson Architects

The compact house known as 'Hut on Sled' in Whangapoua NZ is a 40m^2 one-bedroom holiday retreat (Crosson Architects, 2020a). The space designed by Crosson Architects had won several awards for designing such a compact house, including living, kitchen, dining, bathroom, two sleeping zones. The Hut capture rainwater and use timber cladding as part of its assistance to sustainability. Arrows on the floor plan indicate people's movements within the space.







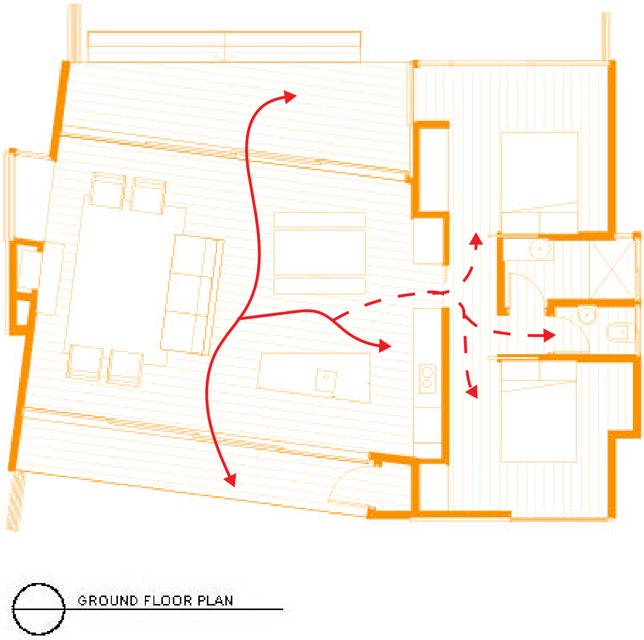
Material sourced from Crosson Architects

WHANGAPOUA HOUSE

2 BEDROOM
CROSSON ARCHITECTS

'Whangapoua beach house' in NZ, also designed by Crosson Architects, is another award-winning two-bedroom compact house (Crosson Architects, n.d.-b). The space uses series of bi-folding slated shutters to control the sunlight. In addition, the house space has been utilized efficiently by providing several concealed cabinets. Arrows on the floor plan indicate people's movements within the space.

Material sourced from Crosson Architects



Material sourced from Crosson Architects

06

SITE SELECTION AND SITE ANALYSIS

6.1 Criteria of Site Selection / Site Location

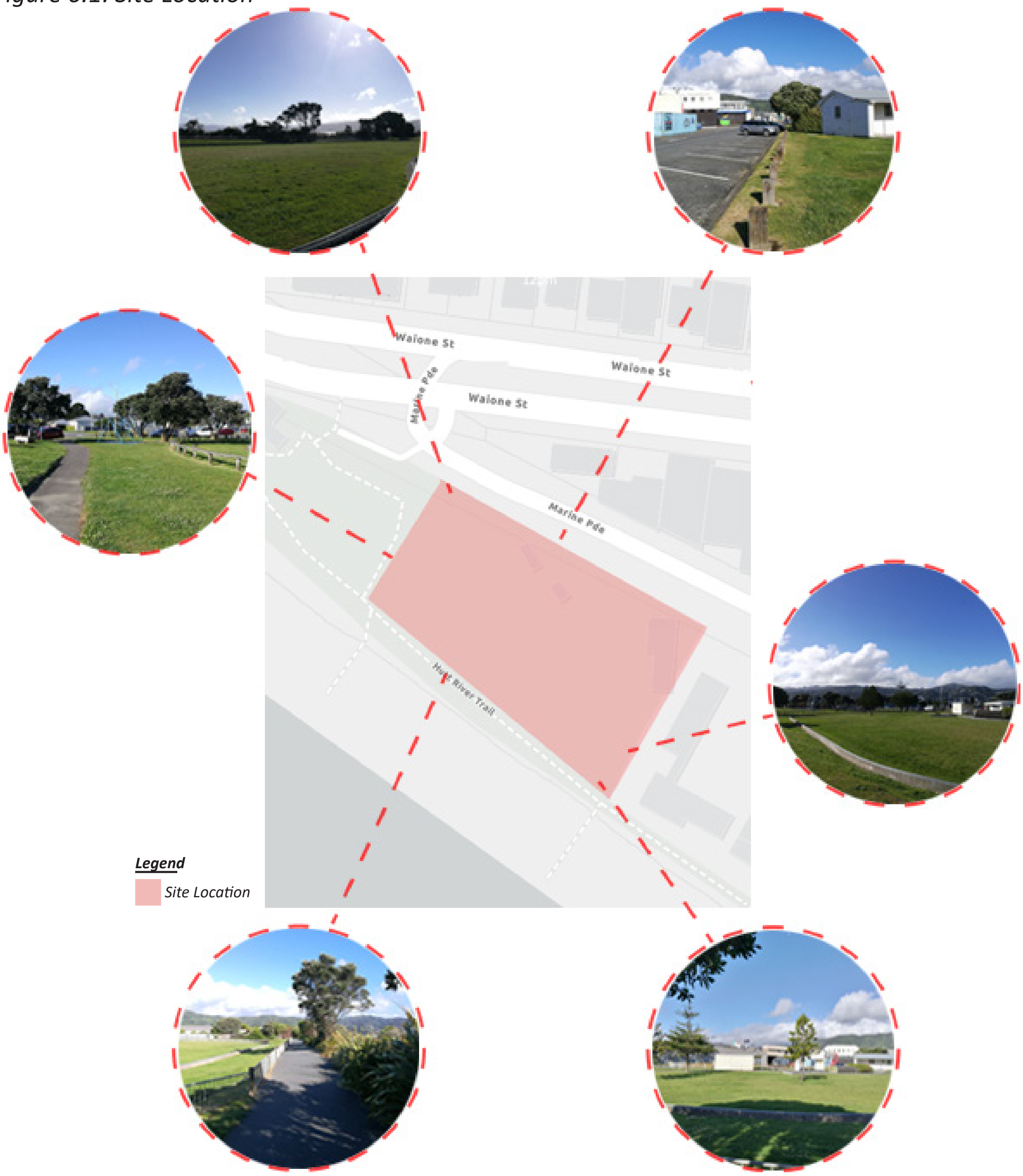
6.1.1 Site Selection

A site in Petone was selected to put up the project houses. Petone is a prominent suburb of Lower Hutt in the Wellington Region of New Zealand's North Island. Petone is at the southern end of Hutt Valley on the northern shore of Wellington. The recreational and social activities in the area and their accessibility also have been considered in selecting the site.

6.1.2 Site Location

The site is located in Marine Parade in Petone. The site is bordering a common playground at the west side and the Empire Table Tennis Club on the east side. The north side of the site is bordering on the Marine Parade. The south side is bordering the Great Harbour walkway. The existing site plan is given below (Figure 6.1).

Figure 6.1: Site Location



6.2 Current Status of the Site

At present, Hutt Valley Model Engineering Society Miniature Railway occupies the site. The Engineering Society will be relocated to a different site, and the structures put up by the Engineering Society will be removed. The site has only a couple of trees and mainly an open flat land.

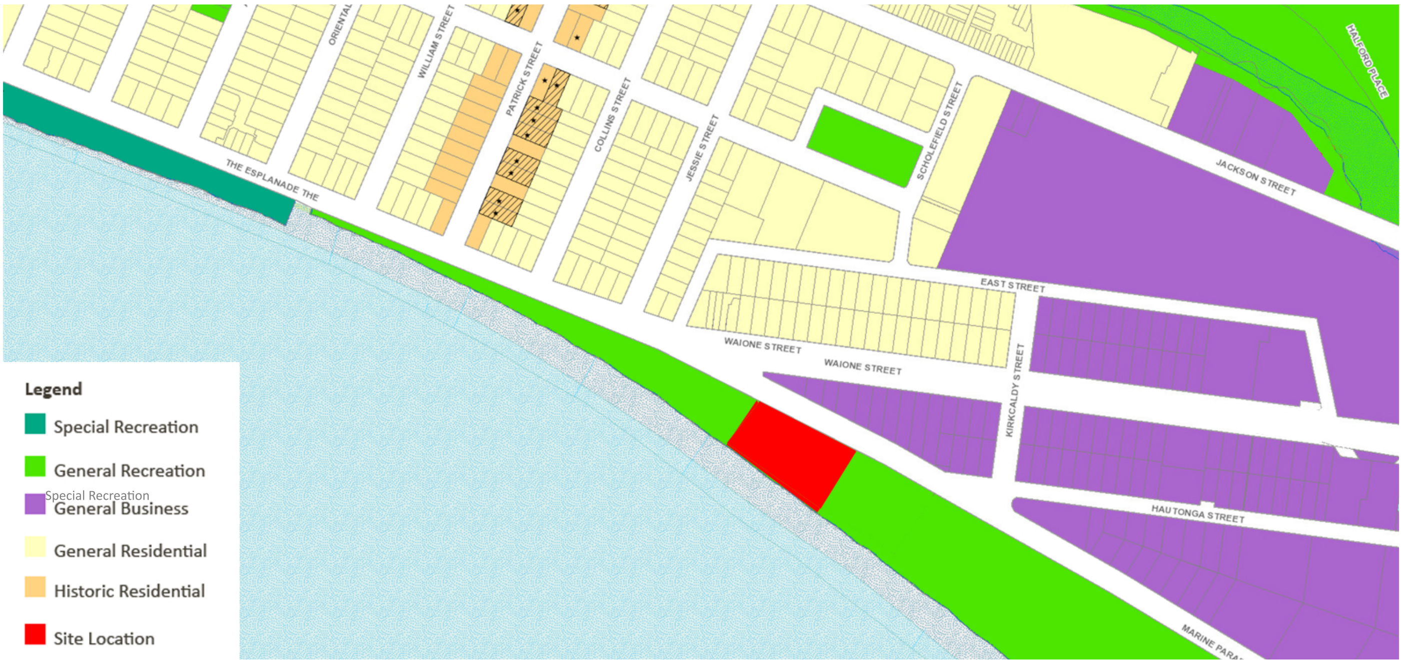
6.2.1 Neighborhood and Surrounding Developments

The Petone Rugby League Club is 200m away from the site, and the Petone beach is in the vicinity. There are no major development activities in the surrounding area.

6.2.2 Zoning and Legal Information

The site is located in a mix-zone of residential and commercial areas, and there is no restriction in putting up the residential buildings (Figure 6.2). The Medium density design guide (Hutt City Te Awa Kairangi, 2021) published by Hutt Valley City Council does not have any restrictions in putting up two-story houses. No recession plane to road boundaries. As there are no existing structures around the site, shading and privacy restrictions, do not apply to the proposed design and structure. There should be a 2.5m setback from the sides of the boundary line. It was assumed that the legal ownership of the site would be adequately secured. The site is not in a heritage area and not an archaeological site.

Figure 6.2: Zoning of the Site Area



6.2.3 Natural Physical Features

The topography of the site is flat. No water bodies are bordering the site. The shape of the site is a trapeze with an area of 4050m^2 and road side has a length of 86.5m.

6.2.4 Utilities

All utilities such as electricity, water, sewer, and telephone services are situated near the site. Therefore, houses that will be put up at the site can be connected to all utility services.

6.2.5 Transport

The site can be accessed by trains and buses. The Petone train strain station is 2.7km from the site and 35min walking. In addition, several bus routes such as 84 and 130 pass the site.

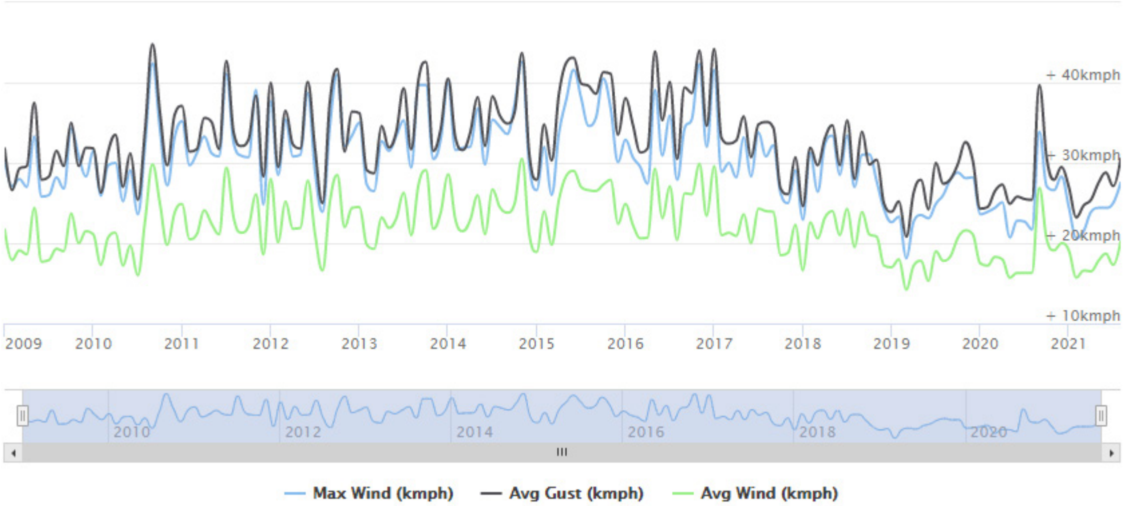
6.3 Climatic Conditions Analysis

The impact for the proposed Project houses from wind patterns, sunlight variations during the year, sea level rises, tsunami, liquefaction, and earthquake have been considered.

6.3.1 Wind

Wind speed in Petone is considered to be high. The average wind speed at the site during the year 2020 varied from 24.3km/h in January to 40km/h in September (World Weather Online, 2021). The wind fluctuations are given in Figure 6.3 below.

Figure 6.3: Max and Average Wind Speed and Wind Gust

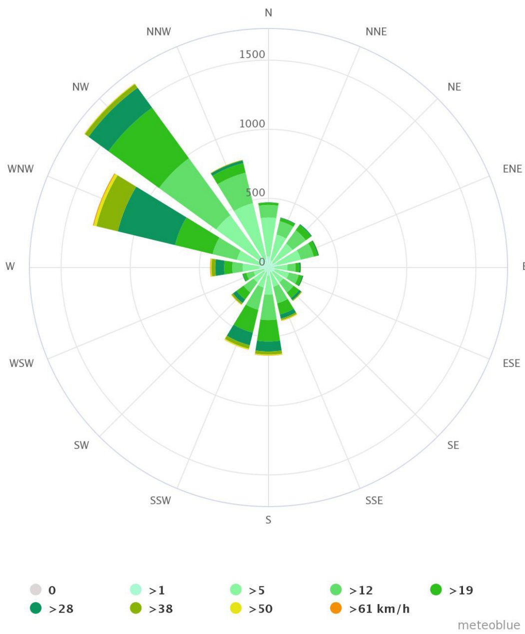


Material sourced from World Weather Online

Figure 6.4 shows the wind direction in Petone at the site. The main wind directions are Northwestern and West Northwest (Meteoblue, 2021). In order to mitigate high wind speed from Northwest, no large windows will be designed in that direction.

The sea is on the Southside of the site, and the wind pattern and the wind speed from the South are moderate; hence, the salt spray issue at the site is minimal. The coldest wind comes from the South and Southwest. However, the wind speed from that direction is moderate.

Figure 6.4: Annual Wind Pattern at The site

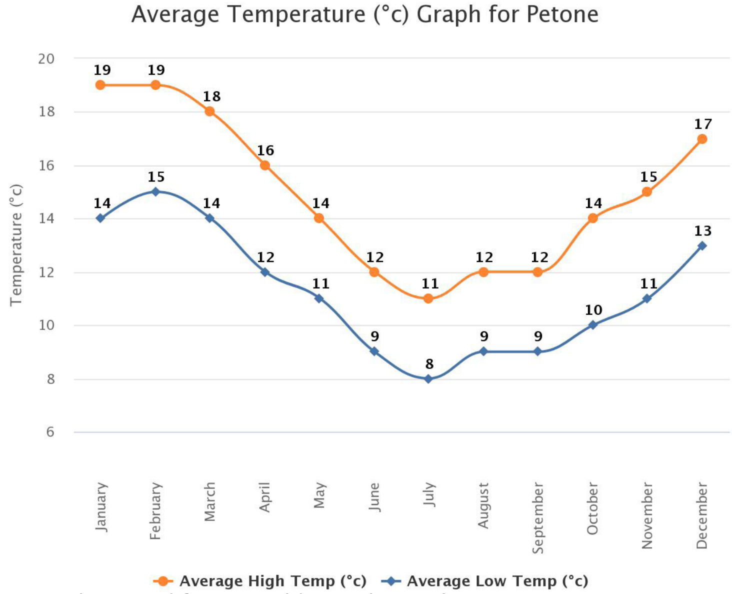


Material sourced from Meteoblue

6.3.2 Temperature and Heating /Cooling

Figure 6.5 given below shows the average temperature variances during the year. The highest temperature is recorded in January and in February, and the lowest is recorded in July.

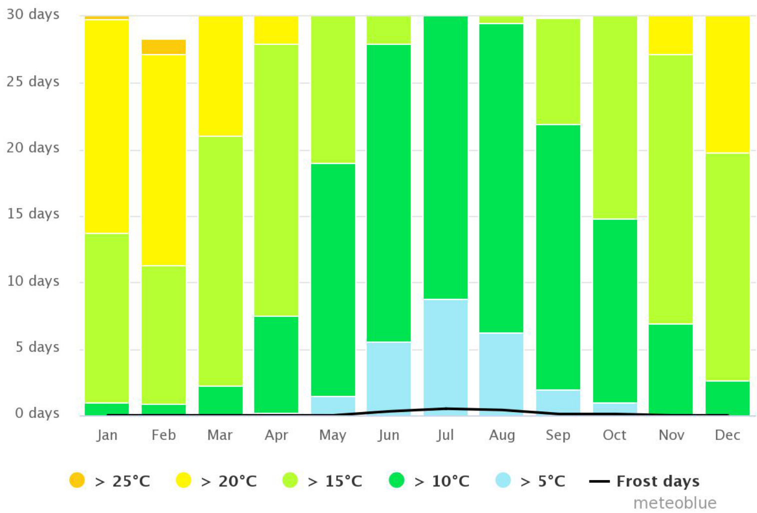
Figure 6.5: Monthly Average Temperature



Material sourced from World Weather Online

Figure 6.6 below the highest average temperature in January and February will be about 20°C and 25°C degrees (Meteoblue, 2021). The temperature could exceed 25°C just a couple of days in the given months. It means the necessity of having air conditioning is minimal. Likewise, between May and September, Petone will have a few days below 5°C degrees temperature. In July, the number of days below 5°C degrees will average to 10°C. As the temperature variances are manageable, the proposed geothermal heat exchange system could minimize the need to use power for air conditioning and heating.

Figure 6.6: Maximum Temperatures



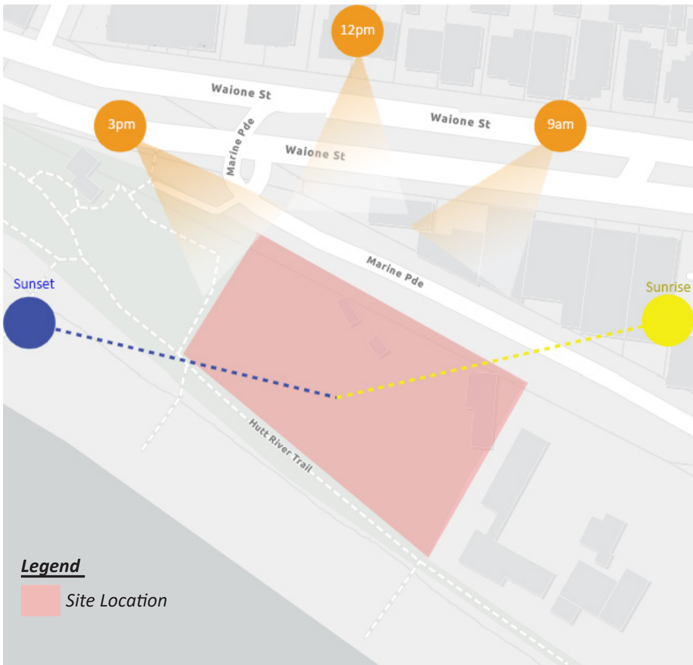
Material sourced from Meteoblue

As detailed in the sunlight and lighting section, most sunlight comes from the North East to the North West-side. For cutting down the heat in the summer, shades will be needed in the northern part of the design to block sunlight. The site has excellent solar access most of the day. Therefore, the living areas could be placed in the northern part of the design. It could minimize the need for energy for heating in winter.

6.3.3 Sunlight and Lighting

Figure 6.7 below shows the sunlight direction at the site. To get the most natural lighting to the design, the opening for lighting should be mainly on the Northern side. Openings in North East and North West could maximize the natural lighting into the design.

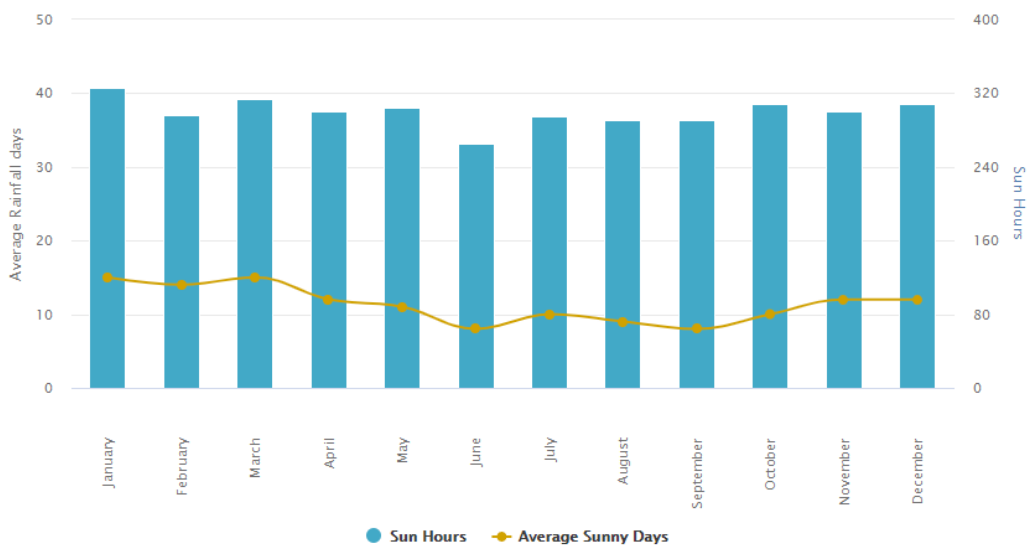
Figure 6.7: Sun Light Direction



6.3.4 Renewable Energy

As given in Figure 6.7 above, the sun's path is mainly from North East to North West. South and east-facing, sloping sites have limited solar access. Therefore, the solar panel should be directed to the North side accordingly to harvest most solar energy. The selected site is flat and open; hence it has access to sunlight without any disruption. Figure 6.8 given below shows the average sun hours throughout the year. The average number of sunny days in Petone varies from 15 days in March to 8 days in June (World Weather Online, 2021). The average sun hours per month vary from 330 hours in January to 273 hours in June. The energy that can be generated by using these sun hours are discussed in detail in Chapter 7.

Figure 6.8: Average Sun Hours for Petone



Material sourced from World Weather Online

6.3.5 Sea Level and Tsunami Threat

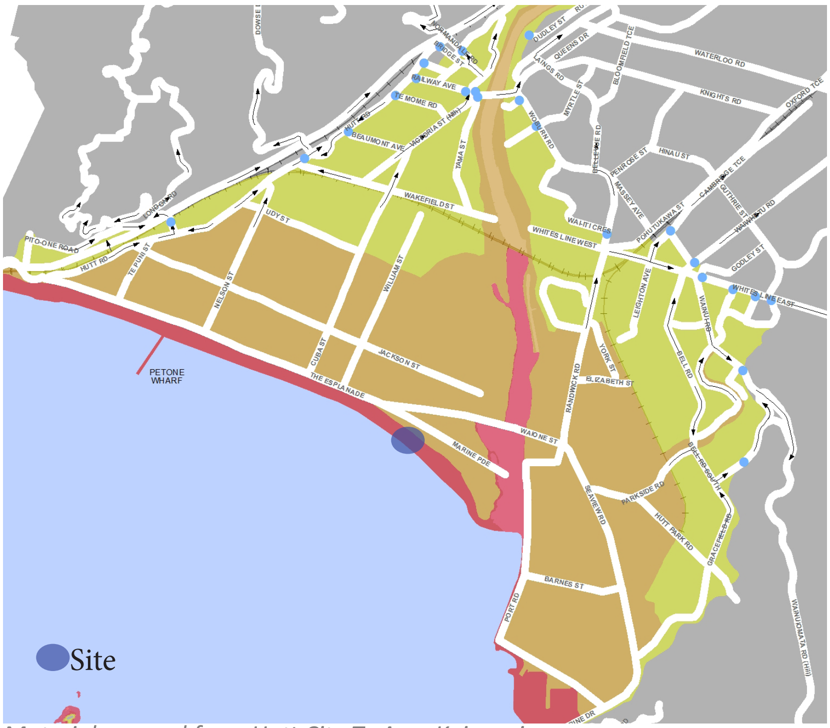
BRANZ claims that "A rise in sea levels as a result of climate change is a real hazard for existing and new buildings in coastal locations. Sea levels around New Zealand have risen by up to 220 mm in the last century and are expected to rise by a further 300–400 mm in just the next 30–40 years" (BRANZ, 2021f). Sea level is known to be rising in the Wellington Region as elsewhere in the world. Currently sea level is rising at about 3mm per year in the region (Greater Wellington Regional Council, 2021). Figure 6.9 below shows a dynamic map of areas in the Greater Wellington region affected by sea-level rise. The site does not have an immediate direct threat from rising sea levels.

Figure 6.9: Sea Level Rise

Material sourced from Greater Wellington Regional Council

Figure 6.10 shown below high light tsunami threat areas around the site. The site is located in the orange zone, and the residents in the area have a slight threat from tsunami. In case of a tsunami threat, residents could move to the Western Hill area. The foundation and the structure need to be strengthened to withhold the tsunami threat.

Figure 6.10: Tsunami Threat

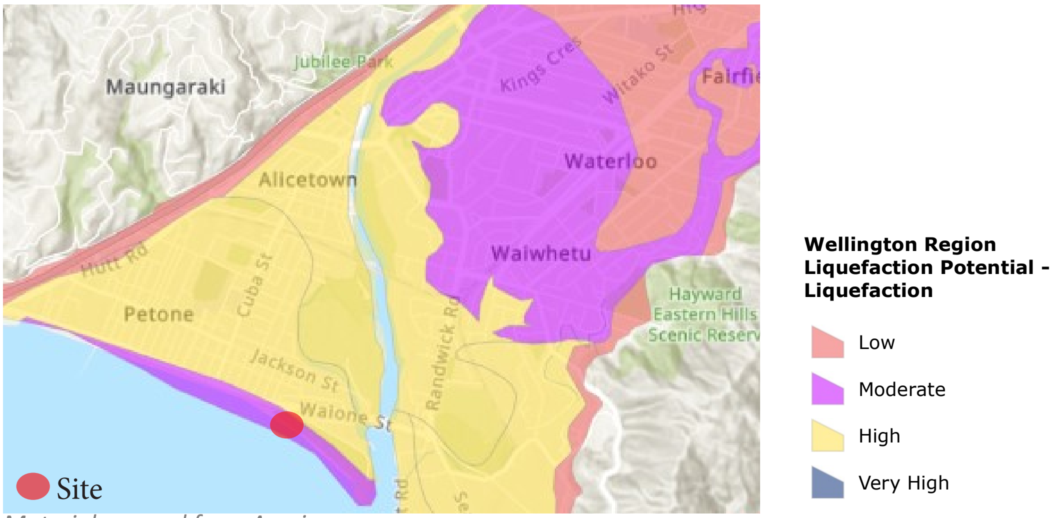


Material sourced from Hutt City Te Awa Kairangi

6.3.6 Soil Condition, Liquefaction, and Earthquake

"New Zealand is a high earthquake hazard region, and earthquake considerations are integral to the design of the built environment. Liquefaction is a real risk to our built environment, especially to buildings" (Saligame, 2020). Figure 6.11 below shows the map of the area with a significant risk of liquefaction occurring and the area that would be affected by the risk of rising sea level. The liquefaction risk at the site is moderate and can be easily mitigated by following the guidance on house repairs and reconstruction following the canterbury earthquake, published in December 2010 (minor potential is when the anticipated lateral spread across the property does not exceed 50mm (New Zealand Department of Building and Housing, 2010). The guidebook recommends excavating and replacing the upper layer of soil with a compacted, well-graded slab foundation for soil with a thin layer of liquefication. The liquefaction of the Project site is considered moderate and hence slab foundations are recommended for all Project houses.

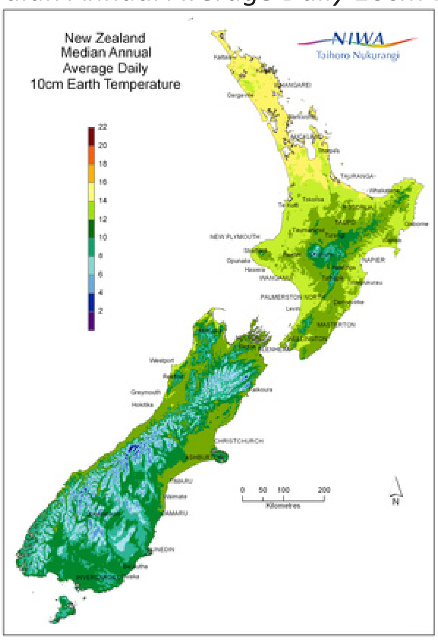
Figure 6.11: Liquefaction Map in Wellington Region



Material sourced from Arcgis

Soil temperature at between 1 – 1.5m depths, the ground in New Zealand can be expected to have a year-round average temperature of 12 – 15°C (GNS Science Te PU AO, 2021). This constant underground temperature could be harnessed for heating and cooling system of the project houses. Figure 6.12 highlights the average earth temperature in NZ. The Para 10.2 of this thesis will discuss how to harness soil temperature for HVAC system.

Figure 6.12: NZ Median Annual Average Daily 10cm Earth Temperature



Material sourced from GNS Science Te PU AO

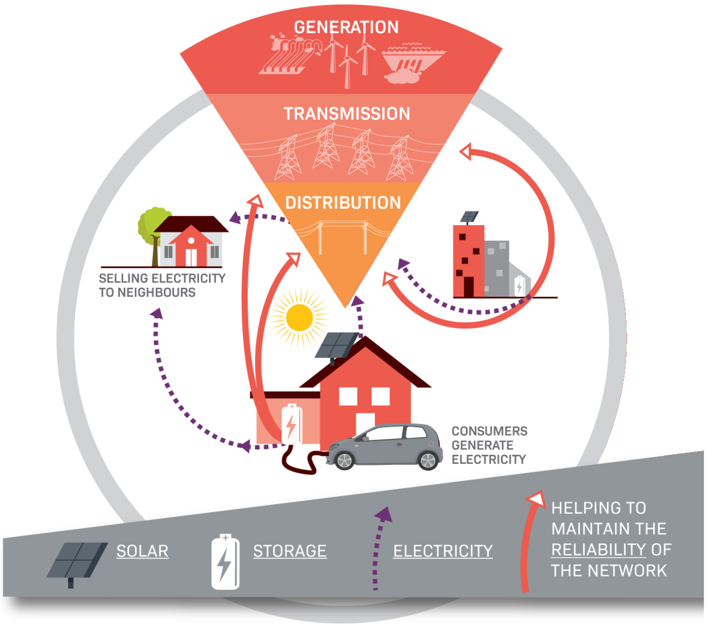
07

NET – ZERO ENERGY

7.1 Energy Generation

Electricity Authority in NZ confirms that "consumers today can generate their own electricity by solar or other means and sell the excess back to their retailer or to the wholesale market. They can also buy electricity from a retailer when they cannot generate enough to meet their own needs"(Electricity Authority Te Mana Hiko, 2018). Electricity Authority's statement confirms that the proposed Project could generate its own electricity by using solar and supply to the Grid during the day. However, when power is needed at night, the proposed project houses could obtain it from the Grid. Figure 7.1 below highlights the electricity generation, supply, and consumption model.

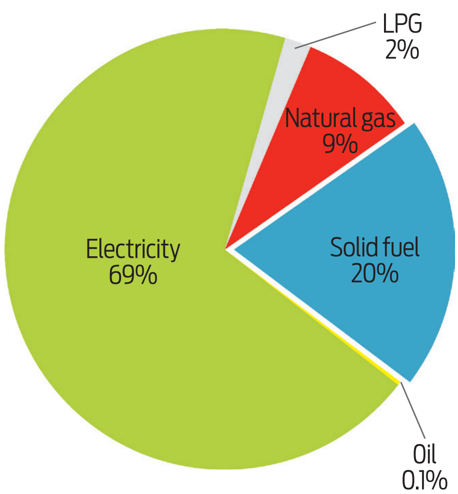
Figure 7.1: Electricity Generation Model



Material sourced from Electricity Authority Te Mana Hiko NZ

Together with the Center for Research Evaluation and Social Assessment (CRESA), CRL Ltd, Building Research Levy, and Foundation for Research Science and Technology, BRANZ Ltd studied the sources of energy used by NZ households over ten years. BRANZ's Household Energy End-use Project (HEEP) collected energy data from around 400 New Zealand homes from 1996–2005. It provided an understanding of how, where, when and why energy was used by measuring fuel use and recording indoor temperatures. The study has identified that 69% of the general household in NZ use electricity as the power source (Overton, 2019). Figure 7.2 below shows energy used by households by fuel type. The proposed Project under this research will also use electricity generated by using Solar panels.

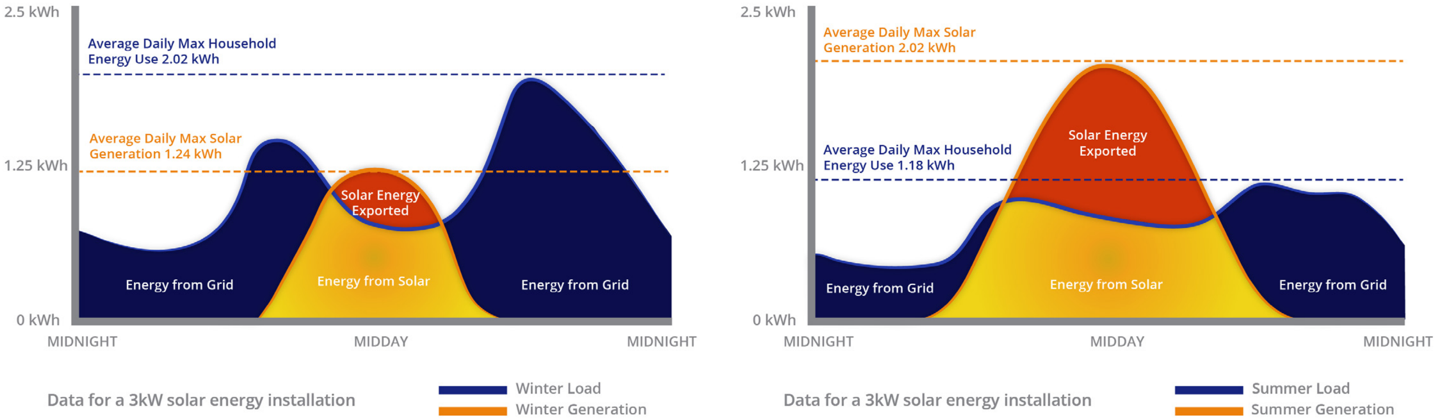
Figure 7.2: Energy Used by Household by Fuel Type



Material sourced from BRANZ

Unison Group, a solar power generation company, has published typical solar power generation and consumption by a household both in winter and summer. Figure 7.3 below shows the details and identifies the power generation levels and power consumption levels throughout the day based on a study conducted by the electricity company Unison. The studied was carried out by using 750 households in Hawke's Bay (Unison, 2020). The area where the study has been conducted is little North of Wellington region and hence can be considered valid for Wellington as well.

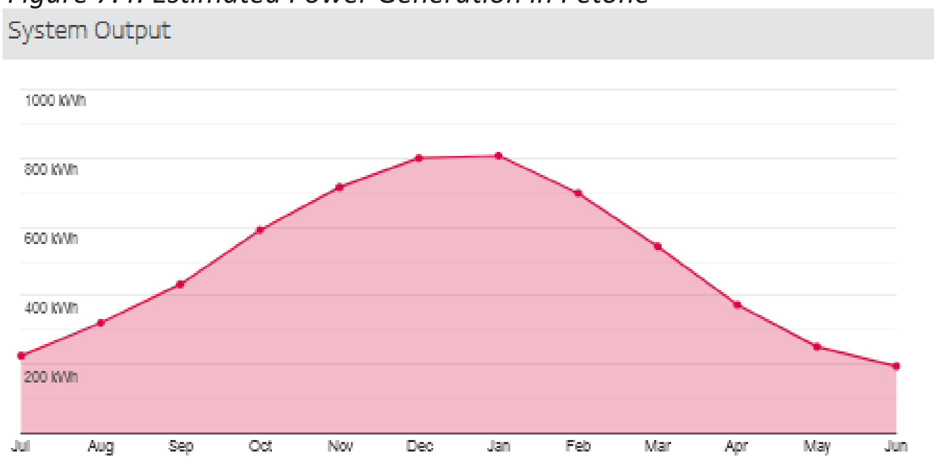
Figure 7.3: Solar power generation and consumption by household



Material sourced from Unison

Figure 7.4 bellow highlights the estimated power generation by using 5kw renewable solar energy system in Petone area. This was generated by using LG power generation model (LG, 2021a). The power generation pattern is similar to the results of the output of the study conducted by Unison which was detail out in Para 7.1. Annual power generation is estimated as 5,958kwh which is nearly 20% higher than the estimated annual consumption by a household with an efficient HVAC system proposed under this project.

Figure 7.4: Estimated Power Generation in Petone



	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Electricity Output(kWh)	226	321	434	591	715	800	807	698	544	374	253	196

Estimated Annual Generated Output (kWh)

5958.74 kWh

Estimated Daily Generated Output (kWh)

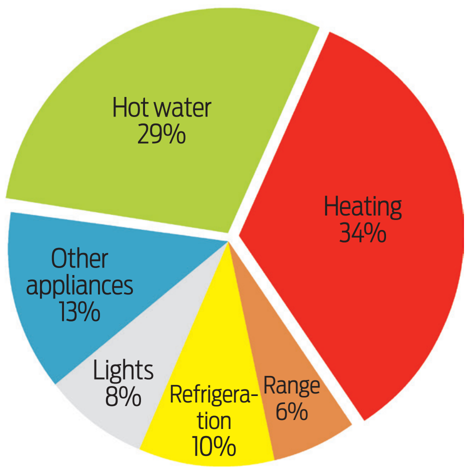
16.33 kWh

Material sourced from LG

7.2 Energy Consumption

Household Energy Use identified that most amount of power is consumed for heating and hot water (Overton, 2019). Figure 7.5 shows the total energy used by the household for various activities.

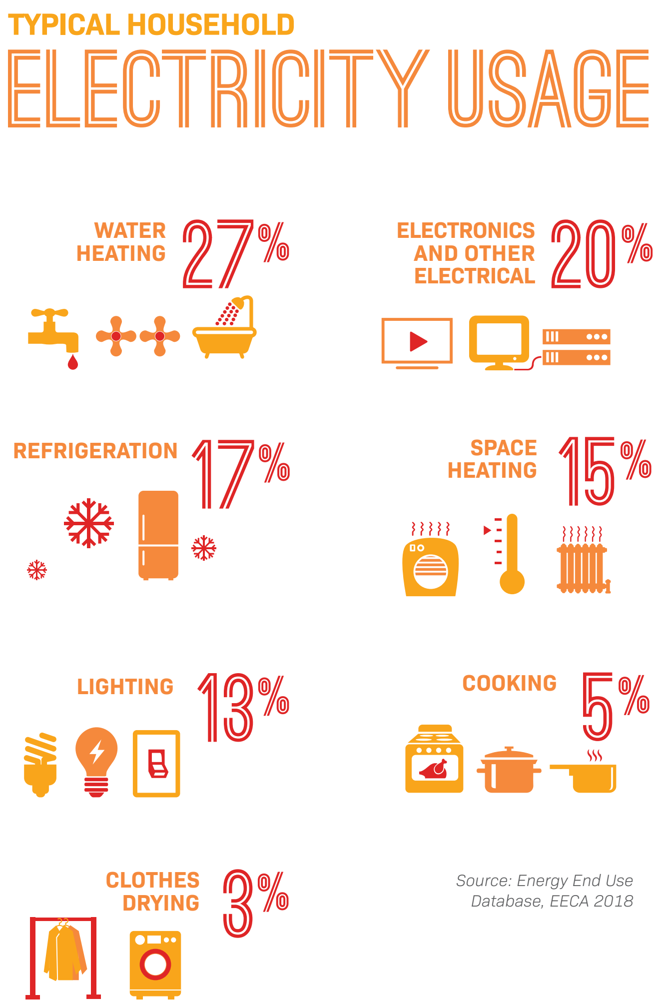
Figure 7.5: Total Energy Used by Household for Various Activities



Material sourced from BRANZ

Based on a study done in 2018, NZ Electricity Authority published electricity usage by a typical household (Electricity Authority Te Mana Hiko, 2018). Figure 7.6 below highlights the results of the study.

Figure 7.6 Electricity Usage



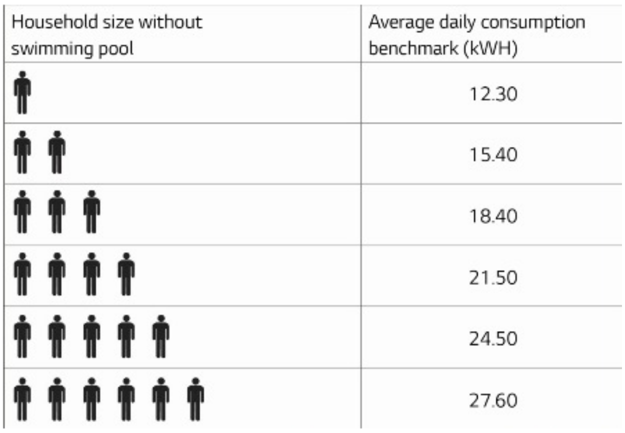
Material sourced from Electricity Authority Te Mana Hiko NZ

The two studies conducted by BRANZ and Electricity Authority showed slightly different consumption figures mainly for heating. As per the above studies, a reduction in the usage of power by a household could have a significant effect when the household has an efficient ventilation/heating system and a solar-powered hot water system. The proposed design under this research will minimize power consumption by providing solar hot water systems and an efficient HVAC system with adequate insulation for main heat loss areas like the roof as detailed out under HVAC system in this research report.

Electricity Authority Te Mana Hiko identified that in 2017 the power consumption by an average household in NZ varied between 5,870kwh and 8,550kwh depending on the area. Thus, the overall average power consumption by a household amounts to 7,000kwh per year (Electricity Authority Te Mana Hiko, 2018). BRANZ has confirmed these figures (BRANZ, 2021c).

LG Solar NZ identifies the daily power consumption of an average household in NZ by various groups of occupants. Figure 7.7 shows the daily average power consumption. As per LG Solar, annual power consumption by a single-person household will amount to 4,490kwh. Likewise, a two-person household consumes 5,621kwh per annum (LG, 2021b). These figures are in line with the average annual consumption published by the Electricity Authority.

Figure 7.7: Daily Power Consumption by Household Type



Material sourced from LG

Smart Guide - Solar Power published by Smarter Homes states that an average non-efficient house consumes around 9,000kwh of electricity each year (Smarter Homes, 2017). It is estimated that a two-member modern house needs less than 5600kwh per annum. An efficient house proposed under this project will need much less than 5000kwh per annum.

7.3 Energy for the Project

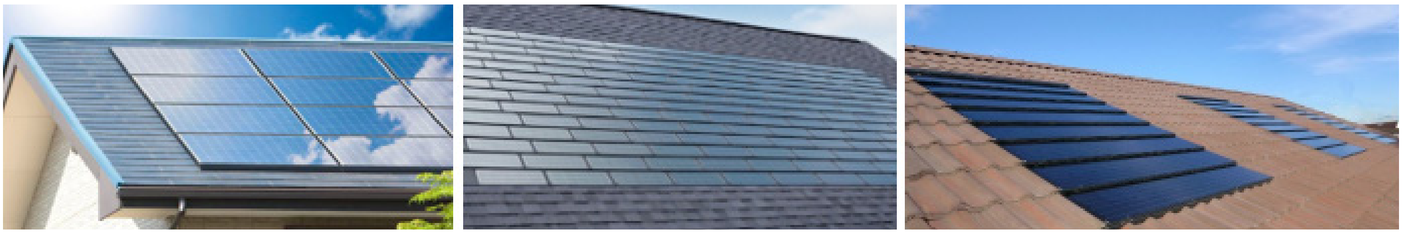
Environmental and Energy Study Institute states that "There are two ways to harness solar energy. Passive systems are structures whose design, placement, or materials optimize the use of heat or light directly from the sun. Active systems have devices to convert the sun's energy into a more usable form, such as hot water or electricity" (Dorsey, 2014). The proposed Project will use both passive and active solar energy.

As explained in Para 2.2 earlier, Electricity Authority in NZ allows consumers to generate power and supply to the Grid. Net-zero energy houses will generate and consume the same quantity of power over a period of time. It is proposed that the Project will achieve net-zero energy consumption on an annual basis. The proposed project houses will be connected to the Grid, and a net metering system will be obtained, allowing households to generate power during the day and export the excess power to the Grid. In the night, power could be imported from the Grid. This way, no power storage system is needed, and no extra cost is incurred for power storage as off the Grid, houses will need an energy storage system which is costly.

As discussed in Para 7.2, in NZ, an efficient house should need less than 5000kwh per annum. The proposed design with efficient ventilation and heat exchange systems is expected to consume much less than 5000kwh per annum. A 20m^2 panel solar system can generate 3400kwh per annum in Wellington (LG, 2020). 25m^2 of solar panels are needed to generate 5000kwh per annum (LG, 2020). The roof has been designed to have an area of 30m^2 to accommodate 5kw solar power generation system and a solar power hot water system. In addition, these solar panels need to be fixed at 30 degrees angle. Therefore, the roof has been designed at a 30-degree angle.

The most common method of harnessing solar power is by using photovoltaic (PV) cells. One can use PV solar panels, PV solar shingles, or PV solar tiles to harness solar power (Figure 7.8).

Figure 7.8: Types of PV Panels

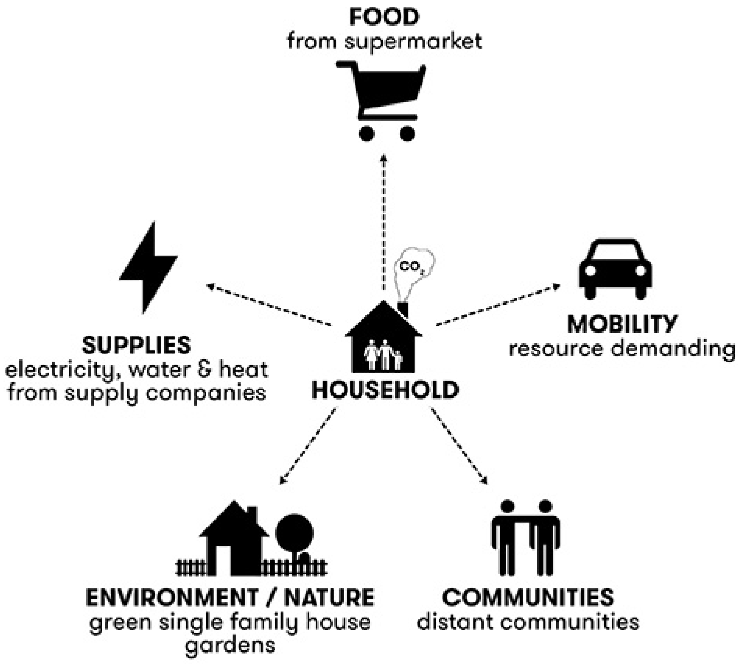


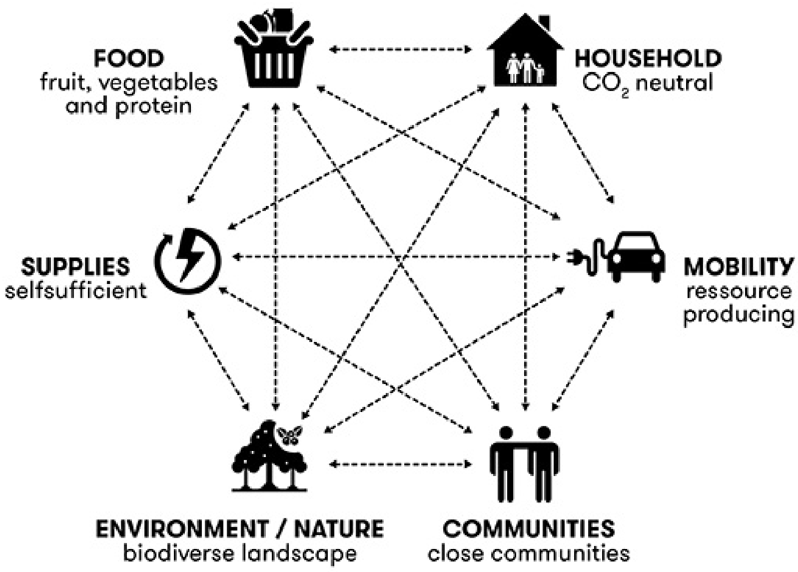
All three types of PV cells have about a 25-years life cycle. Shingles and tiles are more expensive than panels due to their esthetic look. The cost of solar shingles and tiles is about two times higher than solar panels. Besides that, solar panels have a higher efficiency level when compared to shingles and tiles (Solar Guide, 2020). In NZ also the most commonly used solar power generation method is by using PV cells. Therefore, it is recommended that PV panels be used for the power generation of the project house.

08 DEVELOPMENT OF MASTER PLAN

People cannot live in isolation. They need to be connected to various aspects such as the environment, supplies, utilities, mobility, and finally to their community. This concept is graphically shown below in Figure 8.1

Figure 8.1: Connectivity



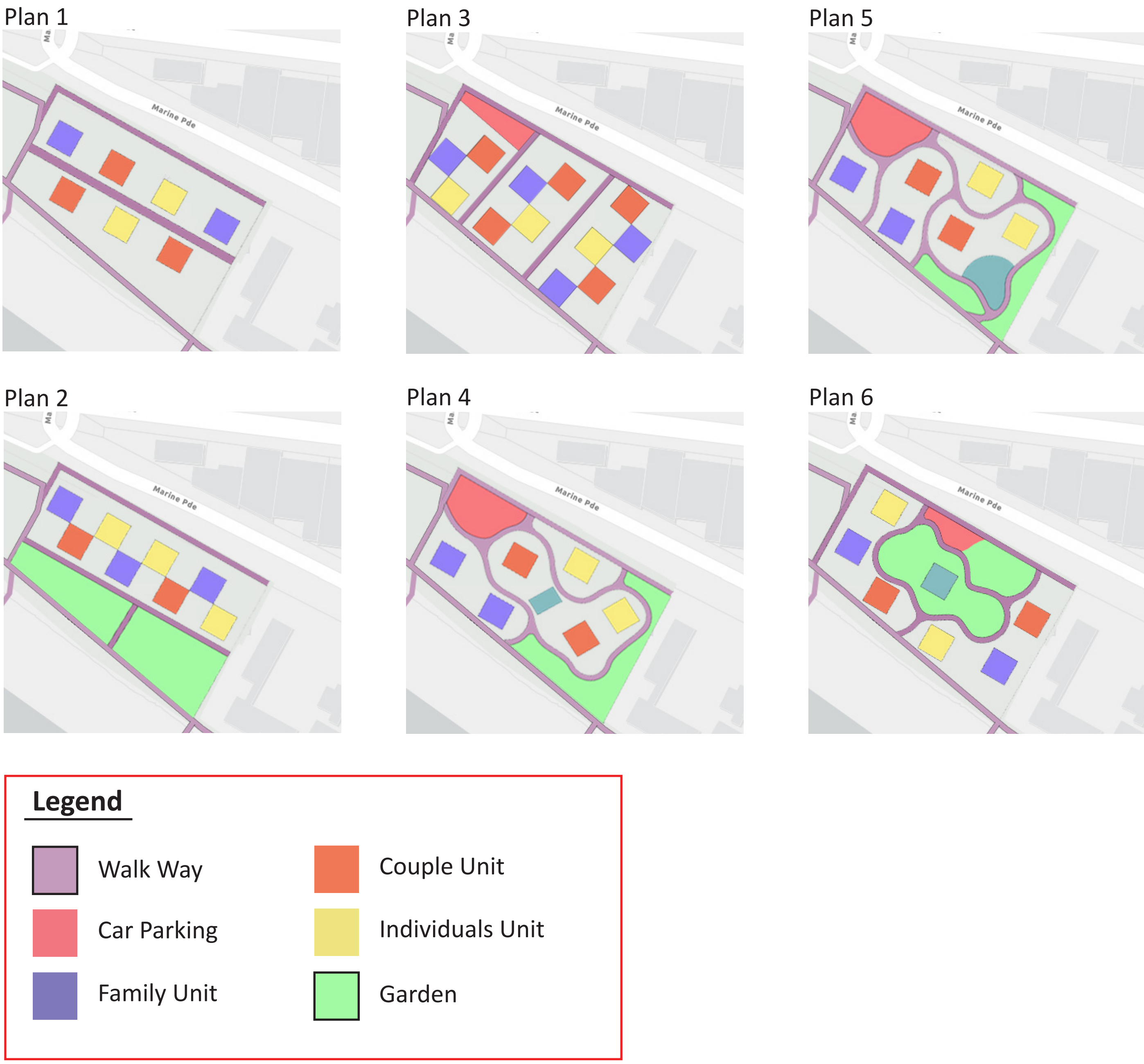


Material sourced from Karres Brands

The architectural concept of 'Living in Harmony with Nature in a Net-Zero Village within the City' has been fallowed in developing the master plan. The proposed small housing units will not have boundaries and will have shared garden areas. Each living space will be surrounded by vegetable and flower beds. A small walking path will connect all the living spaces. There will be a small communal area with BBQ facility to interact with each other. Living spaces will not have parking next to the living space. As part of the promotion of the net-zero energy concept, occupants are encouraged to use public transport. However, a small number of car parking spaces will be provided for visitors and the needy. Most of the available outdoor spaces will be allocated for gardening. The adjoining walking track will also become part of the concept of bringing people together.

Eleven different master plans were developed and evaluated to get to the final master plan. The first six plans were discarded as they did not correctly reflect the architectural concept. Initially, the master plan was developed with houses with 10m by 10m floor area. This floor area was later reduced to 6m by 5m to reflect the architectural concept better. All master plans given above are with the 10m by 10m houses. The layout of the Plan 1, 4, and 5 had poor utilization of land. The other main weakness identified on all of the above master plans was the lack of connectivity among those living in spaces. It was also identified that the layout of Plan 2 and 3 did not correctly reflect the architectural concept of the Village concept. It was also identified that these plans did not allow individual houses to generate optimum solar power as the house units were close to each other and shadows of some house units fell on the others. This weakness was evident mainly in Plan 2 and 3, while other plans also were somewhat affected. Discarded plans are shown below as Figure 8.2

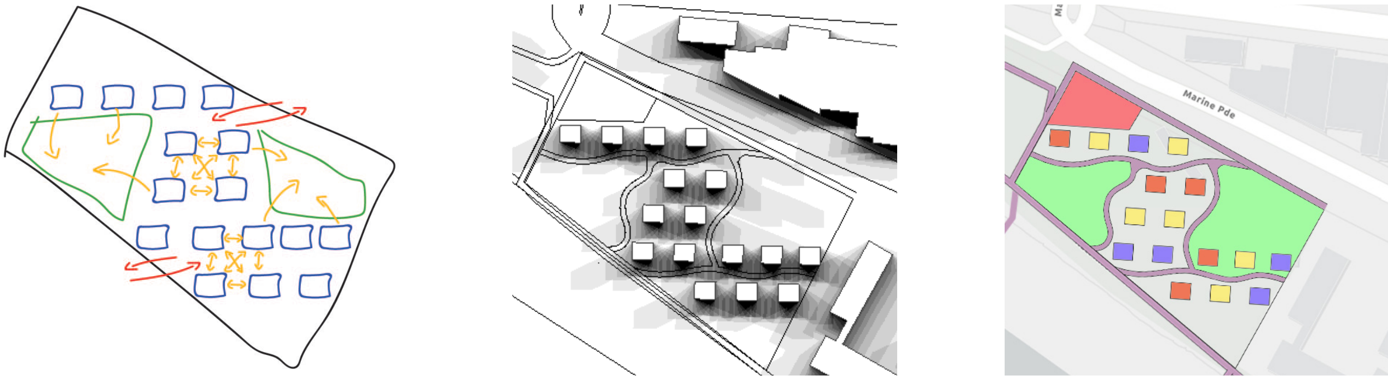
Figure 8.2: Development of the Master Plan 1 - 6



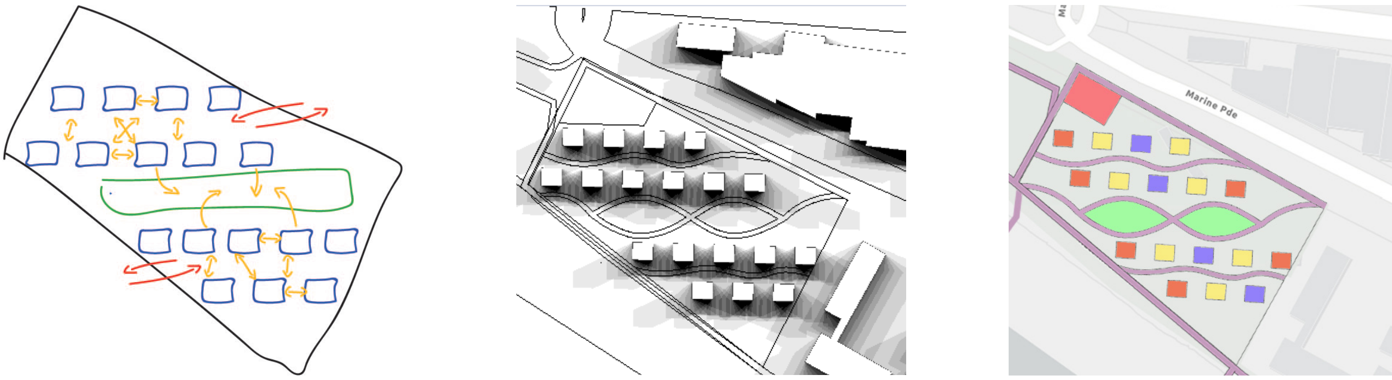
The last five master plans were developed after analyzing shadow study, access, and connection to one another. Figure 8.3 below shows the last five master plans, together with the shadow study and connectivity analysis.

Figure 8.3: Development of the Master Plan 7 - 11

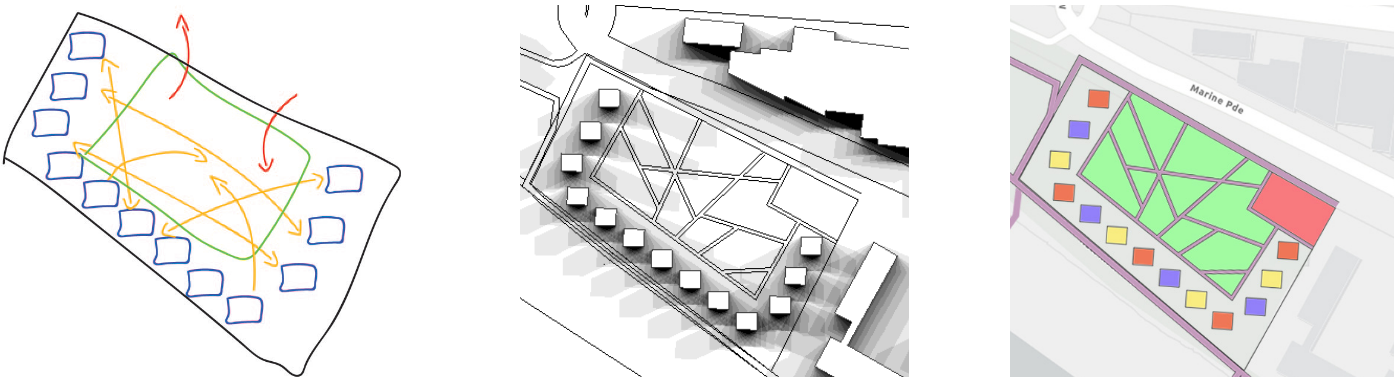
Plan 7



Plan 8



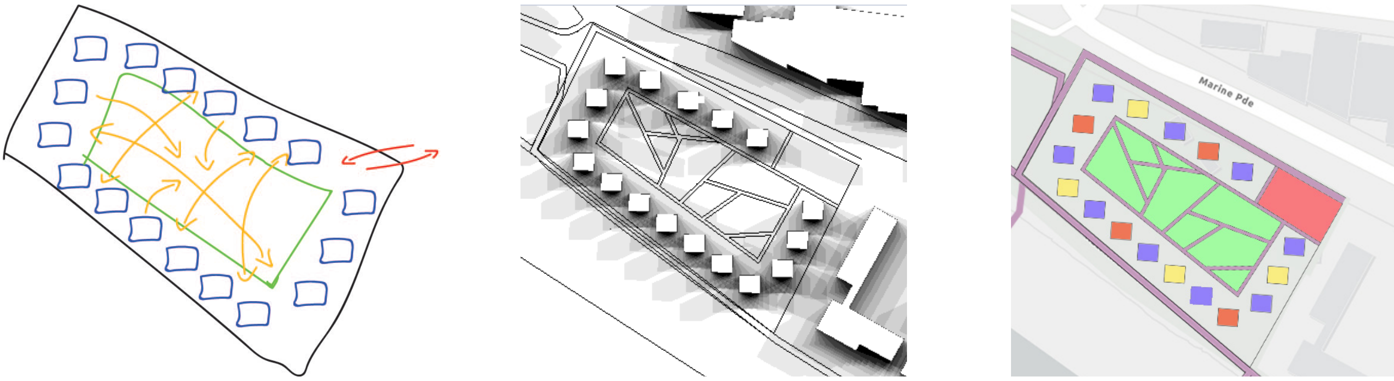
Plan 9



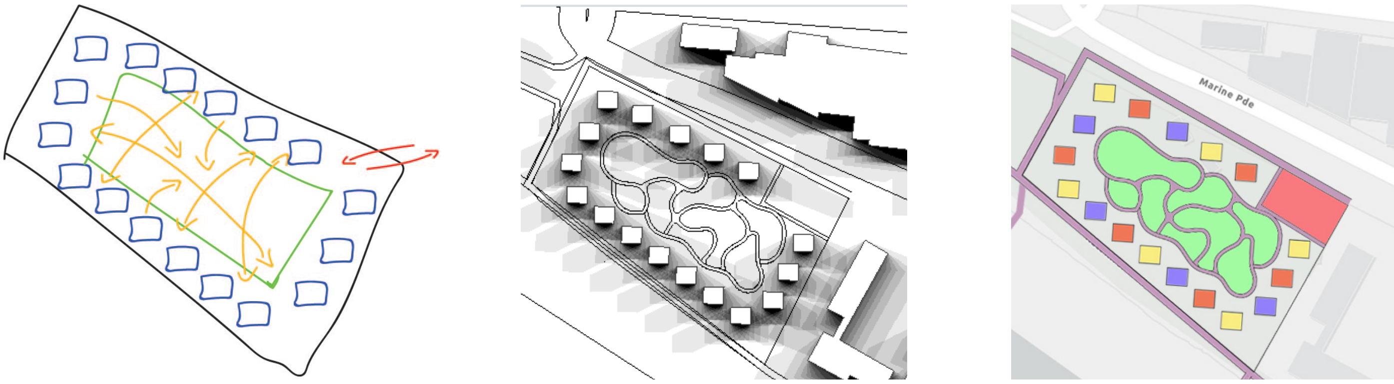
All the master plans given above allowed individual households to have their private spaces and adequate space for landscaping to feel that occupants are closer to green areas. Plan 7 and 8 above did not reflect the expected level of connectivity among households. The house units of Plan 7 laid with a Z shape and houses at two ends didn't have any connectivity. The layout of Plan 8 had two blocks of houses and there was no connectivity between two blocks.

Figure 8.3: Development of the Master Plan 7 - 11 Continued

Plan 10



Plan 11



The shadow study of Plan 7 and 8 had indicated that optimum solar power generation could not be obtained. Households of Plan 9, 10, and 11 were arranged like a central courtyard and had a better connectivity among themselves. These Plans also showed a better result on shadow studies. In addition, Plan 10 and 11 showed better land utilization than plan 9. Plan 10 had been selected as the final master plan as it reflects all the features expected in the architectural concept, such as the concept of the village, connectivity to nature, and compact housing that generates their own solar power.

The Plan 10 have been selected as the final Master Plan. This Plan had a layout like central courtyard with better connectivity and had better results from shadow study. The short walk paths at the center of the Plan connected individual houses to each other and the layout of the houses were more suitable for the shape of the site. In addition, the layout permitted to introduce larger area for the central garden allowing to reflect the architectural concept of eco-friendliness. Figure 8.4 shows the final master plan together with the landscaping.

Figure 8.4: Final Master Plan



09

ARCHITECTURAL DESIGN DEVELOPMENT

9.1 Features of the Proposed Design

As stated earlier in this research, the people who occupy the proposed spaces under this Project are the environmentalists who cares about Eco-friendly housing. Therefore, compact living spaces are provided to satisfy their needs. Two different types of houses are designed for this Project. One-bedroom living spaces for singles and couples plus two-bedroom living spaces for small families. Individuals do not feel that they live in the nature as they did in the past. Apartments have separated from natural environment (Kooshali et al., 2015). Therefore, the Project houses will not consider attached townhouses. In addition to it, as detail out Para 4.1 the Project houses are more permanent dwellings and therefore small compact houses are proposed for the Project.

The architectural concept of 'Living in Harmony with Nature in a Net-Zero Village within the City' had been used in designing project houses. The proposed designs consist of two to three-story compact living spaces which will be put up on a space of 6m X 5m area. There will be two sets of Project houses, one for singles and couples and the other for families. The house for single and couples will have a inside area of $40m^2$ and $10m^2$ of terraces. Family houses will have $60m^2$ interior space and $20m^2$ of terraces.

The exterior walls will be Green walls that can grow their own herbs and other pants. The ground floor will have large bi-fold doors to create the living room extension to the outside environment. These bi-fold doors will combine the living room with nature in the summer and minimize the heating loss in the winter. All bedrooms have a large pop-out window to capture the surrounding views and to be with nature. There is a small window in the bathroom to let light in a while still maintaining the privacy and a ribbon window below kitchen cabinets to brighten up the space.

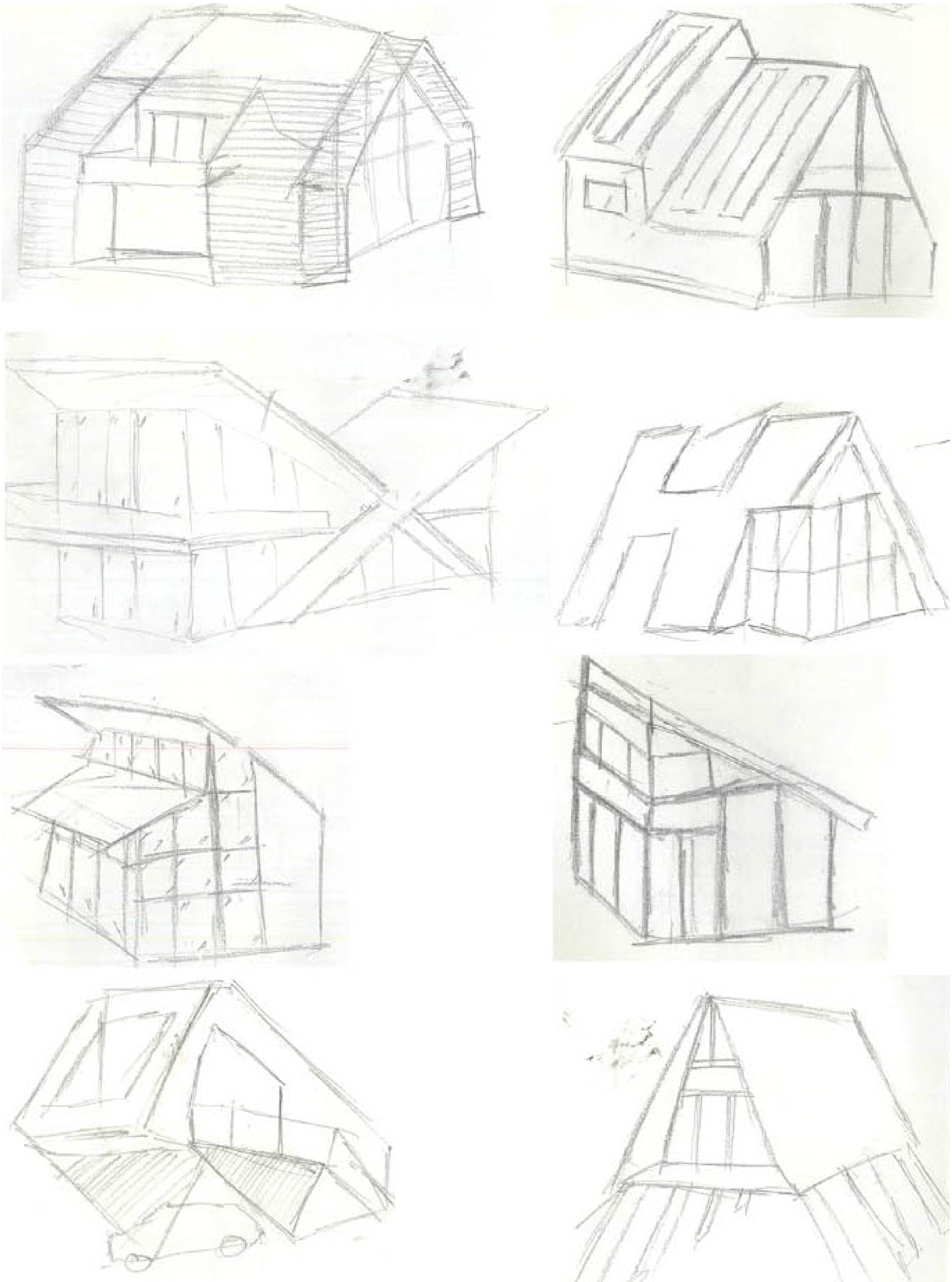
The second floor will be the bedroom and office space for singles and couples. The bedroom and the office space are combined to give a feeling that the space is much larger. Likewise, different functional spaces such as living dining and kitchen on the ground floor do not have barriers. In addition, the second floor will have a balcony where plants could grow on Green walls. The bedroom will have a connection to the garden/ balcony with bi-folding doors. Propose family houses will have an additional floor. This floor will have a play area and an open garden in addition to the children's bedroom. If the family has two children, the children's bedroom on the second floor will have a bunk bed.

The shared outdoor area is planned for residents to feel that they are part of the environment. Various aspects have been planned to promote connectivity among the small community living on the proposed site, which had been discussed in detail under the development of the master plan. Some key features included in the design to enhance the connectivity are a common area within the site where people can come together and have shared vegetable beds. In addition to it, there will be an outdoor gym, a play area for the kids, and a campfire area that is integrated into the design. A natural environment will surround all these facilities, which will give the occupant the feeling of more openness. Openness is essential to counter the occupant's feeling due to the compact housing arrangement and to be in line with the proposed concept.

9.2 Stages of Design Development

Several ideas with different features had been considered for the architectural design of the proposed houses. Concepts considered had different roof styles, such as steep triangle roofs, butterfly roofs, shed roofs, gable roofs, and clerestory roofs. Some of the sketches develop initially are given below in Figure 9.1

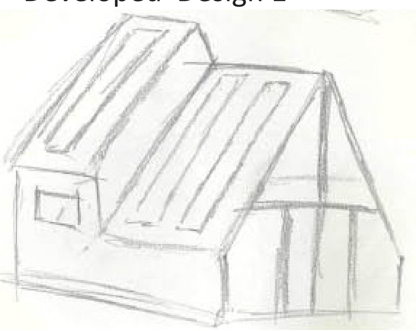
Figure 9.1: Initial Designs Considered



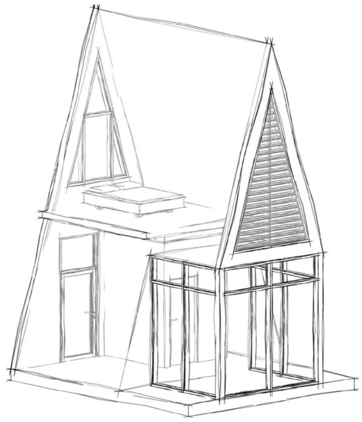
Three sketches had been selected for further enhancement of the design. Enhanced sketches were evaluated by considering the architectural concept to ascertain the pros and cons of those sketches. Figure 9.2 highlight the initial sketches, the enhanced sketches, and the summary of the evaluation.

Figure 9.2: Second Stage of Development of the Design

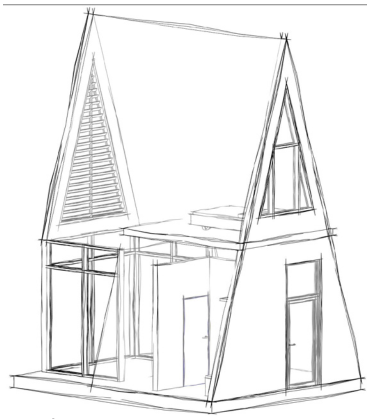
Developed Design 1



took this idea and explored it further



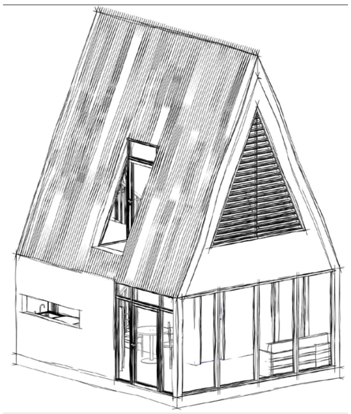
Front View



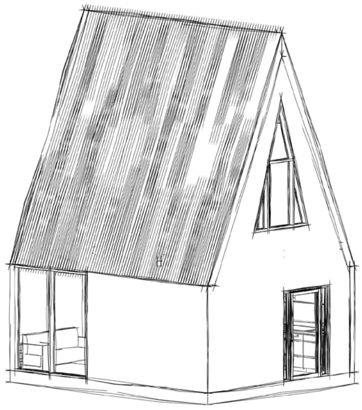
Back View

Developed Design 2

took this idea and explored it further



Front View

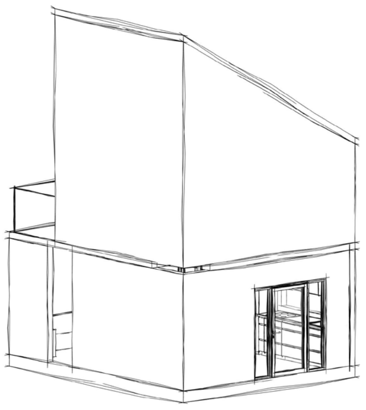


Back View

Developed Design 3

took this idea and explored it further

Front View



Back View

Design 1 had a steep roof and the enhanced Design 1 could be identified as a A-frame house. The Design 1 had the advantage of having angle walls that could have been used to fix solar panels for power generation. Cameron states that it is tough to decorate A-frame houses and loose living spaces due to angle walls which results in cost effectiveness of architecture and land use (Cameron, 2011). Fasone also confirms that A-frame houses provided limited space options but see additional advantages as the frame technology allows concealing all utility pipe lines within the wall (Fasone, 2017). Furthermore, the roof of the enhance sketch of the Design 1 came up to the ground level covering the view of the people living inside. As a result, Design 1 didn't connect with the nature and use of natural day light was restricted.

The initial sketch of Design 2 also had a A-frame but the enhanced Design 2 didn't have a full A-frame and the A-frame structure was limited to the second floor. The semi A-frame structure of Design 2 had similar positives and negatives like in the case of Design 1 but it mitigated some of the disadvantages of A-frame house. The second drawing of the Design 2 had vertical walls at the ground level and was slightly better in space utilization and providing connectivity to nature.

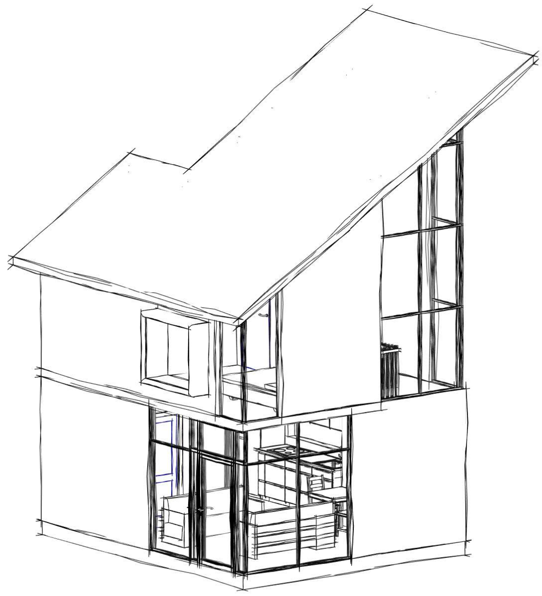
Design 3 has a shed roof. Frost states that "The design of a home with a shed roof can potentially increase the amount of natural light coming into the home and a south-facing shed roof gives you plenty of space on one side of the home to attach solar panels because it consists of one large slope instead of two or more slopes going opposite directions" (Frost, 2011). Frost also see that the shed roofs are more cost effective, susceptibility to high wind and very effective in water shedding and drainage.

The shed roof of Design 3 is ideal for solar power generation where solar panels need to be fixed at a 30^{o} angle. The main limitation of the third design was that the slope of the shed roof always had to be faced towards the north. Unlike the A-frame house, the shed roof house had a better usage of space. However, the proposed Design 3 had limited connectivity to the outside world and usage of daylight. Due to the advantages foreseen, the last sketch with the shed roof had been further developed to get to the final architectural design.

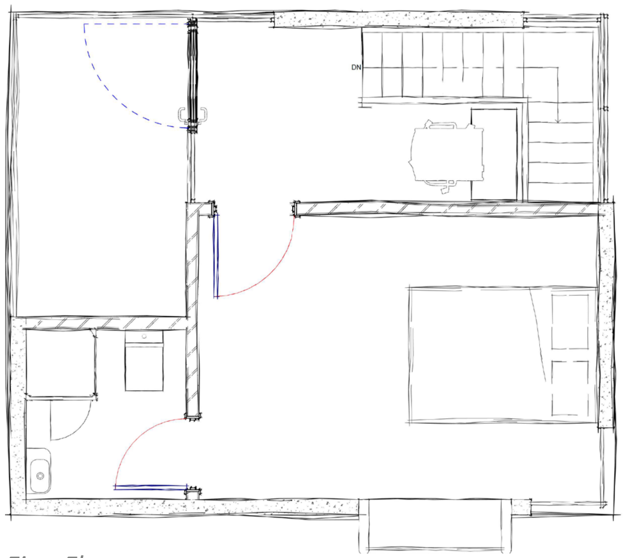
Both single / couple houses and family houses were developed from Design 3. The houses for single and couple were developed in six more additional stages. The perspectives and all floor plans are given for each different stage of development. These developments were done by considering the sun's direction to minimize direct sunlight in the summer and get more sun during the winter.

Development Stages of the House for Single / Couple

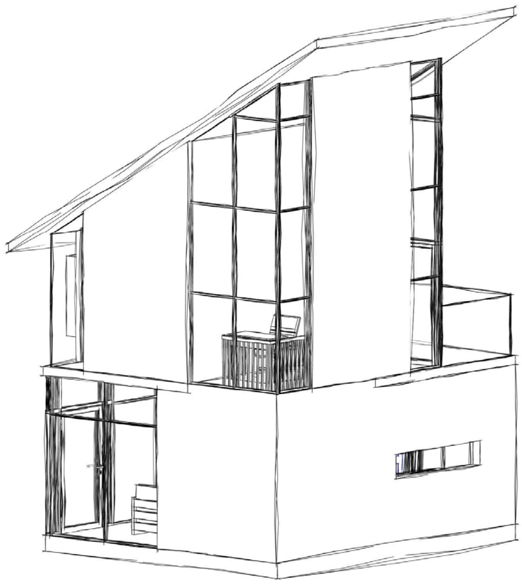
Figure 9.3: Improvement to Single / Couple House – Stage 1



Front Perspective 1



First Floor



Front Perspective 2

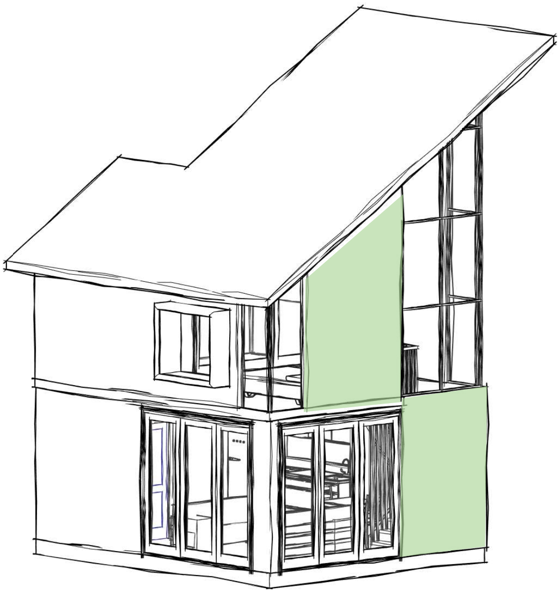
Ground Floor

Back Perspective

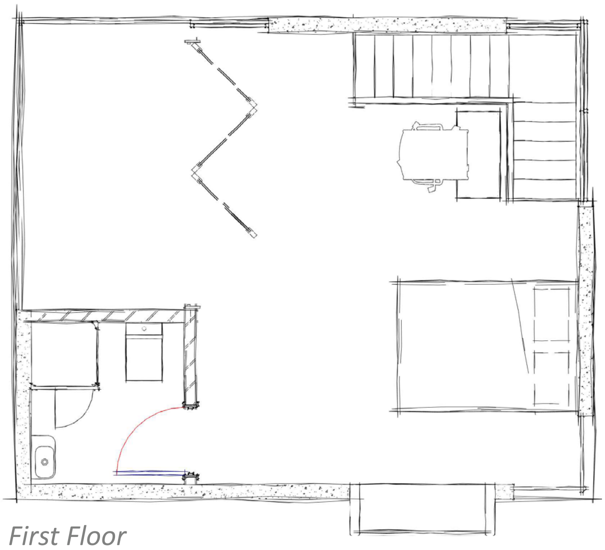
Frost suggested that the tall wall at the front of the house can support tall windows or multiple rows of windows (Frost, 2011). By taking Frost's idea into consideration, at the first stage, as shown in Figure 9.3, to improve the usage of daylight and have better connectivity to the outside, additional large windows and large glass doors have been introduced and change the design of the roof. A pop-out window was introduced for the occupants to sit and enjoy the surroundings.

Development Stages of the House for Single / Couple

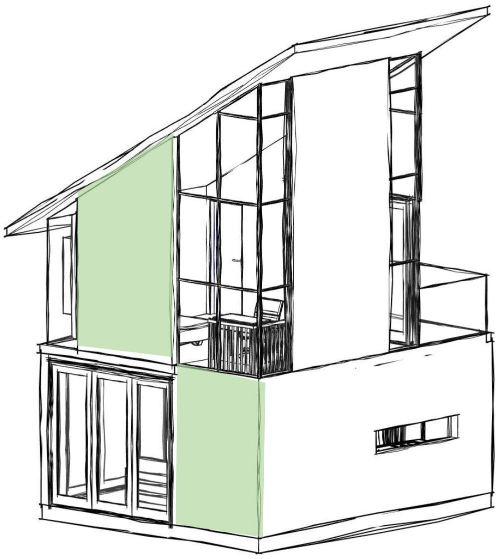
Figure 9.4: Improvement to Single / Couple House – Stage 2



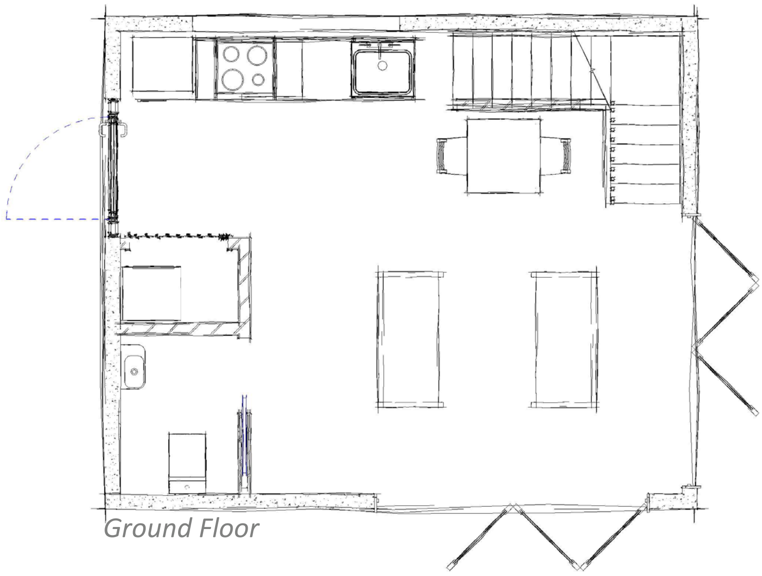
Front Perspective 1



First Floor



Front Perspective 2



Ground Floor

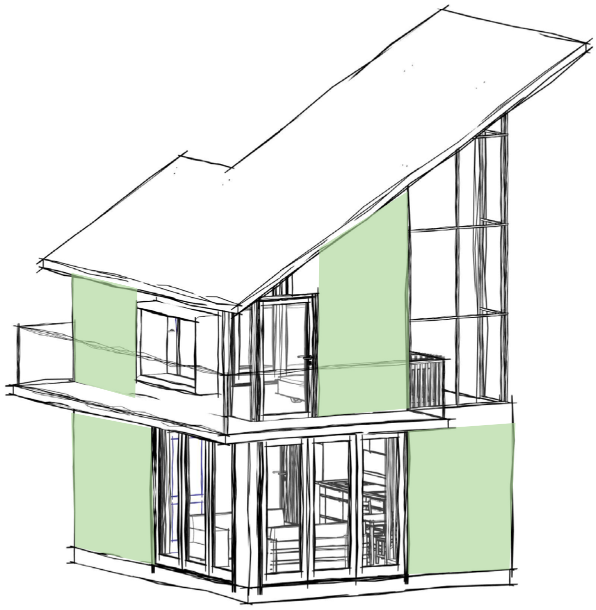
Back Perspective

Alberamonti Architect claims that in their projects they feel paramount to harmonize architecture and natural environment, thus integrating the building with the greenery that surrounds it, penetrates it, inhabits it. Whenever possible, Alberamonti associate building design to green outside, with the design of gardens, green walls and green roofs (Alberamonti Architect, 2021). Eichmann also claims that "Green walls harmonize buildings with nature and provide a living canvas for green wall professions to add the beauty of nature to any man-made structure" (Eichmann, 2011).

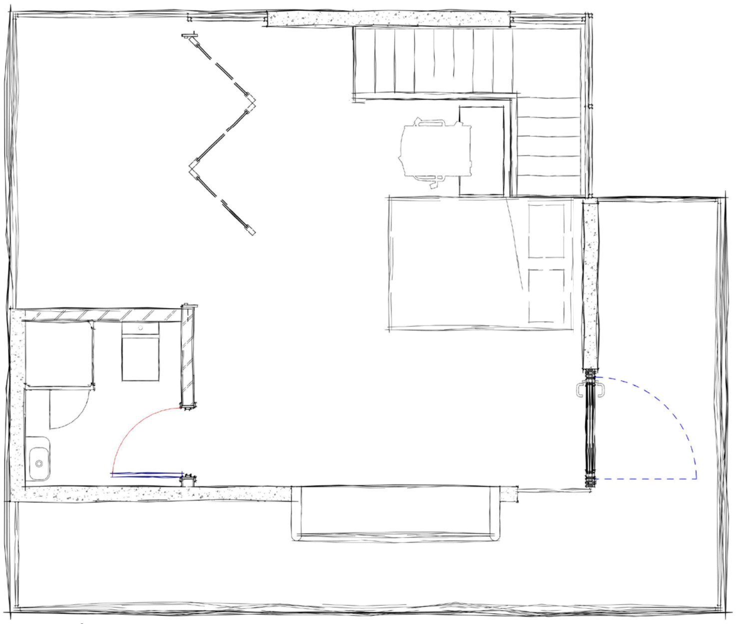
The advice of Alveramonti Architects and Eichmann was incorporated into the design at Stage 2 and Green walls concept has been brought in to harmonize the structure with nature. Bi-fold doors were introduced for the ground and the upper floor to bring more openness into the space. Eliminated the wall between study and bedroom to combine two spaces so that the people feel that they are in a bigger space. Figure 9.4 highlight the changes done in Stage 2 for single house.

Development Stages of the House for Single / Couple

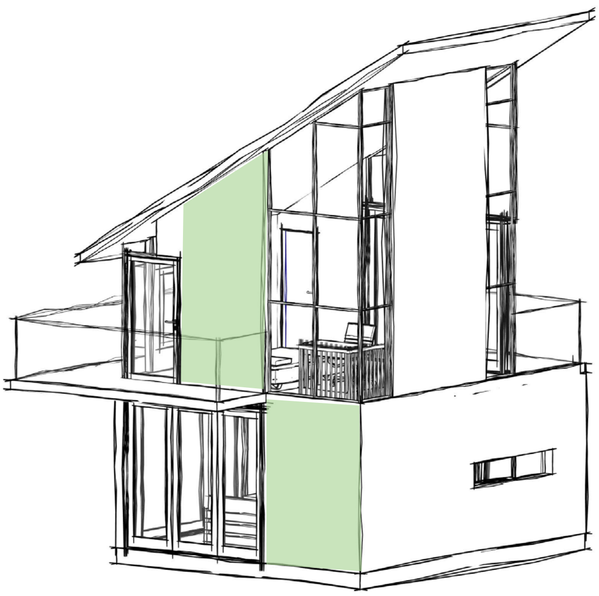
Figure 9.5: Improvement to Single / Couple House – Stage 3



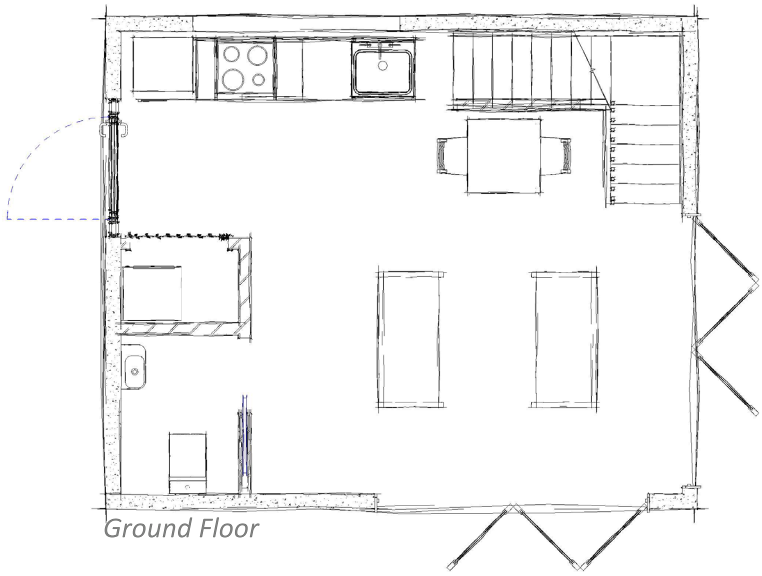
Front Perspective 1



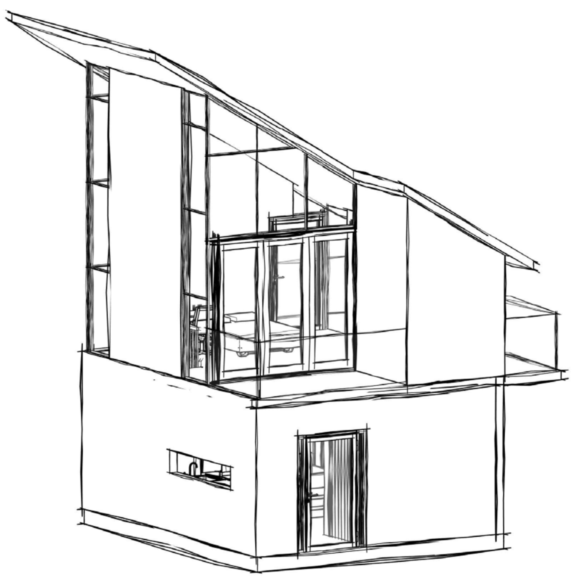
First Floor



Front Perspective 2



Ground Floor

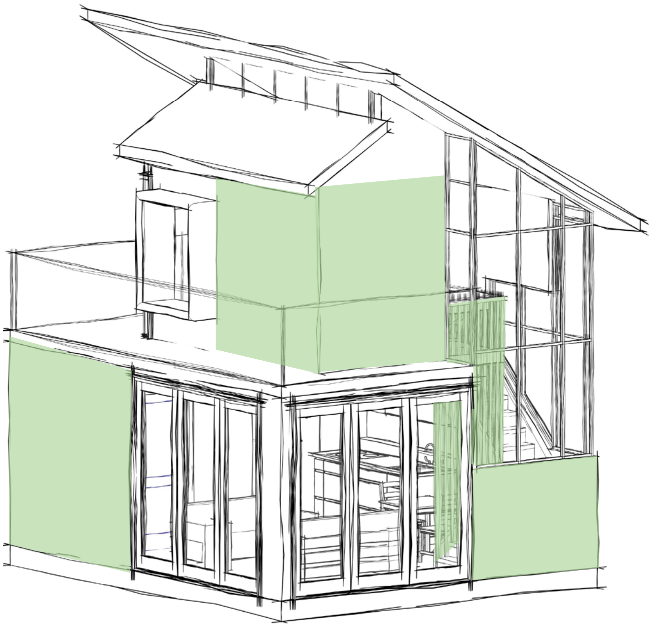


Back Perspective

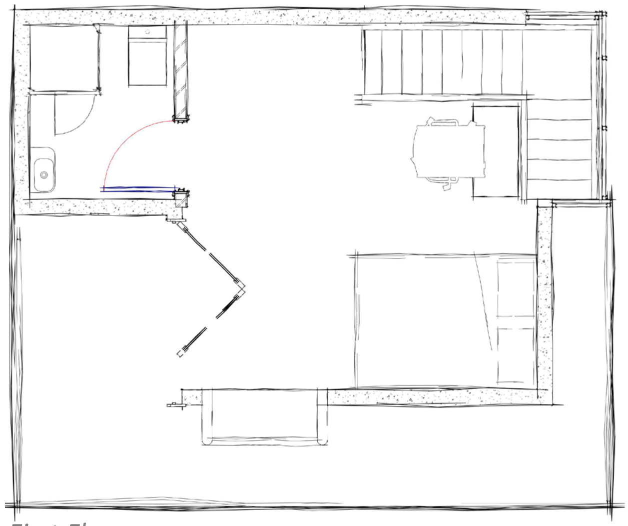
Next, at Stage 3 shown in Figure 9.5, to improve access to the Green wall to the upper floor and enhance the feeling of openness for the occupants of the upper floor, a balcony was added to the upper floor. In addition, Green walls were re-arranged by considering the direction of the sun.

Development Stages of the House for Single / Couple

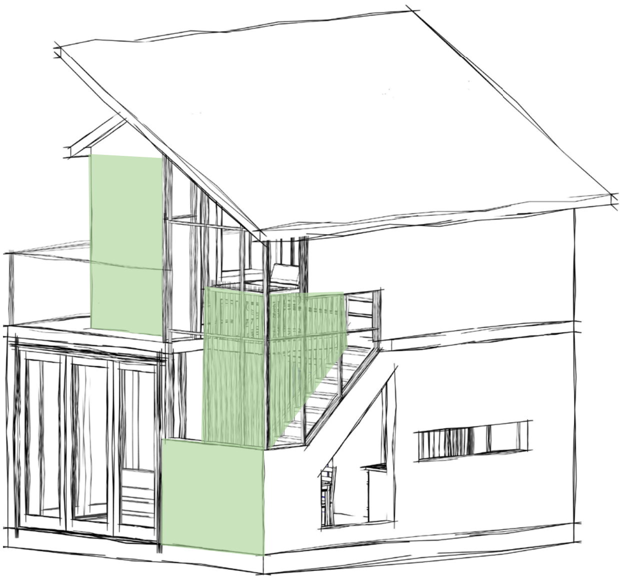
Figure 9.6: Improvement to Single / Couple House – Stage 4



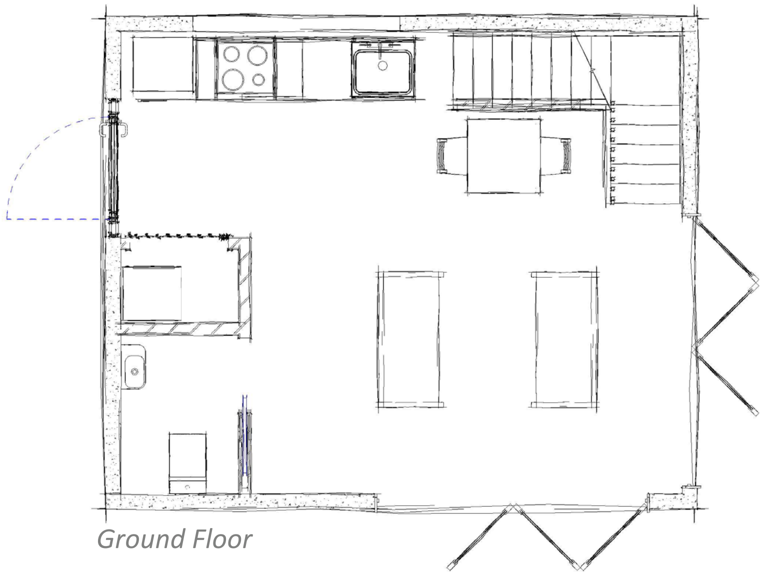
Front Perspective 1



First Floor



Front Perspective 2



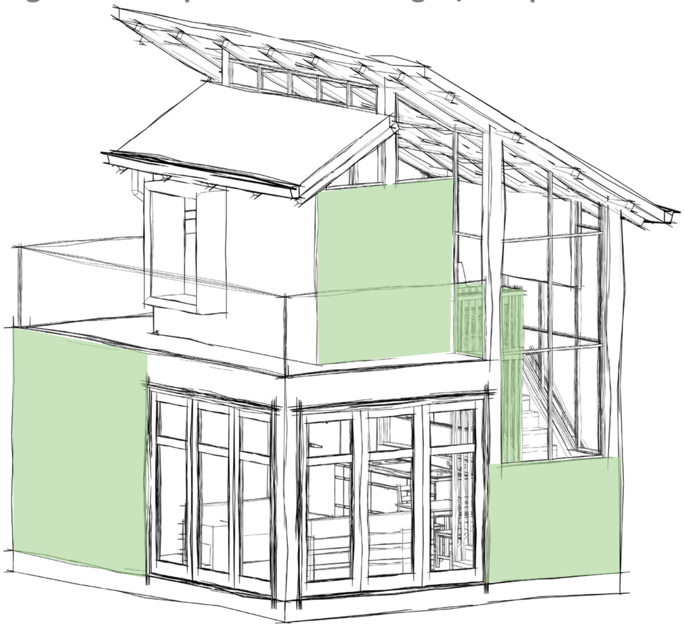
Ground Floor

Back Perspective

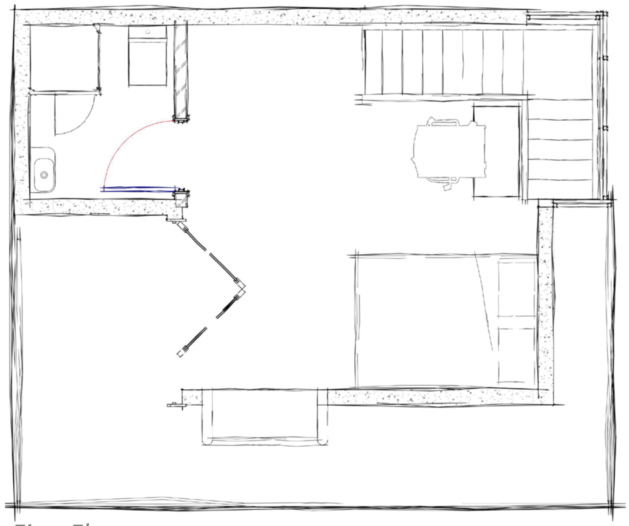
Clerestory roof allows passive cooling and heating techniques and uses natural light for daylighting. Ngowi states that clerestory windows were installed in the houses to ensure that ventilation and natural light reach all the internal spaces (Ngowi, 2001). To improve the cooling system daylight and aesthetic look, as the forth development to the design, shown in Figure 9.6, the roof design has been changed from a shed roof to a clerestory roof and re-arranged the windows to have better connectivity to nature.

Development Stages of the House for Single / Couple

Figure 9.7: Improvement to Single / Couple House – Stage 5

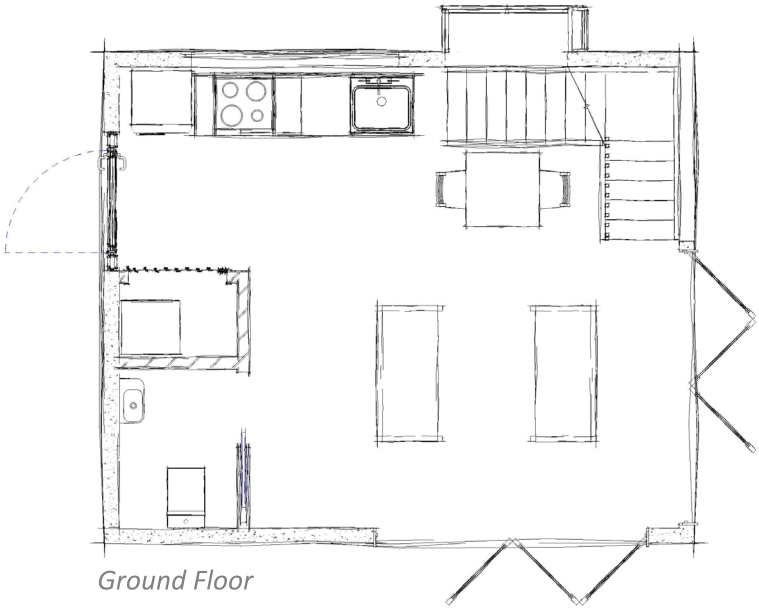


Front Perspective 1



First Floor

Front Perspective 2



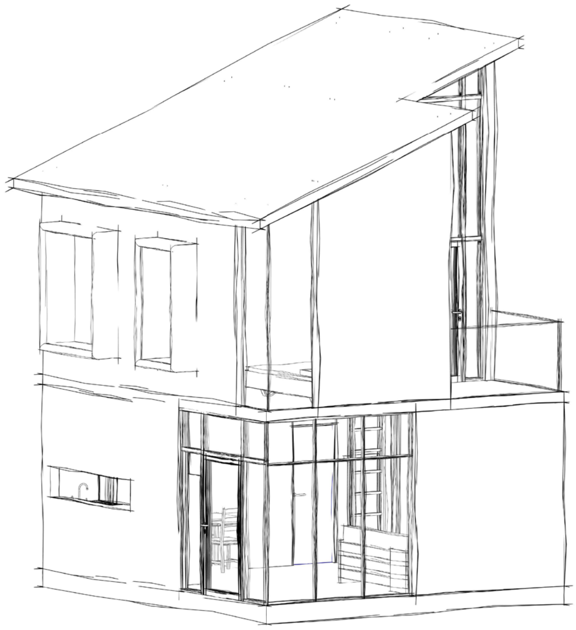
Ground Floor

Back Perspective

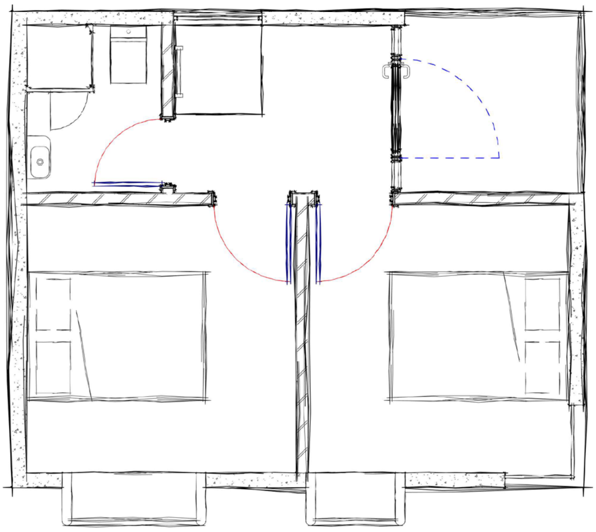
As the final development to the design which is shown in Figure 9.7 changes to the structure were done to support the roof. At this stage cross beams where introduced to support the roof and steel columns were introduced to strengthen the structure.

Development Stages for Family House

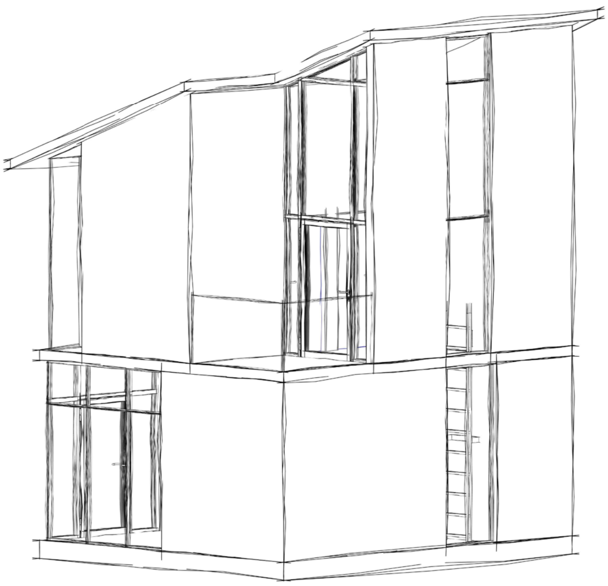
Figure 9.8: Improvement to Family House – Stage 1



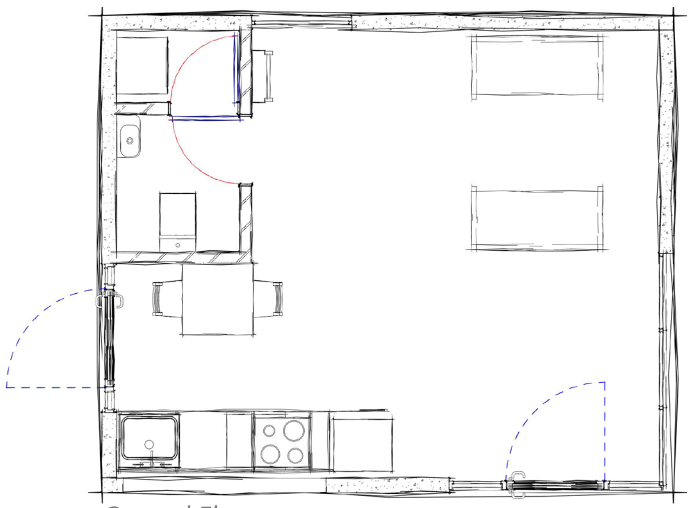
Front Perspective 1



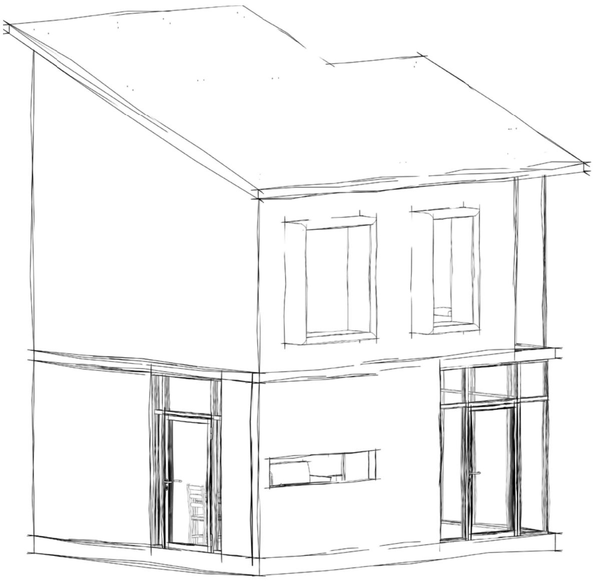
First Floor



Front Perspective 2



Ground Floor

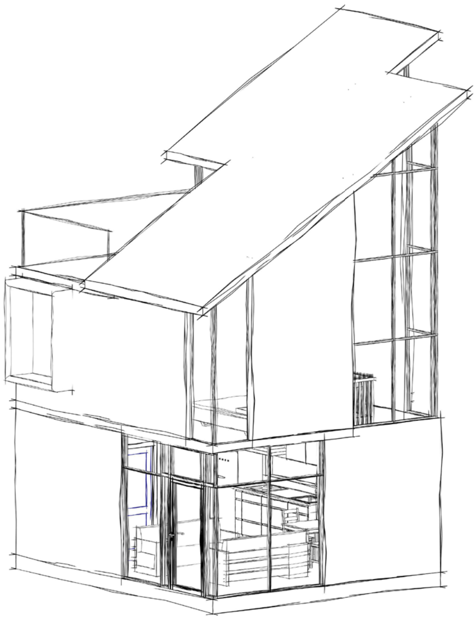


Back Perspective

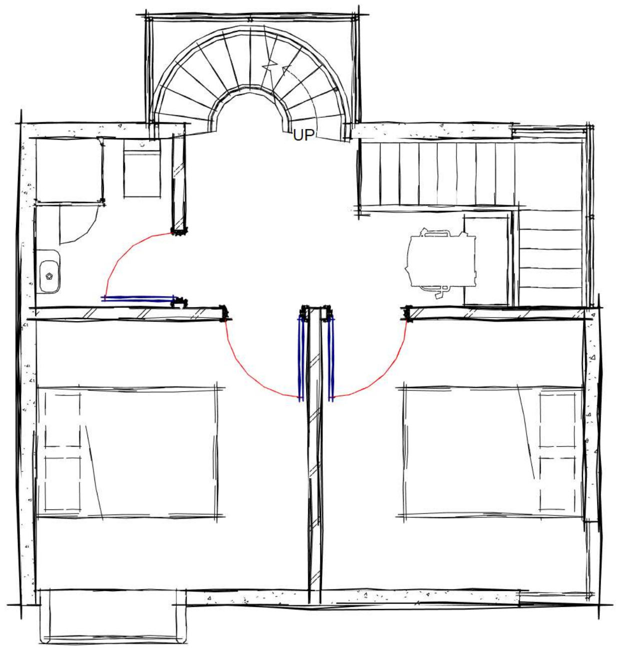
Due to same reasons stated under the development of the single house, family houses were also developed in five stages. The Design 3 given in Figure 9.2 had been further developed to get to the Design of the family house which is shown in Figure 9.8. Like in the case of the single-occupancy house, to improve daylight usage and have better connectivity to outside, additional large windows and large glass doors have been introduced and change the design of the roof. Introduced two pop-out windows for the occupants to sit and enjoy the surroundings. Re-arranged internal spaces for better space utilization. Access to the second floor was expected by using a ladder.

Development Stages for Family House

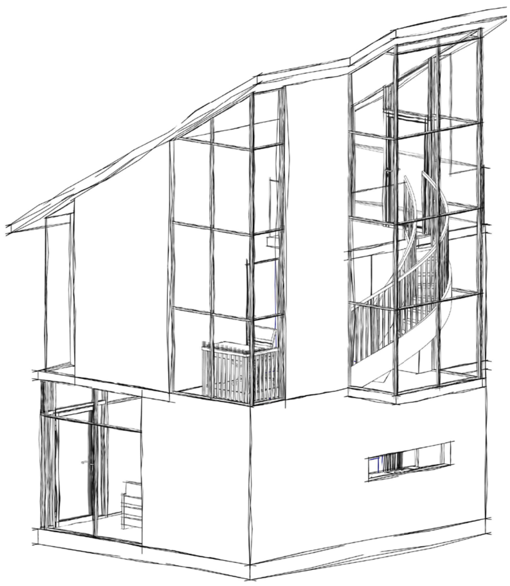
Figure 9.9: Improvement to Family House – Stage 2



Front Perspective 1



First Floor



Front Perspective 2

Ground Floor

Back Perspective

As the next stage of development, to add more safety the ladder access to upper floor was eliminated, and introduced a staircase to access the bedrooms on the upper floor and added more windows to improve natural lighting and connection to nature. Added a play area for the children by adding a new floor. A spiral staircase was added to give access to the new floor. Changed the design of the roof to accommodate the new layout. The Figure 9.9 shows the stage 2 improvement to the family house.

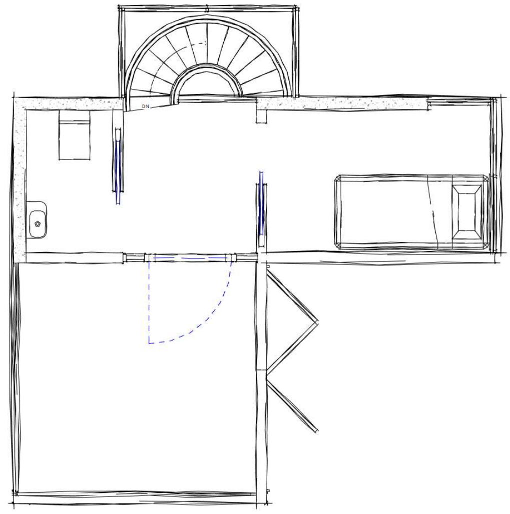
Development Stages for Family House

Figure 9.10: Improvement to Family House – Stage 3

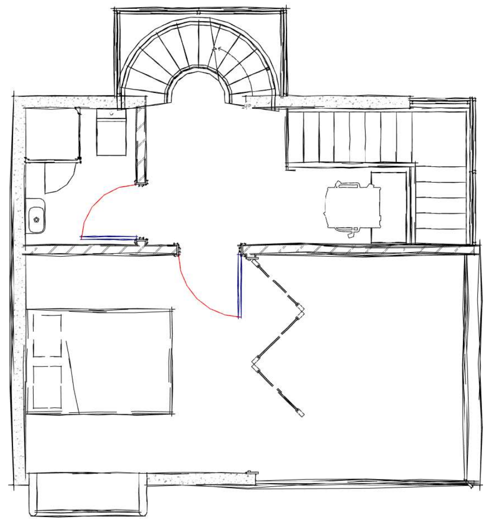
Front Perspective 1

Front Perspective 2

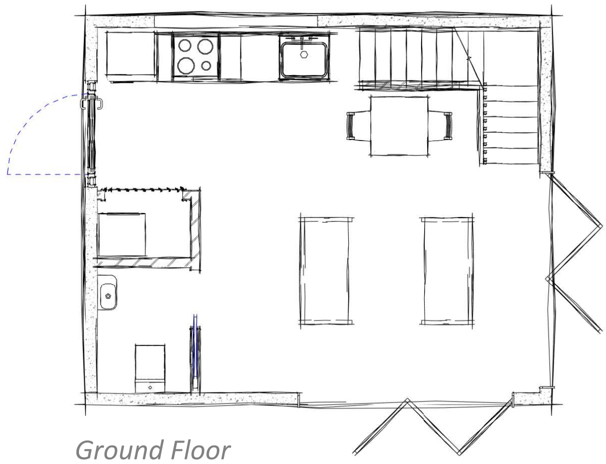
Back Perspective



Second Floor



First Floor



Ground Floor

As the stage 3 development to the family house, the Green wall concept has been brought in to harmonize the structure with nature. Bi-fold doors were introduced for the ground and the upper floor to bring more openness into the space. The children's bedroom was moved from the second level to the third level. A large balcony was added to the second floor for occupants to feel the openness. Minor changes were made to the design of the roof to accommodate the new layout (Figure 9.10).

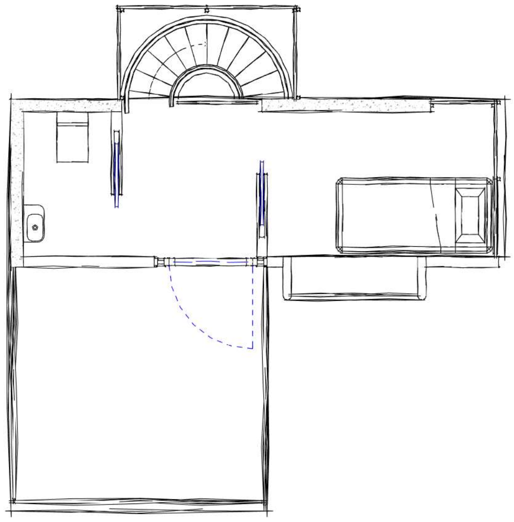
Development Stages for Family House

Figure 9.11: Improvement to Family House – Stage 4

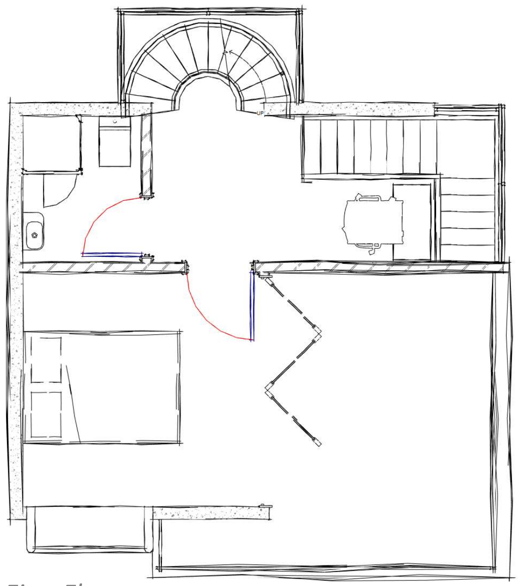
Front Perspective 1

Front Perspective 2

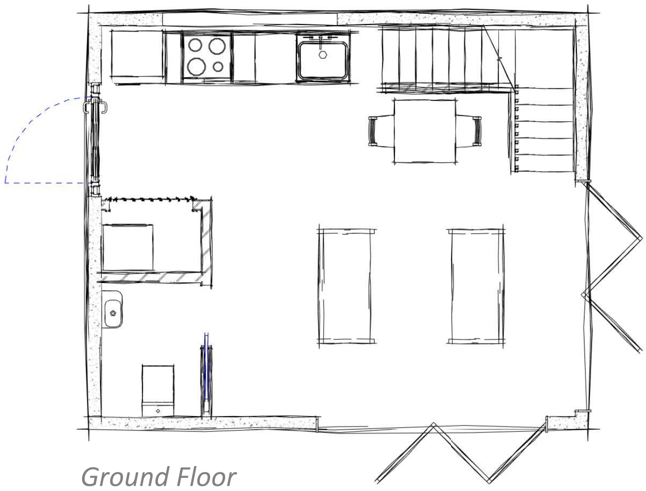
Back Perspective



Second Floor



First Floor



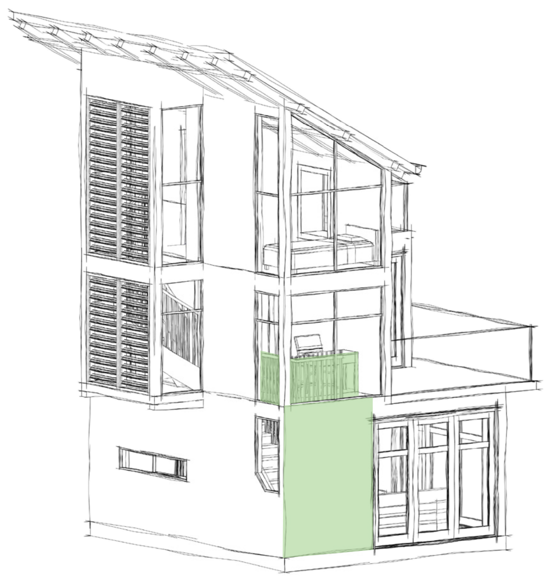
Ground Floor

Green walls were re-arranged by considering the direction of the sun and changed the design of the roof to accommodate the new layout as the stage 4 development to the family house which is shown in Figure 9.11. Also, re-arranged the windows to have better connectivity to nature.

Development Stages for Family House

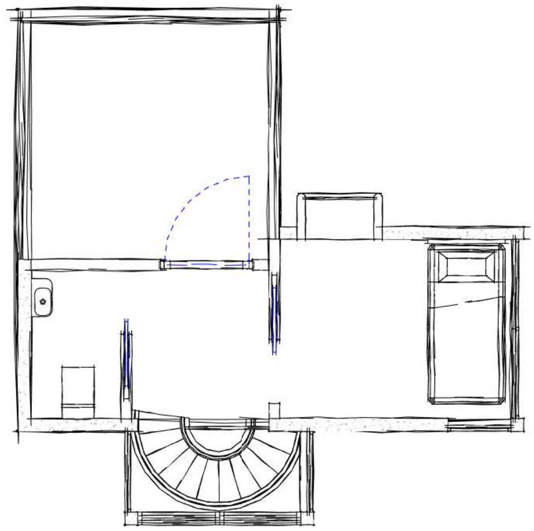
Figure 9.12: Improvement to Family House – Stage 5

Front Perspective 1

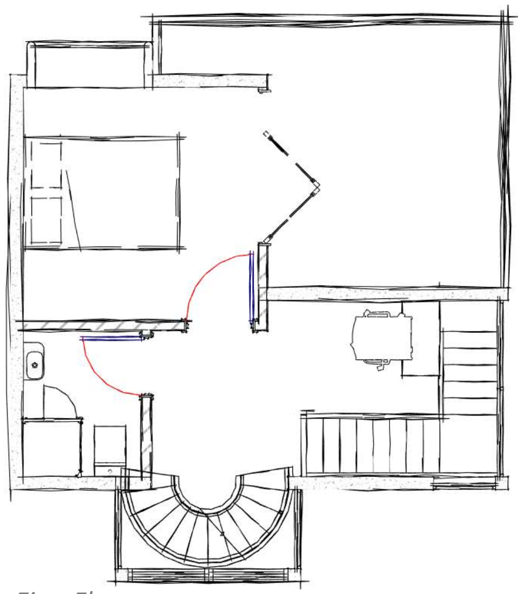


Front Perspective 2

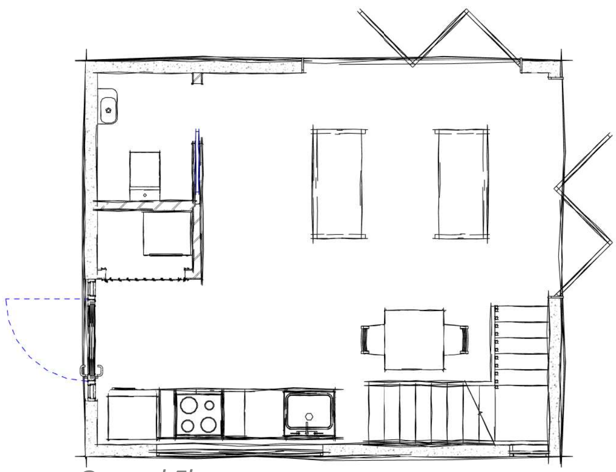
Back Perspective



Second Floor



First Floor



Ground Floor

As the final changes to the family house design, drawings were altered to accommodate the structure of the roof. Also, added shades to the windows (Figure 9.12).

9.3 Structure

Main structure of the house will be done by using steel columns and beams. Roof structure will also consist of steel cross beams. The rest of the house structure will be done by using timber. Concrete will be used for the foundation and the floor slab. Figure 9.13 and 9.14 below gives the structural drawing of both single / couple and family houses.

Figure 9.13: Single House Structral Section

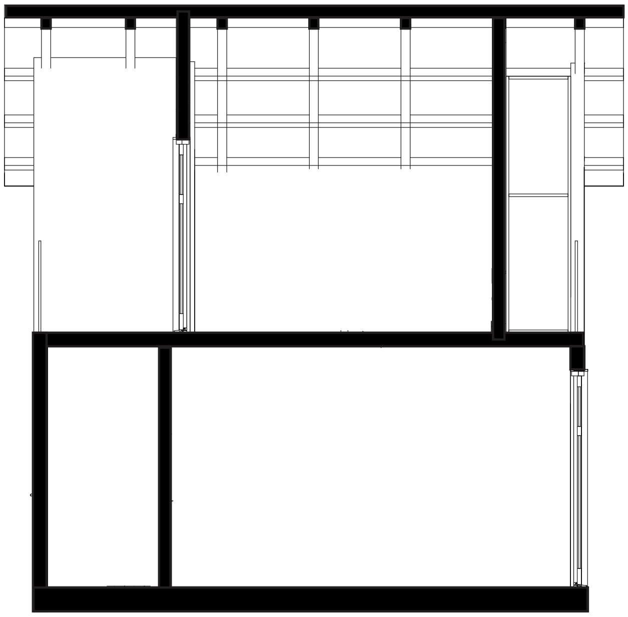
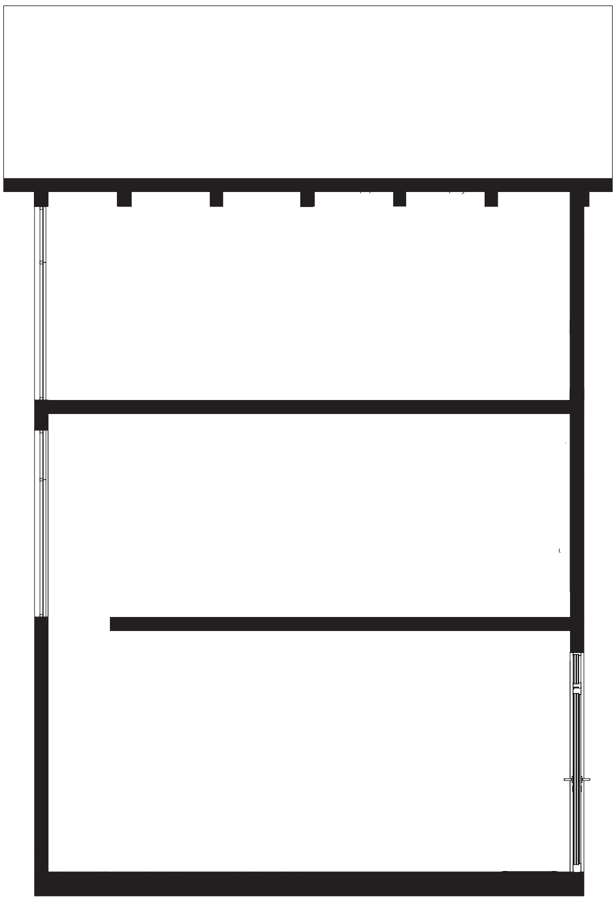


Figure 9.14: Family House Structral Section



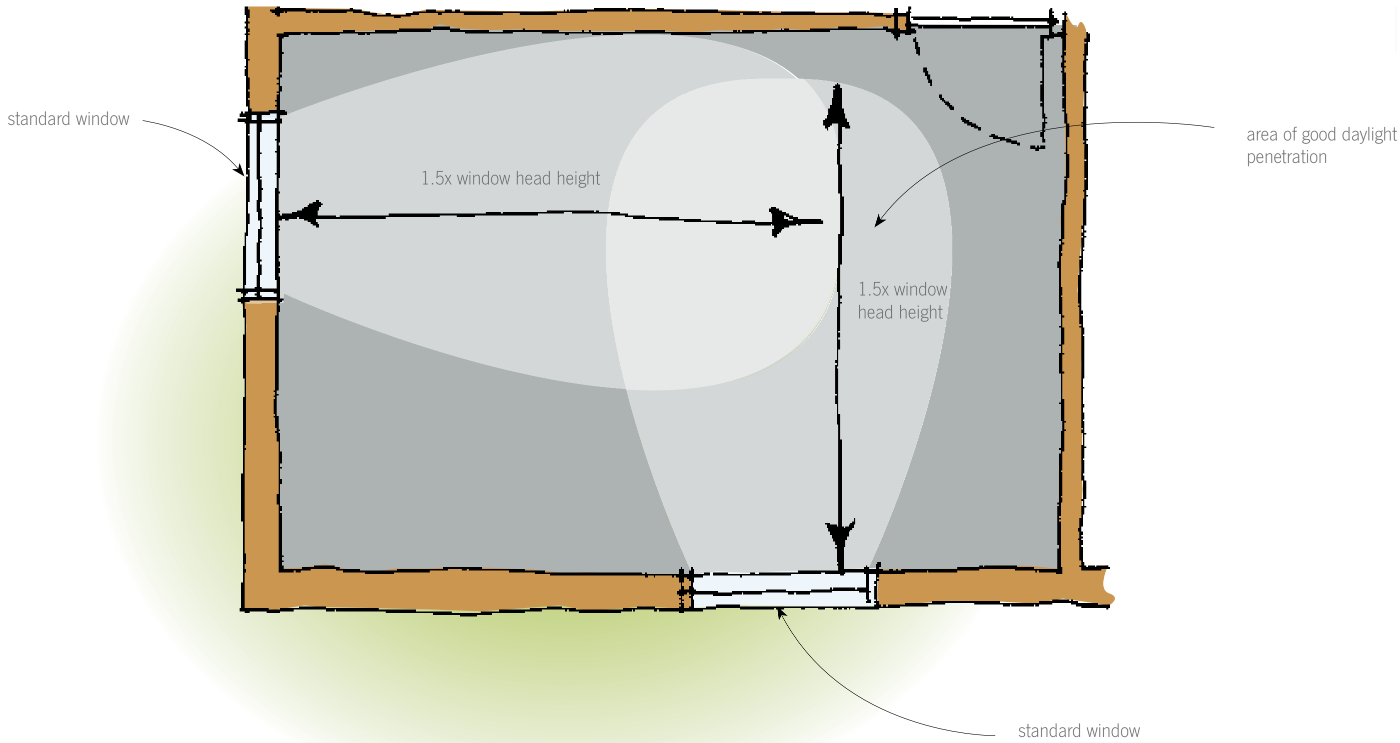
10

SERVICES AND MATERIAL

10.1 Lighting

A BRANZ's studies suggest that lighting accounts for 13% of the electricity used in an average New Zealand home and recommends that daylight be used as much as possible to light a home (BRANZ, 2021g). Usage of daylight will lead to an energy-efficient home and improve the health of the occupants. It is recommended that large windows directed towards the sun from more than one side will get better daylight. Figure 10.1 below shows how natural light could come from more than one direction.

Figure 10.1: Effect of Sunlight from Two Directions



Material sourced from BRANZ

The Gen Less NZ, founded by Energy Efficiency and Conservation Authority, suggests that the main living areas be faced north to get the most sun and put service areas like the bathroom and toilet on the cooler south-facing side. Gen Less identified that if every New Zealand household installed LED lighting, NZ would avoid 82,000 tons of greenhouse gas emissions every year (Gen Less, 2021). Gen Less recommend that warm white LED light used for energy-efficient lighting system in NZ homes.

"New Zealand Building Code clause G7 Natural light requires 30 lux of natural light at floor level for 75% of the year. Clause G8 Artificial light requires 20 lux of natural or artificial light at floor level at all times when the room is inhabited"(BRANZ, 2021d).

A sun study has been undertaken for both proposed house designs, and the orientation of all houses arranged to use the sunlight for lighting is maximized. The study has been done by considering the sun position during summer and the winter. In addition, a mechanical window blinds system is added to all glass doors and windows to cut down the summer heat and the sunlight. Figure 10.2 and Figure 10.3 below show the sun study results.

Figure 10.2: Sun Study on Single / Couple House

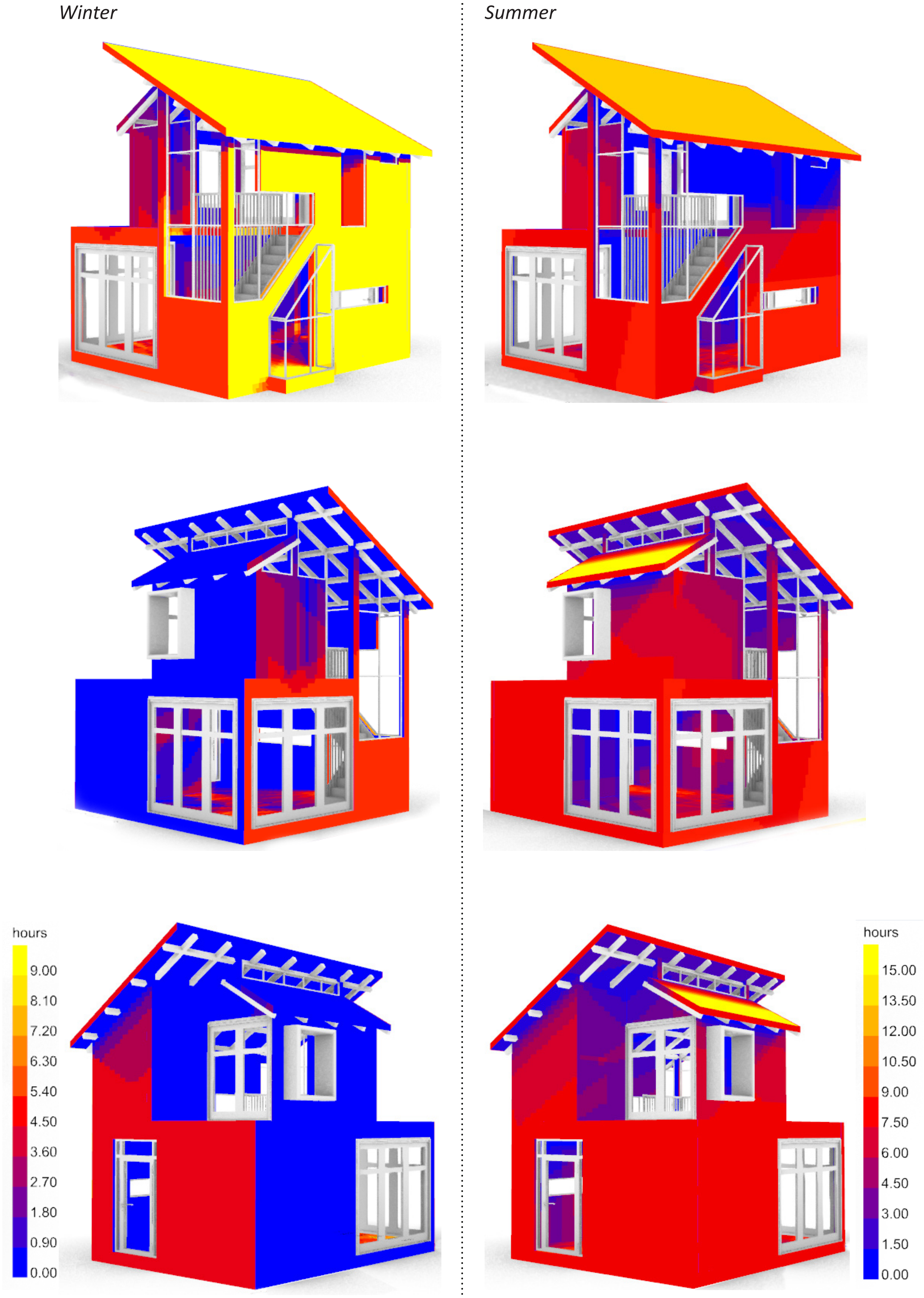
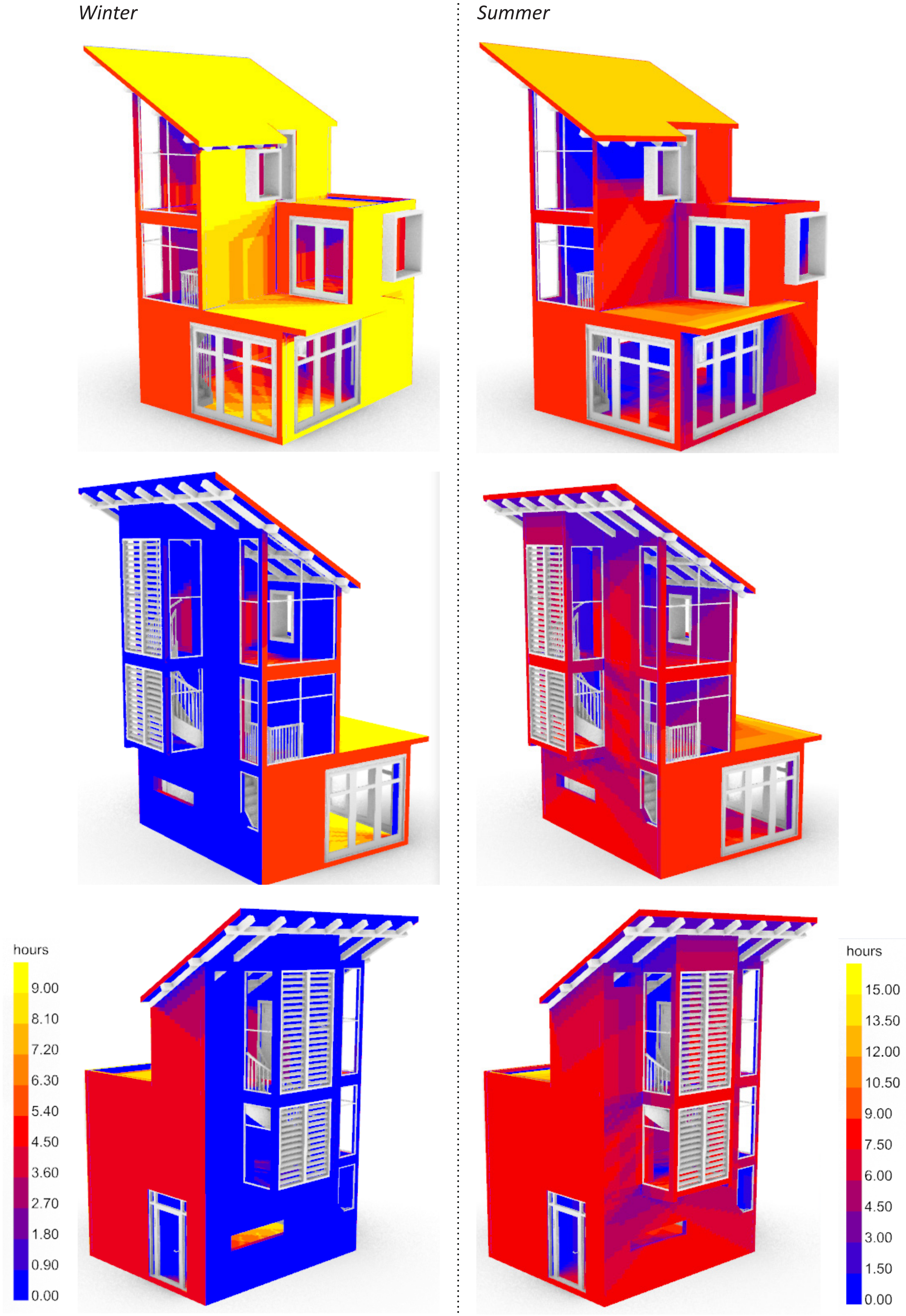


Figure 10.3: Sun Study on Family House



As per the sun study the roof of both single / couple house and the family house gets 8 to 9 hours sun during the winter and 12 to 13 hours during the summer. Most of the walls get 6 to 9 hours sun during the summer. During the winter north side walls get 8 to 9 hours sun and other walls get 4 to 6 hours sun. Longer hours of direct sunlight to the roof will be beneficial for the proposed project houses in generation of solar power. Possible overheating of walls due to the effect of the sun on walls will be mitigated with the introduction of green walls details of which are discussed in Para 10.4.

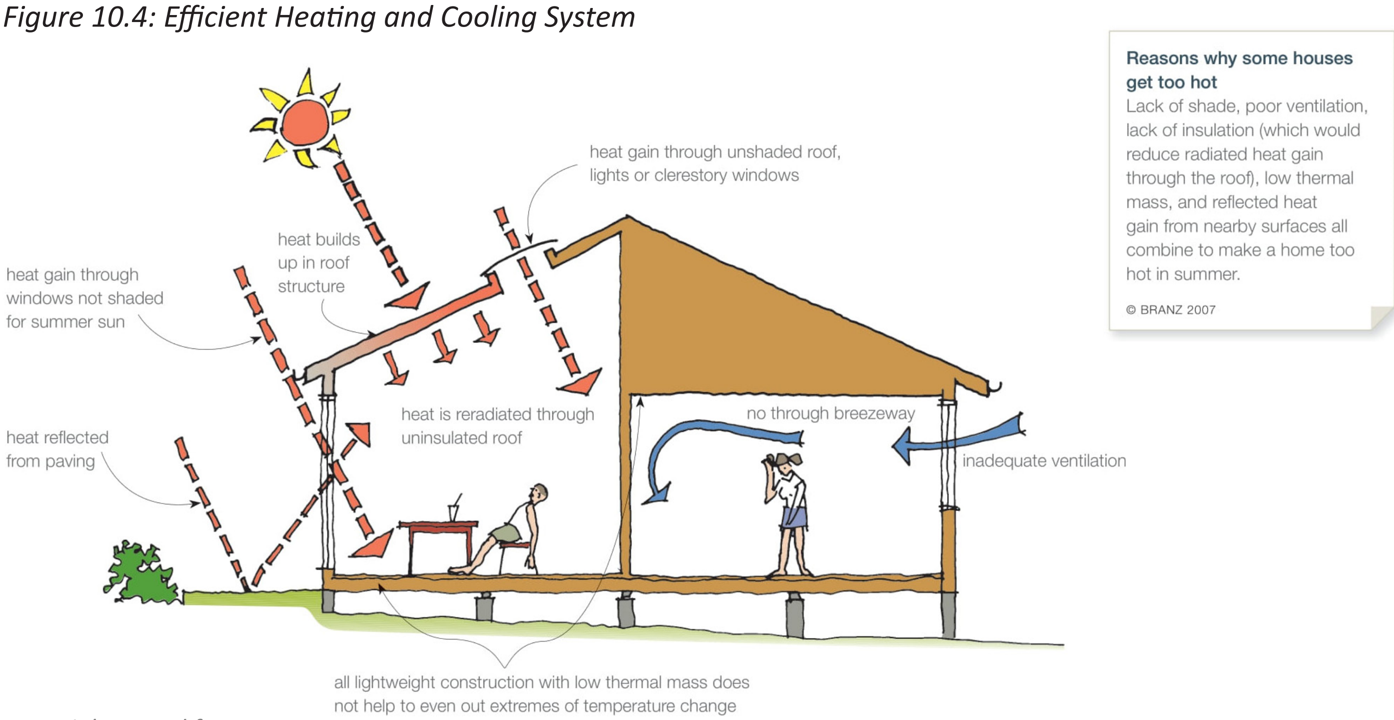
It is proposed that only LED lights be used for night lighting as recommended by Gen Less NZ to get the minimum lighting requirement of LUX amount as stated in New Zealand Building Code.

10.2 HVAC System

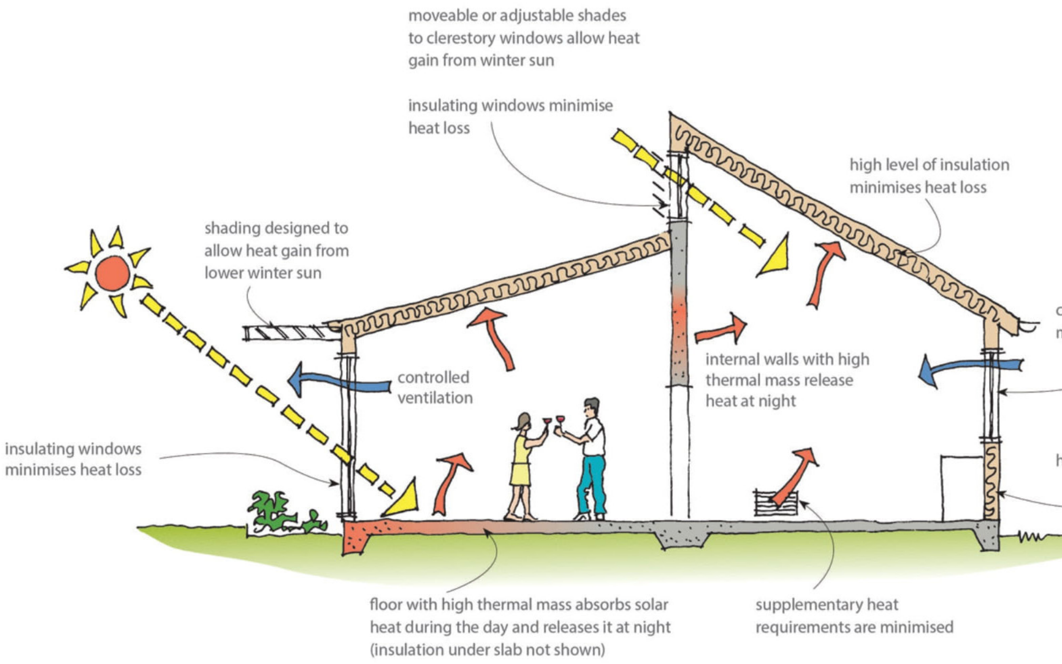
The Essential Guide to Home Heating in New Zealand by Laser Plumbing and Electrical indicates that typical NZ homes are not efficiently heated, and Kiwis are used to live in cold, damp homes. Due to heat loss, the temperature in NZ homes can drop below 16°C. Brad Olsen found that over 21.5% of kiwi houses are damp, and 16.9% are moldy (Olsen, 2020). According to the World Health Organization, 18°C is a healthy temperature for any room (Gen Less, 2021b). However, WHO recommends a slightly higher temperature of 21°C being used for children, the elderly, and ill people. The proposed houses under this research project will maintain recommended temperature of 18°C - 21°C.

To have a passive heating and cooling system, BRANZ proposes taking advantage of natural ventilation flow, using the thermal mass to absorb heat and provide proper insulation. Figure 10.4 below graphically illustrates how an efficient cooling and heating system works and harnesses the sun's energy to the maximum (BRANZ, 2021h).

Figure 10.4: Efficient Heating and Cooling System



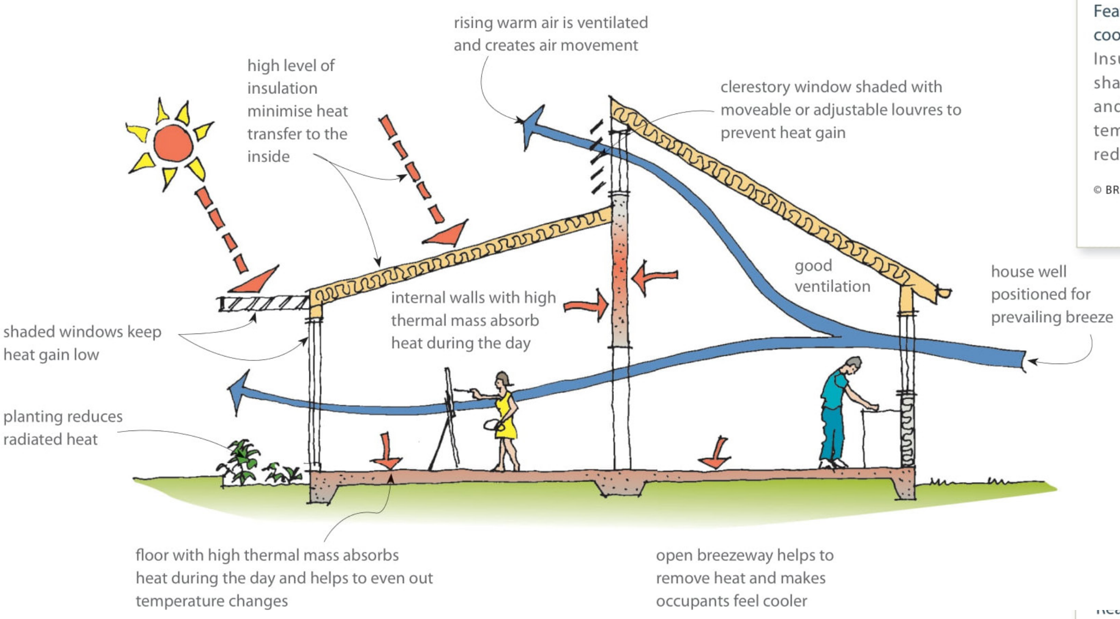
Material sourced from BRANZ



Features of passive design for heating

Passive heating captures, stores and uses the sun's energy to provide heating, through a combination of solar access, insulation and thermal mass. Shade and ventilation are used to prevent overheating.

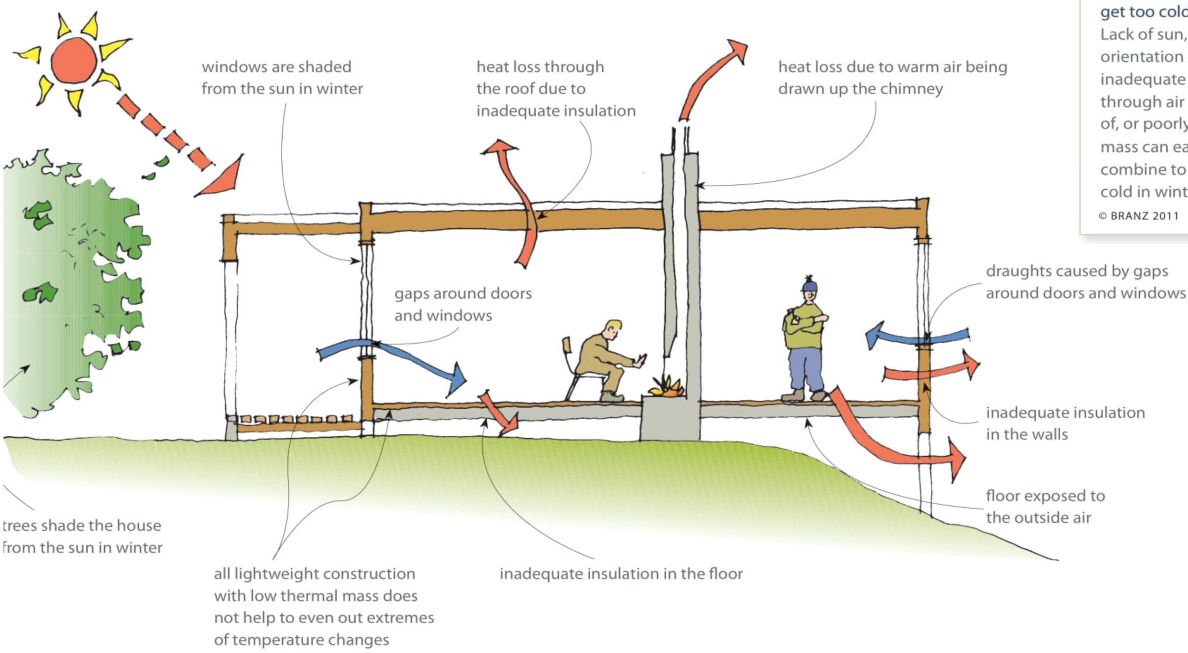
© BRANZ 2011



Features of passive design for cooling

Insulation, thermal mass and shading reduce heat gain, and ventilation provides temperature moderation to reduce interior heat build-up.

© BRANZ 2011



Reasons why some houses get too cold

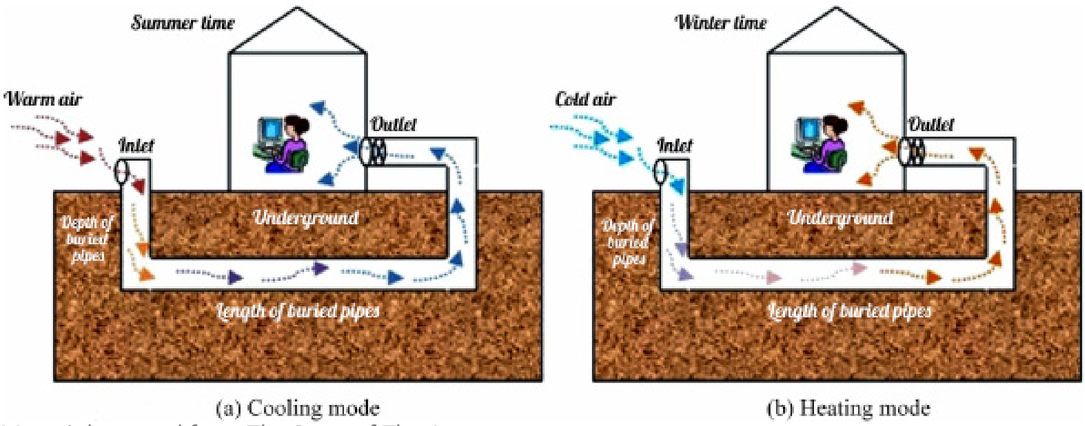
Lack of sun, poor solar orientation of living spaces, inadequate insulation, heat loss through air leakage, and lack of, or poorly placed thermal mass can each contribute or combine to make homes too cold in winter.

© BRANZ 2011

Material sourced from BRANZ

Andrew Trounson suggests that geo-exchange energy be used for heating and cooling for more green and sustainable homes (Trounson, 2017). For harnessing the underground heat, a tunneling system can be used to cool or heat air. The house is designed to have natural ventilation during the summer. However, during the winter, energy efficiency will be achieved by using proper insulation materials and an underground heat exchange system. Figure 10.5 below highlight such a system.

Figure 10.5 : Use of Soil as the Heat Source



Material sourced from The State of The Art

As stated in Para 6.3.6 soil temperature at 1 -1.5m depth in the project area is around 12 – 15^{0}C. This constant temperature will be used for heating and cooling system of the project houses. An underground tunnel will be connected to the two vents inside the house with the heat exchanger fan. During the day hot air will be pumped through the tunnel to bring the temperature down. During the night the cold air will be pumped through the tunnel to increase the temperature within the house. Figure 10.6 and Figure 10.7 below shows the proposed HVAC system together with heat exchanges for the Project houses.

Figure 10.6: Ground to Air Heat Transfer System (Day)

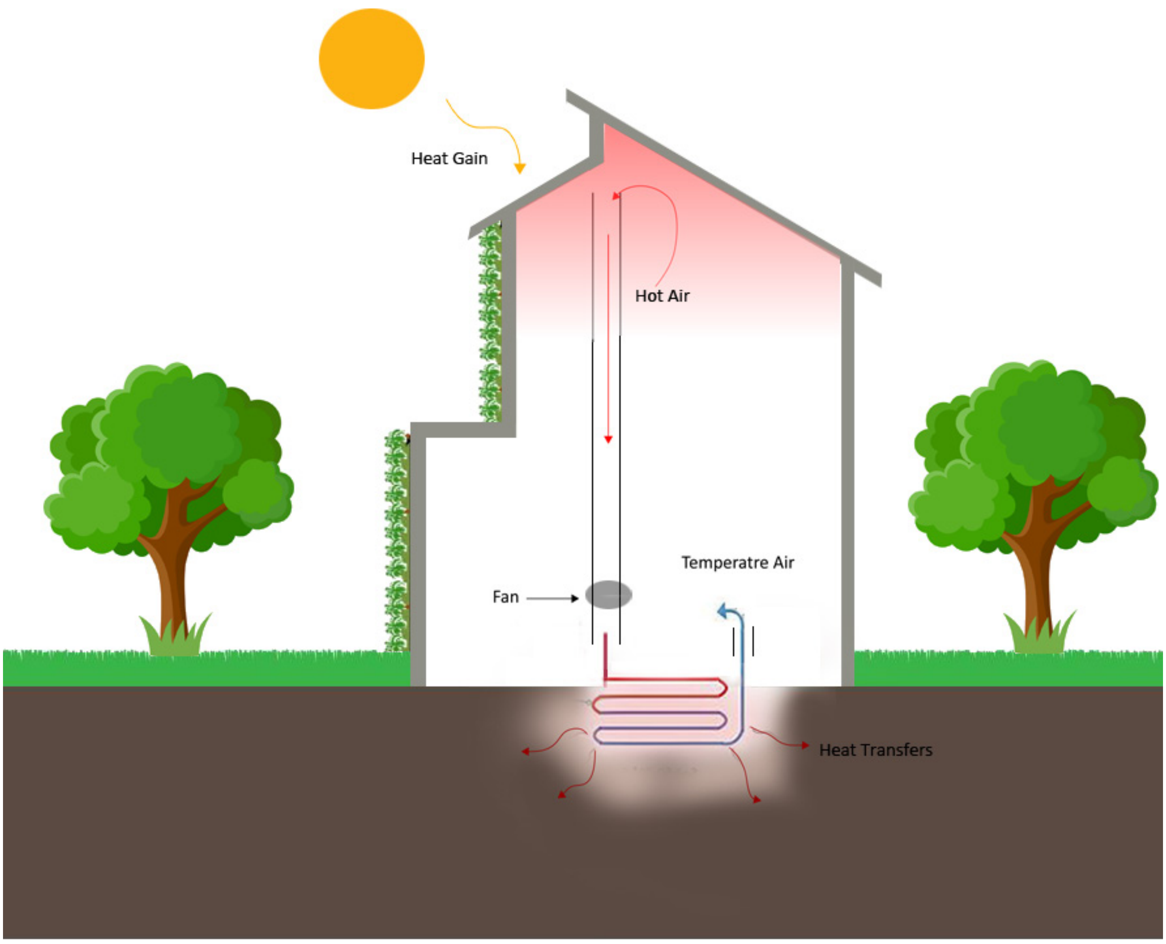
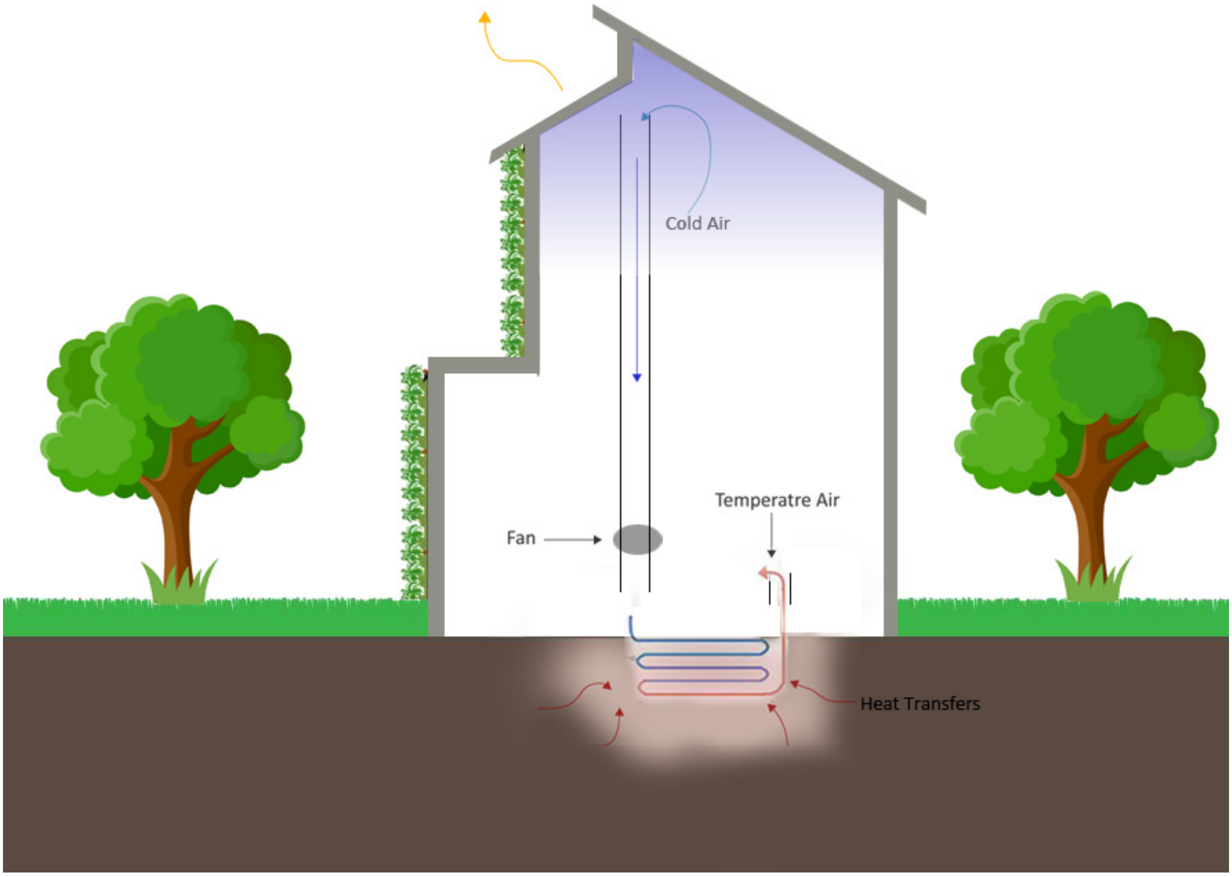


Figure 10.7: Ground to Air Heat Transfer System (Night)



10.3 Rain Water Collection

Rainwater harvesting will reduce the consumption of treated water. It also helps to cut down the water bill, improve the ground water quality, and not require a filtration system for irrigation.

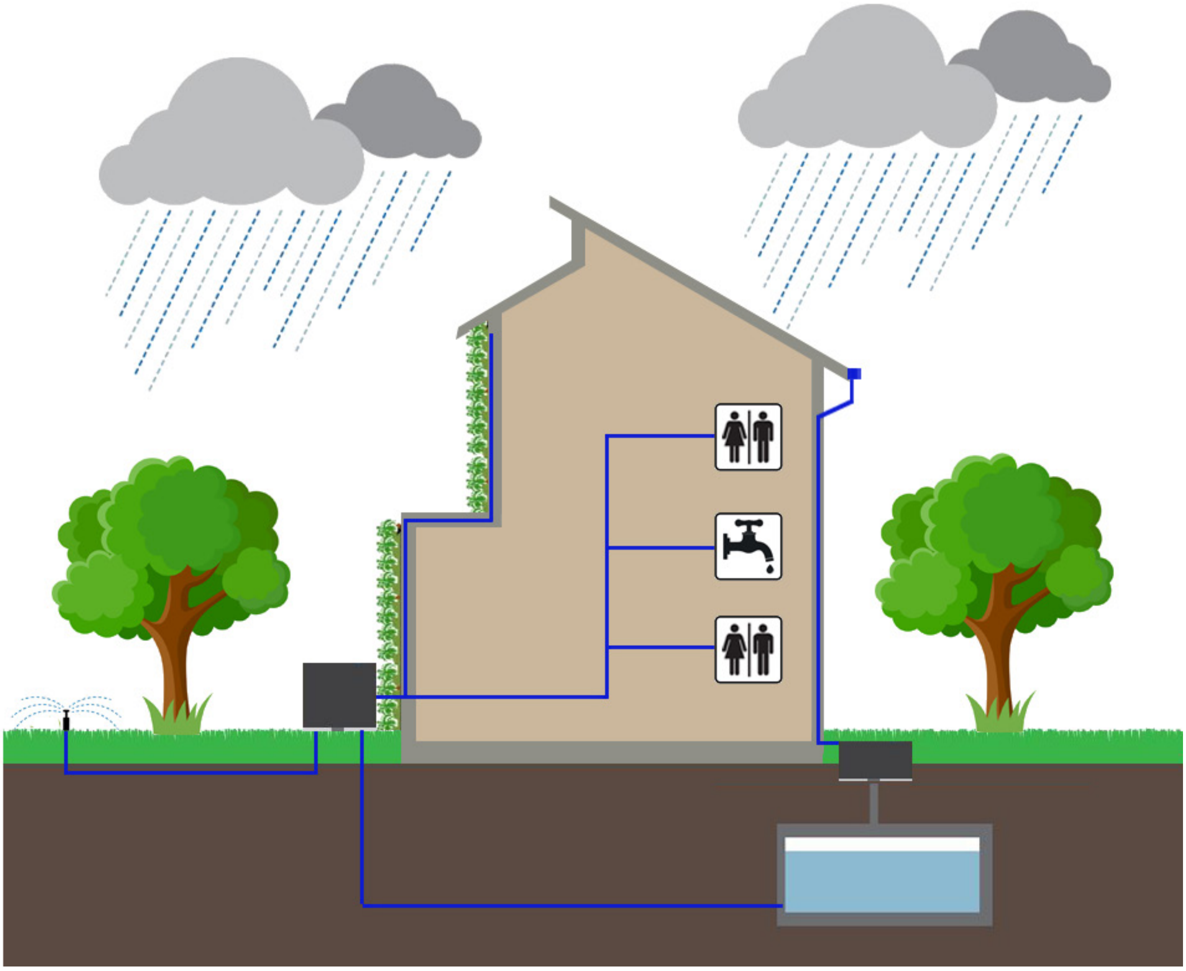
BRANZ NZ conducted a survey and found that most people favor installing rainwater systems for cost savings (reduced town supply consumption), allowable garden irrigation during water restrictions, and environmental reasons (BRANZ, 2018). Survey also indicated that the main barriers to installing rainwater systems in New Zealand buildings are cost, education, and space for the tanks. Figure 10.8 below shows a simple rainwater harvesting system with an underground water tank that can be used to irrigate the garden and Green walls.

Figure 10.8 : Typical Rainwater Collection System

Material sourced from Material sourced from Smart Solutions for Urban Management of the 3 Waters

The use of rainwater to irrigate the garden and Green walls is planned to enhance the eco-friendly aspects of the proposed housing scheme. Rainwater will be collected in an underground tank close to the house. The gutter pipes of the roof are connected to the underground tank. The gutter and the downpipes are hidden, and the downpipe is hidden inside the wall. A small pressure pump connected to the underground tank will provide water to the garden's Green walls. Figure 10.9 below highlight the rainwater collection system and proposed irrigation system for the Green walls and garden.

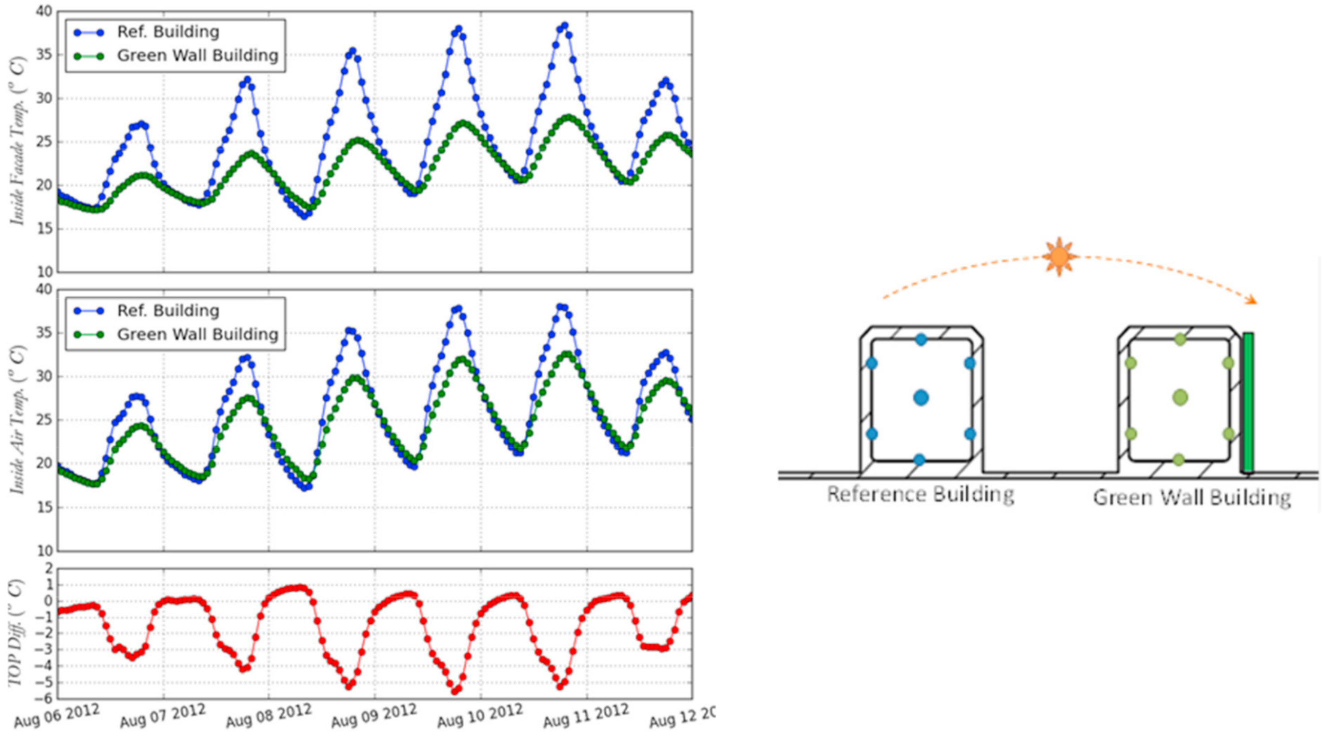
Figure 10.9: Rainwater system for Project houses



10.4 Green walls

Green walls are vertical structures with different types of plants and greenery. Staffordshire University Green Wall Centre defines Green wall as "Vegetation growing on or against a vertical surface" (Mustonen, 2017). The United States Environmental Protection Agency proposes green infrastructure for urban heat. Green walls have many benefits. Purification of air, increasing the feeling of well-being, reducing ambient temperature, reducing ambient noise, and reducing the stress of people living close to Green walls are common benefits of using Green walls for buildings (Tirelli, 2019). Tirelli claims that one square meter of a living wall could absorb 2.3 kg of CO_2 per annum from the air and produce 1.7kg of oxygen. Djedjig et al, in their study on 'Green Wall Impacts Inside and Outside Buildings,' found that Green walls lower the temperature of the building by an average of 5^{0}C (Djedjig et al., 2017). The Sun study on the Project houses are given in Figure 10.2 and 10.3. Green walls will help to bring down the high temperature shown in yellow and red colors on the walls of the Project house. Figure 10.10 below highlights the temperature differences of a normal building and a Green wall building over time. The three graphs show the temperature variances inside the building, inner surface, and operative temperature.

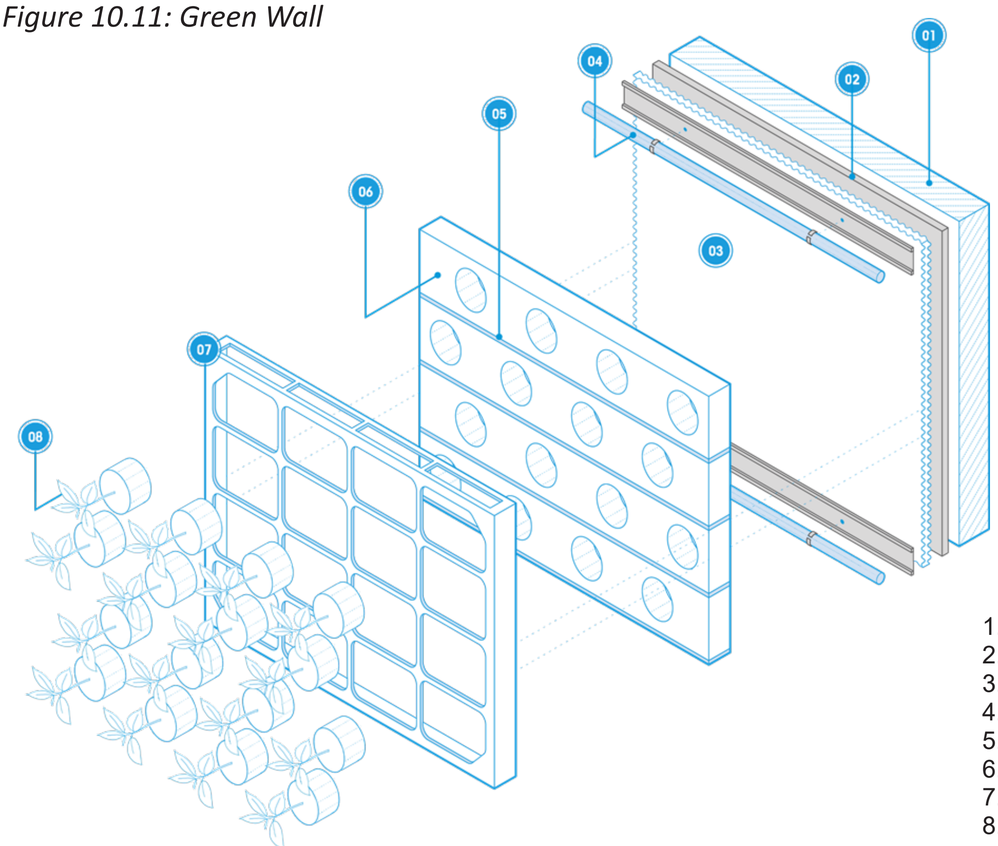
Figure 10.10: Temperature Effect by Green Wall



Material sourced from Green Wall Impacts Inside and Outside Buildings

There are various technologies available for putting up Green walls. GSky Pro Wall, Suite Plants Live Panel, and Sagegreenlife Biotile are some of those technologies (Ambius, 2021). The GSky Pro Wall system is a wall-mounted system with 5 components, Stainless Steel Frames Panels, Irrigation System, Growth Media and Plants that can be attached to an existing structurally sound wall. Suite Plants Live Panel system is used for smaller live plant pictures. Biotile technology is one of the standard techniques available for putting up Green walls. Figure 10.11 below shows the structure of how a Green wall could be attached to a vertical surface.

Figure 10.11: Green Wall



1. Support System
2. Waterproof Backing Board
3. Rear Drainage Layer
4. Aluminium Rails and Dripline
5. Capillary Breaks
6. Grodan Growing Medium
7. Panel Box
8. Plants

Material sourced from Sage Greenlife

10.5 Material

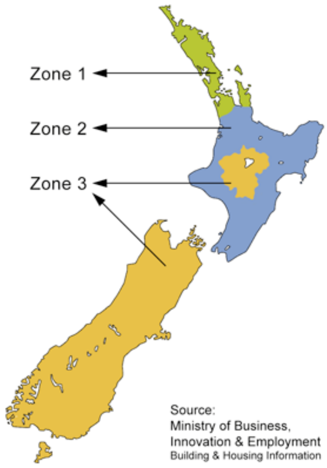
10.5.1 Types of Materials to be Used

The Authority of Sustainable Building requires that buildings be designed following Building Act 2004. Under the Act, designers, builders, local authorities, and building owners must consider: a) minimizing waste during construction, b) using eco-friendly materials, using safe and healthy materials, c) energy conservation and efficiency of materials and systems, and d) the durability of materials (BRANZ, 2021e).

Building materials have environmental labeling, which allows us to identify and select products with better environmental performance. Environmental Choice New Zealand is the NZ official ecolabelling Authority (Environmental Choice New Zealand, 2021). If a material carries a Type 1 label, it is proof of the environmentally best product available. It is vital that when sourcing materials for project houses, more environmentally friendly materials be selected. Different building materials have different heat-resistant capacities. The capacity to resist heat is measured with a measurement called R-value (Archtoolbox, 2019). The Figure 10.12 summarizes the acceptable levels of R-values for NZ homes.

Figure 10.12: Expected Minimum R-Values for NZ Homes

	Climate Zones 1 and 2	Climate Zones 3
Roof	R 2.9	R 3.3
Walls	R 1.9	R 2.0
Floor	R 1.3	R 1.3
Heated floors	R 1.9	R 1.9
Windows	R 0.26	R 0.26
Skylights	R 0.26	R 0.31



Material sourced from Building Performance

Using higher R-value building materials will give an efficient heating and cooling system. Therefore, for an eco-friendly house, there is a need for selecting high R-value building materials. The High-Performance Construction Details Handbook published by Passive House Institute New Zealand identifies high-performance materials and assemblies with high R-values for sustainable housing. Figure 10.13 below highlights details of high-performance assemblies. It is recommended that the High R-value and Environmental Type 1 materials be used for the proposed Project houses.

Figure 10.13: High-Performance Assemblies

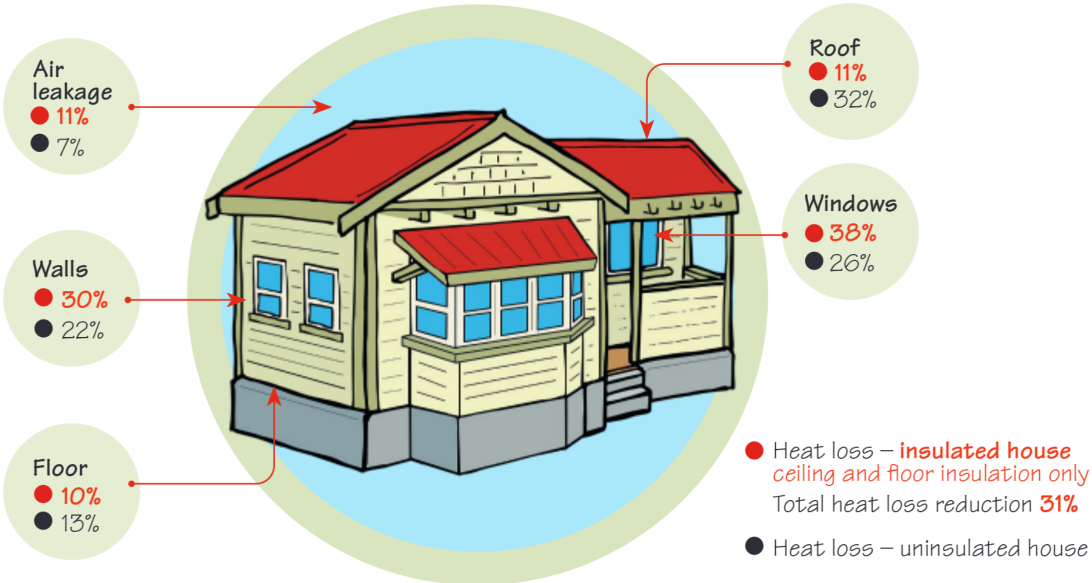
	Description	Area, length, quantity	Performance	Heat Loss Coefficient	Total Heat Loss
Element		Area/Performance = Heat Loss Coefficient			
Roof/Ceiling	Truss at 900mm for 8% timber R8.0 Insulation - Element P	110 m²	R7.8	14 W/K	14%
Wall	140mm studs 15% timber R4.0 / 45mm service cavity R1.2 insulation - Element A	94 m²	R4.4	21 W/K	20%
Floor	150mm EPS insulation under the concrete slab - Element H, A/P=3.5	110 m²	R6.0	18 W/K	18%
Windows	uPVC high-performance 4:/16/4 double glazed low-e argon	30 m²	R0.77	39 W/K	37%
Doors	Insulated panel in uPVC frame	2 m²	R0.9	2.2 W/K	2%

Material sourced from Passive House Institute New Zealand

10.5.2 Insulation

A 2018-19 national housing assessment undertaken by the building research association of NZ found: a) around half of the dwellings lacked adequate insulation in the roof space, b) around half of the dwellings do not have mechanical extract ventilation in the bathroom, and c) over half of the dwellings have no heating in bedrooms (Stats NZ, 2020b). A study conducted by BRANZ together with Beacon, Home Performance Advisor and Sustainability Trust identifies that the primary heat lost in an uninsulated house is from the roof. Heat lost from the roof will amount to 32%, windows 26%, and walls 22% (BRANZ, 2021b). When the house is insulated, the primary source of heat lost becomes windows. Therefore, an efficient HAVAC system should have proper insulation to minimize heat losses, mainly in the roof and walls. Figure 10.14 below shows sources of heat losses. In order to maintain a healthy temperature, houses should have a proper insulation system.

Figure 10.14: Sources of Heat Losses



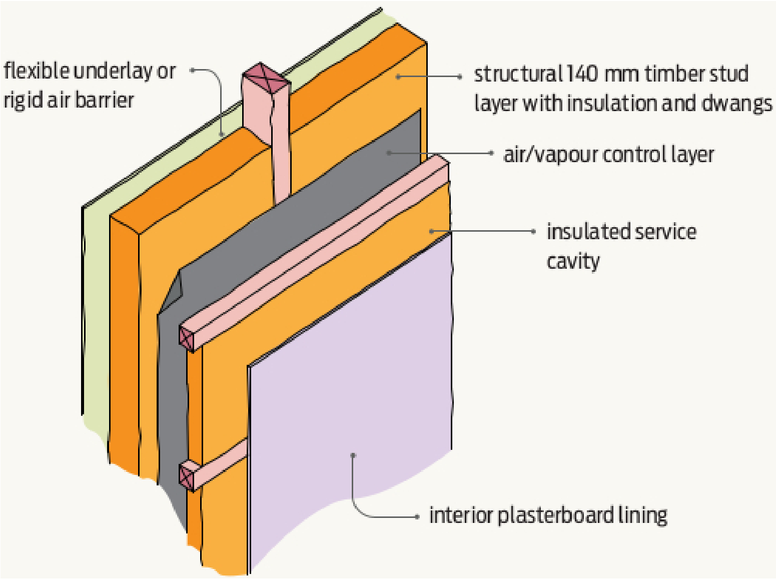
Material sourced from BRANZ

Several insulation materials are being used in NZ, including earth wool, sheep wool, polyester, wool/polyester blend, polystyrene, mineral wool, and macerated paper. The Authority of Sustainable Building provides a fact sheet (Appendix 1) for these insulation materials (BRANZ, 2021a). Due to its lower cost, durability, low maintenance the fire resistance ability, and high R-value, it is recommended that earth wool be used for roof insulation for the project houses.

10.5.3 Construction of Walls

David Hindley in his article on High-performance domestic walls, states that the most common wall construction in high-performance houses in NZ uses timber frame walls with insulated cavities (Hindley, 2021). Figure 10.15 below gives a cross-section of such a wall. As per the NZ's building code requirement expected minimum R-value of house walls should be R1.9 (Building Performance, 2008). PHINZ indicates that high performance wall can have an R-value of 4.4 (PHINZ, 2021). With proper insulation timber walls could easily achieve up to 3.6 R-value (Standards New Zealand, 2009). Therefore, it is recommended that insulated timber cavity walls with 3.6 R-value be used for proposed Project houses.

Figure 10.15: Cross-Section of a High-Performance Wall

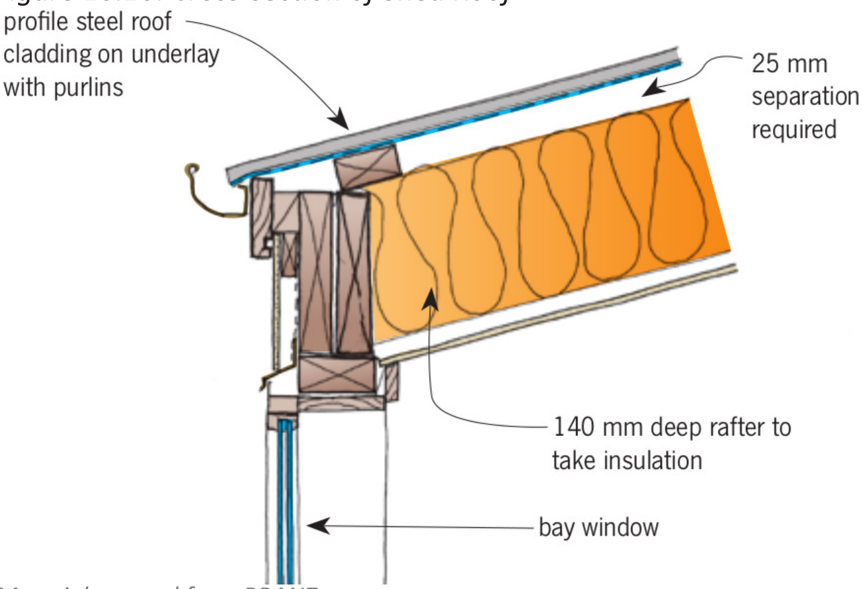


Material sourced from BRANZ

10.5.4 Roofing

NZ homes use six different roofing materials: timber, asphalt, metal, membrane, tile, and slate. Metal roofing is one of the eco-friendliest roofing choices because it can be made out of 100% recyclable materials, and its durability can last up to 60 years (Btadmin, 2017). Therefore, it is recommended that metal be used as the roofing material for the proposed Project. The Project will have the added advantage of using metal for the roof as most roof parts are covered with solar panels. The following Figure 10.16 shows a cross section of standard shed roof with insulation. All Project houses have shed-roof.

Figure 10.16: Cross-section of Shed Roof



Material sourced from BRANZ

The following Figure 10.17 highlights the R-values of roof with different insulation materials (Conder, 2009). To achieve 2.5 R-value 125mm of earth wool insulation is required. It is recommended that R-value of 4 or higher be targeted from roofs of Project houses.

Figure 10.17: R-Value of Roof Insulations Types

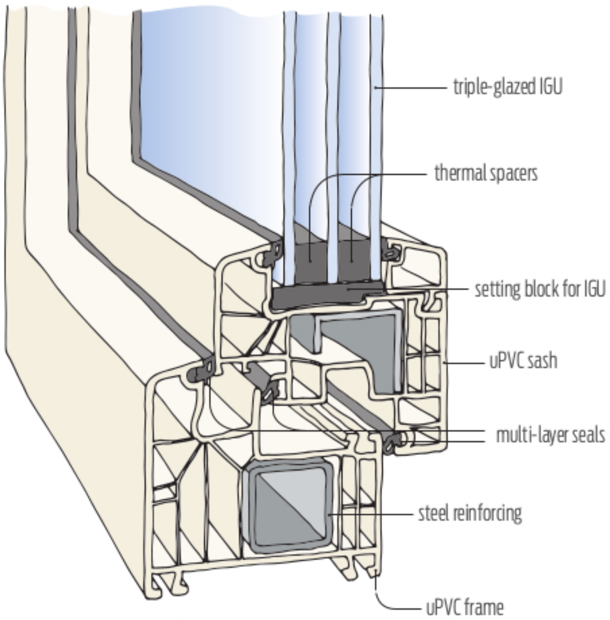
Type	Glasswool						Polyester		Wool	Cellulose
R-value	**Earthwool**	**Polygold**	**Knauf**	**Premier**	**Bradford**	**Pinkbatts**	**Greenstuf**	**Novatherm**	**Ecotherm**	**Insulfluf**
2.3		100			100					
2.5	125		125	100						
2.6					120	140		165		156
2.7				120	125					
2.9				125			175		145	182
3.0	145									
3.2					145	170	180	200		
3.3	150		150	145						215
3.4							190			
3.5	175		175							
3.6		140		155	185	180				
3.8	185									
4.0	195		195	175		190				
4.6						195				
5.0	210		210		210	200				
6.0	275				260					

Material sourced from BRANZ

10.5.5 Glass Doors, Windows and Panels

To maintain high thermal envelope, it is important to have properly insulated doors and windows are used for project houses. There are various methods of glazing being used for high energy efficient doors and windows. A diagram of a high energy efficient glass door is given below (Figure 10.18).

Figure 10.18: Window Details



Material sourced from BRANZ

Figure 10.19 below gives the R-values of different types of windows. For the Project houses it is recommended that to maintain the eco-friendly of the houses, timber frames be used with Insulated Glass Units. These glass units need to be insulated with Low-E Panes and Argon Gas Fill.

Figure 10.19: R-Values of Windows

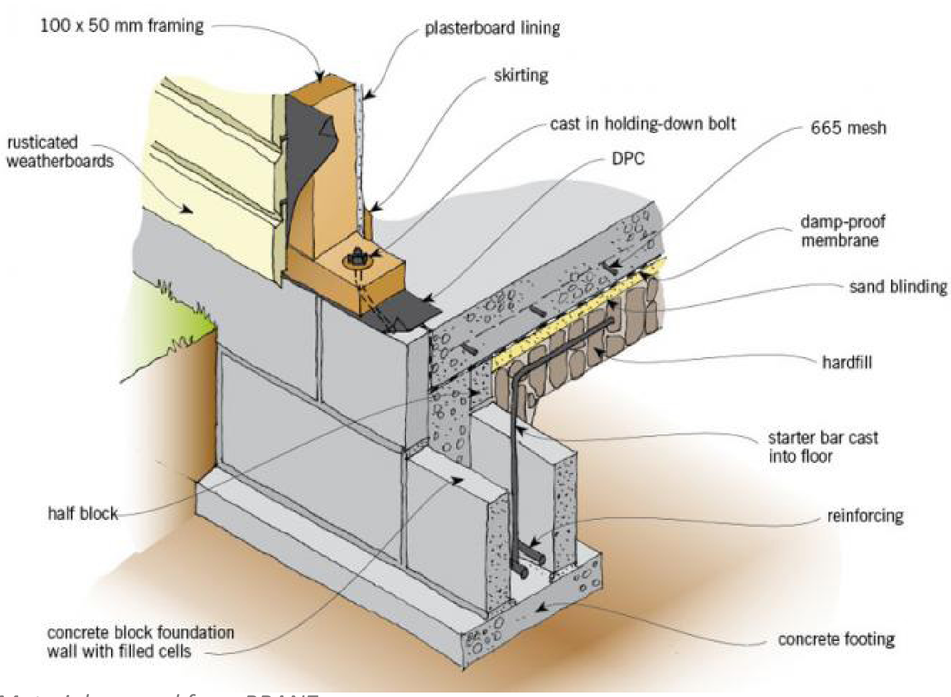
WINDOW FRAME	SINGLE GLAZING	IGU – 4 MM GLASS AND 8 MM AIR SPACE	IGU – 4 MM GLASS AND 12 MM AIR SPACE	IGU – 4 MM GLASS, 12 MM AIR SPACE AND LOW-E PANE	IGU – 4 MM GLASS, 12 MM AIR SPACE, LOW-E PANE AND ARGON GAS FILL TRIPLE-GLAZED	IGU WITH LOW-E PANES AND ARGON GAS FILL
Aluminium	R0.15	R0.25	R0.26	R0.31	R0.32	R0.53
Thermally broken aluminium	R0.17	R0.30	R0.31	R0.39	R0.41	R0.77
Timber	R0.19	R0.34	R0.36	R0.47	R0.51	R1.00
uPVC	R0.19	R0.34	R0.36	R0.47	R0.51	R1.00
Fibreglass	R0.19	R0.34	R0.36	R0.47	R0.51	R1.00

Material sourced from BRANZ

10.5.6 Flooring

As the proposed Project houses are two and three storey tall structures, a separate foundation wall together with concrete masonry foundation wall and concrete floor will give more stability to the structure. Standard diagram of the foundation and the floor recommended by BRANZ is given below (Figure 10.20). To be eco-friendlier floor finishing can be done with timber. As per the NZ's building code requirement expected minimum R-value of house floor should be R1.3 (Building Performance, 2008). PHINZ indicates that high performance floor can have an R-value of 6 (PHINZ, 2021). Therefore, it is recommended that insulated timber floor with R-value of 4 be used for proposed Project houses.

Figure 10.20: Floor Details

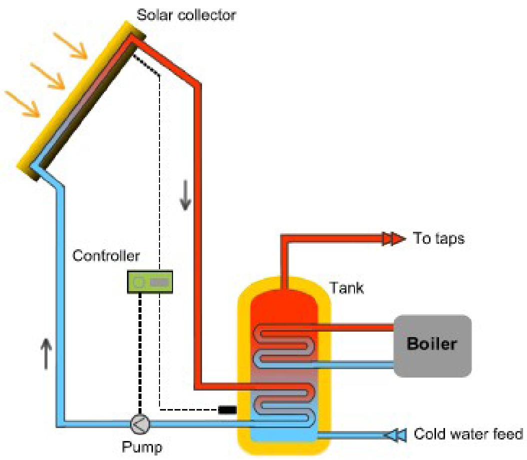


Material sourced from BRANZ

10.6 Hot Water System

As detail out in Para 7.2 27% of the energy consumption of a house goes for hot water system (Electricity Authority Te Mana Hiko, 2018). By using solar energy for hot water system households can save their power consumption. There are two types of solar water heating systems namely active and passive systems. Active solar hot water system requires a storage tank, a pump and a solar collector. Figure 10.21 below shows a standard active solar hot water system.

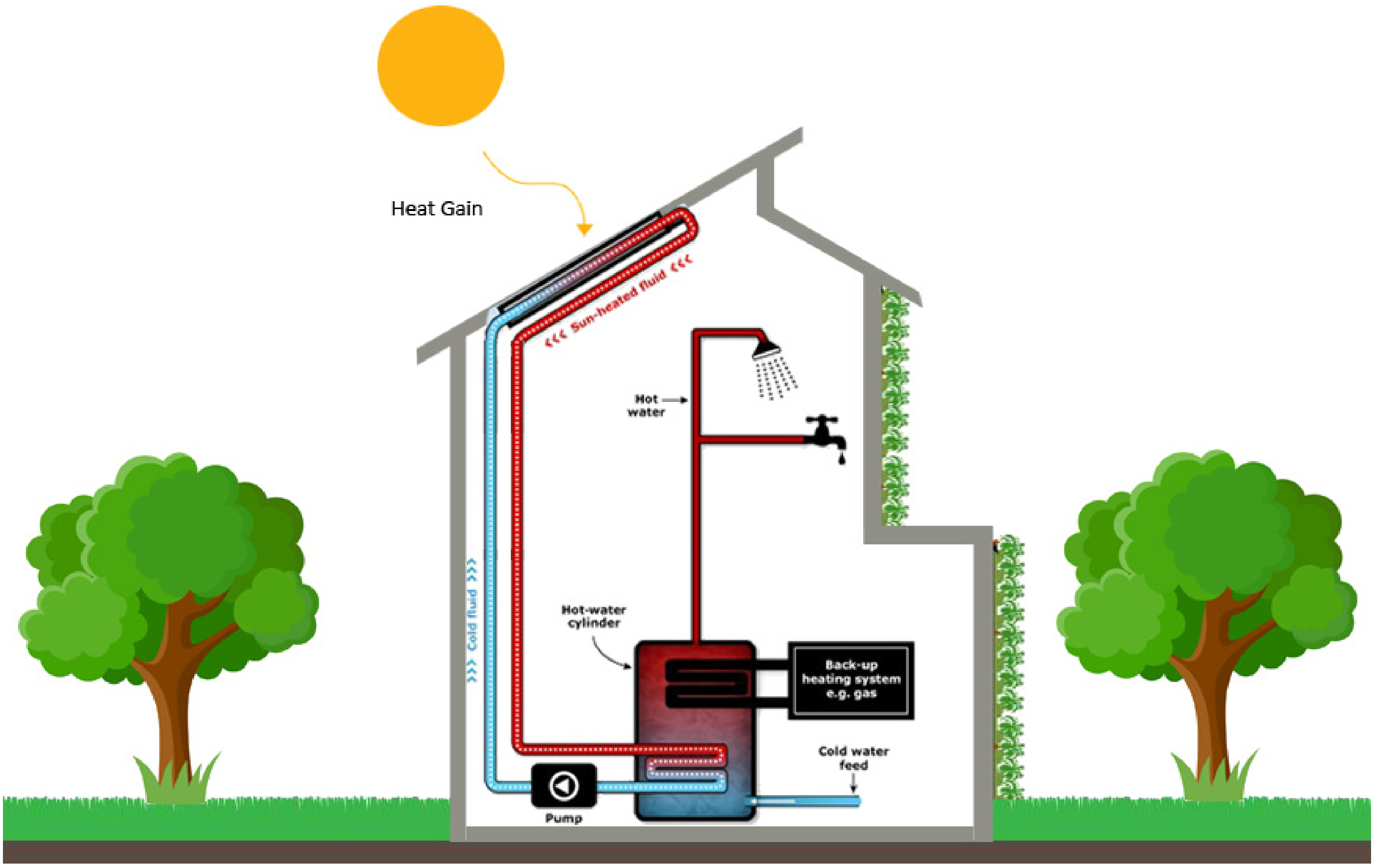
Figure 10.21: Solar Hot Water System



Material sourced from Central Heating New Zealand

Due to material energy saving volumes that can be achieved by using solar hot water system, all Project houses will have solar hot water system. Figure 10.22 below highlight the proposed solar hot water system for project houses.

Figure 10.22: Hot Water System for Project Houses



11

FINAL DESIGN

The final design of the Project houses and the master plan had taken NZ's housing quality frame work, habitability, functionality, environmental, social and cultural sustainability into consideration. All houses were designed to face the seaside and the slop of the roof facing North. This help to harness the maximum solar energy and the best view for the houses. To harness maximum solar energy the roofs of all Project houses has been angled at 30^{O}. Solar panels and the hot water system are placed on the roof.

Green walls were fixed to minimize the effect on sun on to the walls of Projected houses base on the sun study carried out and described in Para 10.1. Green walls were also used to enhance the eco-friendliness of Project houses. Rainwater collection system has been designed to irrigate Green walls and the garden.

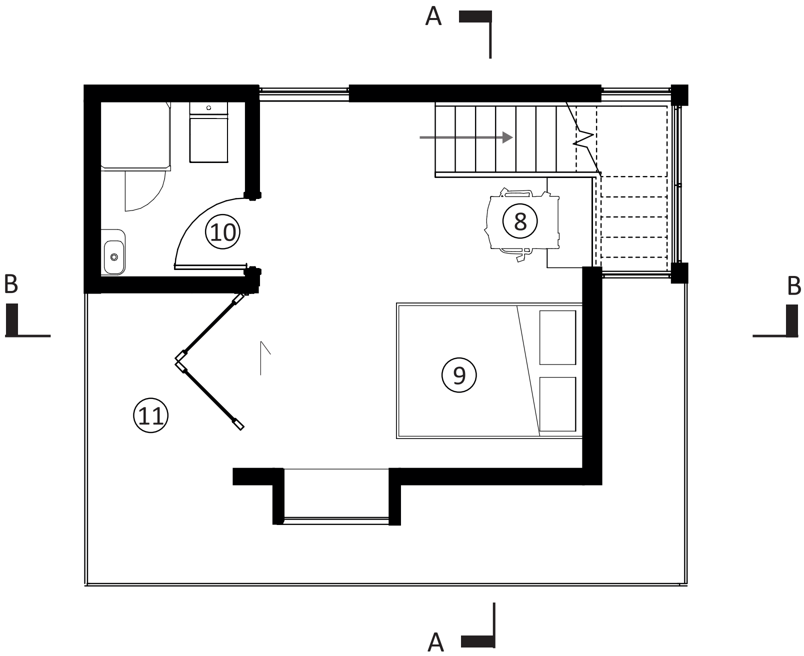
The strongest wind is coming from Northwest. By keeping the slope of the roof towards north, the wind effect on the roof had also been minimized. In order to mitigate high wind speed from Northwest no large windows were designed in that direction. During the winter the cold air is coming from South and large bifold windows are split into two to control the air flow into the house.

Proposed project houses were laid in a manner that reflect the architectural concept of village living. No boundaries were defined among houses and gardens were kept as common area. Though there are no boundaries the garden next to the house is considered as part of the house.

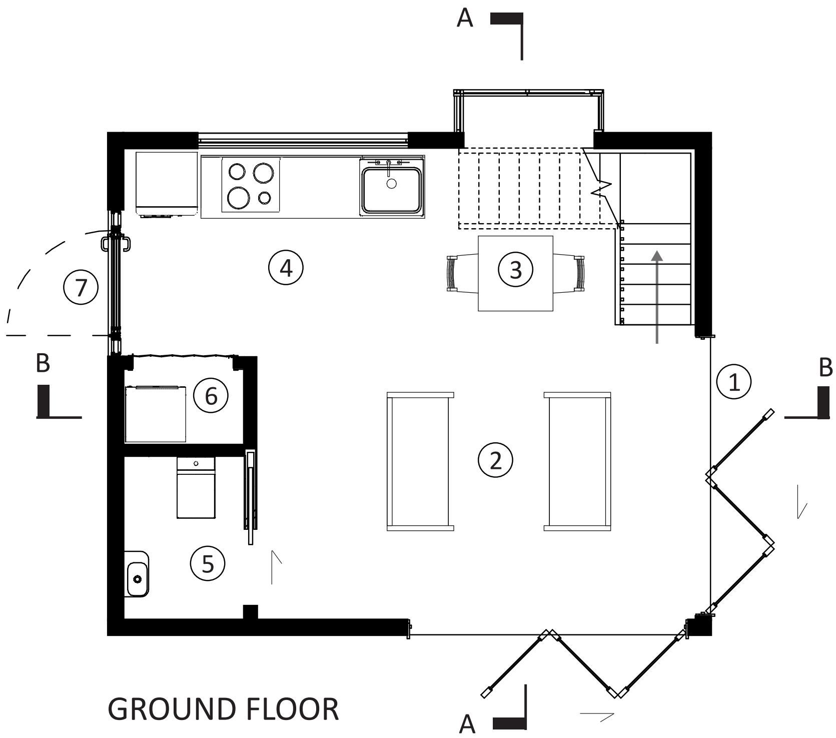
The height limitation of residential buildings at Petone where the site is located, had been fixed as 13m maximum (Hutt City Council, 2018). The height of single / couple and family proposed project house will be 6.8m and 9.6m respectively and well within City Council restrictions.

In order to harness solar energy, the slope of the roof always need to be position towards the north. Because of this positioning, the houses positioned on the west side of the site needs to be mirror images of the houses positioned on the east side of the site. This mirror image was done to get the entrances of houses positioned to have the easy access to the house.

Perspectives, floor plans, and sections of the final design is given below.



FIRST FLOOR

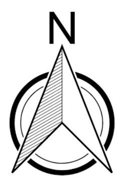


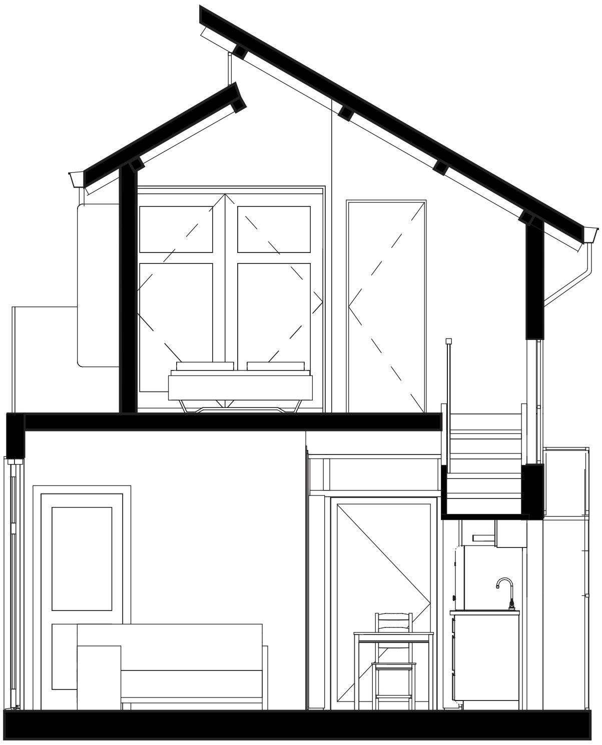
GROUND FLOOR

KEY

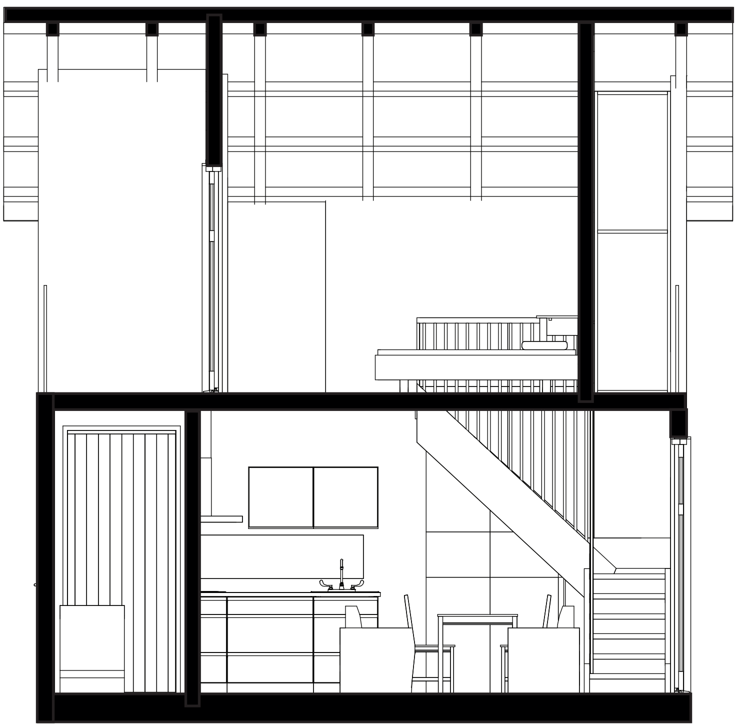
1. Entry
2. Living
3. Dining
4. Kitchen
5. Powder Room
6. Laundry / Storage
7. Outdoor Space
8. Study
9. Master Bedroom
10. Bathroom
11. Balcony

SCALE 1:70 @A4





SECTION A

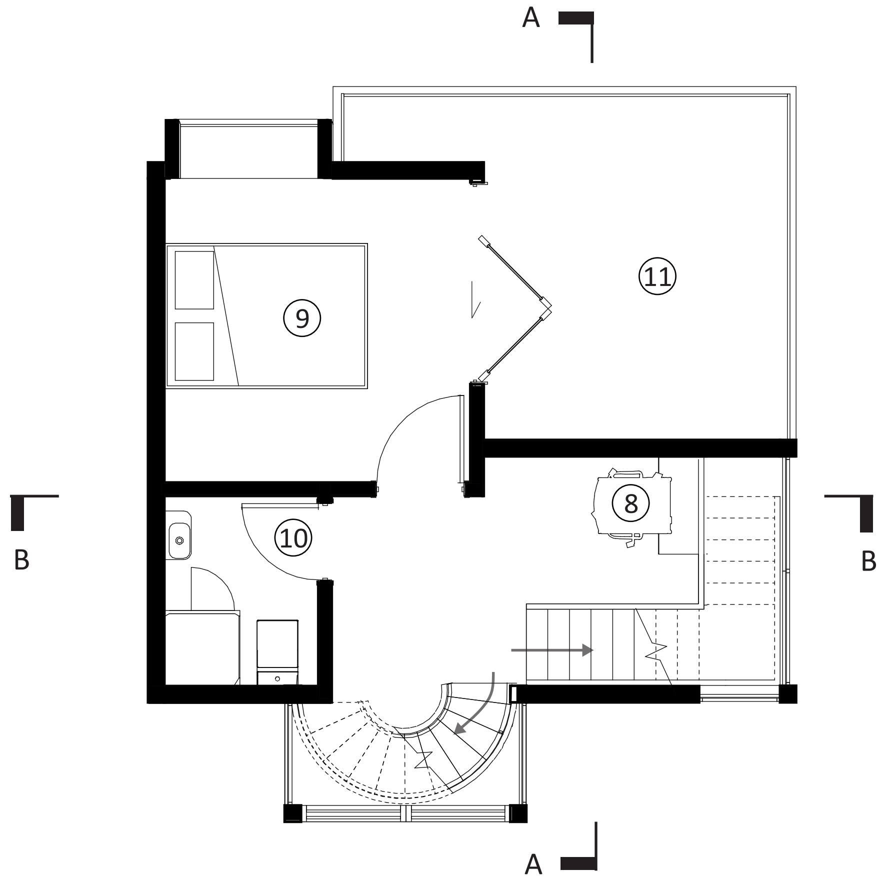


SECTION B

SCALE 1:70 @A4

Final Design for Singles / Couples Houses

Final Design for Family House

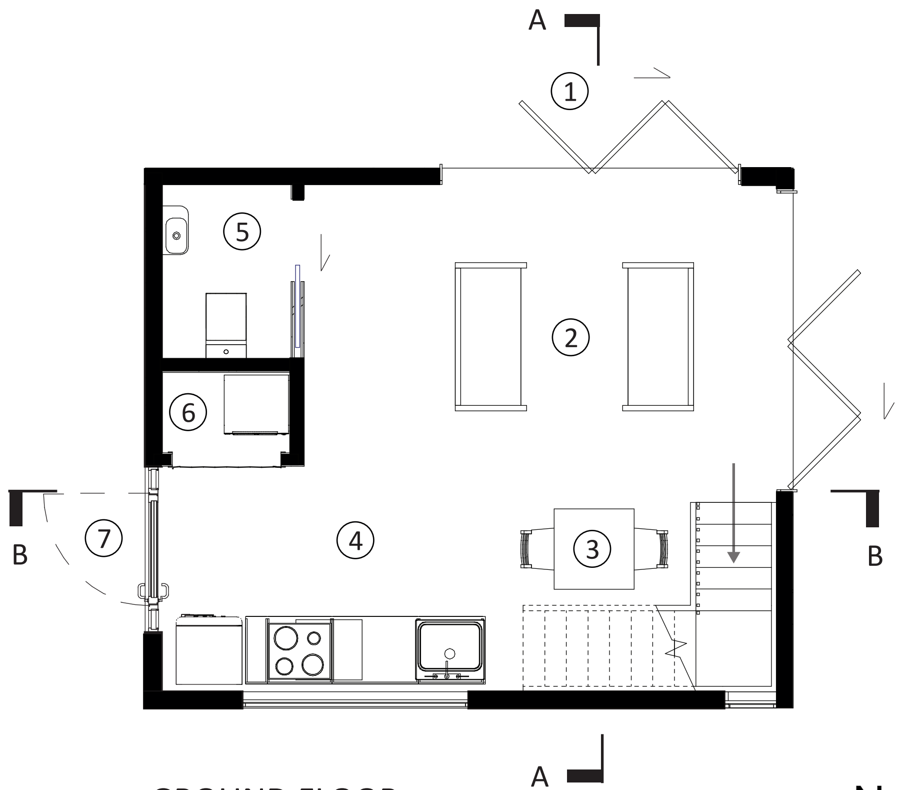


FIRST FLOOR

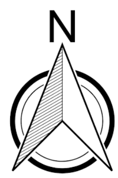
KEY

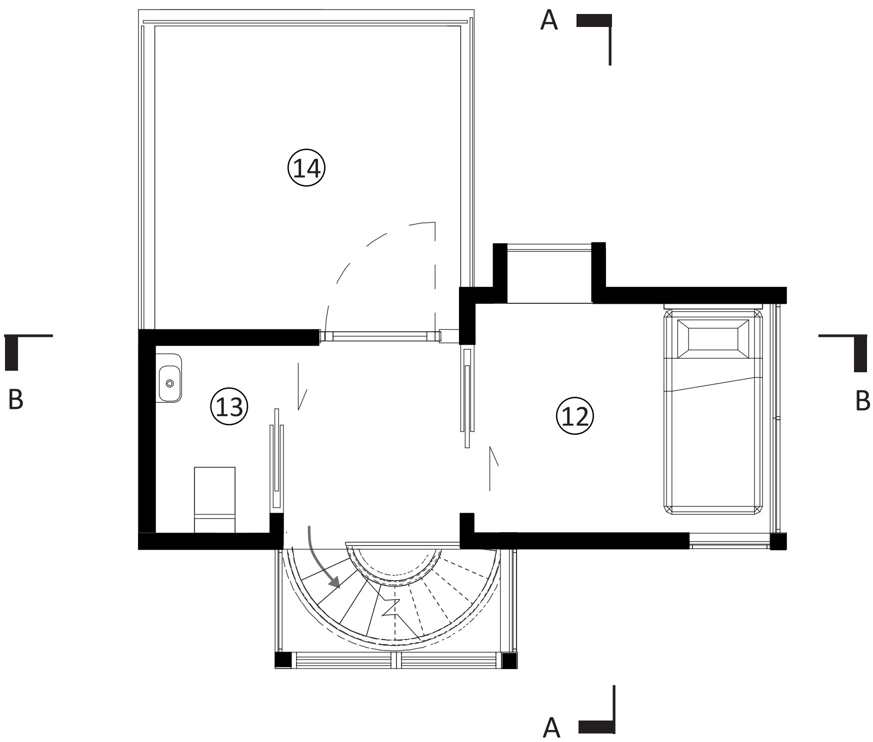
1 Entry
2 Living
3 Dining
4 Kitchen
5 Powder Room
6 Laundry / Storage
7 Outdoor Space
8 Study
9 Master Bedroom
10 Bathroom
11 Balcony
12 Kids Bedroom
13 Bathroom
14 Balcony

SCALE 1:70 @A4



GROUND FLOOR



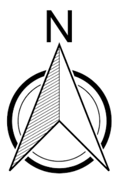


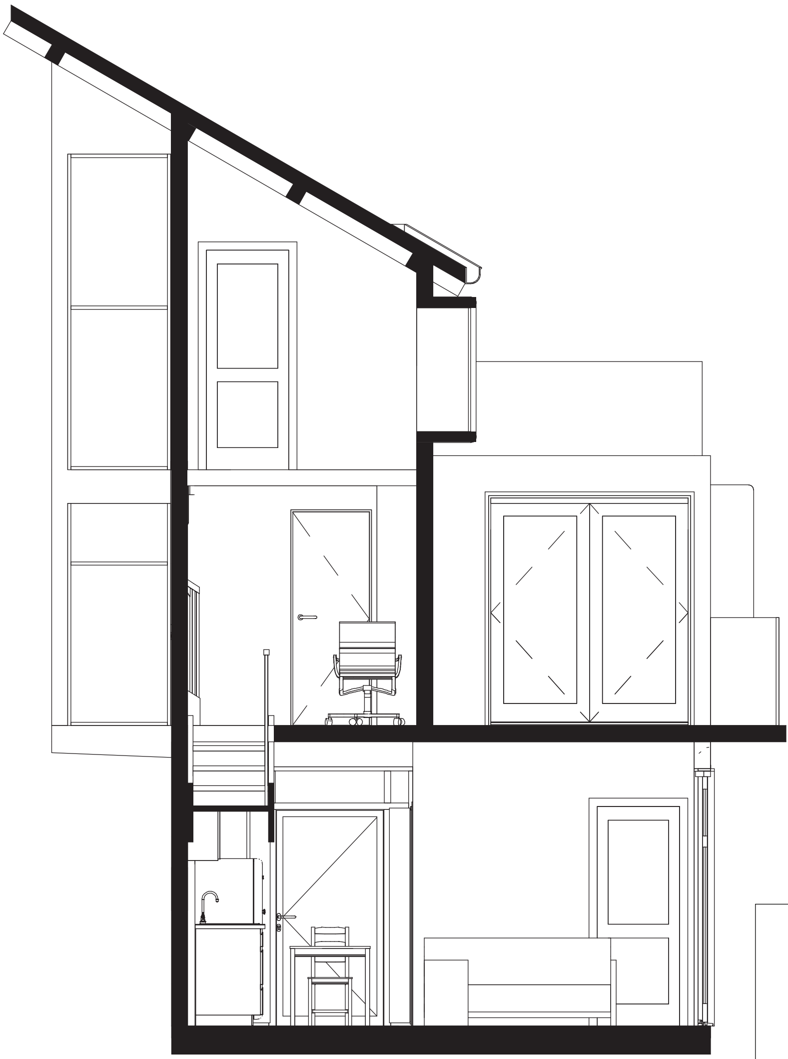
SECOND FLOOR

KEY

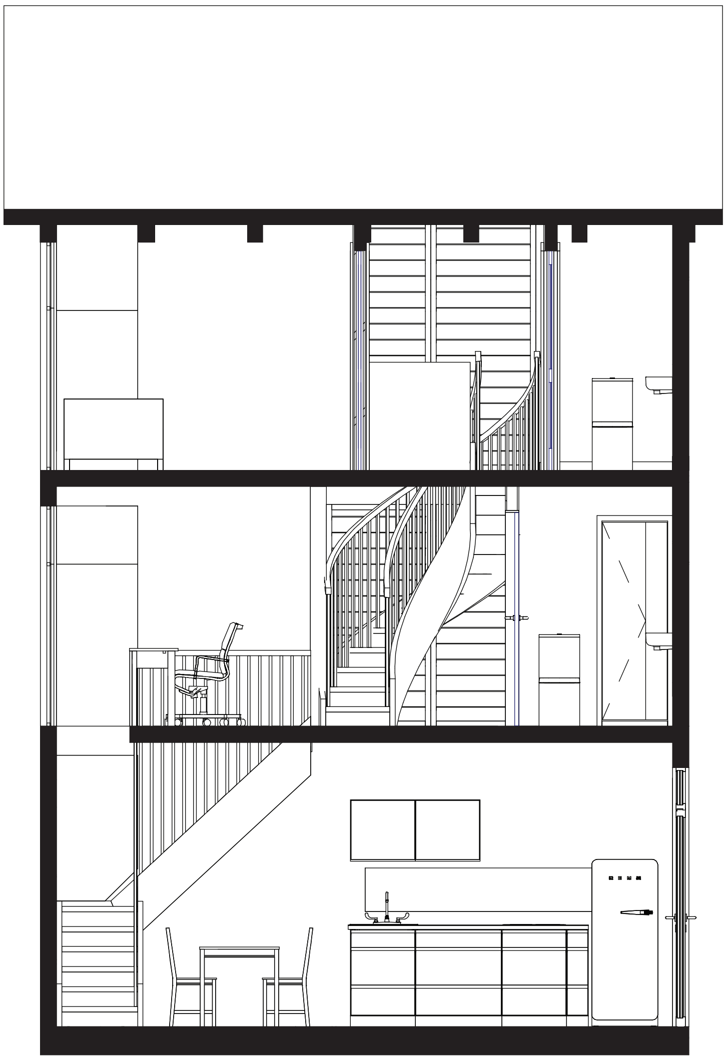
1 Entry
2 Living
3 Dining
4 Kitchen
5 Powder Room
6 Laundry / Storage
7 Outdoor Space
8 Study
9 Master Bedroom
10 Bathroom
11 Balcony
12 Kids Bedroom
13 Bathroom
14 Balcony

SCALE 1:70 @A4





SECTION A



SCALE 1:70 @A4

SECTION B

Final Design for Family House

Final Design for Family House

12

CONCLUSION AND SELF REFLECTION

12.1 Conclusion

The research question is 'How to Provide an Appealing Efficient Living Spaces that Encourages Changes in Environmental Behaviour of Those who Occupy the Dwelling with Net-Zero Energy Consumption?' As explained in Para 1.1 the above research question had two prominent parts namely providing efficient living spaces and achieving Net-zero states. The efficiency factor was considered by looking into two aspects namely efficiency of space utilizations and efficiency of eco-friendliness. The architectural concept of 'Living in Harmony with Nature in a Net-Zero Village within the City' has been introduced to combine the research question with architectural design.

Proving small efficient spaces are very relevant and timely as Foster identified that people in NZ are adapting to change in time by moving into smaller houses (Foster, 2019). This research Project proposes to provide $60m^2$ houses on a land area of 6m by 5m. The Project site will have 16 housing units. As Riggie of YR Architects suggested and detailed out in Para 4.1 space efficiency of these small house units have been arrived by connecting indoors and outdoors and having multipurpose spaces (Riggie, 2016). Proposed project houses were designed by following Riggie concept and space efficiency has been achieved.

As Brebbia suggested the efficiency connected with eco-friendliness has been achieved by use of natural environmental parameters such as sun position and hourly and daily radiation and temperature values into the design (Brebbia, 2013, p. 225). Furthermore, suggested construction materials for the Project houses are environmental Type 1 and high R-value materials. By incorporating these elements into the project design, eco-friendly efficiency has been achieved.

By taking into consideration of Krista Evan's suggestion that it is important to integrate small houses in a manner that is perceived as esthetical pleasing (Krista, 2018), proposed Project houses have been blended with nature by providing green walls and natural shared environment.

"Some behaviours, such as car use and energy conservation behaviours are more strongly correlated with perceived behavioural control, while other behaviours, such as recycling and buying organic foods are more strongly correlated with attitudes and social norms" (Abrahamse, 2019). Kreitzer also claims that environment can influence people's behaviour and motivation to act (Kreitzer, 2016). Furthermore, he states that the environment can facilitate or discourage interaction among people. The surrounding natural environment around the project houses and the eco-friendly approaches such as harvesting rain water and using natural HVAC system would certainly change the behaviour of those who occupy the propose project dwellings. The architectural concept, village within city, of the proposed project would further encourage occupants to interact with each other and change their behaviour towards more environment friendly targets.

The second part of the research question is connected with having a net-zero energy consumption to minimize negative environmental impact. Net-zero energy states of project houses will be achieved by generating solar energy during the day and exporting them to the Grid while importing energy from the Grid in the night. Chapter 7 discussed the details of power generation and power consumption. The use of renewable energy to have a net-zero energy consumption for the proposed project houses will certainly contribute towards the NZ's government plan of reducing the gross carbon emissions by 30 percent below the 2005 gross emission levels by 2030.

In summing up the Project of 'Living in Harmony with Nature in a Net-Zero Village within the City' is a classic example of 'How to Provide an Appealing Efficient Living Spaces that Encourages Changes in Environmental Behaviour of Those who Occupy the Dwelling with Net-Zero Energy Consumption?'

12.2 Self Reflection

I started my masters project with the main focus of providing net-zero energy housing. Initial I brought in the idea of sustainability together with net-zero energy. After doing initial research and a number of discussions with my supervisor I realized the vastness of the subject of sustainability. This resulted in coupling the idea of net-zero energy together with environment friendly features. The initial house designs were normal average houses. Later on, I realized the value of space efficiency and the research question was reframed to include efficiency aspects.

I deviated from the typical town house concept and introduced detached small houses to provide better privacy and interaction with nature to occupants. I believe this has work well in coming up with the final design. Furthermore, the introduction of green walls helped to improve the aesthetic look of houses.

Site selected is appropriate for the project and its close proximity to sea gave additional advantages to the occupants and to the design. No interference of shadows from of other building helped to generate uninterrupted solar power at the site. All city council regulations such as height limits were met in coming up with the final design.

No major negative aspects were noted in the final design. However, if I have selected a bigger site, the village concept could have been reflected better. Also, the behavioural aspects of the occupants of the proposed project houses were not researched in detail. For a future research the behavioural aspects of those who occupy small houses could be considered. Another possible research could be how to convert existing houses into net-zero energy and eco-friendly houses.

13 APPENDIX

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THE AUTHORITY ON SUSTAINABLE BUILDING

BRANZ

Insulation

There is a wide range of insulation materials available on the New Zealand market. The most commonly used has been glasswool mat or blanket. However, there is now a wider range of products to consider such as:

- sheep's wool
- polyester
- wool/polyester blend
- polystyrene
- mineral wool
- macerated paper.

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GLASSWOOL	
Extraction and manufacture	
Impact of extraction	Glasswool insulation is made from up to 85% recycled glass. Chemicals derived (or partly derived) from non-renewable resources may also be added to act as binders or flame-retardant or anti-microbial agents.
Energy use	Signifi cant amounts of energy are required in glasswool insulation manufacture, but this is offset by durability and low maintenance. Embodied energy of glasswool is quoted[1] as 32 MJ/kg
By-products/emissions	None known
Sourcing	
Material sources	Glasswool insulation is both manufactured in New Zealand from imported raw materials and imported (Thailand, Australia) as a finished ready to install product.
Availability	Glasswool insulation is readily available throughout NZ.
Cost	Glasswool is generally the lowest cost option.
Construction/installation	
Health and safety during construction/installation	Protective clothing (gloves, overalls) and masks are recommended during installation to protect against fi bre/skin contact and from breathing in fi bres. New glasswool is generally more operator friendly than in the past – it is no longer considered the risk it once was.
Uses	Glasswool insulation can be used in walls (fi tted tight in framing cavities) and ceiling/roof spaces (installed without gaps) as a blanket or mat. There are also glasswool products designed specifically for insulation under suspended floors.
Ease of installation	Correct installation is necessary to ensure no thermal bridges (gaps to the framing) are created. This is extremely important to maximise insulation value.
Performance	
Health and safety during life of building	Material can collect dust – use protective clothing and masks if working with existing insulation during renovations.
Expected durability (assuming correct installation and maintenance)	50+ years

Moisture resistance	Glasswool is resistant to moisture but insulation value will be lost if it gets wet.
Rot, mould and corrosion	Glasswool will not rot.
Thermal insulation	R-value depends on density and thickness of material and installation quality – see specifi c manufacturer's literature. High performance glasswool insulation is available. Glasswool insulation is only effective if dry.
Sound insulation	Glasswool insulation may provide small benefit in reducing sound transmission through a wall. Special formulations are available for use in sound rated construction.
Fire performance	Glasswool insulation will not support combustion.
Waste disposal/recycling/re-use	
Re-use	Material can be reused provided protective clothing and breathing masks are used during removal and reinsertion.
Recycling	Glasswool insulation is not currently recycled.
Waste disposal	The use of overalls, gloves and masks in recommended.

1. Embodied energy figures taken from work © J. Andrew Alcorn, 2010. (Alcorn, J. Andrew, *Global Sustainability and the New Zealand House*, a thesis submitted to Victoria University of Wellington in fulfilment of the requirements for the degree of Doctor of Philosophy in Architecture, Wellington, 2010.)

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