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and insight
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Roshan Maharjan

Low Cost, Tiny House

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This thesis studied the tiny house concept, an urban interpretation of the modern-day minimalist lifestyle originated from the tiny house.

The tiny house concept was studied from various different perspectives in order to accomplish the design for an effective house. Although every tiny house was quite customized to its owner's lifestyle and it seemed unpractical to design a perfect prototype. A tiny house was detailed in its fullness as it was a small project. The tiny house was constructed which is suitable for the Finnish climate. Therefore, this thesis offered the most appropriate construction methods for the project under European and Finnish standard guidelines.

This study provides a tiny house owner a new sense of community and digital bonding by designing tiny houses. It was shown that a tiny house can be designed with minimum investment by including the standards and principles of the passive house technology. A tiny house was shown to function smoothly with the energy harnessed with renewable source of energy. As a result, this study successfully presented a tiny house design which is affordable, energy efficient and sustainable with a minor ecological footprint and required minimum energy for space heating and cooling.

Keywords	tiny house, minimalist, renewable energy, low energy

Contents

List of Abbreviations

Symbols	Measuring Unit	Description
A_{TFA}	m^2	Treated floor area
A / amp	Ω	Ampere
Ac		Alternative current
DC		Direct current
W	$kg\ m^2 / s^3$	Watt
V	$kg\ m^2 / s^3\ A$	Voltage
P	kWh	Primary energy factor
C_p	Wh/m^3K	Volumetric heat capacity of air: 0.33 Wh/m^3K
G	$kWh/(m^2a)$	Global irradiation on a horizontal surface
EU		European union
N_{50}	$h^{-1.}$	Air change rate @ 50 pa pressure
λ	W/mK	Thermal conductivity

1 Introduction

A typical house is a dwelling that expresses character, experiences and reflects people who live in them. Since a house accommodates to the homeowners rather than every individual in public, houses need to be special and unique as they can be brand. A tiny house prototype, which has been popular in the media and recognised as a nomadic home on wheels, is a remarkable unique trend nowadays. Such a tiny house can also be built anywhere, in any chosen location to allow for life with essential items only.

The tiny house discussed in this thesis provides a lifestyle with many creative and astonishingly attractive features. This thesis aims to show that a tiny house is cheaper to build than a typical home, and it can be built with recycled materials. Also, the owner can take part in the construction process until the end to reduce labour expenses. Owners can avoid typical equipment and gadgets to save costs. Tiny houses also consume less power from the grid and, as a result, produce cheaper bills or no bills at all. In such a way, a tiny house saves more money for any other activities the owner wishes to engage in.

In this thesis, it is suggested that a vital task when building a tiny house is understanding the importance of space. As every square meter of a tiny house matters, owners shall keep essential household equipment only. This process will help owner with zoning. The owner needs to immediately remove any household equipment which is not in use for a long time. A combination of smart storage ideas from the ceiling to the floor, such as lifting a bed on the wall for the day and attaching hangers or extra drawers on the wall is clever. Every creative design is important in a tiny house with determination. Every owner needs a mind-set that embraces minimalist living.

This thesis focuses on designing non-moveable pleasing houses according to the standard and principle of the passive house technology, follows the G1 the national building code of Finland on housing design and Finnish national annex for EN 1995-1-1. The EN 1995-1-1 gives general rules for timber structures together with specific design. The house is designed, and its calculations are carried out with software like archiCad and phpp.

1.1 History of Building Tiny Houses

The foundations of the first true American tiny house and of the philosophy that changed the society's attitude toward personal freedom and man's relationship with Nature were laid in 1845. When Henry David Thoreau, a Harvard dropout from Concord, Massachusetts, travelled with one axe a mile and half to the Walden Pond where he started to build a 3 by 3-meter cabin of logs with recycled boards. Mr. Thoreau fastened recycled boards with salvaged nails and wooden pegs. After completing his tiny house construction, he had settled in it for two years. Mr. Thoreau has inspired many others to follow in his footstep, for example John Vivian who was dedicated to analyze the original tiny house of Thoreau. Vivian presented several suggestions to improve a tiny house design, and his technique has been successful for several tiny house owners and building designer. [1.]

According to Vivian, it is better to build a tiny house close to the clean, tranquil, and nature abundant site. As these smaller homes are often constructed without a foundation, therefore they disturb nature only a little. As Vivian described a tiny house is light and small. A person can easily build in a place where there is limited access of resources. Vivian recommended a place with no harsh geography and no law which forbids conservative construction. Vivian praises Thoreau's 14 m^2 cabin for its admirable use of space. Thoreau's high shallow Rumford-design fireplace and stove were facing towards a dining table and chairs on the other side. At the far wall opposite to the fireplace was a bed to rest, a small desk to keep writing supplies and a separate attic for storing tools and clothing was against the middle wall. [1.]

1.2 Present Situation

Nowadays, the tiny house is considered as an architectural and social movement that encourages living in a small dwelling. The tiny house movement promotes financial carefulness and safeguard. The tiny house movement has received plenty of popularity among older men and woman. People see it as an option to have a lot of space. According to the David Morneau, two out of five tiny house owners are over 50 years old and there has been rise in tiny house interest since 2014 as the average tiny house cost is four times cheaper than that of average homes. [2.]

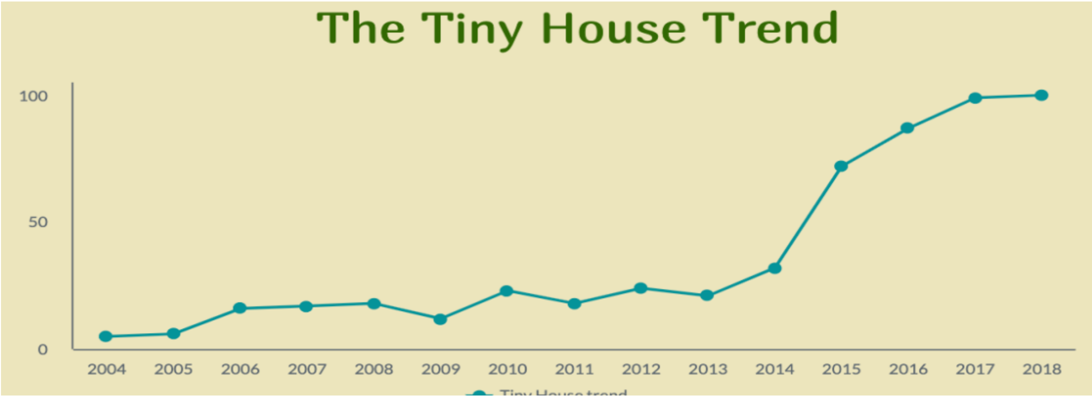


Figure 1. A spike of interest in tiny house [2].

Figure 1 above shows that the tiny house numbers has significantly risen Globally. In the United States of America, there are 10,000 tiny houses. 700 new tiny houses are being built every year by a certified builder, and several more are being built privately. In 2017, the sales of tiny houses in America increased by 67% which is an outstanding increase. A study showed that roughly 50% of the tiny house owners save more money than owners of traditional houses [3]. Similarly, Canada is building 7000 tiny homes for a retired homeless veteran [4]. In the UK, over 8000 tiny houses have been built by 2020 [5].

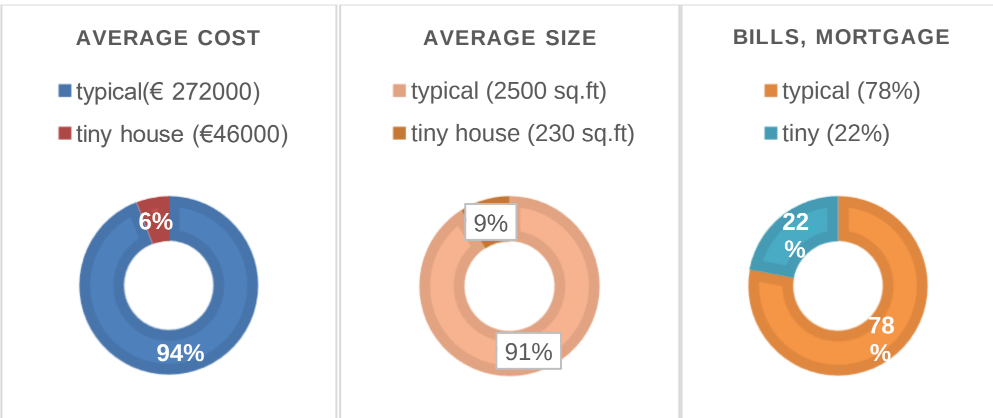


Figure 2. Comparison between typical and tiny house [2].

Figure 2 shows the pie chart compare an average cost, an average size and bills between a full- sized typical house and a tiny house. A cost in a pie chart is based on the data provided in tiny society. The average tiny house cost € 46,600 only compared to build a typical full-sized house which costs € 272,000 [2]. A size is the main reason for cheaper tiny house than a typical house. However, owners of tiny home are able to reduce their costs in other ways as well. Many tiny houses are built with recycled materials. The construction phase of tiny house is also cheaper than typical house construction because tiny house construction requires few labourers. Also, A tiny house is cheaper due to few household equipment used in a house. A tiny house also produces cheaper bills when living on a grid, or even no bills when living off grid.

1.3 Tiny House Design Concept

The general idea for my minimalistic home is a development, mirroring the flexibility of the homes as well as the minimalistic home development. Inside this idea are two individual minimalistic home plans, each named after an alternate type of development. A minimalistic home idea can start by making summary of words that depict a minimalistic home, for example, sustainable, affordable, multi-functional, off the grid, organic, and downsizing. Due to the smaller size of a tiny house, the space must be used and designed in a way to generate an excessive amount of space. The owner needs to reduce the amenities, belongings. Owners of tiny home can also design attached and detached porches to create extra space. It avoids a cramped feeling inside the tiny house. The benefits of downsizing include reduction of the use of electricity and fuel, as well as a reduction in lifecycle emissions. The owners of tiny house are encouraged to use a timber structure, recycled materials, and few appliances. [6.]

A tiny house can be either stationary or on wheels. A stationary tiny house has a permanent foundation, while a tiny house on wheels has a trailer as a foundation. A permanent foundation allows traditional utilities while the tiny house on wheels has the benefit of mobility. There are two individual concepts following below, each named after a different form of development in a house. [6.]

Evolve in a tiny house means developing, modifying, adding, or subtracting modules. Evolving is easier to perform in a prefabricated tiny home. The roofs and wall of it can be raised or lowered in order to create space as the people who live in it increases.

Figure 3. adding a building structure [6].

Figure 3 illustrates a different shape and size structure added in the existing building. It can be deconstructed and reassembled again. Normally, a different part of structure is added in a long term stationary tiny home. [6.]

Flux home means flexible home. A Flux is the most versatile unit, permitting the owner to make diverse spatial arrangements as wanted. The home extends and contracts by the methods for sliding floors, dividers, and roofs. This plan is ideal for the individual who likes to continually change the format of their living spaces. Fluxing creates a completely different dimensional structure. [7.]

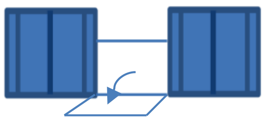


Figure 4. Glass facade transformation [6].

Figure 4 shows the exterior glass facade transformation which can be opened by sliding down a glass door in the middle part of house. This idea helps owner to enjoy outside view while staying inside the house. owner can flip the wall down to open up the space and use the wall as an exterior deck. [6.]

Figure 5. Side exterior flipping door [6]

Figure 5 shows the side exterior wall house is transformed into a flipping door. Lighter facade is used for this transformation. A purpose of this transformation is same as described in figure 4. [6.]

1.3.1 Sustainable Design Strategies

The tiny house movement is about implementing a sustainable architecture strategy. While cost is always a top consideration for a building planner, keeping in mind that spending more up front on sustainable strategies cannot only provide large saving over time, but also positively impact air quality, well-being, and lead to a regenerative future.

Table 1. Tools for a sustainable tiny house.

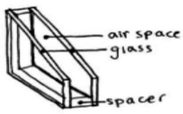
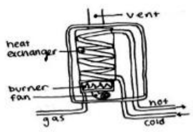
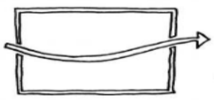
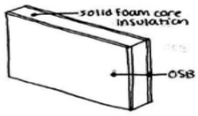
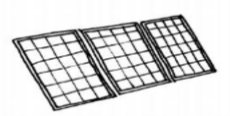
	Minimal environmental impact foundation.		Water conserving fixtures
	Insulated glazing windows		Tankless water heater
	Cross ventilation system		Energy efficient appliances
	Structural insulated panels		Photo voltaic panels
	Water collection system		Using recycled and recycle material
	Composting toilet		biomass stove and renewable energy

Table 1 summarizes the most effective strategies to create sustainable minimalist home. These strategies aim to create ecofriendly living space where natural and recycled materials are used for controlling the environmental impact. A strategy like having cross ventilation system, energy efficient appliances are cheaper and will help owners to minimize an energy requirement. Rainwater management and water conserving fixtures compliments extremely well which encourage minimalist dwellers to live in accordance with the nature and promote sustainable living. Overall, A tiny house will contribute less or minimize the negative effects on the environment by using environmentally friendly materials and renewable energy solutions.

1.4 Pattern of Tiny House

There are several unique tiny houses that have been designed around the world. Some tiny houses features are extremely eco-friendly, futuristic, multi-functional, versatile and sustainable. Couple of tiny houses models which has such features and minimalist dwellers should be inspired from micro cabin by Robin Falck, verstas off grid house, Carole off grid house in Canada, koda and ecocapsule.

1.4.1 Robin Falck Micro Cabin

The structure of the tiny summer cottage (figure 6) is built by Finnish designer Robin Falck. Robin built 15 m^2 one story cabin with a tiny 29 m^2 loft. The micro cabin has two-stories. Its estimated construction cost was €10000 without including his own labor. Construction took only two weeks according to the designer. [8.]

Figure 6. Robin micro cabin [8].

The lower floor is a living room with a tiny kitchen. In the attic, there is a double bed and storage room. Mr. Falck used recycled materials and was succeeded in presenting a fabulous house. All the structures, cabin foundations, and walls of the house are made out of recycled wood materials. A huge window on a slanted side of the wall fills the interior with natural light allowing one to enjoy not only the nature outside but also the night sky. Since it is a summer cottage, it lacks the facilities of a typical house. however, the cottage is functional and satisfying for its cost. This house uses electricity from the grid for light and its tiny kitchen. [8.]

1.4.2 Verstas Off-grid Tiny House

In the busy and crowded area of Helsinki city, verstas Architects have designed a beautiful tiny house or cottage (figure 7) for a family of four-person to escape city life and enjoy nature in Lauttasaari, Helsinki. This tiny cottage located near the sea and surrounded by trees and nature is simple, practical, and ecological. [9.]

Figure 7. Verstas architects house photographed by Andreas Meichsner [9].

This tiny cabin is 14 m^2 in size. It is divided into two parts that are the entrance and the kitchen. The architects have chosen the interior furniture, managed the zone, and other space. The living room has quite a big space. It includes a sofa attached along to the wall of the cottage which can be transformed into a bed for three. It also has loft space. It is for children. [9.]

The building materials used in this cottage are timber as load-bearing beams and columns. All the interior and exterior walls, and the ceiling have insulation. The Exterior and interior wall were designed in gypsum boards. The front part of the house is a kitchen attached to the wall covered with windows which gives a clean air and fresh view of nature. This home has utilized each open space as a creative shelf to store the necessary items. The consumption of electricity in this cottage is very low so that the house can operate with solar panels attached to the top of the roof. The architects explain that this cottage is being used throughout the year. So, a small wood-burning stove is used for space heating during the wintertime. [9.]

1.4.3 Off-grid Tiny House in Canada

The next tiny house to discuss (figure 8) is located in Northern Canada. It is a decorated habitable tiny house with essential amenities like a full-size washer and dryer, bathtub, a full-sized closet, septic system, tiny comfortable living room and kitchen. This house uses gas stove, thermostat, and a normal kitchen size fridge. [10.]

Figure 8. House designed by Carole Lyne robin [10].

Carole home can be considered as an ideal tiny home. Mrs. Lyne home provides the sensation of typical house. Mrs. Lyne home is tiny but have tiny version of traditional house spaces such as tiny bathroom, washroom, kitchen, bedroom, septic tank, and a huge deck where she increases her living space, places tiny garden and dining tables and chairs. The owner is satisfied due to its off-grid strategy, energy efficiency and affordability. [10.]

The walls, floor, and roof are well-insulated with pre foam insulation. The foundation of the house was a vehicle trailer. The owner uses four solar panels which give 960 watts from April to October to provide electricity. From November to March, the owner uses a generator Honda EU3000. The owner replaces propane gas four times a year and uses it for hot water, stove, thermostat heat generator, and for washer and dryer. The owner pays € 200 for a propane gas once in a year. During winter, the owner uses a heat trace line inside a water supply line for hot water. The owner is happy to live a self-sufficient life with cheaper bills. [10.]

1.4.4 Koda

The following tiny house is called a KODA (figure 9) is provided by a kodasema. It's a prefabricated tiny house which is designed in Estonia. It also received a winning prize at the world Architecture festival 2016 [11].

Figure 9. A tiny house designed by Kodasema [11.]

KODA home incorporates an open space living room, a full-size sleeping area, a shower room with a toilet, a kitchen, and a wooden terrace with an aggregate of floor area 25 m^2 and a height of 9 m up to the ceiling. KODA needed no foundation as it is incorporated with sufficient weight bearing capacity of concrete wall and floor. KODA uses electrical floor heating and electric water boiler. Its glass facade helps to reduce overheating. It has ventilation system which exchanges the air and maintains the heat, and air quality. Other feature which provides comfort in KODA homes is insulation. KODA insulation includes 200 mm mineral wool in wall and 250 mm in ceiling and floor. [11.]

KODA is a sustainable tiny house. KODA houses make an energetic combination of homes and inns, workplaces, cafes, collaborating spaces, administration spots and shops, and a network region in a snap. Its features can be adapted in any surroundings.

It is compact and portable through trailer in any location for a living. KODA uses miniature versions of kitchen, bathroom, bed, living room and a small storage room. Water, sewage and electricity needs municipality connections, but the house also has roof top solar panels to generate sufficient energy during sunny days. [11.]

1.4.5 Ecocapsule

The following tiny house discussed is called ecocapsule (figure 10). It is an example of a smart, self-sufficient and sustainable mini house that is equipped with both solar cells and wind turbines. Its tiny, light size allows the owner to transport the house to any location as long the ground is levelled. Its space is wide enough to have a bed, a tiny kitchen, storage, a working or dinning space and even a bathing space. [12.]

Figure 10. A portable ecocapsule [12].

Ecocapsule has a gross floor area of 8.2 m^2 and weight of 1570 kg with full water tanks. Ecocapsule consists of efficient solar cells with a solar power of 880 W and wind motor of 750 W which ensures the harvesting of electrical energy which is stored in battery capacity of 9.7 kWh. The wind turbine on it with the capacity of yielding 750 W during day and night. Its wind turbine is silent and can produce electricity for 24 hours a day. It is well insulated as well. [12.]

Ecocapsule body is made from high capacity, insulated fiber glass overlaid on a steel framework which ensure the smallest heat loss from inside the body to outside. Its heating and ventilation are done by Ac unit with low energy consumption, direct ventilation through window as well as indirect through passive heat recuperation unit. It has water heater for kitchen and sanitary. Ecocapsule designers claim that its unique shape minimizes heat loss but also helps to collect rainwater on the surface, where it is collected to water tank and filter for the use. [12.]

2 Energy Sources for a Tiny House

The term renewable source of energy refers to the energy generated from natural resources like the sun rays, wind, rain, tide, and geothermal energy. These sources of energy are renewable, efficient, clean, cheap, and abundant in nature. Renewable energy is often used in electricity generation, heating, and cooling [13]. Especially, the use of electricity produced from renewable sources is more efficient than heat. It can be converted into heat, or mechanical energy with high efficiency. Hence, it leads to significant decrease in the use of primary energy. [14.]

2.1 Solar Energy

Solar energy is a renewable source of energy that is free, clean, and abundant in nature. Solar energy is a radiation light of source from the sun that harnessed by using a solar heater, photovoltaic system, or as solar thermal energy. The production of solar energy depends on the intensity of radiation of the sun. Solar energy can be harnessed more while sun hours are long. Sun hour is an hour of a day during which the intensity of sunlight is high. Solar panels absorb higher radiation while facing towards the south. [15.] Solar energy from the sun can be converted into electrical energy, solar heat to warm a water, and form steam. Photovoltaic cell technology absorbs solar energy and converts into electricity. The use of Solar energy is sustainable, contributes to a lower carbon footprint, and reduces global warming. [14.]

It is essential to understand the logic in the intelligent solar system design, solar panel orientation and inclination as well. A solar panel provides the best performance at a steep angle of 60°. During the springtime, a solar panel should be adjusted at an angle of 45°. and during the summertime, when the sun is high above the sky, solar panels should tilt at 20°. During wintertime, Owners of tiny homes must aim to utilize sun hour to produce more solar electrical energy. During summer, Owners of tiny homes shall aim to store excess electrical energy produced by solar panels into the battery. [14.]

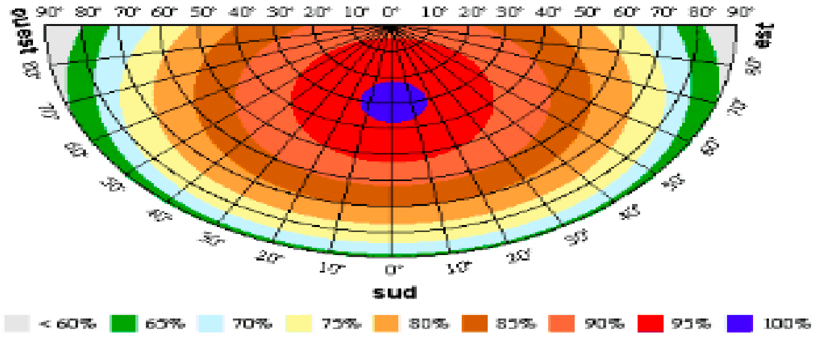


Figure 11. Optimal orientation and tilt angle for solar panels [16].

Figure 11 above shows the variation of sunlight with orientation and tilt angle to best optimize the production of solar panels. During wintertime, it is better to optimize the angle, orientation of solar panel as shown in figure 11 to capture the most sunlight. The graph in figure 11 also shows that east-facing panels will produce more energy in the morning, and west-facing panels in the late afternoon. Also, a solar panel provides the best performance at a steep angle of 60°. [16.]

2.2 Wind energy

Wind energy is also a renewable source of energy. Wind energy is produced by the wind and it requires wind turbines. A wind turbine is a mechanical device that converts the winds kinetic energy of wind into electrical energy. When wind strikes the propeller of wind turbines, its wind's kinetic energy provides mechanical power which rotates to spin a generator and produce electricity. Wind turbines can have either a vertical or horizontal axis. Wind energy is a type of energy source that is not always available as the wind constantly varies in the nature. Hence, tiny house must be incorporated with other electric sources or energy storage batteries to supply energy. [17.]

2.3 Use of Wood

Wood is an organic material that are products of the trees. Wood is an abundant carbon-neutral renewable source [18]. However, when wood is used as a fuel to provide heat, hot water, and electricity in a non-sustainable way, wood is a non-renewable source of energy. Wood fuel is an easily available, cheap, and energy efficient solution to eliminate the energy shortage of a tiny house to heat water and spaces. Wood fuel is firewood, charcoal, wood chips, and sawdust. [18.]

Wood fuel is suitable option to adapt for an off-grid tiny home. A tiny home needs a fireplace or woodstove to burn the wood to add warmth. Owners of tiny homes can also use the heat of wood stoves for cooking. Such a stove has a dual function of heating and cooking. It will further reduce the consumption of electricity. Also, a wood stove with a water boiling system will provide hot water. [18.]

In Finland, the price of energy produced with forest chips and wood pellets is lower than the price of other fuels, like natural gas, according to the statistics Finland information about the market price of fuels [19]. Therefore, Owners of tiny home in Finland can easily depend on wood for a wood fuel in cheaper price.

2.4 European Union Energy Policy

The European Union has consistently introduced common energy policy that aims to deploy renewables energy in electricity sector, renewables energy in the heating and cooling sector, and boost sustainability. The EU plans to increase cooperation, determination, and solidarity between its member states. It has always established a new binding for renewable energy and reduce greenhouse effect. The European Union also encourages to strengthen the views and objectives of the EU policy while deciding to use new energy technologies with the EU countries. [20.]

The Eu policy framework encourages homeowners or industries to rely on sustainable and clean Renewable source of energy. The EU encourages homeowners or industries to save energy and use of biomass and biofuels to produce heat or electricity for heating and cooling purpose. The EU has a future policy framework for offshore wind energy, and an ocean energy strategy for a sustainable and efficient source of energy. The EU has also categorized ocean energy as blue energy and has forwarded policy for blue energy. A blue energy's distribution starts in 2020 and targets to distribute renewable energy produced by ocean energy by 2030. So, Blue energy is also a beneficial for a tiny house owner who decides to use cheap and clean renewable source of energy. Additionally, The EU intends to advocate about Renewable source of energy to those interested. [20.]

2.5 Renewable Source of Energy in Finland

Finland has the second-highest share of renewables sources of energy in Europe. Finland uses renewable sources of energy in the production of electricity and district heating. Renewable energy in Finland is generally from hydropower, wind power, solar power, aerothermal energy, and geothermal heat energy. A higher number of wood-based fuels and biodegradables and waste fuels are sources of heat energy as well. Finland statistics show that the production and supply of renewable energy are growing. [19.]

Solar energy in Finland is yield by using a photovoltaic system to generate electricity. Finland is one of the northernmost countries in Europe. Summer days are quite long, and winter days are short which means the sun hours are either very long or very short. The angle of sun in Finland is also low in relation to the horizon. There is less solar irradiation in a northern European country like Finland than in central and Southern Europe. [21.]

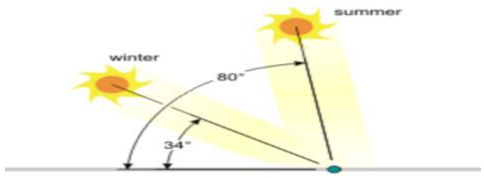


Figure 12. sun angle at 33° north latitude [15].

In the winter in Finland, when the sun angle is lower to the horizon. A solar panel performs the best performance at a steep angle of 60°. During the springtime, a solar panel should be adjusted at an angle of 45°. During the summertime, when the sun is high in the sky, solar panels should tilt at 20°. [16.]

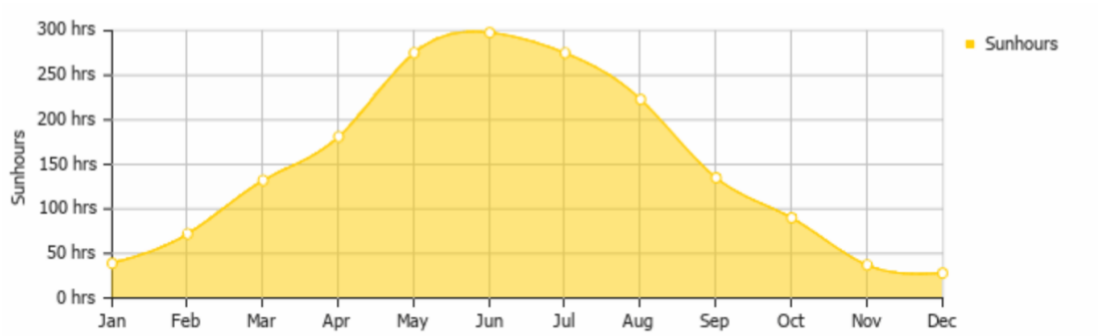


Figure 13. Monthly sun hours of a year [21].

Figure 13 above shows the average weather and climate information in Helsinki, Finland. During the month of June and July, the sun hours are very long and during the month of November to February, sun hours are very short. This means the solar panels absorb higher radiation during the month of June and July and lower radiation during the month of November to February. Thus, solar energy can be harnessed more during the month of June and July and less during the month of November to February. [21.]

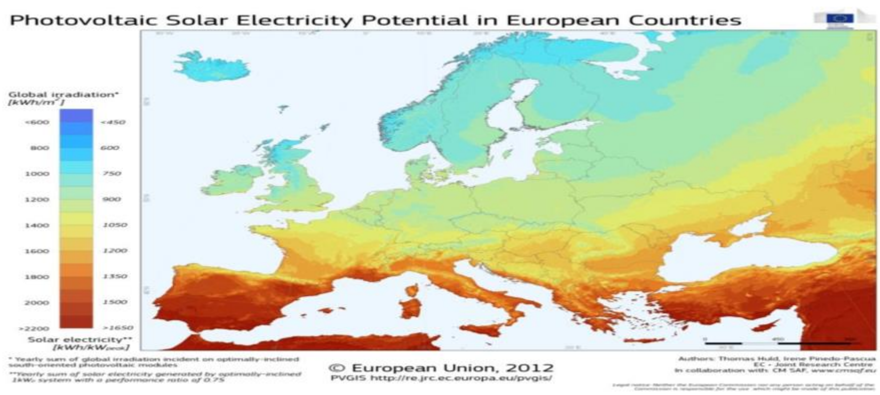


Figure 14. A yearly sum of global irradiation [22].

According to the joint research center, the yearly irradiation in Finland was about 900 kWh/m^2. The Helsinki area had higher solar irradiation i.e. 960 kWh/m^2. These levels of irradiation enable significant potential for producing solar energy and heat which is ecological. [22.]

A photovoltaics installation in a tiny house is capable of producing enough electricity during the spring and summer months of Finland while wind energy can be used to produce electricity to compensate electricity required for other months of the year and vice versa [22].

Wind energy can be a suitable supplementary source of energy in the context of Finland. Finland is situated in the zone of western air disturbances. In winter especially, the air pressure and winds fluctuate a lot. Throughout Finland, the wind flows more from the southwest and less from the northeast. The wind speed is usually moderate, between 2.5 and 4 m/s, in the inner areas, and higher close to the coastal areas and 5 to 7 m/s at the coast. The Wind speed is generally higher during the winter and lowest during the summer months. In Finland, also wind speeds over 20 m/s occurs as well, at least a few times in a month on the open sea in autumn and winter. Thus, wind-energy can use to supply the electricity required for Owners of tiny home in Finland. [23.]

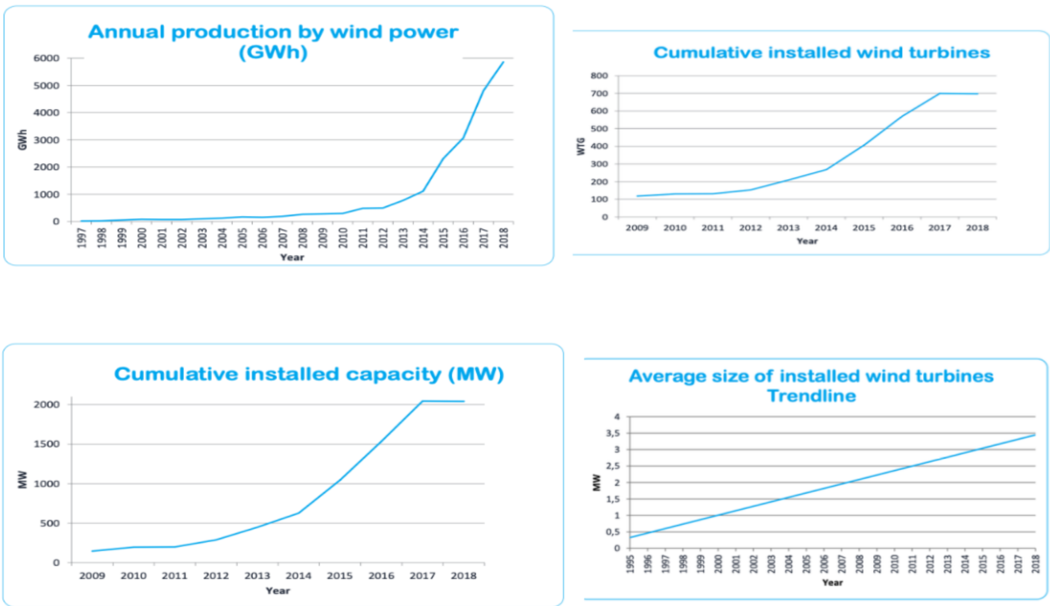


Figure 15. Data produced of wind power in Finland [24].

Figure 15 illustrates the data about Wind power in Finland. Finland generates renewable sources of energy with hardly subsidies. Finland has successfully shown positive transitions from null to the considerate amount of wind energy and momentum in national production statistics of wind energy have broken each year. In 2018, there were 700 installed wind turbines with a combined capacity of 2000 MW, producing a total of 6 terawatt hours. Wind power construction in Finland began in 2012 and 2013 roughly. By 2019, there were 754 installed wind turbines with a combined capacity of 2284 MW. In 2019, wind turbine generated about 6,7 % of Finnish electricity consumption [24]. Finland's renewable power production also plays a vital role to mitigate the climate change. Finland expects to grow wind power capacity considerably. Finland plans to achieve at least 30 TWh of annual wind power production in 2030 every. [24.]

2.6 Condition of Housing in Finland

The statistics Finland shows that the number of household- dwelling units living in rented dwellings has increased particularly in urban municipalities. Around 49 percent of rented dweller is living alone [25]. The statistics Finland shows that those rented dwellers are living in overcrowded dwellings which are often expensive and smaller in size. The average size of household dwelling unit for a person living in crowded dwellings is about 16,5 m^2 [26].

According to Statistics Finland, the average floor area occupied per dwellings was 75 m^2 in the 1990s. This number had increased to 77 m^2 in 2000, 79 m^2 in 2010, and it is 79.5 m^2 at the moment. An average floor area occupied by per person has also inclined by 75 % over the past decade. The number has increased to 31,4 m^2 in 1990, 40,8 m^2 in 2017 and it is 45,1 m^2 in 2019 [26].

Figure 16. The cost figure of rented dwellings and real estate homes [26].

In addition, the average price of owner-occupied homes rose from 2853 € per m^2 in 2010 to 3664 €/ m^2 in 2018 [23]. A home is becoming expensive to buy than renting a household- dwelling unit. This is a sign of an increasing number of dwellers who are choosing to live in a rented household- dwelling unit. the averages rental prices of dwellings have also risen from 4,33 € /m^2 in 2010 to 18,78 €/m^2 in 2018. [26.]

Homes in Finland are safe, well designed, well equipped, and warm throughout the year. Homes and apartment buildings are usually close to nature, in cities, and have accessible transportation. However, renting is often expensive. Finns often prefer to buy or build a home as it is cheaper in the long-term [27]. It is also possible to build a small house as tiny as 20 m^2 which will be cheaper to rent than in a crowded dwelling.

2.7 Finnish Housing Policy

The Finnish rules and regulations of Finland about housing design, and the country's policy for new technologies have been carefully improved. On the 1st October 2004, the ministry of the Environment decree had adopted the guidelines and regulations on housing design for construction. The regulation and guidelines have notified in accordance with directive 98/34//EC, amended 98/48/EC. In general, the regulations and guidelines of housing design 2005 contains land use and building Acts which must be followed by owner of home. [28.]

Tiny home is a tiny habitable room that is intended for living with kitchen, a hall, corridor, bathroom, and all other necessary rooms. According to the housing design regulation and guidelines 2005, The minimum distance to the opposite building in front of the main window of a habitable room in the same or neighboring property should be equal to the height of the opposite building measured from the floor level of a room unless otherwise provided by the town plan. However, there should be up to a distance of at least 8 meters of unbuilt space in front of the main window. [28.]

According to the housing design regulation and guidelines 2005, a tiny habitable house has to follow some major rules about its size and shape, smallest height, windows, as well as its relationship to the surroundings, and to the environment. The smallest net floor area allowed for a habitable house is 20 m^2 and the smallest net room area is 7 m^2. The minimum room height of a habitable room is 2500 mm. A habitable room must have a window with an opening of 1/10 of the net room area to receive light and a pleasant environment. It should also have a fresh air inlet connected to a habitable room. [28.]

Moreover, there must be a convenient and safe access from any dwellings to the areas designed for recreational activity. there should also be parking spaces, waste disposing spaces, chemical or similar system-based toilets, and other management facilities, as well as enough protection to prevent the risk of fire and environmental hazards. [28.]

3 Passive House Principles

A passive house is a voluntary standard for energy efficiency in a building, which reduces the building's ecological footprint. It results in ultra-low energy building that needs low energy for space heating and cooling. A passive house is characterized by the concepts like a super-insulation, thermal bridge- free construction, compact form, airtight building envelope, solar gains and mechanical ventilation with heat recovery. The main objective of following the passive house criteria when constructing a tiny house is to lower the energy demand of the tiny house so that renewable source of energy is enough to meet the energy demand of the house, or so that the cost of grid electricity would be cheaper for the owner. [29.]

A passive house designer can follow the detailed criteria enlisted in the version of the Passive house planning package. This manual also helps the designer to store a requirement data in the PHPP software. According to the manual, the major requirement that certifies the residential building as a passive house is the requirement on the maximum heating load and total cooling demand which are to be 15 kWh/(m^2a) or 10 W/(m^2) of usable living space or less [29]

Due to the small size of tiny houses, it is more difficult to achieve the Passive house Standard. Passive house standard stands for quality, comfort and energy efficiency. However, a tiny house can fulfil the passive house requirements of good insulation, low emissive windows and orientation, possibly ventilation with heat recovery, airtightness, and without thermal bridges. Some reference values for constructing a tiny passive house are listed below.

- Exterior building element must have a U value 0.15 W/(m^2K).
- External envelope mustn't have thermal bridge.
- All window glazing must have U values under 0.8 W/(m^2K).
- The measured air leakage must not exceed 0.6h^{-1} at pressure differential of 50 Pa.

3.1 Building Form

The surface area to the volume (SA/V) ratio is a major factor that explains the loss or gain of heat and impacts the heating and cooling demands of the building. The wider the surface area the more heat loss or a gain will occur through a building envelope. In hot dry or cool dry climates, the SA/V ratio should be as small as possible to minimize heat gain or minimize heat loss respectively. Further, the building envelope materials should be ones that it do not store heat. [29.]

In principle, a cube is a possible building shape that minimizes the heat transfer through the building envelope more than any orthogonal building shape. This can be demonstrated mathematically by considering the SA/V equation for a cube

$$\frac{S}{AV_{cube}} = \frac{6x^2}{x^3} = \frac{6}{x} \quad (1)$$

Where, $\frac{S}{AV_{cube}}$ is the surface area to volume ratio of a perfect cube (regular hexahedron),

and X is the length of one side of the cube(m).

Thus, it can be seen that the larger the dimension(x), the smaller the SA/V ratio.

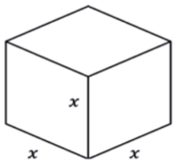


Figure 17. SA/V mathematical demonstration of cube [29].

However, the factors that influence the heat transfer through a cube, like the temperature of the ground, air or snow in contacted with the building, the direction and speed of wind and solar radiation incident, can cause a cube may not be the optimum shape for a building. In order to establish the optimum form, the following diagram, taken from computer simulation software for a different building shapes can be used. A cost-effective SA/V for a small domestic building should generally be less than 0.7m^2/m^3. [29.]

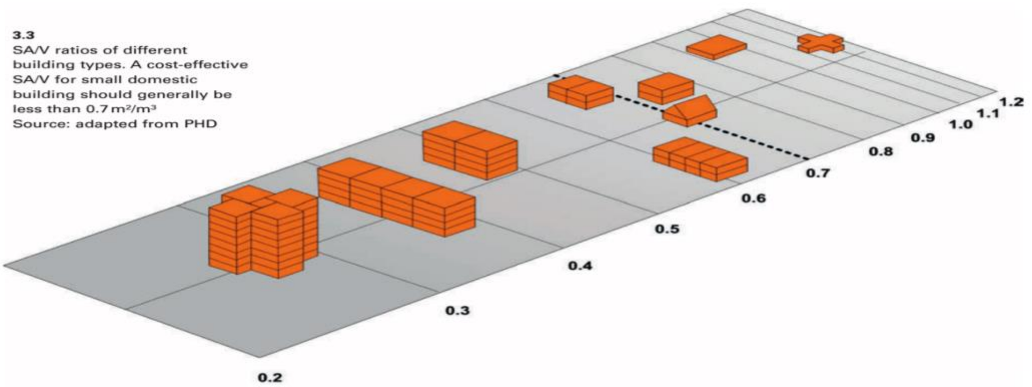


Figure 18. SA/V for a different type of buildings [29].

It is particularly used to contrast the compactness of building with various shapes and structures that have a similar treated floor area (TFA). An SA/V ratio of 0.7m^2/m^3 is viewed as reaching the higher limit beyond which small tiny domestic homes in a central European atmosphere may become uneconomic in order to comply with the passive House standard. [29.]

3.2 Calculation of the U-values

In an energy efficient building like a passive house, the entire building envelope has to be properly insulated. The building envelope should provide a comfortable inner climate irrespective to the climate outside. The range of U values, indicating the rate of heat transfer through a building component considering a given area, of the insulation in passive houses should range from 0.10 to 0.15 W/(m^2 K). These values are the most cost-effective ones. The smaller the U-value the better the quality of insulation. [30.]

The U-values of a building envelope which consists of a homogeneous layer of materials can be deduced by

$$U = \frac{1}{R_{si}+R_1+R_2+\cdots+R_n+R_{se}} \quad (2)$$

Where,

Rs is thermal resistance at interior surfaces,
Rse is the thermal resistance at exterior surfaces, and
R1…. Rn are thermal resistance of individual material layers.

Thermal conductivity or lambda value is the term used to describe the rate at which heat (in watts) passes through a length of material at a given temperature differences (W/mk). the thermal conductivity of materials is temperature dependent and also varies according to moisture content and density. The material variation in the conductivity occur due to the inhomogeneous nature of materials at cellular level. [29.]

Table 2. Thermal conductivities of building materials [30].

Material	Thermal Conductivity λ [W/(mk)]
Concrete reinforced	2.1
Lightweight concrete	0.15-0.3
Aluminum	160
Steel	50
Gypsum plasterboard	0.18-0.56
Natural stone	1.5-3.5
Hardwood	0.18
Softwood	0.13
Mineral wool	0.035-0.045
Solid clay brick masonry	0.8- 1.2
Expanded polyurethane foam	0.025-0.04
Stainless steel	17
Solid plastic	0.17-0.3
Fiber insulating material	0.035-0.05
Cellular glass	0.045-0.06
Wooden softboard	0.04-0.07

Table 2 above shows the thermal conductivity of various building materials. The thermal conductivity of the materials varies from the highest 160 W/(mK) to the lowest 0.03 W/(mK). A higher the thermal conductivity means the thermal resistance is low and the lower means the thermal resistance is high. The smaller lambda value is considered to be good insulating material for a building envelope. [29.]

Building envelope areas can be thicker if the insulating effect of the insulating material is good. Also, the superstructure will be thinner if the thermal conductivity of the insulation material is less and lower is better. [29.]

The design of thermal mass is also crucial part. Thermal mass plays a vital role in a building with high internal gains to help dampen the extremes of daily internal temperature cycle. Thus, it provides comfort. Thermal mass that need to be in practice for a passive house design are shown below.

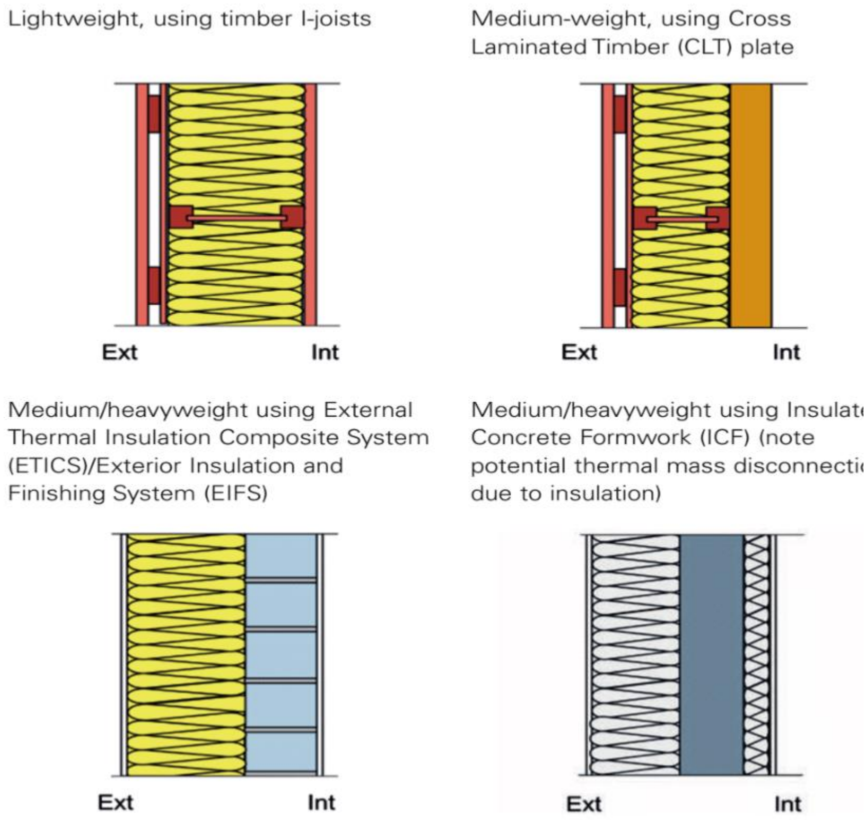


Figure 19. suitable wall constructions for passive houses [29].

During the heating season in cold climatic place, passive home can make high use of solar and internal gains. In situations where solar access is poor and intermittent heating systems are used, thermal mass could store heat and even increase winter heating requirements. However, a material which store heat, absorbs moisture vapour. Moisture can increase the latent heating load and summer dehumidification loads. Therefore, it is also necessary to add moisture barrier or an air barrier on the external side of the thermal mass to increase the air tightness and to preserve heat.

the total sum of the specific thermal loss of the building component and the air tightness of a passive house can be measured with the following equation. [29]

$$\sum Hder = \sum(U\ external\ wall\ \times\ A\ external\ wall) + \sum(U\ upper\ wall\ \times\ A\ upper\ wall) + \sum(U\ base\ floor\ \times A\ base\ floor) + \sum(U\ window\ \times A\ window) + \sum(U\ door \times A\ door) \quad (3)$$

Where,

∑Hder is the total sum of the specific thermal loss of the building component, W/K

U is the thermal transmittance coefficient of the building component, W/ (m^2 K), and

A is the area of the building component, m^2.

To measure the airtightness of a house, a pressurization or a blower door test could be performed with a 50 Pa pressure difference between the inside and outside of the building. The test gives the result of n_{50} number, which indicates the percentage of air change per hour (1/h) of the building. The value of n_{50} is considered to be the requirement needed to be a passive house. Equation (4) below from the passive house designer manual is used to find the n_{50} rate. [29.]

$$n^{50} = \frac{V50}{Vn50} \quad (4)$$

Where,

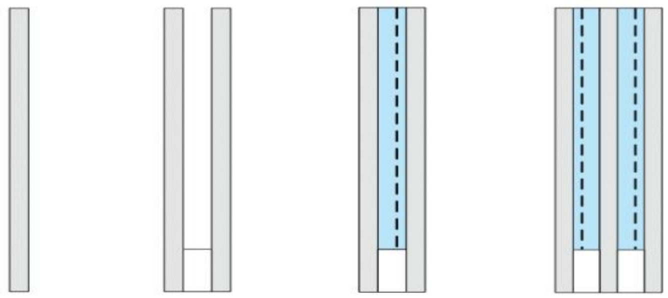
n50 is the number of air changes per hour at a pressure differential of 50 Pa (h^{-1})

V50 is the mean volumetric air flow at a pressure differential of +/- 50 Pa (m^3 /h), and

Vn50 is the net air volume within the building (as defined by BS EN 13829:2001 and PHI) (m^3).

3.3 Passive House Windows

Windows are an essential part of a passive house. They act as the radiators of the radiator. They help a passive house to gain solar heat and to cut the heating load. Windows with a lower thermal resistance (u- value) must be chosen in order to reduce heat transfer. Also, the sum of the total width of the windows should be 55 percent of the total width of the facade. The glazed area of the windows should be at least 10 percent of the floor area and 30 percent of the facade area. Figure 20 shows a comparison of a single, double and triple glazed windows with a respect to a spacer, u values, internal surface temperature and a g value. [29.]



Type of glazing	Single glazing	Air-filled double glazing	Double glazing with gas-filled spaces and selective coating	Triple glazing with two gas-filled spaces and two selective coatings
Spacer	none	Stainless steel	Warm edge spacer	Warm edge spacer
U_w value in [W/m²K]	5.60	2.80	1.20	0.65
Internal surface temperature* [°C]	–1.8	9.1	15.3	17.5
g value [–]	0.92	0.80	0.62	0.48

* Note: the above internal surface temperatures are based on an external design temperature of –10°C.

Figure 20. Comparison of passive house windows [29].

A double-glazing low emissivity coated window or a triple glazed window uses inert gas to fill the air gap. Due to the inert gas-filled gap, triple-glazed windows are even more energy efficient than modern double glazing. Passive buildings require glazed U-values lower than 0.8 $W/m^2 \cdot K$. High-performance double-glazed windows (with argon gas) can achieve U-values of 1.1 $W/m^2 \cdot K$ or lower, while some triple-glazed windows (with argon gas) can achieve U-values as low as 0.6 $W/m^2 \cdot K$. In comparison to any double-glazed window, A triple glazed filled with an inert gas are most preferable for a passive house. A triple glazed window reduces the heat losses through glazed area by more than 50 percent. [29.]

4 Design Concept and Development

The design of the tiny house made for this design is based on achieving a better form of simplicity, space, calmness, ecological impact and sustainability. Its major features are that it is affordable, multi-functional, comfortable, and offers freedom. The location of the house is thought to be built in Helsinki, Southern Finland, 25 m above the sea level. The interior design temperature of the house for planning and verification purposes, is set at no less than 20 degrees in the winter and no more than 25 degrees in the summertime to determine the frequency of overheating. The maximum number of occupants chosen for this house are two persons.

4.1 Floor plan and zoning

The tiny house designed in the thesis has a circular base with a diameter of 6.18 m. To support the self- sufficiency of the house, its roof is circular and 10° slanted with as solar panel and wind turbine on the top of roof to harness energy.

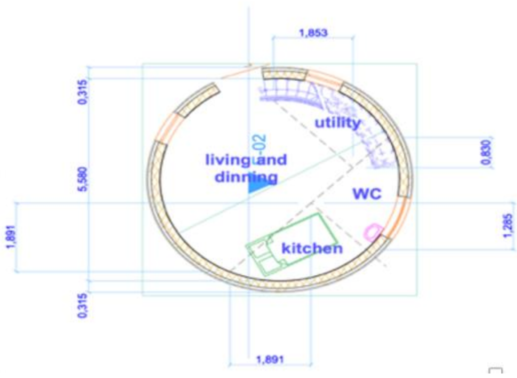


Figure 21. Floor plan of the tiny house designed in the thesis.

The ground floor of the house has four zones. they are living area, technical utility room, bathroom and tiny kitchen. The utility room, the bathroom and the kitchen area are placed next to each other on one side of the room and the living area is in the opposite to them to obtain a larger space. The loft of the tiny house is a sleeping area and tiny library. The washroom has a shower with water conserving fixtures and a composting toilet. The Kitchen consist of a few energy efficient appliances which consumes only little electrical energy.

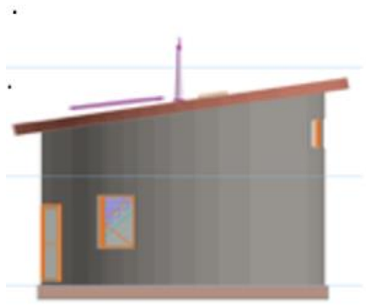


Figure 22. East elevation of the tiny house designed in the thesis.

Figure 22 reflects the exterior of the tiny house from east elevation. The exterior wall component of the tiny house designed in this thesis is made out of wooden façade which is cladded in a vertical way. The east elevation of house consists one window. Window will absorb day light and window opens to inlet clean fresh air.

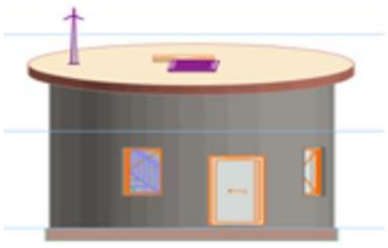


Figure 23. West elevation of the tiny house designed in the thesis.

Figure 23 shows the west elevation of a house designed in this thesis. The exterior wall consists of two wide windows and a sliding door. The roof of the house seen in the figure is made out of durable timber. The Windows on the walls and the sliding window on top of the roof are used to create natural ventilation and to absorb sunlight and warmth through it. The roof of the house is equipped with solar panels facing towards south and a tiny wind turbine.

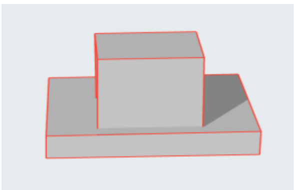


Figure 24. Reinforced footing concrete.

Figure 24 above is the reinforced footing used in the tiny house designed in this thesis. It is made of structural bearing concrete and a footing size of 300×300 mm and column size of 100×100 mm.

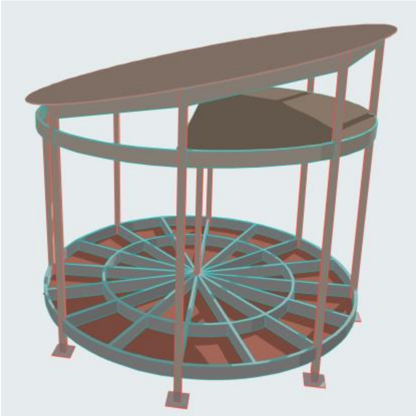


Figure 25. Wooden building frame.

Figure 25 above shows the building frame which consists of beams, size of 50× 200 mm, and columns with the dimensions 100×100 mm. The base floor slab of the house is made out of a wooden frame above the footing foundation. Wooden base floor has solid wooden joist bean. An arc dimension between centre to centre of each joist is 1061 mm and arc dimension between centre to centre of column is 2142 mm. Columns are properly waterproofed to avoid rotting and to increase the durability and strength.

The wooden floor in the tiny house designed in this thesis is preserved wood foundation. A preserved wooden foundation is polished and painted all side of each timber before assembly. The gaps between the framing members are insulated with mineral wool.

4.2 Enclosed Volume and Floor Area

The gross volume of the tiny house is 116 m^3 and the treated floor area is 24,26 m^3 are calculated as shown below in equation 5 and 6 respectively.

$$V = \pi r^2 h + ½ \times \pi r^2 h \tag{5}$$

V = 3.14×2,782×4,33 + ½ ×2,782× 0,91= 105m^3 + 11 m^3 = 116 m^3 and

$$A_{TFA} = \pi r^2 \quad (6)$$

A_{TFA} = 24,26 m^2

The floor is circular because a circular for results in a smaller SA/V ratio for house = 0,21 m^2/m^3. Thus, the heat loss and gain of the house is small.

4.3 Mechanical cooling

Usually, a tiny house is cooled by the means of passive cooling such as solar protection and night ventilation. However, if the building requires an active cooling, the energy demand of an active cooling system shall be installed. In the tiny house designed in this thesis, natural ventilation is preferred.

4.4 Building Structure

For the frame of the tiny house designed in this thesis, a dimensional lumber wood is used for framing to provide a wall, roof and floor structure. A lumber wood is cut to specific defined sizes of, for example, 50×200 mm. A lumber wood is a cheaper option too. For the external siding of the building envelope, a wind and weather resistant wooden cladding was chosen. The wooden slats can be cladded horizontally or vertically to get rid of precipitation. Thus, the building envelope will not be damp and have mould.

A spray foam is also used to fill all the nooks and cracks around the cladding, windows, and door. The R-value of the spray foam is 6 m^2 K/W. It means that the spray foam is a good insulation to resist the conductive flow of heat. Furthermore, it is also 24 times less permeable to air infiltration than any other insulation. Therefore, it gives a better airtight seal than mineral wool insulation or any other insulations. The spray foam also acts as a perfect moisture barrier as it is impermeable to water and does not allow water and moisture to access into the insulation and other materials in building envelope. A spray foam is also an inert polymer group which prevents the growth of mould and bacteria. The Hybrid insulated wall of the house designed in this thesis is depicted in figure 26 below.

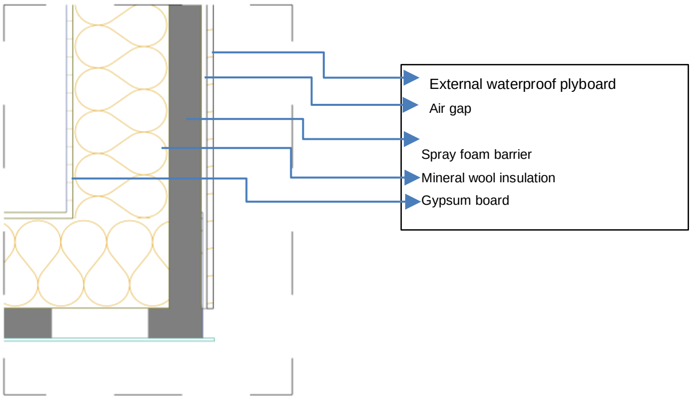


Figure 26. Insulated building wall from a designed house.

The calculation, done in the passive house planning package software (PHPP), of the U-Values for the external walls, roof and basement floor are shown in table 3 below. given below.

Table 3. U-values calculations for wall, roof and floor of the tiny house designed in this thesis.

Assembly no.: 1 — Building assembly description: Exterior wall — Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,01 exterior R_{se}: 0,00

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	gypsum plaster board	0,040					10
2.	mineral wool	0,035	wood studs	0,180			150
3.	Spray foam	0,025					50
4.	external wood cladding	0,180					10
5.							
6.							
7.							
8.							
	Percentage of sec. 1	100 %	Percentage of sec. 2		Percentage of sec. 3		Total 22,0 cm

U-value supplement W/(m²K) — U-Value: 0,151 W/(m²K)

Assembly no.: 2 — Building assembly description: roof — Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,10 exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	wood softboard	0,040					10
2.	mineral wool	0,035	wood studs joist	0,180			150
3.	spray foam	0,025					50
4.	ply board	0,040					5
5.	wood cladding	0,180					10
6.							
7.							
8.							
	Percentage of sec. 1	100 %	Percentage of sec. 2		Percentage of sec. 3		Total 22,5 cm

U-value supplement W/(m²K) — U-Value: 0,146 W/(m²K)

Assembly no.: 3 — Building assembly description: basement floor — Interior insulation?

Heat transfer resistance [m²K/W] interior R_{si}: 0,13 exterior R_{se}: 0,13

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Parquet	0,130					20
2.	mineral wool	0,035	wood beam	0,180			150
3.	spray foam	0,025					50
4.	plyboard	0,040					10
5.							
6.							
7.							
8.							
	Percentage of sec. 1	100 %	Percentage of sec. 2		Percentage of sec. 3		Total 23,0 cm

U-value supplement W/(m²K) — U-Value: 0,144 W/(m²K)

The calculation of the U- values of the external wall is performed in the PHPP software. Of the U- values should be between 0.10 to 0.15 W/ (m^2 K) for the walls, roof and base floor slabs [30]. The building materials used for the tiny house designed in this thesis are wood lumber, plyboards as a frame, internal cladding and external cladding. Similarly, mineral wool is used as an insulation material, not only because its cheap and easily available, but also because its thermal conductivity is low. A thin layer of spray foam is added in wall envelope to airtight sealing and resist the conductive flow of heat. The Exterior wall, for example, consists of a 10 mm gypsum board with a thermal conductivity 0,04 W/m.K, 150 mm mineral wool with a thermal conductivity of 0,035 W/m.K, spray foam and wood cladding with a thermal conductivity of 0,025 W/m.K and 0,18 W/m.K respectively. Thus, the overall U- values of the wall is 0,15 W/m^2 K. In practice, the external wall is a well-insulated wall. It is airtightly sealed and will provide a comfortable interior temperature.

The windows of the tiny house designed in this thesis are triple glazed windows, with three planes of glass, and an insulating gas layer between two planes, to have a minimum heat loss property. Five windows are installed in order to gain solar heat and an adequate source of daylight. The U- value of the window is 0.8 W/m^2 k which satisfies the requirements of a Passive house. For a better sealing between the window frame and the wall, spray foam is applied. The Higher number the number of triple -glazed windows in a house, the smaller the heat loss and energy bills. The heat loss can be reduced educes heat loss up to 70 %.

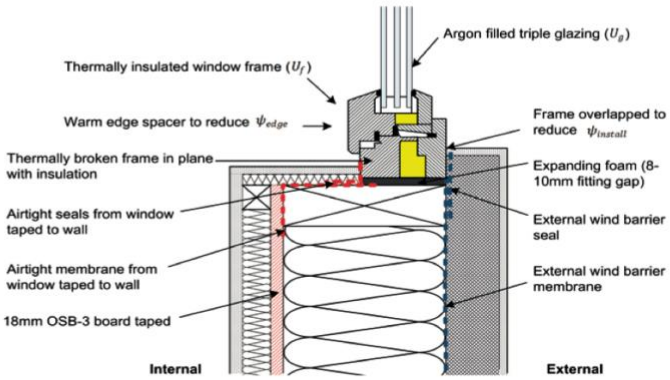


Figure 27. Well insulated window with the wall [29].

Figure 27 above shows the window in lightweight wood frame wall. A tiny house designed in this thesis have windows like in figure. These windows have the high-quality triple plane low emissivity glazing. A triple glazed window is chosen to maintain a comfortable indoor climate and favorable energy balance, especially during winter months.

4.4.1 Electric and Natural Lighting

When designing tiny passive houses, the application of low energy lighting with a high efficiency appliance is recommended in order to reduce the energy use. Natural light through a window also contributes to minimizing the energy use for a lighting. An energy use calculator is used to establish the most efficient, cheapest and least energy consuming electric bulb.

Table 4. Comparing power consumption between light bulbs [31].

	LED	CFL	Incandescent
Lifespan in hours	10,000	9,000	1,000
Watts (equivalent 60 watts)	10	14	60
Cost per bulb	$2.50	$2.40	$1.25
Daily cost*	$0.005	$0.007	$0.03
Annual cost*	$1.83	$2.56	$10.95
Cost for 50k hours @ $0.10 kWh	$50	$70	$300
Bulbs needed for 50k hours	5	5.5	50
Total cost for 50k hours with bulb price	$62.50	$83.20	$362.50

* Assuming 5 hours a day @ $0.10 per kWh.

The comparison shows that either compact fluorescent lighting (CFL) or LED lighting is recommendable as CFL lamp bulb uses five times less energy than a normal incandescent lamp and a LED light uses as little as 25 percent of the electricity required by a normal incandescent lamp, as can be seen in figure 30. A single LED equivalent to 60 watts incandescent light bulb is running at 10 watts for 50,000 hours at the electricity cost $0.10 per kWh is $ 50 while CFL cost is $ 70, and incandescent bulb cost is $ 300. In addition, LED and CFL is cheaper and has significantly higher longevity ratings. At the same time, LED and CFL is environmentally friendly. Thus, LED or CFL is a suitable option to use in minimalist house. [31.]

4.4.2 Space Heating and Hot Water System

In the tiny house designed in this thesis, a wood burning stove is used for a space heating. A wood burning stove often delivers efficient heating by increasing the temperature in the house within short period of time. A tiny cube stove is sufficient to provide warmth for around 30 m^2 of enclosed space. Usually, a small wood stove will heat an area of 60 to 90 m^2 area. [32.]

Figure 28. Cubic mini wood stove [32].

A benefits of cubic mini wood stove are cheap, durable, and affordable. A cubic mini stove can be used for cooking. Also, it has minimal smoke emission.

The Hot water system for the tiny house designed in this thesis is based on a water boiler with a six-gallon water tank. The system needs a main cold-water supply which passes through a boiler before reaching the tap. This kind of a system requires the user to heat water before showering and switch the pump in the boiler off immediately afterwards to save electricity. [33.]

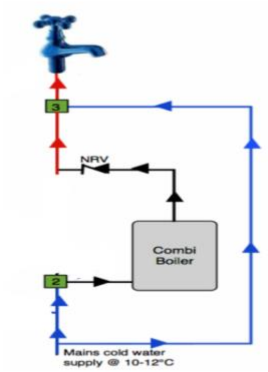


Figure 29. Water boiler preheat system [33].

For the tiny house designed in this thesis, the boiler chosen is a compact boiler of 120 v 12 A, consuming 1.44 kWh a day when used.

4.4.3 Hybrid Renewable Power Systems

The tiny house designed in this thesis is equipped with both a solar energy and wind energy system (figure 30). The hybrid system of solar panels and wind energy generator is one of the best methods, out of all the possible options available in best non-conventional sources for energy. This system requires a big investment at first but reduces the energy costs in the long-term bill. [17.]

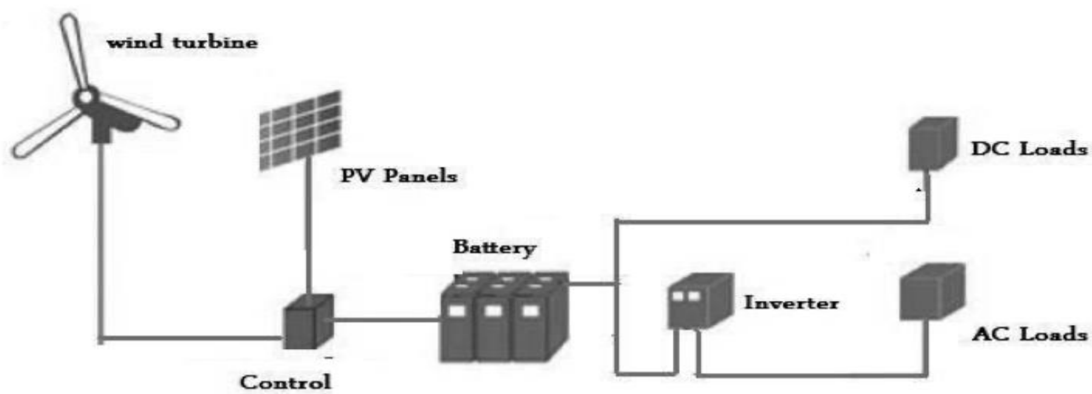


Figure 30. Hybrid system of solar panels and wind generator [17].

Figure 30 shows the integration of solar panels and wind turbine. The output of this system is used to charge batteries. An energy stored in batteries can be transferred to DC loads directly or transferred to the inverter to convert DC current in battery into AC to power AC loads. Wind turbine can be used to produce electricity separately and solar panels can be also used separately when solar radiations are available. The usage of battery is to provide constant power supply. [17.]

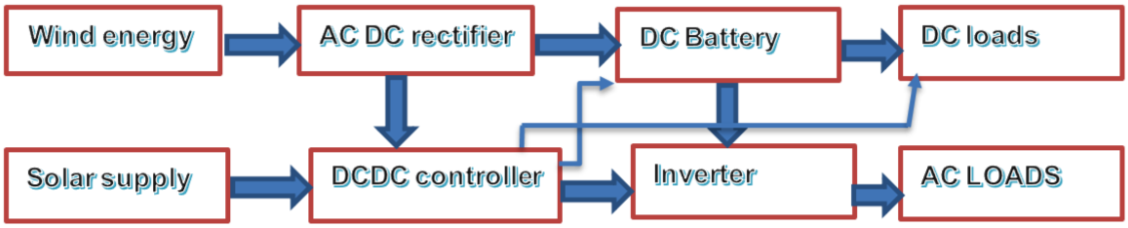


Figure 31. Block diagram of a hybrid system in a designed house.

Figure 31 is a block diagram of a hybrid system in a designed house. the power output of wind energy is AC which is converted into DC with the help of rectifier. DC controller can be used in the system to step up or step-down voltage. Inverter works in the system as the converter of DC output of battery into AC voltage to feed the AC loads. Inverter in this system must have voltage protection and short circuit protection.

In the system designed for the tiny house, five solar panels and one vertical- axis wind turbine are mounted on the top of the roof. The solar panels face towards the southern orientation of the house. The panels are connected in series combination in order to yield higher output of solar energy. Wind turbine is mounted on the southwestern part of the roof as the wind mostly blows from southwest side in Finland [23]. The electricity is then stored in a battery to provide a continuous power supply for the house.

The electrical power required for the house is assumed on the basis of the usage of a household appliance such as lighting bulbs, electric mechanical ventilation with heat recovery unit, a computer, a refrigerator, and an electric stove. In this thesis, a total amount of loads on the hybrid system is estimated more than or equal to 3 kWh a day. The energy consumption of electrical appliances is roughly calculated. For example, 5 CFL 15-watt bulbs which lights up for 6 hours a day requires 0,09 kWh a day, a combined 200 watt of Computer and mobile devices require 0.4 kWh a day, 75-watt Compact Refrigerator requires 1.8 kWh per day, a combined 2000 watt of Microwave and other kitchen appliances used for an hour a day requires 2 kWh, 200-watt TV requires 0.8 kWh a day, 120 v 12 A Combi boiler requires 1.44 kWh a day and Auxiliary appliances is estimated to consume 2 kWh a day. The power required is satisfied by renewable sources of energy or by grid electricity if the hybrid energy system of the house does not produce enough electricity.

Time of Year	Maximum Power generated per day, Fixed mount (Solar Panels Used)					
	1	2	5	10	20	30
Winter Worst Peak Sun Hours 0.81	1.62 Kw	3.23 Kw	8.08 Kw	16.16 Kw	32.33 Kw	48.49 Kw
Summer Best Peak Sun Hours 12.39	24.78 Kw	49.57 Kw	0.12 Mw	0.25 Mw	0.50 Mw	0.74 Mw
Year round average Peak Sun Hours 6.60	13.20 Kw *$8.29*	26.40 Kw *$16.57*	66.00 Kw *$41.44*	0.13 Mw *$82.87*	0.26 Mw *$165.75*	0.40 Mw *$248.62*
Peak Amps at 12v	1,588.78 A	3,177.56 A	7,943.90 A	15,887.80 A	31,775.60 A	47,663.40 A
System Amp rating at 12v	128.21 A	256.41 A	641.03 A	1,282.05 A	2,564.10 A	3,846.15 A
Peak Amps at 24v	794.39 A	1,588.78 A	3,971.95 A	7,943.90 A	15,887.80 A	23,831.70 A
System Amp rating at 24v	64.10 A	128.21 A	320.51 A	641.03 A	1,282.05 A	1,923.08 A

Figure 32. The power generated by 2000W 24 V solar panels in the house designed for the thesis [34].

A 2000-watt solar panel with 60 A maximum power point tracking (MPPT) of 24 V charge controller which has electricity production capacity of total 1,62 kW per day are installed according to the solar irradiation in southern Finland on the roof of the tiny house designed in this thesis.

The remaining primary energy demand is compensated by power generated by the wind turbine. Wind is a supplementary renewable source of energy in the tiny house designed in this thesis. A wind turbine is device that converts the kinetic energy of wind into electric energy. A vertical axis wind turbine is chosen in the tiny house designed in this thesis. A vertical axis turbine has a generator connected to the shaft of the blades which converts the mechanical energy into electrical energy. The output of the turbine depends on the speed of the wind. [17.]

A vertical axis wind turbine rotor has diameter of 0.34 m, can be seen in figure 36. wind turbine is connected with a three-phase permanent magnet suspension generator such that It can safely operate up to wind speed of 40 m/s. A DC charge controller is placed to limit the overcharging the battery, can be seen in figure 34. The input current of DC controller is 5 A, and the maximum input current is 25 A [35].

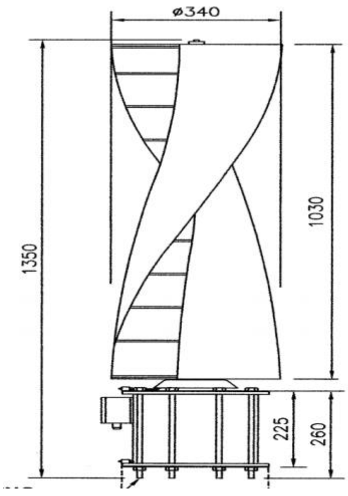


Figure 33. Wind turbine for a tiny house [35].

Wind energy is more efficient than solar energy in the Finnish climate. A wind turbine rotates at wind speed of 2.5 to 4 m/s or 5 to 7 m/s at peak in the Finnish climate. The wind turbine produces more electricity than the solar panels as it functions the whole day. The power generated by a wind turbine is calculated with equation.

$$P_w = \frac{1}{2} k \times \rho \times A_w \times V^3 \times C_P \quad (7)$$

Where,

P is power in watts (kW),
ρ is the air density in kilograms per cubic meter (kg/m^3),
AW is the swept area by air in square meters (m^3),
V is the wind speed in meters per second (m/s), and
C_p is power efficiency of turbine (0.5)

$$P_w = \frac{1}{2} \times 1.225 \times 1{,}76 \times 5^3 \times 0.5$$

Thus, Pw = 0,05 KW, and Energy generated on a day = 1,2 Kwh.

4.4.4 Battery

The batteries are utilized in order to store the power that is delivered from wind and sun powered energy. The capacity of battery may vary depending upon the size of the wind turbine or solar panels. Battery must not have charge leakage or charge leakage should be low. Regarding these parameters, Lithium-ion battery is the best option. Lithium-ion battery is a rechargeable battery. this battery has a high energy density, no memory effect and low self- discharge [17]. these batteries can be connected in series and parallel to increase or decrease the capacity of the battery, depending upon the output from the hybrid system (figure 30).

Five pieces of 12 v lithium-ion battery with a nominal capacity of 200 AH or energy capacity of 2.6 kWh is chosen to be installed in the tiny house designed in this thesis. The Batteries are used to store the electricity by the hybrid energy system in order to provide a backup power during power shortages. The Batteries are connected in series to increase the voltage and to reduce the overall ampere hour capacity. Since some of the electronic appliances require AC voltage, an 8000 W, 120 V inverter converts the DC output from the DC controller to AC voltage which powers the AC electronics. The inverter has capacity to power up of electronic devices up to 32 A without any spikes in the voltage or current.

4.5 Cost of Project

The total estimate cost of the project depends on the project equipment, the labour cost and some minor costs. The cost of wood and steel is estimated on the basis of the area of the building and on the assumption that the products are purchased using various cheap websites. The assembly is assumed to require either very few laborer's or to be done by the owner.

Table 5. Estimated cost of the project equipment [36- 43].

Project equipment	Price of the system	Labour expenses	Total price € Vat 24%
Solar panels	€2,200	€1,400	€3,600
Charge controller	€140	€50	€190
AC DC rectifier	€100	€50	€150
Wind turbine	€700	€500	€1,200
Inverter	€1,200	Included in hybrid energy system	€1,200
Batteries	€3,000	Included in hybrid energy system	€3,000
Water boiler	€250	Included in hybrid energy system	€250
Plyboard and Parquet	€5,000	€1,500	€6500
Footing, Beams and Columns	€5,000	€1,600	€6,600
Insulation	€5,000	€800	€5,800
Total			**€26,500**

The cost of concrete in the tiny house designed for this house is calculated on the basis of the volume of concrete with 40 MPa strength for 16 piece of footing foundation. The total volume of concrete require is 0,03m^3 or 0,05 m^3 or 50 kg. the cost per cubic meter volume of concrete with 40 MPa strength in the tiny house designed for this thesis is 250 euros. [44.]

The cost for building wooden frames is calculated on the basis of the area of the base, walls, ceiling and roof of the tiny house designed in this thesis. According to a retailer in Finland, the price of load bearing Gulam beam is 1,687.39 euros per m^3. The total volume of the beams and columns required in the tiny house designed for the thesis is nearly 2 m^3. [42.]

The cost of plyboard in the tiny house designed for the thesis is calculated on the basis of the total surface area of the external walls, internal walls, surface area of the roof and the base of the building. The cost of plyboard in the tiny house designed for the thesis per m^2 is 20 to 35 euros per m^2. The area covered by plywood in the tiny house designed for the thesis is 158 m^2. [41.]

4.6 Carbon Footprint of Wind Turbine and Solar Panel

Despite the fact the hybrid energy system designed for the tiny house in this thesis only uses renewable energy, the hybrid energy system still leaves carbon footprint to the nature. Figure 34 shows the amount of CO_2 emissions for different sources of energy.

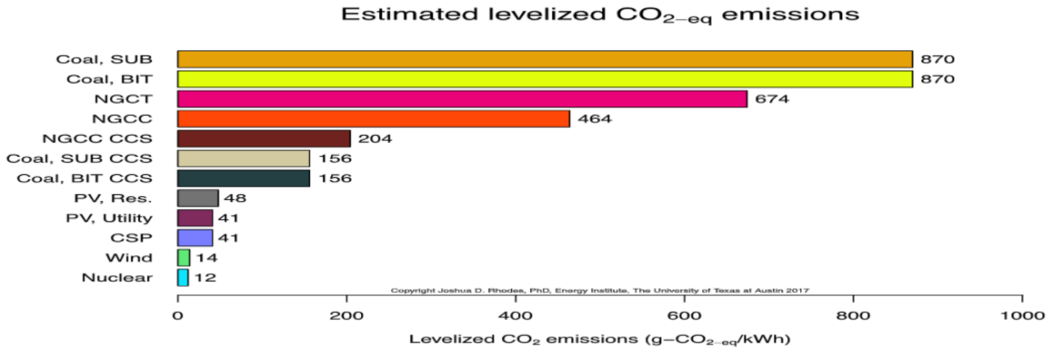


Figure 34. Carbon footprint of electricity according to the fuel [45].

From the bar chart in figure 34, it is clear the carbon footprint of wind energy and solar energy is very low compare to the sources of energy. Wind energy emits around 14 grams of CO_2 per kWh a system while solar technology produces around 48 grams of CO_2 per kWh a system. Among solar technology and wind energy system, Wind energy have the lowest levelized carbon intensity. A study also showed that the life cycle CO_2 emissions from solar and wind energy systems are low and less than 90 times those emitted by the technology based on coal or natural gas. Solar energy system has the third- lowest levelized carbon intensity. Therefore, wind and solar energy are considered to be clean during the operation and after its in use. [45.]

5 Conclusion

The tiny house designed in this thesis is meant for owners who either appreciate a pleasant life in a small dwelling with fewer amenities than a typical, oversized house has, belong to a lower income group, or are tiny house enthusiasts whose intention is to enhance the experiences, and promote and innovate technology for a tiny house. The tiny house is an example that can show the general public that a minimalist dwelling is affordable, sustainable and friendlier with nature.

The tiny house designed in this thesis incorporated the concepts of generating free renewable energy, the passive house concept of good insulation, air tightness and low emissive windows, and the installation of energy efficient appliances. These concepts helped to solve the shortage of electric energy, reduced the energy consumption and energy bills. The tiny house was given bones and muscles that formed a structural shape to achieve the structural strength, withstand the stress and pressure of the building itself and natural loads in order to provide safe, stable and secure living throughout the use of the house. Load bearing timber was used in the design according to the stress and loads that the building and nature lay on the house. Similarly, a suitable concrete footing foundation was designed.

A tiny house can be more economical, simple, easier to build and more sustainable than a conventional house in an attractive way. If the tiny house design and construction are simple like cubical in shape with lower height or without an additional loft, a tiny house can even be cheaper than a tiny house designed in this thesis by constructing a tiny house with recycled materials. I would highly recommended the use of timber, hardwood and softwood structures as wood is environmentally friendly, cheaper, durable, and has good mechanical properties. In the tiny house designed in this thesis, timber was used for beams and columns. Softwood was used for interior and exterior cladding.

The thesis can be useful as a basic guideline for enthusiastic tiny house dwellers who are interested in designing a tiny house in Finland, or why not anywhere else on the globe. This type of a house can be attractive to an individual with low income and students who desire to live peacefully.

References

1 Vivian, John. 1998. The rustic temporary microhouse. Kansas: Mother Earth news.

2 Morneau, David. 2018. Tiny house statistics. Online. Tiny house society <https://www.tinysociety.co/articles/tiny-house-statistics/>. Accessed 10 October 2019.

3 Fredgard, Maria. 2018. Tiny house statistics: 8 really Encouraging Numbers & Facts. Online. Go Downsize. <https://www.godownsize.com/tiny-house-statistics/> Accessed 10 December 2019.

4 Meadows, Christine. 2019. Veterans village of tiny homes pitched for north Edmonton. Online. Global News. <https://globalnews.ca/news/6155542/veterans-village-tiny-homes-north-edmonton/>. Accessed 15 December 2019.

5 Tiny house in UK sale price, design and how to heat. 2020. Online. The Switch. < https://theswitch.co.uk/blog/technology/tiny-house-uk>. Accessed 3 January 2020.

6 Danielewicz, Alyssa. 2017. Tiny house, big thesis. University of Hartford.

7 USC flux home, A house designed to be rebuilt. 2013. Online. USC < https://www.youtube.com/watch?v=1ETwxksE1KIZ>. Accessed 10 October 2019.

8 Willliamsom, Caroline. 2012. Micro cabin in Finland. Online. Design milk.<https://design-milk.com/micro-cabin-in-finland/>. Accessed 14 October 2019.

9 Tiny cottage in Finland is an Ecological Urban Retreat. 2018. Online. Off Grid World. <https://offgridworld.com/tiny-cottage-in-finland-is-an-ecological-urban-retreat/>. Accessed 16 Ocotober 2019.

10 Woman Living off-Grid in her tiny house in Northern Canada. 2029. Online. Exploring Alternatives. <https://www.youtube.com/watch?v=iPR9QRXbeAI>. Accessed 16 October 2019.

11 KODA light standard equipment. 2019. Online. Kodasema. < https://www.kodasema.com/wp-content/uploads/2018/10/181115_KODA-Light-standard-equipment.pdf >. Accessed 24 October 2019.

12 Self- Sustainable microhome. 2020. Online. Self- Sustainable microhome <https://www.ecocapsule.sk/>. Accessed 24 October 2019.

13 Renewables 2020 global status report. 2020. Online. REN21. < https://www.ren21.net/gsr-2020/>. Accessed 25 October 2019.

14 Amaroli, Dr. Nicola. 2015. Solar Electricity and solar Fuels. Status and perspectives in the context of the energy transition: Chemistry Europe.

15 NLPIP lighting answers. Vol. 9, Iss. 3. Photovoltaic Q&A. Online. <https://www.lrc.rpi.edu/programs/nlpip/lightinganswers/photovoltaic/14-photovoltaic-tilt-angle.asp>. Accessed 25 October 2019.

16 What is the optimal orientation and tilt angle for solar panels?. 2019. Online. Dual sun. <https://news.dualsun.com/co-en/12/2014/what-is-the-optimal-orientation-and-tilt-angle-for-solar-panels>. Accessed 25 October 2019.

17 Singh, Raj, Bharat & Dubey, Krishna, Bal. 2018. Solar-Wind Hybrid Power Generation System. Uttar Pradesh: International Research Journal of Engineering and Technology.

18 Wood. Online. Wikipedia <https://en.wikipedia.org/wiki/Wood>.Accessed> Accessed 2 November 2019.

19 The prices of import fuels fell and of domestic fuels rose. 2019. Online. Statistics Finland.<http://www.stat.fi/til/ehi/2019/04/ehi_2019_04_2020-03-12_tie_001_en.html>. Accessed 5 November 2019.

20 Renewable energy. 2019. Industrial Energy and research polices. Online. EU parliament. <https://www.europarl.europa.eu/factsheets/en/sheet/70/renewable-energy >. Accessed 3 November 2019.

21 Monthly hours of sunshine in Helsinki, Finland. 2019. Online. < https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Helsinki,Finland>. Accessed 10 November 2019.

22 Hakkarainen, Timo; Tsupari, Eemeli; Hakkarainen Elina & Ikäheimo Jussi. 2015. the role and opportunities for solar energy in Finland and Europe. Researchgate. VTT technical research centre of Finland ltd.

23 Winds and Storms. 2010. Online. Finnish Meteorological Institute. < https://en.ilmatieteenlaitos.fi/climate-elements>. Accessed 12 November 2019.

24 Operating and dismantled Wind turbines. 2018. Wind power projects in Finland. Online. Suomen Tuulivoimaydhdistys. <https://tuulivoimayhdistys.fi/en/wind-power-in-finland/wind-power-in-production-and-dismantled >. Accessed 20 November 2019

25 Rental living of families and persons living alone has become more common. 2020.online. Statistics Finland <https://www.stat.fi/til/asas/2019/01/asas_2019_01_2020-10-14_tie_002_en.html>. Accessed 4 December 2019.

26 Housing. 2019. Online. Statistics Finland <https://www.stat.fi/tup/suoluk/suoluk_asuminen_en.html>. Accessed 2 December 2019.

27 Buying a home. 2020. Online. Infofinland. < https://www.infofinland.fi/en/living-in-finland/housing/owner-occupied-housing >. Accessed 6 December 2019.

28 Ministry of the Environment Decree on housing design G1
THE NATIONAL BUILDING CODE OF FINLAND. 2005. Online. <https://www.ymparisto.fi/download/noname/%7bC51AB657-009E-4799-BB82-B0129C0F8767%7d/31553>. Accessed 7 December 2019.

29 Mcleod, Robert, S. 2015. A technical guide to a low and zero energy buildings. New York: Routledge.

30 Feist, Wofgang; Pfluger, Rainer; Schnieders, Jurgen; Kah, Oliver; Kaufmann, Berthold; Krick, Benjamin; Bastian, Zeno & Ebel, Witta. 2013. Passive house planning package Version 8. Darmstadt: Passive house institute.

31 Electricity usage of a LED light bulb. Online. Energy use calculator. <http://energyusecalculator.com/electricity_ledlightbulb.htm>. Accessed 10 January 2020.

32 Davidson, Josh. 2020. Best wood burning stove for a small space. Online. Tiny living life. <https://tinylivinglife.com/2020/02/best-wood-burning-stove-for-small-spaces-comprehensive-review-2/>. Accessed 17January 2020.

33 Plumbing in solar thermal to a combi boiler. 2020. Online. Solar twin <https://www.solartwin.com/solartwin-features/basic/plumbing-in-solar-thermal-to-a-combi-boiler-combination-boiler-geyser/>. Accessed 19 January 2020.

34 Solar Power Calculator. 2009. Online. Eco Who. <https://www.ecowho.com/tools/solar_power_calculator.php>. Accessed 20 January 2020.

35 600 W spiral Type Vertical Axis wind turbine generator 24V. Online. Shanghai Sihao Machinery Equipment Co. <https://www.alibaba.com/product-detail/100W-300W-400W-500W-600W-Spiral_60820550914.html?spm=a2700.wholesale.deiletai6.2.2a8859dcpJlvQ7>. Accessed 26 February 2020.

36 Aurinkopaneeli Amerisolar 285W. Online. ESCO heater. <https://www.heater.fi/fi/energia/aurinkosahko/aurinkopanelit/aurinkopaneeli-solarxon-amerisolar-as-6p-270w-24v.html>. Accessed 22 February 2020.

37 60A MPPT solar charge controller 60-amp panel battery charge controller 48V 36V 24V 12V auto max150 VDC. Online. One solar. <https://www.amazon.com/Controller-Battery-Charger-Flooded-Lithium/dp/B07JLVPVGR/ref=sr_1_5?dchild=1&keywords=60+amp+mppt+24v&qid=1594209779&sr=8-5>. Accessed 23 February 2020.

38 8000W 48V inverter. Online. WZRELB. <https://www.amazon.com/WZRELB-Continuous-Inverter-Converter-Camping/dp/B089RDMRBD?ref_=ast_sto_dp>. Accessed 27 February 2020.

39 Nordmax HD Käynnistysakku 12V 200A 1300 EN. Online. ESCO heater. < https://www.heater.fi/fi/energia/akut-ja-akkujen-hallinta/akut/nordmax-hd-kaynnistysakku-12-v-140-ah-950en-8155.html>. Accessed 27 February 2020.

40 Central Heating pump. Online. Jassferry store. <https://www.amazon.co.uk/Central-Circulator-Circulation-Replacement-Warranty/dp/B083KJD768/ref=redir_mobile_desktop?ie=UTF8&aaxitk=Y9KqSP9NUYJc8Fvntb3aLQ&hsa_cr_id=1305115000102&ref_=sbx_be_s_sparkle_mcd_asin_0>. Accessed 2 March 2020.

41 Structural softwood Plywood CE2+- 18mm *1220mm*2440mm. Online. Wickes. <https://www.wickes.co.uk/Structural-Softwood-Plywood-CE2+---18mm-x-1220mm-x-2440mm/p/120945>. Accessed 5 March 2020.

42 Detkin, Viktoria. 2016. Timber in Bridge Structures. Page 31. Metropolia university of applied sciences

43 Product catalogue" Rockwool insulation- industry". Online. Kespet oy. < https://www.kespet.fi/wp-content/uploads/2020/02/Rockwool-pipes-industry.pdf>. Accessed 3 April 2020.

44 Concrete 25 kg, C32/40. Online. Biltema. < https://www.biltema.fi/rakentaminen/muuraus/betonit-laastit-ja-sementit/betoni-25-kg-c3240-2000044152 >. Accessed 3 April 2020.

45 Nuclear and wind power estimated to have lowest levelized CO_2 emissions. 2017. Online. The university of Texas at Austin Energy Institute. < https://utexas.app.box.com/s/kavxa4peaq3qtcs8l4yacqc8k39ftloz >. Accessed May 2020.

Appendix 1. Building Element information

Table 1. Wall Elements

Element ID	2D Plan Preview	Wall Type	Height [m]	Thickness [m]	Area [m2]	Net Volume [m3]	Perimeter [m]
SW - 009		Generic Wall/Shell	6,000	0,32	2,92	12,19	19,15
SW - 010		Generic Wall/Shell	6,000	0,32	2,92	14,68	19,15
						26,87 m³	

Table 2. Window Elements

Window Schedule					
Element ID	SKY - 004	WD - 001	WD - 002	WD - 004	WD - 005
Dynamic ID by Classification	Skylight - 004	Window - 001	Window - 002	Window - 004	Window - 005
Opening Name	Skylight Pivot Hung…	Window 23	Window 23	Curved Window 23	Curved Window 23
Quantity	1	1	1	1	1
From Zone	<Undefined>	<Undefined>	<Undefined>	<Undefined>	<Undefined>
To Zone	<Undefined>	<Undefined>	<Undefined>	<Undefined>	<Undefined>
W x H Size	---	0,900×1,500	0,900×1,500	1,667×0,818	1,200×1,500
Orientation	---	L	L		
Sill height	---	1,000	1,000	3,768	1,000
Head height	---	2,500	2,500	4,586	2,500
2D Symbol					
3D Back View					
Fire Resistance Rating	<Undefined>	<Undefined>	<Undefined>	<Undefined>	<Undefined>
Thermal Transmittance [W/m²K]	0.8	0.8	0.8	0.8	0.8
Sound Transmission Class	<Undefined>	<Undefined>	<Undefined>	<Undefined>	<Undefined>

Table 3. Building material Measurement

Components by Elements					
Parent ID and Classification	**Name**	**Classification (Material)**	**Component**		
			Thickness [m]	**Volume [m3]**	**Area [m2]**
FU - 001, Furniture					
	---	---	---	0,85	---
FU - 005, System Furniture					
	---	---	---	0,00	---
RAILING - 001, Railing					
	Steel - Structural	Structural Metal	---	0,02	---
RT - 003, Roof					
	Insulation - Mineral Hard	Mineral Thermal Insulation	0,18	34,64	51,43
	Insulation - Plastic Soft	Plastic Thermal Insulation	0,08	3,40	45,76
	Membrane - Rainproof	Plastic Waterproofing	0,01	0,23	45,73
	Plaster - Gypsum	Gypsum Plaster	0,02	0,87	43,75
	Plywood	Timber Cladding & Finishes	0,01	0,46	45,70
	Steel - Stainless	Metal	0,01	0,52	51,72
SLA - 003, Slab					
	Insulation - Mineral Hard	Mineral Thermal Insulation	0,18	7,17	40,96
	Insulation - Plastic Soft	Plastic Thermal Insulation	0,08	3,07	40,96
	Membrane - Waterproof	Plastic Waterproofing	0,05	2,05	40,96
	Plywood	Timber Cladding & Finishes	0,02	0,82	40,96
	Reinforced Concrete - Prefab	Structural Prefab Concrete	0,08	3,07	40,96
SLA - 005, Slab					
	Timber - Structural	Structural Timber	0,05	0,65	13,00
STAIR - 004, Stair					
	Timber - Structural	Structural Timber	---	0,05	---
SW - 009, Wall					
	Insulation - Mineral Hard	Mineral Thermal Insulation	0,20	7,62	38,24
	Insulation - Plastic Soft	Plastic Thermal Insulation	0,08	2,99	39,83
	Membrane - Vapor Barrier	Plastic Waterproofing	0,01	0,18	36,76
	Plaster - Gypsum	Gypsum Plaster	0,01	0,18	36,82
	Timber - Structural	Structural Timber	0,03	1,21	40,44
SW - 010, Wall					
	Insulation - Mineral Hard	Mineral Thermal Insulation	0,20	9,15	46,06
	Insulation - Plastic Soft	Plastic Thermal Insulation	0,08	3,62	48,33
	Membrane - Vapor Barrier	Plastic Waterproofing	0,01	0,22	43,79
	Plaster - Gypsum	Gypsum Plaster	0,01	0,22	43,88
	Timber - Structural	Structural Timber	0,03	1,48	49,19
TR - 004, Site Geometry					
	GENERIC - ENVIRONMENT	Nature	---	672,95	672,95

Appendix 2. Design value of Geometrical Data from EN 1995-1-1: Eurocode 5

Table 1. Values of factor k_{mod}

Values of k_{mod}

Excerpt of EN 1995-1-1 table 3.1

MATERIAL	SERVICE CLASS	LOAD-DURATIÒN CLASS				
		Permanent action	Long Term Action	Medium Term Action	Short Term Action	Instantenous Action
Solid Timber, Gluelam and Plywood	1 2 3	0,60 0,60 0,50	0,70 0,70 0,55	0,80 0,80 0,65	0,90 0,90 0,70	1,10 1,10 0,90

Table 2. Strength properties of timber and gluelam

Eurokoodikoulutus

Strength properties of timber and gluelam

Grade		C18	C24	C30	C35 (T40)	GL28c (L30)	GL32c (L40)
Strength properties (N/mm²)							
Bending strength	$f_{m,k}$	18	24	30	35	28	32
Tensile strength parallel to the grain	$f_{t,0,k}$	11	14	18	21	16,5	19,5
Tensile strength perpendicular to the grain	$f_{t,90,k}$	0,5	0,5	0,6	0,6	0,4	0,45
Compressive strength parallel to the grain	$f_{c,0,k}$	18	21	23	25	24	26,5
Compressive strength perpendicular to the grain	$f_{c,90,k}$	2,2	2,5	2,7	2,8	2,7	3,0
Shear strength	$f_{v,k}$	2,0	2,5	3,0	3,4	2,7	3,2
Stiffness properties (kN/mm²)							
Mean value of modulus of elasticity parallel to the grain	$E_{0,mean}$	9	11	12	13	12,6	13,7
Syysuuntaisen kimmokertoimen 5% fraktiilia vastaava arvo	$E_{0,05}$	6,0	7,4	8,0	8,7	10,2	11,1
Mean value of modulus of elasticity perpendicularto the grain	$E_{90,mean}$	0,30	0,37	0,40	0,43	0,39	0,42
Density (kg/m³)							
Density (characteristic value)	ρ_k	290	350	380	400	380	410
Density (mean value)	ρ_{mean}	350	420	460	480	430	470

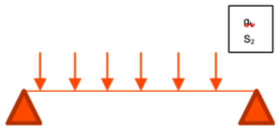
Table 3. Characteristic value of wood class

EN 338 - Table 1 - Strength classes - Characteristic Values

Wood Class	Strength Properties (in N/mm^2)						Stiffness properties (in kN/mm^2)				Density (in kg/m^3)	Density (in kg/m^3)
	Bending	Tension Paralel	Tension Perpendicular	Compression Parallel	Compression Perpendicular	Shear	Mean modulus of elasticity parallel	5% modulus of elasticity parallel	Mean modulus of elasticity perpendicular	Mean shear modulus		
	$f_{m,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{v,k}$	$E_{0,mean}$	$E_{0,05}$	$E_{90,mean}$	G_{mean}	r_k	r_{mean}
C14	14	8	0.4	16	2	3	7	4.7	0.23	0.44	290	350
C16	16	10	0.4	17	2.2	3.2	8	5.4	0.27	0.5	310	370
C18	18	11	0.4	18	2.2	3.4	9	6	0.3	0.56	320	380
C20	20	12	0.4	19	2.3	3.6	9.5	6.4	0.32	0.59	330	390
C22	22	13	0.4	20	2.4	3.8	10	6.7	0.33	0.63	340	410
C24	24	14	0.4	21	2.5	4	11	7.4	0.37	0.69	350	420
C27	27	16	0.4	22	2.6	4	11.5	7.7	0.38	0.72	370	450
C30	30	18	0.4	23	2.7	4	12	8	0.4	0.75	380	460
C35	35	21	0.4	25	2.8	4	13	8.7	0.43	0.81	400	480
C40	40	24	0.4	26	2.9	4	14	9.4	0.47	0.88	420	500
C45	45	27	0.4	27	3.1	4	15	10	0.5	0.94	440	520
C50	50	30	0.4	29	3.2	4	16	10.7	0.53	1	460	550
D18	18	11	0.6	18	7.5	3.4	9.5	8	0.63	0.59	475	570
D24	24	14	0.6	21	7.8	4	10	8.5	0.67	0.62	485	580
D30	30	18	0.6	23	8	4	11	9.2	0.73	0.69	530	640
D35	35	21	0.6	25	8.1	4	12	10.1	0.8	0.75	540	650
D40	40	24	0.6	26	8.3	4	13	10.9	0.86	0.81	550	660
D50	50	30	0.6	29	9.3	4	14	11.8	0.93	0.88	620	750
D60	60	36	0.6	32	10.5	4.5	17	14.3	1.13	1.06	700	840
D70	70	42	0.6	34	13.5	5	20	16.8	1.33	1.25	900	1080

Appendix 3. ULS design load combination calculation

Considering weight of floor structures g_k = 0,5 KN/m



Imposed load on a residential building floor (category A)

q_k = 2 KN/m^2 (table 6.2 in Finnish National annex for EN 1995-1-1)

ULS Load Combinations on a beam

We have, snow load (S_2) = 2 KN/m.

Case 1 for a permanent load: P_d = 1,35 × 0.5 KN/m = 0,68 KN/m

Case 2 permanent load with imposed load: P_d = 1,15 × 0.5 KN/m + 1,5 × 2 KN/m = 3,5 KN/m

In each load combination, the design load P_d must comply with P_d ≥ case 1, satisfied.

Therefore, load duration class is medium term. It is determined by the shortest-term individual load in combination.

ULS verification

Load combination 1: permanent (P_d = 0,68 KN/m)

Bending moment check: must apply: $\sigma_{m,d} \leq f_{m,d}$)

ULS design value of bending moment: $M_d = \frac{wl^2}{8}$ = 0.68 × 3.1^2/8 = 0,82 KNM

ULS design bending stress: $\sigma_{m,d} = \frac{M_d}{W}$

W = $\frac{b.h^2}{6}$ [section modulus for a rectangular cross section beam]

$$\sigma_{m,d} = \frac{0{,}82 \times 10^6\ Nmm}{\frac{50\ mm \times 200^2 mm^2}{6}}$$

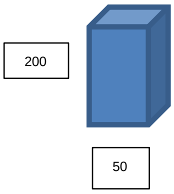
$\sigma_{m,d}$ =2,46 N/mm^2

ULS design bending strength for C24 timber beam

$f_{m,d} = K_{mod} \times \frac{fm,k}{\gamma_m}$ [service class 1 “permanent” : $K_{mod} = 0{,}6$]

γ_m = 1,4 (Partial factor for a solid timber property) [according to Finnish National Annex EN 1995-1-1]

$f_{m,k}$ = 24 N/mm^2 for C24



Therefore, $f_{m,d} = 0{,}6 \times \frac{24Nmm^2}{1{,}4}$ = 10,28

It is clear that ULS bending stress is less than ULS bending strength of a beam which is satisfied values to design timber beam 50mm × 200mm floor structure k400 or $\sigma_{m,d} \leq f_{m,d}$.

<u>Shear force check</u>

In this case: ULS design shear stress shall be less than ULS design shear strength to satisfy the floor design. Such that

$\sigma_{v,d} \leq f_{v,d.}$

ULS design shear force:

$V_d = \frac{P_d}{2}{}'L$ = 0,68 × 3,1 / 2 = 1,05 KN

ULS design shear stress:

$\sigma_{v,d} = \frac{3}{2}\frac{V_d}{b_{ef} \times h}$; $b_{ef} = k_{cr} \times b$

K_{cr} = 0,67 for timber service class 1 and K_{cr} = 1 for class 2 and 3

Since, class 1 is required, K_{cr} = 0,67.

Such that, $\sigma_{v,d} = \frac{3}{2}\frac{1050\,N}{0{,}67 \times 50mm \times 200\,mm}$ = 0,24 N/mm^2

ULS design shear strength:

$f_{v,d} = k_{mod} \times \frac{f_{v,k}}{\gamma_m} = 0{,}6 \times \frac{4\ N/mm2}{1{,}4} = 1{,}71\ N/mm^2$ [$f_{v,k}$ = 4 N/mm^2 for timber C24]

It is clear that ULS design shear stress is less than ULS design stress strength of a beam which is satisfied values to design timber beam 50mm × 200mm floor structure or $\sigma_{v,d} \leq f_{v,d}$.

Similarly, for medium load combination of case 2, P_d = 3,5 KN/m, ULS verification is carried as follows:

Bending moment check:

$M_d = \frac{wl^2}{8}$ = 3,5 × 3.1^2/8 = 4,2 KNM

$$\sigma_{m,d} = \frac{3{,}5 \times 10^6\ Nmm}{\frac{50\ mm \times 200^2 mm^2}{6}}$$

$f_{m,d} = 0{,}8 \times \frac{24}{1{,}4}$ = 13,71 N/mm2 ; Kmod = 0,8 [class medium term]

$\sigma_{m,d} \leq f_{m,d}$. satisfied

Shear check:

$V_d = \frac{P_d}{2}$´L = 3,5 × 3,1 / 2 = 5,425 KN

$$\sigma_{v,d} = \frac{3}{2} \frac{5425\ N}{0{,}67 \times 50 mm \times 200\ mm}$$

$\sigma_{v,d}$ = 1,21 N/mm^2.

$f_{v,d} = k_{mod} \times \frac{f_{v,k}}{\gamma_m} = 0{,}8 \times \frac{4\ N/mm2}{1{,}4} = 2{,}3\ N/mm^2$ [k_{mod} =0,8 for medium term action]

It is clear that ULS design shear stress and bending moment is satisfied.

Failure Verification and Design of column with cross section 100 mm × 100 mm buckling length 3000 mm timber of strength C22 according to EN 338 annex. ($f_{c,0,k}$ = 20 MPa and $E_{0,05}$ = 6700 MPa). Design compressive force f_d = 20 kN (considering medium-term). Service class 1 building.

Design compressive strength:

$$F_{c,0,d} = K_{mod} \times \frac{f_{c,0,k}}{\gamma_m} = 0{,}8 \times \frac{20}{1{,}3} = 12{,}3 \text{ MPa}$$

Design compressive stress:

$$V_{c,0,d} = \frac{f_d}{A} = \frac{20\,.\,10^3\,(N)}{10\,.\,10^3\,(m^2)} = 2\text{MPa}$$

Slenderness ratio:

$$\lambda = \frac{l_{ef}}{i} = \frac{3000}{0{,}29\,.100} = 103{,}8$$

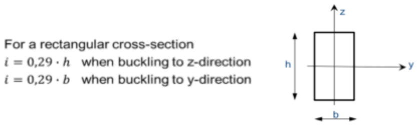


Figure 35. Radius of gyration (EN 1995).

Buckling resistance:

6.3.2 in Finnish National annex for EN 1995-1-1

$$\sigma_{c,}\text{ critical} = \pi^2 \frac{E_{0,05}}{l^2} = \pi^2 \frac{6700}{103{,}8^2} = 6{,}1 \text{ MPa}$$

$$\lambda_{rel} = \sqrt{\frac{f_{c,0,k}}{\sigma_{c,critical}}} = \sqrt{\frac{20}{6{,}1}} = 1{,}8 \text{ (column deflection)}$$

$$K = 0{,}5\,[\,1 + \beta_c\,(\lambda_{rel} - 0{,}3) + (\lambda_{rel})^2] = 0{,}5\,[1 + 0{,}2\,(1{,}8 - 0{,}3) + 1{,}8^2] = 2{,}27$$

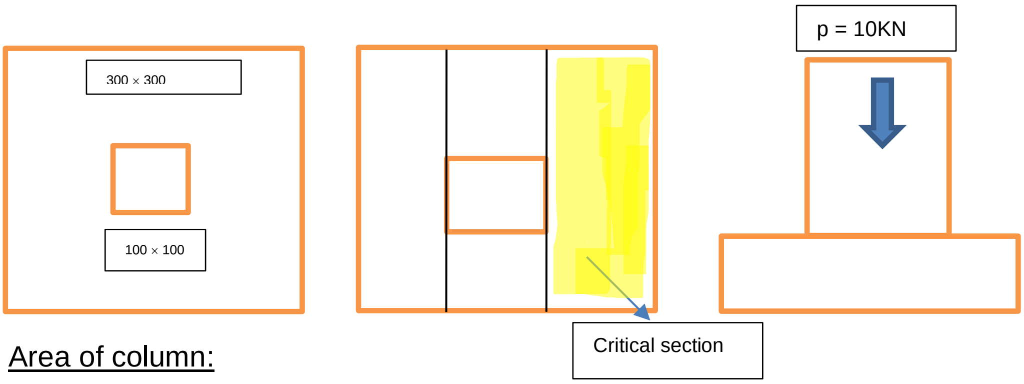
$K_c = \frac{1}{k+\sqrt{k^2-\mathrm{lrel}^2}} = \frac{1}{2{,}27+\sqrt{2{,}27^2-1{,}8^2}} = 0{,}29$

Verification of failure condition

$\frac{s_{c,0,d}}{k_c f_{c,0,d}} \leq 1 = \frac{2}{0{,}29\,.\,12{,}3} = 0{,}83 \leq 1$

Design of column 100× 100mm is suitable.

Design the size of column square footing foundation with M20 grade concrete and calculate depth of footing. [design square footing of ACI 15.8]



Area of column:

First, the load on column is increased by 10 %, that is P = 11 KN.

Area of column (A) $= \frac{10\%\ of\ p + p(P)}{soil\ bearing\ capacity} = \frac{11\ KN}{150\ KN/m^2} = 0{,}07\ m^2\ [A \geq \frac{P}{soil\ bearing\ capacity}]$

Footing size = $\sqrt{A} = \sqrt{0{,}07} = 0{,}3$ m = 300 mm. [for square footing B ≥ $\sqrt{A}$]

Factor moment:

$M_u = P \times B \times (\frac{B-D}{2})^2 \frac{1}{2} = 11 \times 0{,}3 \times (\frac{0{,}3-0{,}1}{2})^2 \frac{1}{2} = 0{,}0165$ KNm

Required depth of footing (d)

$$d = \sqrt{\frac{\mathrm{Mu}}{0{,}138 \times f_{c,0,k} \times s}} = \sqrt{\frac{0{,}0165 \times 10^{6}\, N}{0{,}138 \times 20 \frac{N}{mm2} \times 300mm}} \approx 10\text{mm}$$

Depth of foundation:

Consider the normal angle of repose 25°

$$D = \frac{\mathrm{qk}}{w}\left(\frac{1-sin\theta}{1+sin\theta}\right)^{2} = \frac{2000}{2000}\left(\frac{1-sin25}{1+sin25}\right)^{2} = 0{,}16\text{m} = 160\text{mm}$$

q_k= building load in Finland 2000 Kg/m^2

W= density of soil 2000kg /m^3

Ultimate soil bearing capacity for this square footing by using Terzaghi's equation:

For square footing 0,3 × 0,3 m resting 0,16m below ground level with factor of safety 3.

Terzaghi's bearing capacity equation for square footing as follows:

$Q_u = \gamma D N_q + 0{,}4\gamma B N_\gamma$ [Nq, N_γ Terzaghi's bearing capacity factors from table 1 in appendix]

[γ unit weight of clay soil]

Q_u = 1700kg/m^3 × 0,16m × 12,7 + 0,4 × 1700 kg/m^3 × 0,3m × 9,7 = 5433 Kg/m^2

So, Allowable soil bearing capacity is $Q_a = \frac{\mathrm{Qu}}{F.S} = \frac{5433{,}2}{3}$ = 1811 kg/m^2 = 17,7 KN/m^2 which is suitable to design tiny house.

Table 1. Terzaghi's Bearing Capacity Factors.

ϕ	Nc	Nq	Nr
0	5.7	1	0
5	7.3	1.6	0.5
10	9.6	2.7	1.2
15	12.9	4.4	2.5
20	17.7	7.4	5
25	25.1	12.7	9.7
30	37.2	22.5	19.7
35	57.8	41.4	42.4
40	95.7	81.3	100.4