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An Approach Towards Energy Efficient Buildings for Sub-tropical Climate of Nepal

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The main aim of the final year project was to study about maintaining good thermal comfort in a residential house without consuming much energy. Both traditional and modern houses built with different materials in a sub-tropical region of Nepal were studied. The thesis studied the passive technology and its implementation in sub- tropical region.

The performance of the houses was simulated with Ida-Ice Software. The houses simulated were a traditional, modern and an improved modern house with some of the passive technology.

The performance of the traditional house was better than that of the modern house, but the passive house performed best. It was established that passive technologies alone are not enough to maintain room temperature in a sub-tropical region and active cooling is a must for the hottest days in the summer.

The thesis can be used as a starting guide for the design of energy efficient houses in sub-tropical regions.

Keywords	energy efficient houses, sub-tropical climate, indoor thermal comfort

Contents

1 Introduction

The houses that are designed to use less amount of energy required for heating, cooling or ventilation in order to maintain thermal comfort in the building are called energy efficient houses. The main aim of energy efficient houses is to reduce the amount of energy used without reducing the level of comfort. Reduction of energy in buildings leads to the saving of energy which further helps to reduce the energy costs and as a result to overcome the costs for the implementation of other efficient technology systems. [1.]

Energy efficient houses use more efficient technology that reduces energy loss and hence make the house energy efficient. With the new efficient technology, energy efficient houses also utilize the provided energy in efficient ways. Some examples of energy efficient techniques in house construction are the use of sky lights and LED bulbs for the lighting instead of traditional incandescent bulbs which can save significant amount of energy. Other energy saving methods can be insulating structures like the roof, floors and walls and reducing the amount of energy required by different mechanical equipment for heating, cooling and ventilation. [2.]

2 Nepalese Conditions

This thesis is a study about energy efficient houses in Nepal. Nepal is a South Asian small country with the bordering countries China in the north and India on the other three sides as shown in figure 1. Nepal has an uneven topography and hence the climate differs from sub-tropical climate (below 500 meters) to tundra climate (above 5000 meters). The research region, Chitwan, lies in the sub-tropical climate of Nepal where the weather is extremely hot in the summer and cold both outdoors and indoors in the winter. There are different types of houses built in Nepal. However, the houses fail to provide better thermal comfort according to the weather. Despite the budget, the houses when built are focused on the exterior beauty rather than the indoor thermal comfort. Nevertheless, the designers, engineers and clients are conscious about structural sustainability since the earthquake in 2015. People have been living a difficult life as there is just a small temperature difference between the indoors and outdoors because of the poor construction techniques. [3.]

Figure 1. Location of Bharatpur in Nepal [4]

Global warming and climate change are a major problem worldwide. The Intergovernmental Panel on Climate Change (IPCC) reported human activity as the dominant cause of global warming in 2013. The largest human influence is the emission of greenhouse gases such as nitrous oxide, methane and carbon dioxide. Nearly half of the carbon dioxide emissions that cause global warming comes from buildings. According to the World Bank collector indicator 2012, the total greenhouse gas emissions of Nepal was recorded as 40763 kt of CO2 equivalents while the change of total greenhouse gas emissions from 1990 is recorded to be 62.28%. There are many serious effects that will happen in the future if the global warming continues. Many scientists have declared that the biodiversity and the whole ecosystem will be endangered due to the extreme weather conditions. [3.]

Moreover, Nepal has faced great difficulties in its economic development. Despite the tremendous efforts on eliminating poverty, Nepal lies in the twenty fifth position in the list of the top poorest countries. According to the report of NEA (Nepal Electricity Authority) 2012, people of Nepal face power cut (load shedding) problems daily lasting for up to fourteen hours in the summer and five to six hours in the winter as a result of huge gap between the power supply and demand by different domestic, commercial and industrial sectors. However, the situation is improving due to some current hydroelectric projects, and the authority of Nepal electricity believe that Nepal will get rid of the problem of power shortage by 2020. [5.]

One of the solutions to many of the above stated problems could be an approach towards sustainable housing. Sustainable housing could help to get rid of the problem through a wise use of natural resources. This could be possible with intelligent management and the minimization of the use of non-renewable resources. Minimizing the use of nonrenewable resources such as fossil fuels, coal, and petroleum means minimizing the emissions of greenhouse gases which consequently could prevent ocean, weather, food sources and health of living beings from being adversely affected. [6.]

Furthermore, the sustainable and energy efficient HVAC techniques can play a vital role to minimize the growing energy demand in Nepal. The majority of the electricity is consumed by residential houses. The NEA reported that both electricity consumption and the number of electricity consumers is growing rapidly at a rate of 9% annually. The use of energy efficient technology minimizes the dependency of the house on the national grid for electricity. In addition, another major problem, poor indoor thermal comfort, could also be improved with sustainable housing. This could be possible if people were to focus on the selection of proper technology and long-term sustainability rather than short term costs and advantages. The houses in Nepal are generally not insulated and therefore there is a great difference in the indoor temperatures which, consequently, affect the health of the occupants. The houses in Nepal are generally of reinforced concrete structures and thus finding the proper kind of insulation for Reinforced Cement Concrete structures could greatly help to balance the temperatures and improve the indoor environment. [7.]

2.1 Climate

The Nepalese climate depends largely on the altitudinal features. Because of the broad variations of altitude, starting from 70 meters above the sea level to 8848 meters, the climate of Nepal is divided into five climatic zones as illustrated in table 1. They are, the sub-tropical climatic zone which lies below 1200 meters the warm and temperate zone which lies between the range of 1200 meters to 2100 meters the cold temperate zone lying between 2100 meters to 3300 meters alpine climatic zone lying between 3300 meters to 5000 meters and lastly tundra climatic zone lying above 5000 meters. [8.]

Table1. Climatic Zones of Nepal [9]

Climatic zones	Altitude (M)	Mean Temperature	
		Winter	Summer
Sub-tropical	0-1200	15	>30
Warm temperate	1200-2100	10	24-30
Cold temperate	2100-3300	<5	20
Alpine	3300-5000	<0	loka.15
Tundra	Above 5000	<0	<0

Generally, Nepal is divided into three main regions on the basis of its geographical features. They are the Himalayan Region, Mountain Region and the Terai Region.
The region that is looked into in this thesis, Bharatpur, is in the Chitwan district of the Terai Region at the latitude of 27.6487°N, 84.4173°E and at the altitude of 208 m.

Table 2. Monthly Average weather of Bharatpur [10]

Months	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Average Temp (°C)	15.7	17.7	22.7	27.5	29.2	29	28.4	28.3	27.3	25.5	20.7	16.1
Minimum Temp (°C)	9.4	10.5	14.7	19.8	22.8	24.4	24.7	24.4	23.3	20.5	14.3	9.5
Maximum Temp (°C)	22	24.9	30.7	35.3	35.7	33.7	32.2	32.3	31.4	30.6	27.1	22.8
Average Temp (°F)	60.3	63.9	72.9	81.5	84.6	84.2	83.1	82.9	81.1	77.9	69.3	61.0
Minimum Temp (°F)	48.9	50.9	58.5	67.6	73.0	75.9	76.5	75.9	73.9	68.9	57.7	49.1
Maximum Temp (°F)	71.6	76.8	87.3	95.5	96.3	92.7	90.0	90.1	88.5	87.1	80.8	73.0
Precipitation (mm)	19	14	19	38	102	360	507	523	309	90	8	4

The climate of Bharatpur is very hot during the summer and also cold in the winter as shown in table 2. The maximum temperature of Bharatpur in summer is above 36°C in the month of May while the minimum temperature in winter is 9.4°C in January. The largest precipitation of rainfall is 523 mm in August and the smallest is just 4 mm in December. Relative humidity is below 60% during pre-monsoon and increases up to 90% in monsoon. [10.]

2.2 Urbanization

Nepal is a poor agricultural country seeking to become more advanced economically and socially. Nepal has an area of 1,47181 sq. km and population of 26.4 million. Despite the tremendous efforts on eliminating poverty Nepal lies in the twenty fifth position in the global list of top poorest countries. Nepal is one of the least urbanized country and also Nepal is one of the top ten fastest urbanizing country. The level of urbanization reached 18.2% with an urban population of 5,130,000 with a 3.4% urbanization rate. (MoUD, 2015, Pradhan, 2015). Kathmandu, the capital city Pokhara and other cities located in the Mahendra highway are haphazardly urbanized. The research region Bharatpur has also sustained 4% growth rate per year. [5.]

Table 3. Urbanization in Nepal [5]

Year	Towns in Nepal	Population of Urban area (in millions)	Urban population (percentage)	Average annual urban growth rate in percentage
1961	16	0.336	3.6	1.65
1971	46	0.462	401	3.23
1981	23	0.957	6.3	7.55
1991	33	1.696	9.2	5.89
2001	58	3.28	13.9	6.65
2011	58	4.53	17	4.7
2015	217*	5.307	18.62**	3.18**

Table 3 above represents the rate of urbanization in Nepal from 1961 to 2015. The main reason for rapid urbanization in Nepal is migration. People mostly migrate from rural areas to urban areas in Nepal for job opportunities. Other reasons that cause people to migrate are education, health and for a better living style. The urban population distribution is uneven across the country. 33.5 percent of the urban population is concentrated in 16 urban centers of the country. The number of municipalities has increased from 58 at the time of the census in 2011, to 217 in the census of 2015. During the time 2014-2050, Nepal will remain amongst the top ten fastest urbanizing countries in the world (the only country in the top ten outside of Africa) with a projected annual urbanization rate1.9%. [5.]

2.3 Energy Situation

Energy is a foremost factor for developing modern societies. Energy is used for almost all purposes of our daily life, like for cooking, lighting, ventilation, communication, transportation as well as in the industries which produces our daily basic needs. An easy and comfortable life has been only possible because of energy. The per capita energy consumption of a country is an important factor for the development of the country. The developed countries have a higher per capita consumption than the developing countries. Nepal has the lowest per per capita energy consumption compared to other Asian and European countries. Table 4 below represents the comparison of per capita energy consumption of Nepal with other countries. [6.]

Table 4. Energy Situation in Nepal [11]

Energy Consumption per capita (GJ/year)	Country					
	Iceland	Japan	Nepal	Norway	London	US
2010	714.97	163.62	15.96	291.46	135.44	300.78
2011	762.62	151.80	16.33	237.40	124.60	295.23
2012	740.46	148.82	15.43	248.20	127.18	286.12
2013	763.44	149.96	15.53	270.43	125.06	290.47
2015	738.51	145.75	-	245.87	115.57	290.53

The rate of energy consumption in Nepal grew by 27% from the year 2000 to 2013. It is expected that the energy consumption will continue to increase because of the growing population and increased economic production. The energy demand of Nepal grew by 6.4% per year between 1990 and 2010. Despite this growth, the energy demand in Nepal is the lowest in Asia. Although the total quantity of energy consumed by Nepal is low, the energy consumed relative to economic output is very high. The amount of energy consumed per unit of GDP in Nepal is 1.8 times higher than that in India and China, 4.5 times higher than that in Bangladesh and 4.5 times higher than the world average. Nepal suffers from widespread energy poverty. [12.]

The total energy consumption in Nepal was 475PJ. According to the 2013 energy report of Nepal, four-fifths of the energy consumed in Nepal in 2013 was used in the residential sector. Over 20 million people in Nepal, 82% of the people, lack access to clean and safe methods for cooking. Most people living in rural areas depend highly on biomass sources that include fossil fuels, crop residue, wood animal dung etc. [12.]

2.4 Energy Supply

The National grid is the only state-owned company responsible for the generation, transmission and distribution of electricity in Nepal. Nepal is blessed with plenty of water resources. The majority of the generation is hydropower, owned either by the Nepal electricity Authority, NEA a national utility, or by independent power producers. The total installed electricity generation capacity in Nepal was 856 MW in the fiscal year 2014/15 with 851 MW fed into the grid, and 4.5 MW installed as isolated mini-grids (figure 2). The estimated total potential of Nepal to generate hydropower is 83,000MW but unfortunately Nepal has only utilized 1% of the potential. In fact, Nepal imported 1072 GWh of power from India which is 23% of Nepal’s domestic supply. [6.]

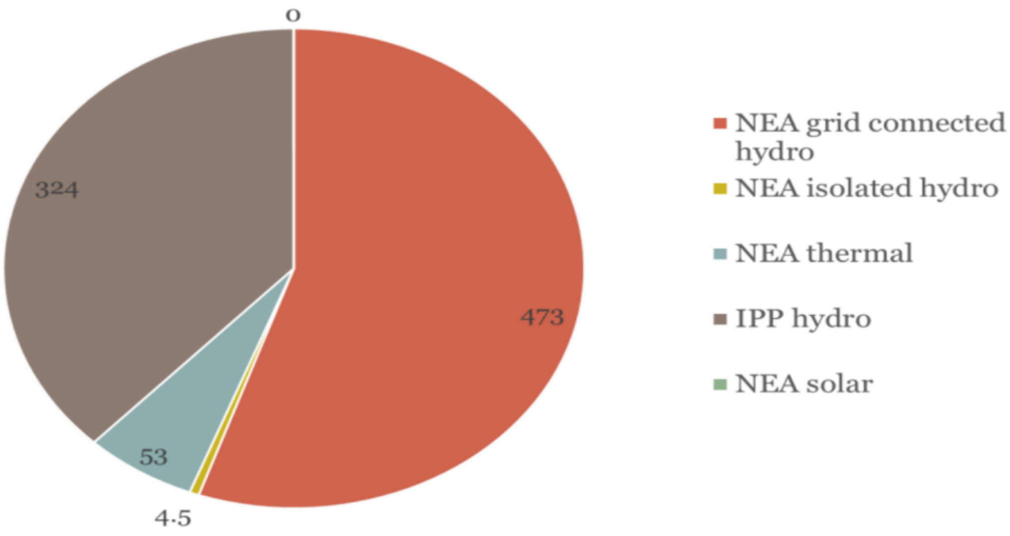

Figure 2. Energy Supply in Nepal [12]

Nepal is also facing a power crisis problem. This is because of inconsistent hydropower of Nepal Electricity System. The NEA has reported that electricity consumption and the number of electricity consumers is growing rapidly at the rate of 9% annually. The red part in figure 3 below shows the electricity supplied by the NEA; blue color represents the electricity supplied by independent power producers(IPPs); yellow/purple represents the electricity released from NEA's storage capacity and lastly the purple represents the unmet demand due to load shedding. [6.]

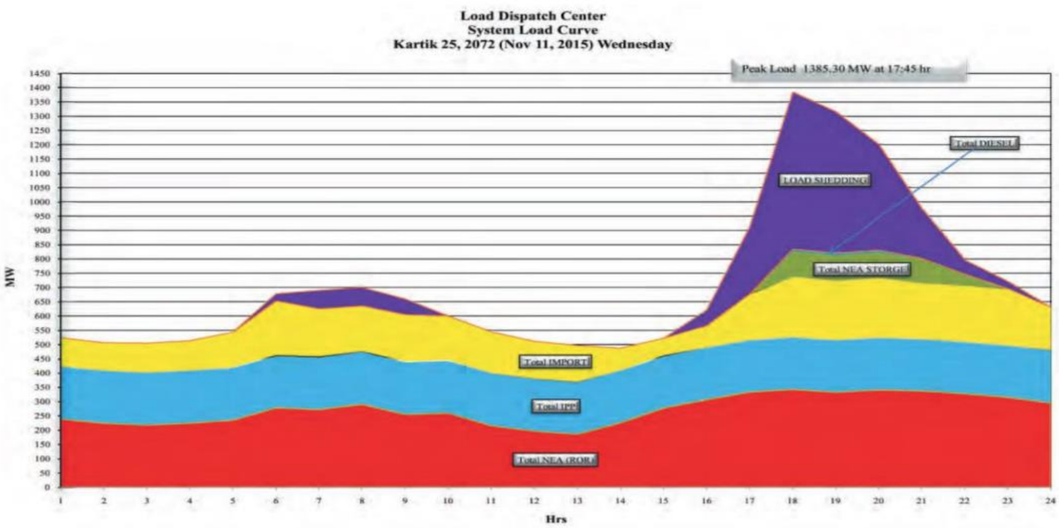

Figure 3. Nepal Electricity Load Curve [12]

Nepal is not blessed with fossil sources like oil, gas or coal. The limited electrical power capacity cannot meet the growing energy demand in Nepal. The majority of the population living in rural areas are deprived from basic electrical facilities. Though NEA and many experts believe that Nepal can generate clean and renewable energy on its own to meet the energy demand throughout the country, and the situation has greatly improved now but it may take time to completely eradicate the power crisis. [12.]

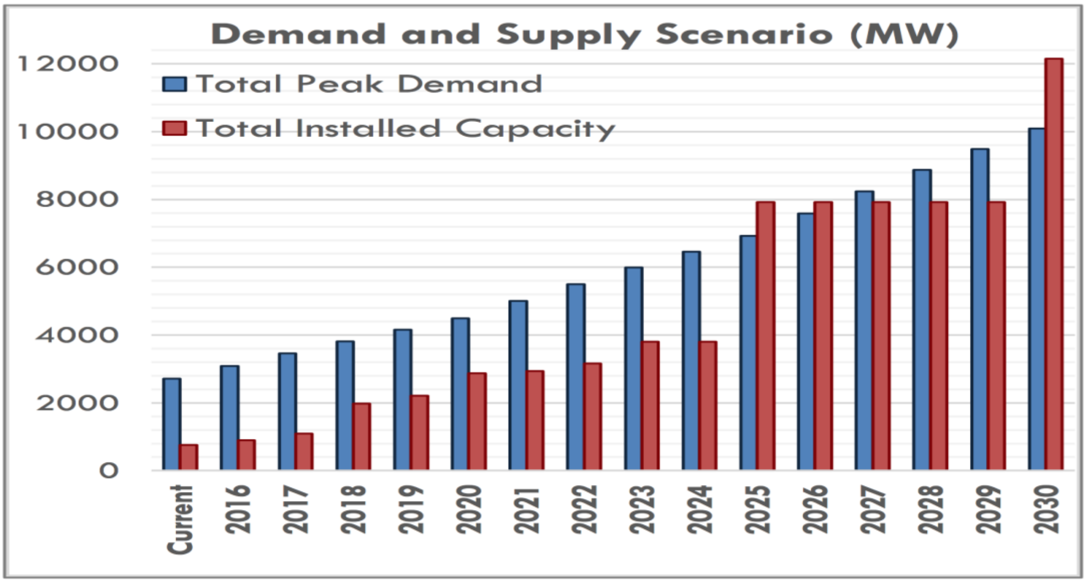

Figure 4. Electricity Demand and Supply projection trend in Nepal [11]

Figure 4 above shows the electricity demand and supply projection trend in Nepal from the year 2014 to 2030. However, the data recorded is from 2014 and the situation has improved to a great extent. There are still power cuts in some areas in Nepal. To get rid of there, energy should be used efficiently. 80% of the energy is used by residential buildings. Energy efficient technologies such as solar photovoltaic panel, insulation, passive heating and cooling could be used in the residential houses could help to balance the energy demand and supply and consequently minimize the energy crisis. Therefore, awareness about the technologies should be spread in Nepal. [12.]

2.5 Energy Use

Electricity is mostly used by the houses in urban areas in Nepal. Electricity is used for lighting, heating or cooling and cooking purpose and for electrical appliances. Figure 5 below represents the electricity uses in Nepal. The total of 14.5% of residential energy is consumed by the houses in urban areas.

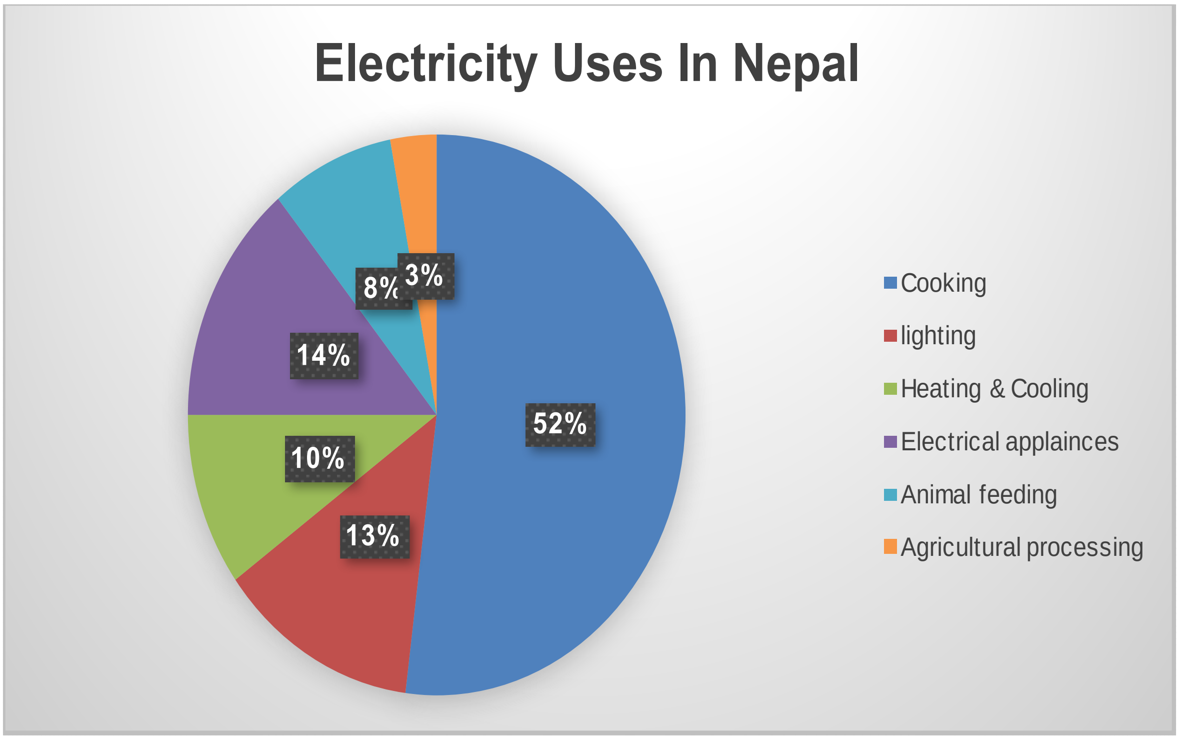

Figure 5. Electricity Uses in Nepal [6]

The growth rate of electricity consumption by household sector of urban areas was 2.3% per year. About half of the electricity used by urban houses is used for cooking, 14% of the energy is used for electrical appliances, 13% of the energy is used for lighting and the energy used for heating and cooling and animal feeding or agricultural processing is 10% and below. [5.]

3 Nepalese Design Strategy

The houses in Nepal are designed according to the geographical regions, their climatic condition, and materials available in the location. According to the census 1991-2001, the houses are divided into four categories on the basis of materials used for construction: permanent house, semi-permanent house, temporary house, and others. Figure 6 below represents the type of housing in Nepal in percentage. [13.]

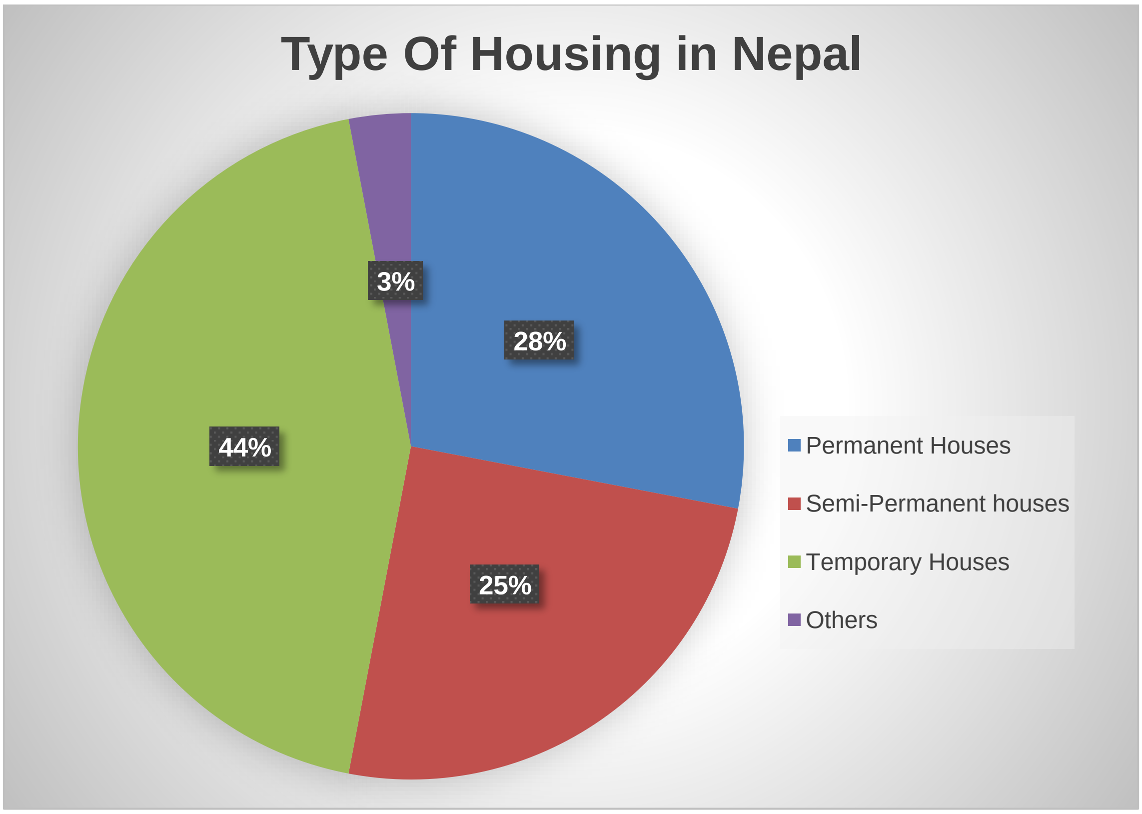

Figure 6. Types of Housing in Nepal [13]

The permanent houses are also called Pakki Ghar. Materials like stone, cement, reinforced concrete, galvanized sheet and tile are used for components like walls roof and floors in the permanent houses. The semi-permanent house is also called Ardha Pakki Ghar. The material used for the roof or walls of Ardha Pakki houses are permanent materials and the other elements are temporary materials. Temporary materials are non-durable materials such as unbacked bricks, wooden flakes, mud, straw or thatch and bamboo. Temporary houses are made with temporary materials. Houses that are like huts or tents are mostly made from non-durable materials like plastic-sheets, straw/thatch or bamboo. They belong to the category others. [13.]

4 Types of Buildings in Nepal

Nepal is rich in diversity. The diversity is also found in the types of buildings in Nepal in terms of building design and building materials. The residential houses in Nepal are basically of two types; traditional houses and modern buildings. The types of houses are briefly described below.

4.1 Traditional Houses

Traditional houses are houses built with traditional and cultural architecture. The traditional houses made of dried bricks are popular in Terai and the hilly region of Nepal. The houses are built in a continuous row facing the street with some free space for social gathering, air and space and lighting as shown in figure 7. These traditional houses are generally load bearing structures. The beam component is generally made from thick wood the transfers the load to the other components of the house. [14.]

Figure 7. Traditional houses in Nepal [13]

The thickness of the wall can extend to a meter depending on the type of structure. Burnt or sun-dried bricks with clay or cement mortar are used to construct the external and internal wall. These types of walls have a low U value (1.014 W/m^{2}C, thickness- 505 mm). The sun-dried bricks make the indoor environment more comfortable as they absorb 10 to 20 times more moisture than the kiln dried bricks used in modern houses. The houses have small doors and windows. The open area is limited to 10% of floor area. [14.]

Traditional Tharu houses in Chitwan

Traditional houses in Chitwan are mostly single floor houses. These houses are also called traditional tharu houses. Tharu is one of the ethnic groups of Chitwan. The houses are not so densely situated along the roads. The climate in Chitwan is hot and humid and hence the houses are built so as to prevent direct radiation from the sun, heavy rainfall, as well as to keep the indoor climate warm in the winter. Figure 8 below shows the typical Tharu house in Chitwan.

Figure 8. Traditional Tharu house in Chitwan [14]

The roofs of the houses are made of straw or thatch with large overhangs which act as shading for the windows, walls and the verandah. The element wall of the Tharu house is made with wood, bamboo sticks and claw mortar. The floor or the plinth level is raised high with stone and mud in order to protect the house from flood or heavy rain. Very small hole like windows are made in the walls. The ceilings are kept high in order to enhance ventilation in the house. [14.]

4.2 Modern Houses

Modern houses in Nepal are made of Reinforced Cement Concrete structures. The structural members slabs, beams and columns are made from RCC according the national building code. The roof material is also concrete or galvanized sheet. Brick and cement plaster are the mostly used materials for wall construction. Figure 9 below shows the typical modern house in Nepal. The external wall of a RCC building is 230 mm and internal wall 100 mm thick. These types of houses are found in hilly and Terai regions of Nepal. [14.]

Figure 9. Modern House in Nepal [14]

Modern houses are popular nowadays due to the modernization and the economic growth because of which people are more attracted towards modern design and the use of modern construction materials in the design. Although the houses are constructed with modern materials and look aesthetically pleasant, the houses fail to provide better thermal comfort as they lack minimum design criteria such as ventilation requirements, insulation in the walls, roof and floors, thermal bridges and air infiltration. The houses are colder during the winter and warmer in the summer. Therefore, large amount of energy is wasted to make the houses comfortable. It is very common that the residents put on heavy clothes even inside the house in order to make themselves comfortable in the winter. Electricity is mainly used for lighting, cooking, cooling and heating. [14.]

5 Passive houses

According to Passipedia, *Passive house is a building standard that is used to design and build homes to be more energy efficient than a conventional building*. The energy efficiency is achieved by adding actual insulation in the wall, by improving the performances of the windows, by creating a shield layer around the building and preventing any heat from escaping. Passive houses can reduce the energy required for active heating and cooling to almost half. Not only reducing energy, passive houses can also be more comfortable and affordable at the same time. Swedish professor Bo Adamson and German physicist Wolfgang Fiest were the first to introduce Passive Design Concept in the year 1988. [15.]

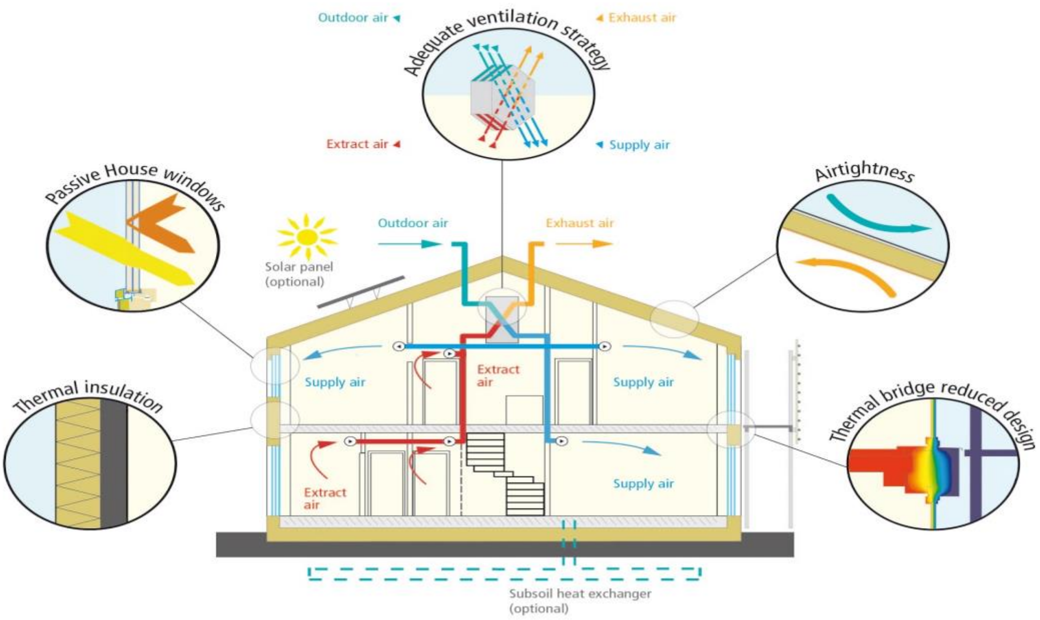

Figure 10. A Passive house [16]

According to passipedia, Passive houses are highly comfortable in comparison to normal houses. The comfort level is maintained by the passive techniques like conventional heating systems and shading to make the comfortable indoor temperatures in summer and winter respectively as illustrated in figure 10. Passive houses also use insulations in walls, floor and roofs and also special kind of windows and doors that helps to maintain good thermal comfort. Passive houses can save buildings heating and cooling energy up to 90% and above 70% in comparison to other contemporary houses. [17.]

5.1 Passive House Requirements

There are certain conditions needed for a house to achieve passive house certification. The structures of the house like wall, roof and floor must have good insulation with the heat transfer coefficient of less than 0.15W/m^2°C. The windows should be well insulated with the U-value less than 0.8W/m^2°C. The leakage through any gaps of the building should be less than 0.6 of the total house volume per hour during a pressure test at 50 Pascal. There should not be air leakages from the connections or joints to avoid thermal bridges. The key elements of Passive design are orientation, thermal mass, insulation, shading and windows. All of them are discussed in more detail below. [18.]

5.1.1 Orientation

The primary principle in a passive house design is orientation. The amount of heat or cold to enter a building in the first place depends on its orientation. The overall efficiency of the building depends upon the location of the site which means the direction of wind and the sun on the site. Thus, in order to save proper amount of heating or cooling costs, the house should be properly designed with appropriate location of the rooms. It is well known that the sun rises from the east and sets in west. The building facing the south can gain maximum solar radiation. Thus, the wall that needs to gain maximum solar radiation must be in southern part as shown in figure 11. [19.]

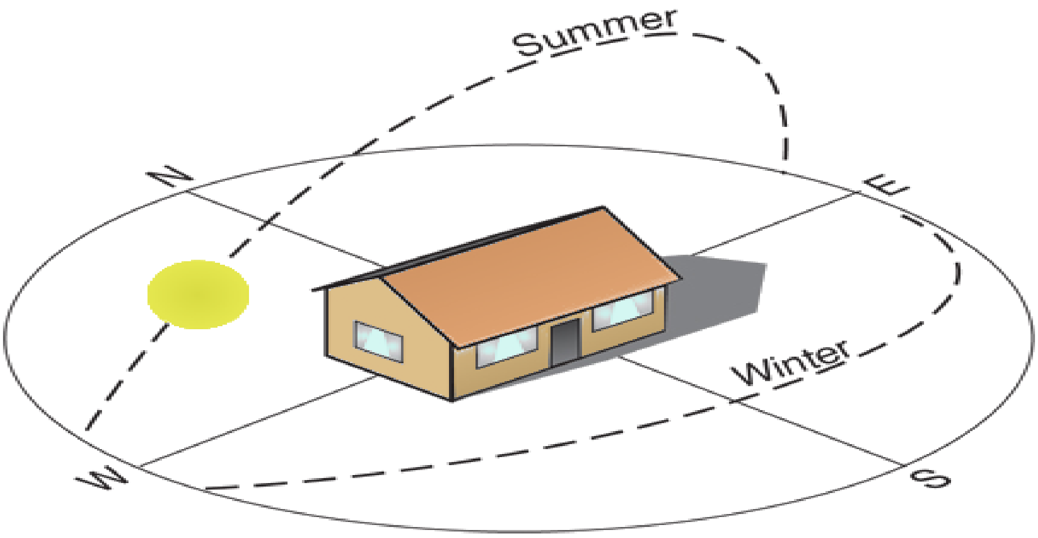

Figure 11: Building Orientation for optimum energy [20]

Not only the walls, the windows of the building also need to be considered for the passive design. As the light can enter the room from the windows and the openings, its always recommend to have windows facing south as the southern part of the building has maximum potential of receiving sunlight and heat by the thermal mass and distribute to other rooms. [18.]

5.1.2 Thermal Mass

Thermal mass can simply be defined as the property of a material which has the ability to absorb, store and release heat when needed. A thermal mass receives the heat when it is sunny, stores it and releases it when it is cold according to the temperature fluctuations outside. Thermal mass should be used properly with the combination of passive solar design techniques in order to obtain any result. The thermal mass is directly proportional to the density of the material. [21.]

Table 5. Thermal capacity of different materials [21]

Building Material	Density (kg/m^3)	Specific heat capacity (J/kg.K)
Water	1000	4190
Air	1.0035	1204
Brick	888	840
Concrete	2240	1130
Stone, Granite	2640	820
Stone, Marble	2600	800

Table 5 above shows the thermal capacity of different materials. The materials like concrete, brick and tiles have high thermal capacity. Hence they can absorb large amount of heat whereas a material like timber has a low thermal capacity and can absorb less heat than materials with high thermal capacity value. Water has the highest volumetric capacity, compared to other commonly used material in construction. [21.]

5.1.3 Insulation

Insulation plays a vital role in passive houses. All structures of the house like walls, roofs, and floors, can lose heat. Adding insulation in the structures helps in reducing heat loss in the winter and also in maintaining a cool environment during the winter. Different types of insulation used in passive house are mineral wool, EPS, glass wool, cotton, sheep's wool, fiberglass and cellulose as shown in figure 12. Insulation materials act as a hurdle between the exterior and interior walls which make the indoor environment warm in the winter and cool in the summer. [18.]

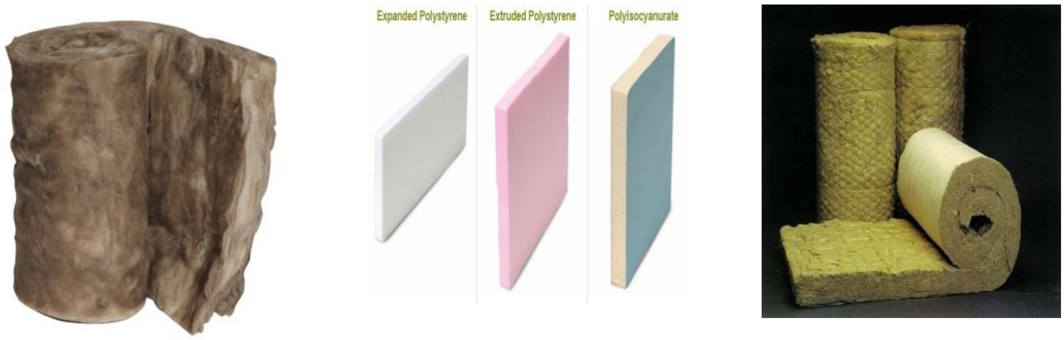

Figure 12: different types of insulation [17]

The level of effectiveness of a insulation depends on the U-value. which is called thermal heat loss coefficient. U value can be defined as rate of transfer of heat through a structure divided by the difference in temperature in structure. The unit of U-value is W/ (m^2°C) which means the amount of heat loss in watts per m^2 at a standard temperature of 1-degree kelvin. The lower the u value the better is the material. [19.]

5.1.4 Shading

Shading is one of the most important strategies of a Passive house. Shading provided for the building openings can reduce the temperature and save energy. Preventing heat to enter is the primary goal for cooling. Shading is usually designed with glazing. But sometimes, shading is also integrated with many other passive strategies such as day lighting techniques to remain fully functional all year round. A house can be shaded both externally and internally. However, external shading is mostly used. [16.]

External shading can be done simply by adding eaves or other fixed overhangs which protects the structure from solar gain. The shading devices can be horizontal or vertical. The eaves and overhangs should be designed to avoid solar gain in the summer and admit the sun in the winter. A horizontal shading device depends on the height of the facade to be shaded. Vertical shading is generally used for fixed shading in the east or west direction. In order to allow the winter sun and avoid the summer sun, angular vertical shading can be used. For proper shading, it is important that other strategies like location, orientation, thermal mass, window size, and placement are also considered. [19.]

5.1.5 Windows

The main goal of a passive house is to maximize the energy efficiency. Passive houses use high performance doors and windows in order to maximize energy efficiency. The high-performance windows have lower U-Values and g values respectively. The U-Values of the windows must not exceed 0.80 W/m^{2}K and the g value must be around 50%. However, high performance windows are expensive than normal windows. [18.]

Figure 13. Windows for a Pasive House [18.]

Figure 13 represents a passive house windows. The window frames should have insulation and the windows should also be fitted with Argon and Krypton in order to prevent heat transfer. The glazed surface of the windows should face south direction so that the house gets the optimum radiation from the sun. To ensure the most effective orientation of windows, wind direction, sun direction should also be considered. [19.]

5.2 Passive Houses in Nepal

The concept of Passive houses is not yet so popular in Nepal. However, people have always adopted different techniques from ancient years to make the house comfortable. Moreover, the concept of passive house is slowly developing. People are trying to adopt some of the many passive techniques. For example, the houses in cold regions are often oriented to the south east and large glazed windows are in the south to achieve maximum solar radiation and keep very small openings face the north. However, new construction still lacks the key design elements like high performance windows with low U-value, insulation, air infiltration rate and thermal mass that helps in maintaining good thermal comfort. [14.]

In some areas like Kathmandu, the situation has improved a little bit and people are interested in adopting western technology to make their house comfortable. Both the people and the government are more conscious about the energy efficient houses that could greatly help in improving the energy savings, economy, and environment of the country. But there is a lack of proper policy and guidelines about energy efficient houses. There was a devastating earthquake in Nepal in 2015. Since then, people are focusing on structural sustainability and forgetting the energy efficiency and thermal comfort. People are concerned with the short term construction cost rather than long term sustainability and comfort. [22.]

6 Case Study: Residential Building in Bharatpur Nepal

This thesis looks into a residential building from Bharatpur, Nepal. The building is located in the sub-tropical climatic region of Nepal. The components, construction materials and its energy situation are looked into and are described below. The residential house studied in the thesis is shown in figure 14 below.

Figure 14. The Residential house

The main entrance of the building faces west. There are no houses close to its sides at the moment. The building gets natural light from three sides. There is also a Kitchen garden available at the side. The case building is a three storey building. The house is a Reinforced Cement Concrete house. Flooring is marble in the staircases, kitchen, and external floors, and plaster in other spaces. Corrugated galvanized sheets are used for the roof. External and internal walls are made of bricks with cement mortar finishing.

Table 6. Materials used in the chosen residential Project

Material	Element of house	Thermal Conductivity (W/m K)	Thickness (mm)	U- Value (W/m^2 K)
Brick	Walls	0.65	230, 110	1.909,3.088
Cement	Plaster finish for walls and floor	1.2	10	5.607
Concrete	Internal floors	2.0	110	4.545
Wood	Doors and windows	0.13j	0.25	2.277
Galvanized sheet	Roof	50	0.4	5.882
Marble	Floor	3.5	0.3	5.6

Table 6 above shows the materials used in the case building. The size of the element are according to the building code of Nepal. Thermal Conductivity and U values are taken from Ida- Ice Software.

Water Supply and Energy

The building is connected to the municipal water network. Tap water is available for a limited time in the morning and in the evening. The are also overhead and underground water tanks available for storage. Filter is only used for water purification. Bath water is heated with a boiler.

Table 7. Energy Balance of the building

Energy Source	Use	Qwantity (kWh/y)
Electricity	Lighting, electrical equipments like television, washing machine, rice cooker, mobile phones, music player, desktop, laptop, electrical water boiler	3624
LPG Gas	Cooking	$4.19*10^{12}$
Water	Drinking, washing, bathing, cleaning, kitchen gardening	58 m^3/month

The energy supplied to the building is from the national grid. An Inverter is used for the electricity back up in the building. Several pieces of electronic equipments like CFL bulbs, ceiling fan, Refrigerator, Washing Machine, Rice cooker, Television, Laptop, Desktop, Mobile phones, music player are used in the building. LPG gas is used for cooking and to heat wa0ter in a water boiler for drinking. The total electricity and gas consumption of a case building was 3624, $4.19*10^{12}$ kWh/y as shown in table 7.

Indoor Thermal Comfort

Although a large sum of money was invested in the building, indoor thermal environment of the building is poor. The space is hot in the summer and cold in the winter. Natural ventilation and a ceiling fan used to cool the space are not sufficient to maintain thermal comfort. No heating system is used for heating inside the house in the winter. The residents put on heavy clothes indoors to keep them warm in the winter. Sometimes, they burn firewood to keep themselves warm in case of excessive cold.

7 Ida Ice Simulation

Energy simulation was carried out in Ida-Ice software for the case building. Ida-Ice is a simulation software that allows the simulation of a whole year as well as a multiple-zone indoor climate and energy simulation of a building body. Since the Ida-Ice software does not contain the exact climatic data and location of the research region, the avilable climatic data closest to the research region, Surkhet, was used. The location used for the simulations was India. First, the simulation of a typical traditional Tharu house was carried out. The materials and the specifications used in the simulation are described below in table 8.

Table 8: Properties of Materials of a Traditional House

Name of Material	Density(kg/m^3)	Thermal conductivity (W/mK)	Specific heat capacity (J/kgK)
Clay	1267	0.288	850
Straw	100	0.06	2000
Bamboo	650	0.25	1007
Wood	400	0.1	1300
Stone	1584	0.83	820

Since no active heating or cooling is used in a traditional Tharu house, all extra energy losses and distribution losses were removed. Also, the air handling system was set to no AHU and the heating system was removed. The windows were set to be open from 11 am to 2 pm in the winter and from 6 am to 11 pm in the summer. The thermal bridges are set very poor. From the report of simulaion, the maximum temperature of the house was 35.52 degrees celsius in the summer and the minimum temperature was above 10 degrees celsius in the winter as illustrated in figure 15 below.

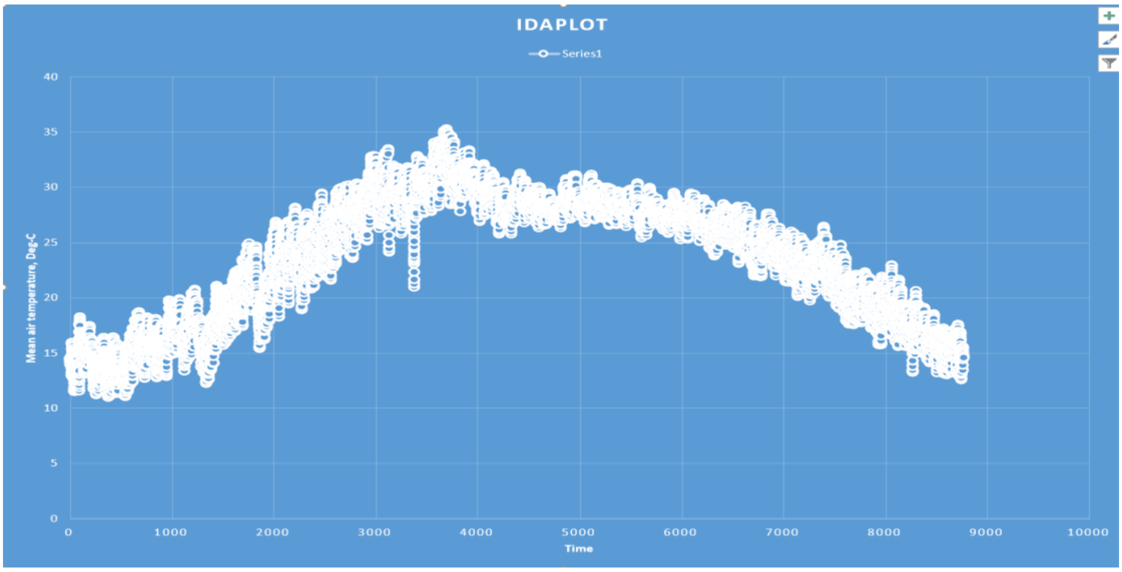

Figure 15. Main temperatures in a traditional house

Second, a simulation was carried out for the case house using the same area with different materials, window sizes and building height. The properties and materials are typical for modern houses in the region. They have higher U-values compared to the traditional houses. Reinforced concrete for the floor, galvanized sheet for the roof, and the kiln bricks for the wall have higher thermal conductivity compared to the traditional house materials like bamboo, straw and wood. Table 9 below describes the material properties used in the simulation. The values are the standard values from the Ida-Ice software.

Table 9. Properties of Materials of a Modern house

Name of Material	Density(kg/m3)	Thermal conductivity (W/mK)	Specific heat capacity(J/kgK)
Galvanized sheet	7500	50	450
Brick	100	0.65	2000
Cement Plaster	2000	1.2	1000

Wood	500	0.13	1600
Stone (marble)	2800	3.5	1000
Concrete	2400	2.0	1000

The window used in the simulation was of the type 4mm clear available in Ida-Ice. The glazing U- value of the simulation window is 6.075 (w/m^2 K). The solar heat gain coefficient 0.868 and the solar transmittance and visible transmittance were 0.83 and 0.9 respectively. The glazing area was taken to be 30% of the window area. The recess depth was taken as 0.1. The windows are set to be open from 6 am to 11 pm in the summer and from 12 am to 2 pm in the winter. The simulation report obtained from Ida ice showed a maximum operative temperature of 43.76 degrees Celsius in June and the minimum temperature of 6 degrees Celsius as shown in figure 16 below. This showed that the modern houses are warmer than traditional houses in the summer and also colder than traditional houses in the winter.

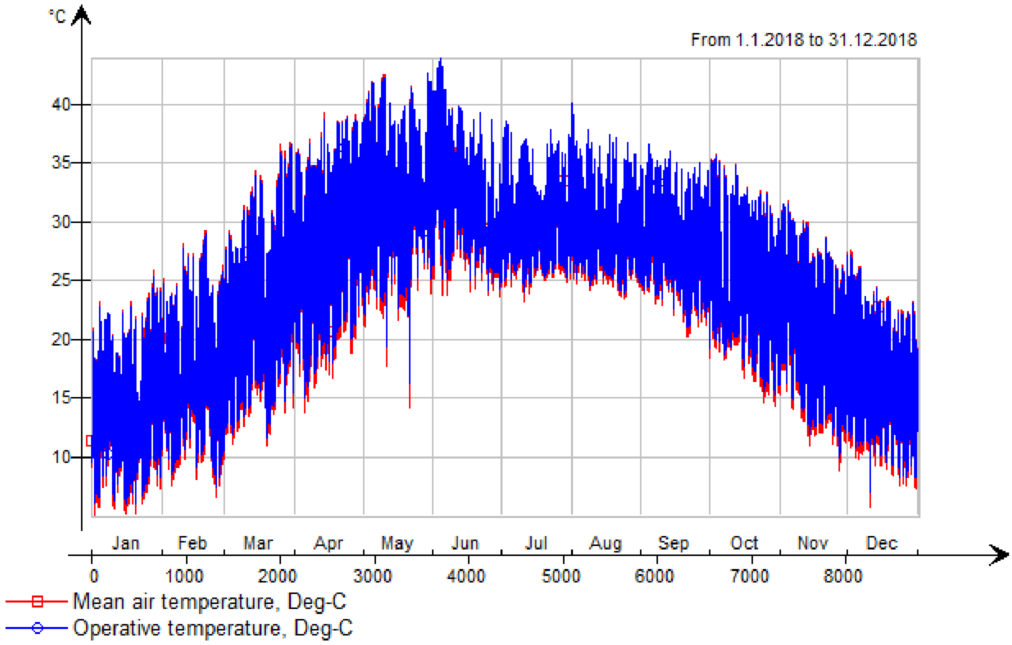

Figure 16. Main temperatures in a modern house

In the third stage of simulation, the materials of the modern house were modified and passive techniques were applied to improve the indoor temperature of the house. The walls were provided with exterior insulation which had thermal conductivity of 0.04

(W/mK) and the roof was provided with insulation also. Fixed shading devices were added to the house to avoid the direct radiation from the sun. The materials and parameters added to improve the building are listed in table 10.

Table 10. Improved parameters used for a Passive House

Name of Material	Density(kg/m^3)	Thermal Conductivity(W/mK)	Specific heat capacity(J/kgK)
Polystyrene	15	0.04	1500
Thatch	100	0.06	2000
Horizontal Shading device			
Double glazed window- U-value- 3.05 (W/m^2 K). Solar heat gain coefficient- 0.769, Solar transmittance- 0.692			

The single pane windows with a U-value of 6.075 (W/m^2 K) were replaced with double glazed windows with a U-value 3.05 (W/m^2 K). The windows had solar heat gain coefficient of 0.769, solar transmittance of 0.692 and visible transmittance 0.815. When the simulation was carried out with the modified model, the report demonstrated a result of maximum indoor temperature of 36.71 degrees Celsius for the summer and the minimum temperature of 10 degree Celsius in the winter

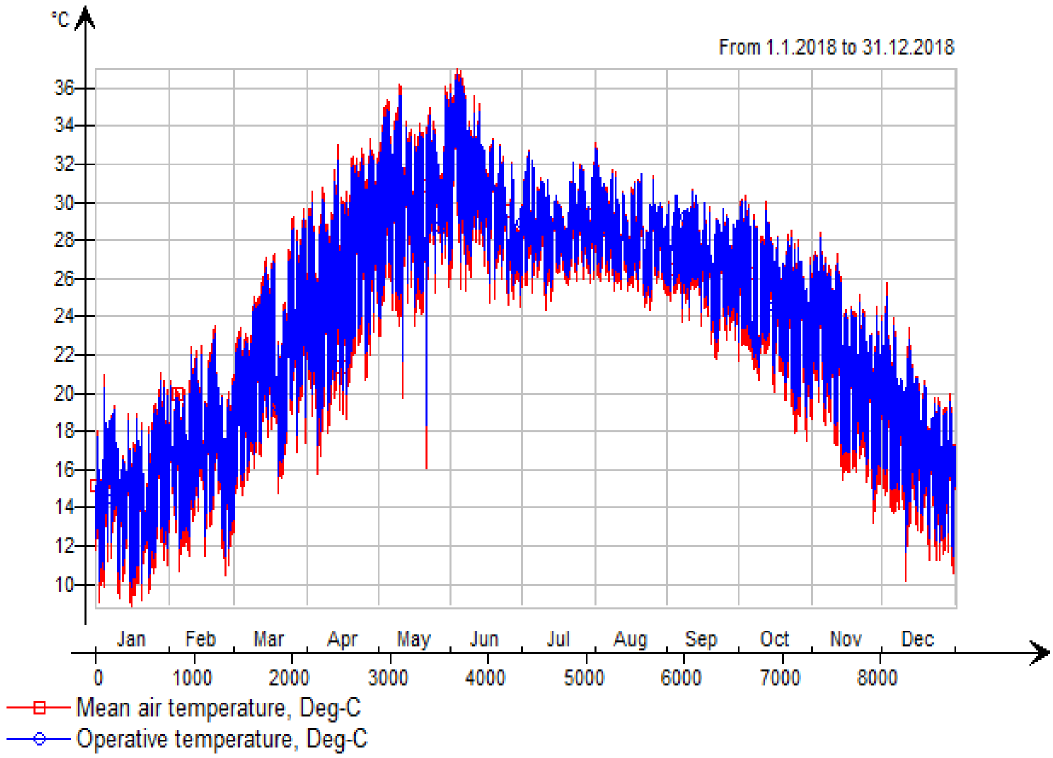

Figure 17. Main temperature, Case 3 with improved parameters

With the insulation added to the walls and roof and the shading devices added the temperature reduced by 7 degrees Celsius for the summer and increased one degree Celsius for the winter as shown in the figure 17.

8 Solutions for Active Heating and Cooling

Although there was a great change in the indoor temperature when the insulation, shading devices and windows were added to a modern house. 36.71 degrees Celsius which is the maximum temperature during May and June, is quite much from the indoor comfort point of view. So, it is demonstrated that passive techniques alone cannot maintain the room temperature in a house in a sub-tropical region. So, active cooling is must during the hottest days in the summer. Furthermore, active heating can be used to create more comfort in the winter during January and February. As the sub-tropical regions have maximum sunny days, solar power is the best alternative source of energy which can be used in the region. The amount of electricity required for active cooling and heating is provided through solar photovoltaic panels. Also, solar water heater is recommended to use for domestic hot water.

Solar Water Heating System

Nepal has over 300 days of sun annually. Therefore, a solar photovoltaic panels are proposed as an alternative electricity source for the case building. A solar water heating system transforms sun light into heat by using a solar thermal collector for water heating. The system consists of a solar thermal collector, storage tank and interconnecting pipes and a fluid system. Evacuated tubes are made of high quality borosilicate glass. Stainless steel is generally used, as tanks of iron rust easily. This kind of a solar heater works with the principle of natural water circulation between the tubes and the water tank as shown in figure 18. The theory is that the water in the tubes when heated rises up to the tank and the cold water, which is heavier than the heated water flows down to the vacuum tubes causing circulation in the system. [23.]

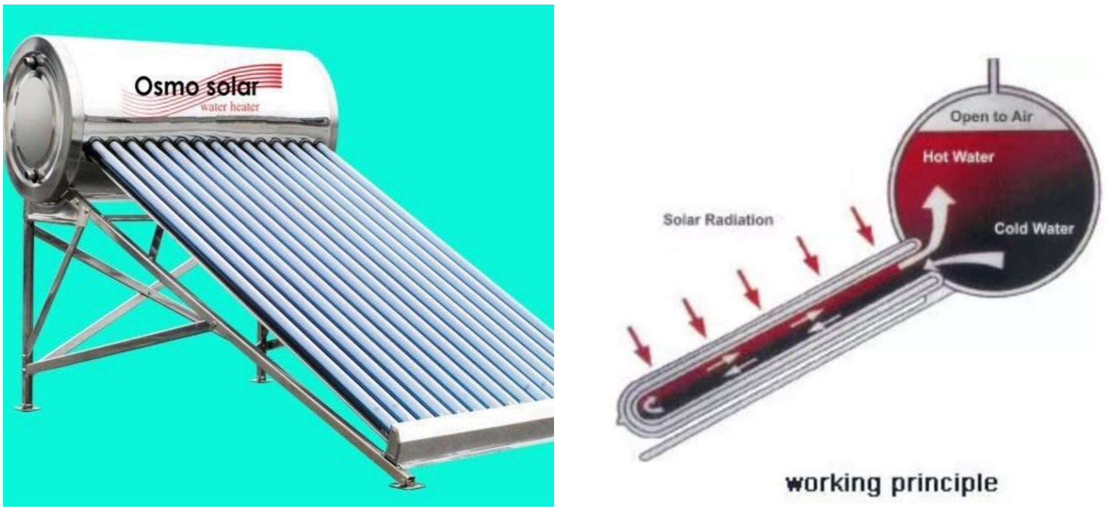

Figure 18. Solar water heater proposed in a house [23]

The calculation for solar yield was done through T-Sol online application. When the solar thermal system of $4m^2$ was used at the inclination of 30 to keep the water warm at a minimum of 40 degree Celsius with the tank capacity of 300l, the system yield was

2761kwh annually with 100% solar fraction. In the Bharatpur region, a solar heater with 24 tubes is recommended for a single family. The capacity of one tube in the system is 12.5 litres and the capacity of the tank above is 300 litres. In order to make the system more effective, it is recommended to keep the top of the collectors just one feet below the tank. Furthermore, large dimension pipes, shorter runs, and are recommended gentle bends in order to achieve adequate flow rates.

Solar Photovoltaic System

Solar photovoltaic panels are made to generate electricity by the means of photovoltaic cells. Photovoltaic cells consist of silicon, which is a semi conducting material. When the sun light falls on the material, an electric field with an electric flow is created. There are two types of solar panels: monocrystalline solar panels and poly crystalline solar panels. Monocrystalline solar panels are a bit more expensive than polycrystalline solar panels, and also more efficient than polycrystalline solar panels. Figure 19 below shows an example of solar photovoltaic system connected to grid.

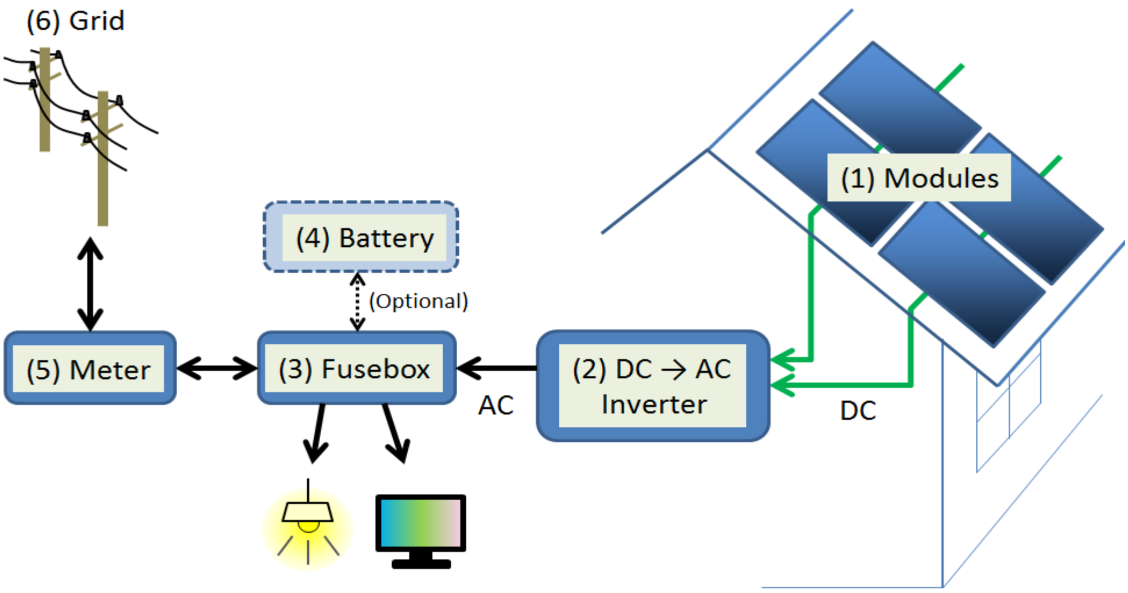

Figure 19. Example of Solar Photovoltaic Panel [24]

The total consumption of electricity of a house is 302KWh/month. A calculation for the solar photovoltaic panel yields was carried out with PV Sol Online. A module that is similar to a product available in the market was chosen in the software. Two modules of 250 Wp are used with a production of 811 kWh annually. According to the simulations, 343 kWh of the electricity produced by the photovoltaic panel could be used in the case building which is 23% of the total consumption. And the rest could be sold to the grid. [24.]

9 Conclusion

The research and the reports obtained from the simulation carried out in the project suggest that traditional houses are warmer in the winter and cooler in the summer than modern houses. The galvanized sheet used as roof material in modern houses has higher U-value which makes the house extremely hot during a summer day. Furthermore, concrete, brick, marble and cement mortar used in modern houses has higher U-values than the traditional materials like clay, straw, bamboo and wood used in traditional houses. However, the modern houses can be made more comfortable with passive and active techniques of heating and cooling with less energy use. The house simplified with the passive methods like shading, insulation and windows had 20% better thermal performance than the common house. However, passive methods alone cannot maintain the room temperature inside a house in the sub-tropical regions. So, active cooling is a must for the hottest days in the summer which lasts from May to October. A solar thermal collector of 3 m^2 was recommended to be use of domestic hot water. According to the available solution in the region, two modules of solar photovoltaic panel of power 0.5 kwh were proposed which could save 23% of the energy consumption by the house.

From the results, it was established that the modern houses improved with passive methods were better than commonly built modern houses, and improved modern houses with active cooling and heating when necessary were the best. To build these kind of energy efficient houses is expensive from the economical point of view. However, the main goal is to maintain thermal comfort inside a house without consuming much energy. Despite the huge investment, energy efficient houses are advantageous from the environmental point of view and long term financial approach.

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Ida Ice Reports and Drawings

EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
FIN YMa1010/2017Erillinen_pientalo Mallinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus YMa1010/2017 mukainen. -Vuotoilma YMa1010/2017 kohta 4.3.3 ja 2.3.2(tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty "YMohje ("D5") 2018" arvoilla seuraavasti: -"YMohje ("D5") 2018" taulukko 3.1-3.3, rakenteiden väliset kylmäsillat (betoniset rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, "YMohje ("D5") 2018" taulukko 7.1 (ja 7.2) -Lämmitysjärjestelmien lämmönjaon ja -luovutuksen vuosihyötysuhde, "YMohje ("D5") 2018" taulukko 6.1 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, "YMohje ("D5") 2018" taulukko 6.1 -Lämpimän käyttöveden häviöt "YMohje ("D5") 2018" kohta 6.3 (ei varaajaa). Kiertojohdon ominaispituus 0,20 m/m2. Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 44 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohdon häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden lämmitysenergian nettotarpeelle ei ole käytetty YM asetuksen 5/13 mukaista asuntojen lukumäärään sidottua rajoitetta. -Lämpimän käyttöveden pumpun sähkönkulutus "YMohje ("D5") 2018" kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D) -Tasauslaskimeen(IDA-tuloste) kaikki lähtötiedot syötetään lämpimien tilojen mukaisilla arvoilla. Käyttäjän tulee itse täydentää ja tarvittaessa myös muuttaa tietoja tasauslaskentatulostukseen. -Halutessaan energiatodistustulosteen(IDA-tuloste) luokan 9 rakennukseen käyttäjä voi valita rakennuksen mallipohjaksi jonkun luokan 1-8 rakennuksista ja muuttaa sitä suunnittelutapausta vastaavaksi. Simuloinnin jälkeen käyttäjä voi sitten muuttaa rakennuksen käyttötarkoitusluokan IDA-energiatodistustulosteen sivulle 1.		Model floor area	56.6 m^2
Customer		Model volume	110.4 m^3
Created by	Jyoti Kandel	Model ground area	56.6 m^2

Location	New Delhi/Safdarjun_421820 (ASHRAE 2013)	Model envelope area	119.8 m²
Climate file	NPL_Surkhet.444160_SWERA	Window/Envelope	2.0 %
Case	traditional building-case 1- 29degrees.idm door and windows time	Average U-value	1.044 W/(m² K)
Simulated	4.12.2018 16.59.18	Envelope area per Volume	1.085 m²/m³

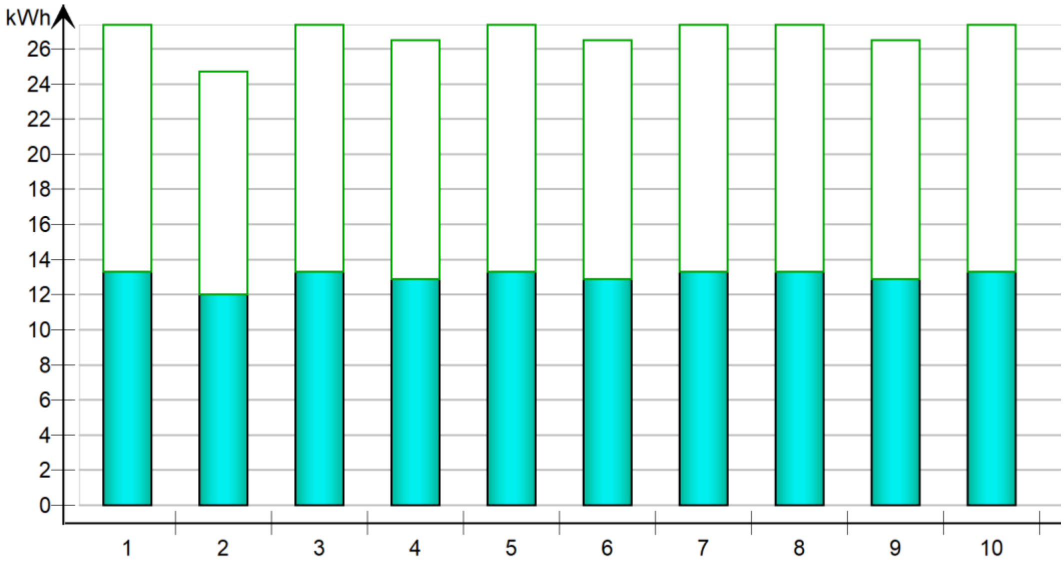
9.1.1 Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	0 %

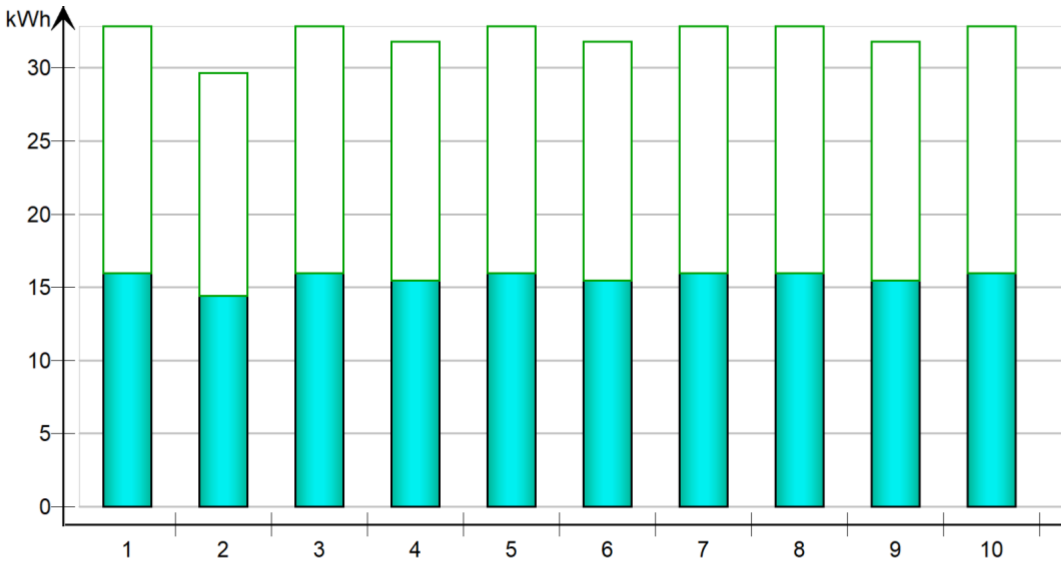
9.1.2 Delivered Energy Overview

	Purchased energy		**Peak demand**	**Primary energy**	
	kWh	**kWh/m²**	**kW**	**kWh**	**kWh/m²**
Jäähdytys	0	0.0	0.0	0	0.0
LVI sähkö	157	2.8	0.02	188	3.3
Total, Facility electric	157	2.8		188	3.3
Lämmitys, kaukolämpö	0	0.0	0.0	0	0.0
LKV, kaukolämpö	0	0.0	0.0	0	0.0
Total, Facility district	0	0.0		0	0.0
Total	157	2.8		188	3.3
Laitteet, asukas	166	2.9	0.02	199	3.5
Total, Tenant electric	166	2.9		199	3.5
Grand total	323	5.7		387	6.8

9.1.3 Monthly Purchased/Sold Energy



9.1.4 Monthly Primary Energy



Month	Facility electric		Facility district		Tenant electric
	Jäähdytys	LVI sähkö	Lämmitys, kaukolämpö	LKV, kaukolämpö	Laitteet, asukas

	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	14.1	16.9
2	0.0	0.0	12.0	14.4	0.0	0.0	0.0	0.0	12.7	15.3
3	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	14.1	16.9
4	0.0	0.0	12.9	15.4	0.0	0.0	0.0	0.0	13.6	16.3
5	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	14.1	16.9
6	0.0	0.0	12.9	15.4	0.0	0.0	0.0	0.0	13.6	16.3
7	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	14.1	16.9
8	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	14.1	16.9
9	0.0	0.0	12.9	15.4	0.0	0.0	0.0	0.0	13.6	16.3
10	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	14.1	16.9
11	0.0	0.0	12.9	15.4	0.0	0.0	0.0	0.0	13.6	16.3
12	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	14.1	16.9
Total	0.0	0.0	156.6	187.9	0.0	0.0	0.0	0.0	165.7	198.8

IDA Indoor Climate and Energy

Version: 4.8

License: IDA40:ICE40XL:ED143/W7N6Y (educational license)

EQUA SIMULATION TECHNOLOGY GROUP

<table>
<tr><td colspan="2"></td><td colspan="2">Delivered Energy Report</td></tr>
<tr><td colspan="2">Project</td><td colspan="2">Building</td></tr>
<tr><td colspan="2">FIN YMa1010/2017Erillinen_pientalo
Mallinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus YMa1010/2017 mukainen.
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Mallinnusta täydennetty ”YMohje (”D5”) 2018” arvoilla seuraavasti:
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-Lämpimän käyttöveden lämmitysenergian nettotarpeelle ei ole käytetty YM asetuksen 5/13 mukaista asuntojen lukumäärään sidottua rajoitetta.
-Lämpimän käyttöveden pumpun sähkönkulutus ”YMohje (”D5”) 2018” kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D)
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<tr><td>Customer</td><td></td><td>Model volume</td><td>152.2 m³</td></tr>
<tr><td>Created by</td><td>Jyoti Kandel</td><td>Model ground area</td><td>58.6 m²</td></tr>
<tr><td>Location</td><td>New Delhi/Safdarjun_421820 (ASHRAE 2013)1</td><td>Model envelope area</td><td>140.5 m²</td></tr>
<tr><td>Climate file</td><td>NPL_Surkhet.444160_SWERA</td><td>Window/Envelope</td><td>7.9 %</td></tr>
</table>

Case	case 2 redone with door and windows	Average U-value	2.344 W/(m^2 K)
Simulated	4.12.2018 17.09.57	Envelope area per Volume	0.9231 m^2/m^3

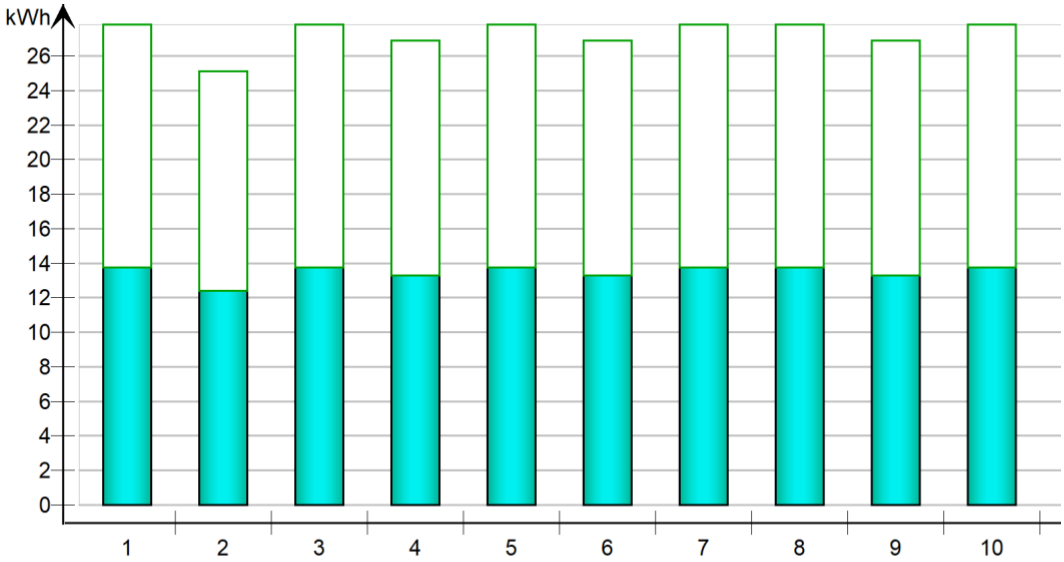
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	0 %

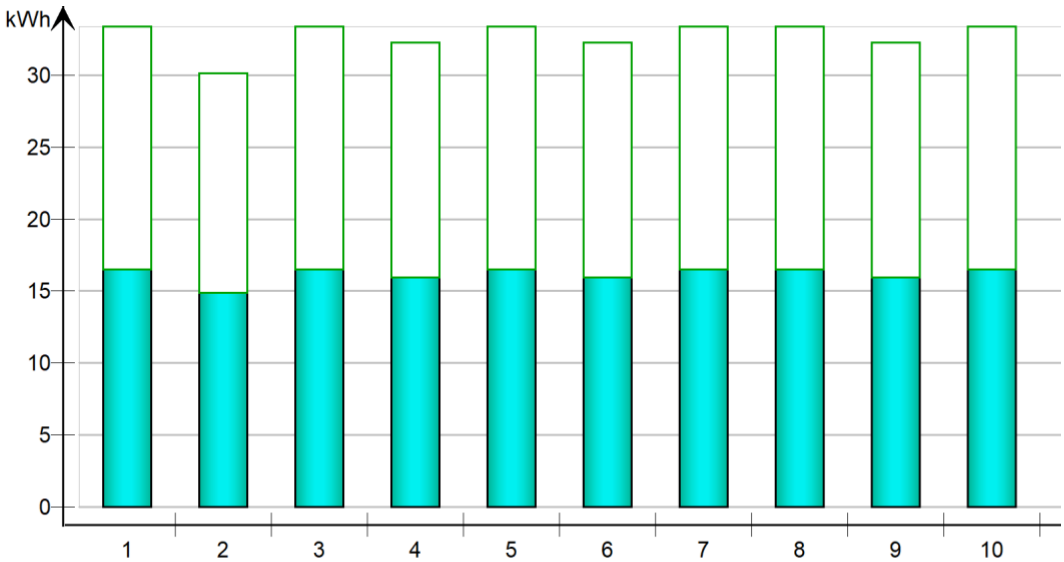
Delivered Energy Overview

	Purchased energy		Peak demand	Primary energy	
	kWh	**kWh/m²**	**kW**	**kWh**	**kWh/m²**
Jäähdytys	0	0.0	0.0	0	0.0
LVI sähkö	162	2.8	0.02	194	3.3
Total, Facility electric	162	2.8		194	3.3
Lämmitys, kaukolämpö	0	0.0	0.0	0	0.0
LKV, kaukolämpö	0	0.0	0.0	0	0.0
Total, Facility district	0	0.0		0	0.0
Total	162	2.8		194	3.3
Laitteet, asukas	166	2.8	0.02	199	3.4
Total, Tenant electric	166	2.8		199	3.4
Grand total	328	5.6		393	6.7

Monthly Purchased/Sold Energy



Monthly Primary Energy



Month	Facility electric				Facility district				Tenant electric	
	Jäähdytys		LVI sähkö		Lämmitys, kaukolämpö		LKV, kaukolämpö		Laitteet, asukas	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
2	0.0	0.0	12.4	14.9	0.0	0.0	0.0	0.0	12.7	15.3
3	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
4	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3

5	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
6	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3
7	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
8	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
9	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3
10	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
11	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3
12	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
Total	0.0	0.0	161.9	194.2	0.0	0.0	0.0	0.0	165.7	198.8

IDA Indoor Climate and Energy

Version: 4.8

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SIMULATION TECHNOLOGY GROUP	**Deliv** **Energy**

Project		**Building**	
FIN YMa1010/2017Erillinen_pientalo Mallinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus YMa1010/2017 mukainen. -Vuotoilma YMa1010/2017 kohta 4.3.3 ja 2.3.2(tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty "YMohje ("D5") 2018" arvoilla seuraavasti: -"YMohje ("D5") 2018" taulukko 3.1-3.3, rakenteiden väliset kylmäsillat (betoniset rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, "YMohje ("D5") 2018" taulukko 7.1 (ja 7.2) -Lämmitysjärjestelmien lämmönjaon ja -luovutuksen vuosihyötysuhde, "YMohje ("D5") 2018" taulukko 6.1 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, "YMohje ("D5") 2018" taulukko 6.1 -Lämpimän käyttöveden häviöt "YMohje ("D5") 2018" kohta 6.3 (ei varaajaa). Kiertojohdon ominaispituus 0,20 m/m2. Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 44 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohdon häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden lämmitysenergian nettotarpeelle ei ole käytetty YM asetuksen 5/13 mukaista asuntojen lukumäärään sidottua rajoitetta. -Lämpimän käyttöveden pumpun sähkönkulutus "YMohje ("D5") 2018" kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D) -Tasauslaskimeen(IDA-tuloste) kaikki lähtötiedot syötetään lämpimien tilojen mukaisilla arvoilla. Käyttäjän tulee itse täydentää ja tarvittaessa myös muuttaa tietoja tasauslaskentatulostukseen. -Halutessaan energiatodistustulosteen(IDA-tuloste) luokan 9 rakennukseen käyttäjä voi valita rakennuksen mallipohjaksi jonkun luokan 1-8 rakennuksista ja muuttaa sitä suunnittelutapausta vastaavaksi. Simuloinnin jälkeen käyttäjä voi sitten muuttaa rakennuksen käyttötarkoitusluokan IDA-energiatodistustulosteen sivulle 1.		Model floor area	58.6 m^2
Customer		Model volume	152.2 m^3
Created by	Jyoti Kandel	Model ground area	58.6 m^2
Location	New Delhi/Safdarjun_421820 (ASHRAE 2013)1	Model envelope area	139.7 m^2
Climate file	NPL_Surkhet.444160_SWERA	Window/Envelope	7.9 %
Case	improved house redone- 34.98 degrees	Average U-value	0.9178 W/(m^2 K)

Simulated	5.12.2018 20.19.33	Envelope area per Volume	0.9174 m^2/m^3

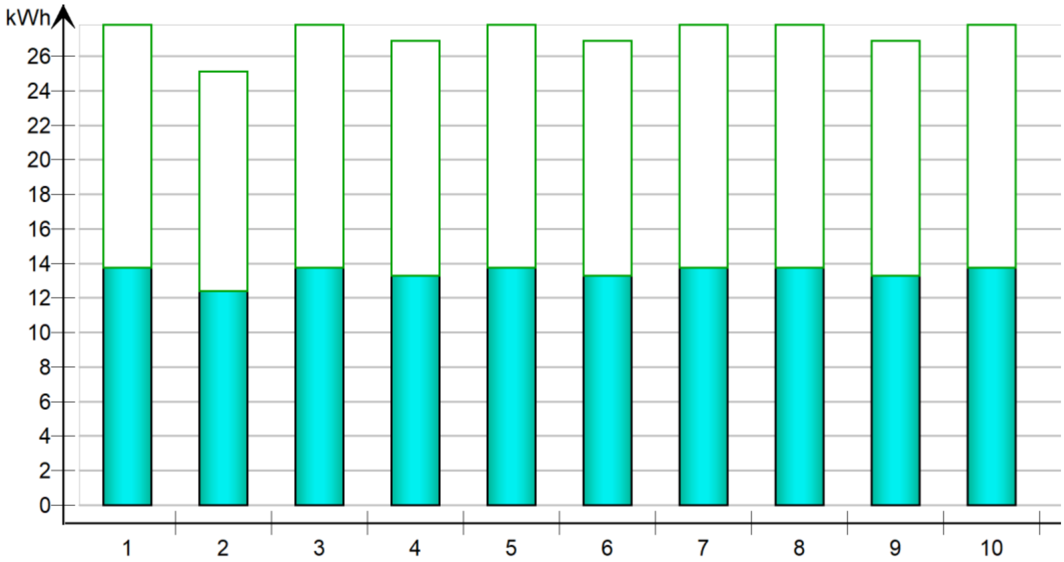
9.1.5 Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	0 %

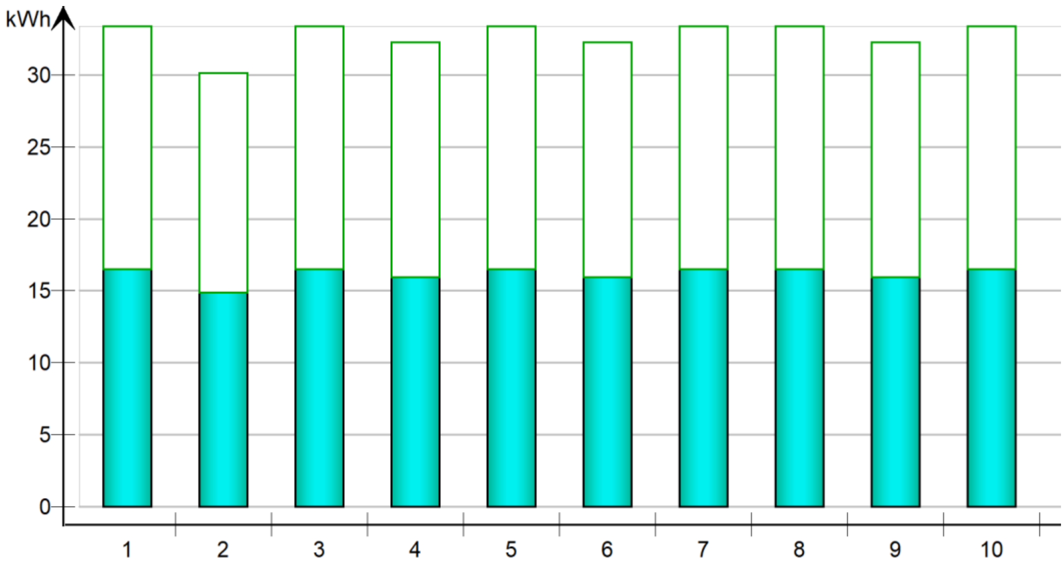
9.1.6 Delivered Energy Overview

	Purchased energy		Peak demand	Primary energy	
	kWh	**kWh/m²**	**kW**	**kWh**	**kWh/m²**
Jäähdytys	0	0.0	0.0	0	0.0
LVI sähkö	162	2.8	0.02	194	3.3
Total, Facility electric	162	2.8		194	3.3
Lämmitys, kaukolämpö	0	0.0	0.0	0	0.0
LKV, kaukolämpö	0	0.0	0.0	0	0.0
Total, Facility district	0	0.0		0	0.0
Total	162	2.8		194	3.3
Laitteet, asukas	166	2.8	0.02	199	3.4
Total, Tenant electric	166	2.8		199	3.4
Grand total	328	5.6		393	6.7

9.1.7 Monthly Purchased/Sold Energy



9.1.8 Monthly Primary Energy



Month	Facility electric		Facility district		Tenant electric
	Jäähdytys	LVI sähkö	Lämmitys, kaukolämpö	LKV, kaukolämpö	Laitteet, asukas

	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
2	0.0	0.0	12.4	14.9	0.0	0.0	0.0	0.0	12.7	15.3
3	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
4	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3
5	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
6	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3
7	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
8	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
9	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3
10	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
11	0.0	0.0	13.3	16.0	0.0	0.0	0.0	0.0	13.6	16.3
12	0.0	0.0	13.8	16.5	0.0	0.0	0.0	0.0	14.1	16.9
Total	0.0	0.0	161.9	194.2	0.0	0.0	0.0	0.0	165.7	198.8

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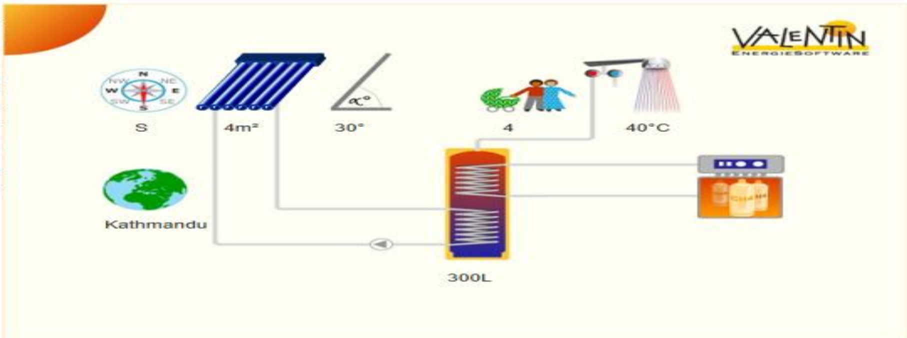
Calculation

Online Solar Thermal Calculation Help

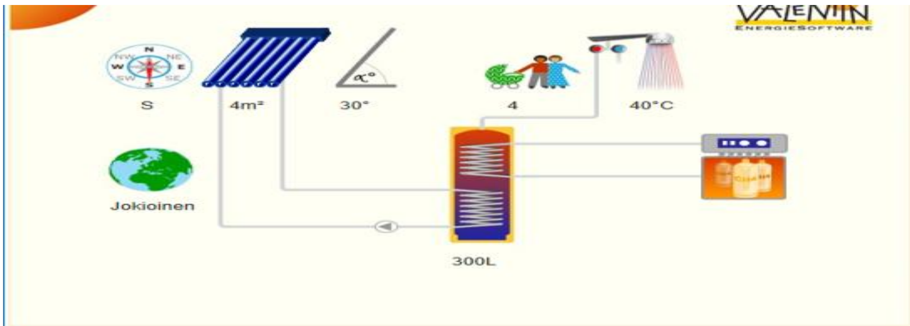


Results

Irradiation:	8.176 kWh/a
System yield:	2.761 kWh/a
Solar fraction:	100 %
CO^2 savings:	560 kg/a

Irradiation:	Solar radiation onto the tilted surface of the collector absorber surface, over one year
System yield:	Solar system's available energy
Solar fraction:	Percentage of the total energy requirement produced by the solar system (= system yield)
Efficiency:	System yield/irradiation
CO^2 savings:	Emissions avoided by use of the system in kg/year

T*SOL Professional is available for detailed calculation and simulation of solar thermal systems.
Full information: www.valentin-software.com



Results

Irradiation:	4.357 kWh/a
System yield:	1.453 kWh/a
Solar fraction:	66 %
CO^2 savings:	294 kg/a

Irradiation:	Solar radiation onto the tilted surface of the collector absorber surface, over one year
System yield:	Solar system's available energy
Solar fraction:	Percentage of the total energy requirement produced by the solar system (= system yield)
Efficiency:	System yield/irradiation
CO^2 savings:	Emissions avoided by use of the system in kg/year

T*SOL Professional is available for detailed calculation and simulation of solar thermal systems.
Full information: www.valentin-software.com