# POTENTIAL FOR DEVELOPING NET ZERO ENERGY HOUSING IN SRI LANKAN URBAN SECTOR

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Degree of Master of Engineering

Department of Mechanical Engineering

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Thesis submitted in partial fulfillment of requirements for the degree Master of Engineering in Energy Technology


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**DECLARATION**

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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**ABSTRACT**

Energy has become a fundamental need of humans in the world to fulfill their day today requirements. Mainly primary energy is supplied by Fossil fuel (Oil, Natural Gas, Coal), Nuclear, Hydro and other renewables. Among these energy sources, Fossil fuel contribution for the total energy supply is around 82% out of the total energy supply in 2012. But according to the current available data, all fossil fuel will run out before end of this century. And also other main concern in between environmental scientist is the global warming due to the greenhouse gas (GHGs) emissions which are mainly released at the fossil fuel burning. So definitely, renewable energy sources will be the only option to get required energy as much as possible as an alternative for the fossil fuel and also to reduce the GHGs emission.

In Sri Lanka this figure is slightly different. Biomass is the major energy supply source. In connection with the electricity generation Sri Lanka, thermal electricity generation has the highest contribution to total generation. As well the generation from renewable energy sources has increased year by year. In connection with the electricity consumption, domestic sector consumes 38% out of total energy consumption while commercial sector consumes 26% and industrial sector 34%. So it can be seen that the domestic sector is the highest electricity consumer. From this thesis, the potential for net zero energy home in Sri Lankan urban sector will be discussed. If this is successful, 38% electricity consumption can offset from the renewable energy generation at the each home including rural sector also. Then the thermal generation can be minimized while using renewable energy sources as much as possible to cater the demand of industrial sector and also commercial sector. Hence massive expenses for oil and coal can be reduced and then it will be a significant contribution for reduction of GHGs emission as well.

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**CONTENTS**

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| NZEH | Net Zero Energy Home |
| GHG | Green House Gas |
| USA | United State of America |
| UK | United Kingdom |
| SLSEA | Sri Lanka Sustainable Energy Authority |
| SEA | Sustainable Energy Authority |
| EU | European Commission |
| IEA | International Energy Agency |
| CEC | California Energy Commission |
| CPUC | California Public Utility Commission |
| NZSE | Net Zero Site Energy |
| NZSE | Net Zero Source Energy |
| NZEC | Net Zero Energy Cost |
| NZEE | Net Zero Energy Emissions |
| NIST | National Institute of Standard and Technology |
| CUF | Capacity Utilization Factor |

# 1 INTRODUCTION

This chapter will give a brief introduction of energy supply and consumption statistics in global sector and also in Sri Lankan context.

## 1.1 Background

Energy is a very important and is directly linked to well-being and prosperity of the human across the world. It has become a fundamental to the quality of human lives and nowadays we are totally dependent on uninterrupted supplies of energy to carry out our day to day work. As well it is a key ingredient in all sectors of modern economies.

The main primary energy sources can be categorized as fossil fuels (oil, natural gas and coal), nuclear, hydro, biofuels, biomass & waste, solar, wind and Geothermal.

The global fossil fuel consumption is rising with rapid economic growth of developing countries. At the same time, the rate of addition of GHGs to the environment is also increasing rapidly due to this increasing of fossil fuel consumption. So this is directly effect to the global warming.

Issues of the global warming and climate changes are being discussed among the scientists and environmental campaigners in a very high rate during past several years. These global issues are becoming significant for all countries specially for developed countries to raise awareness of the consequences of global warming to the public and set new regulations, standards and goals to control the concerns of global warming to the earth and humanity.  Main focus to reduce the global warming is, minimize the fossil fuel usage and find the alternatives renewable energies for that.



## 1.2 Global Primary Energy Supply and Consumption

According to the energy supply data by source (IEA, 2014), it can be noticed that the energy supply from the fossil fuel (Oil, Natural Gas and Coal) is around 81.7% percentage from the total energy supply while the nuclear energy supply is 4.8%, hydro energy supply is 2.4%, biofuel and waste energy supply is 10% and wind, solar, geothermal and biogas energy supply is 1.1% as indicated in figure 1.1.

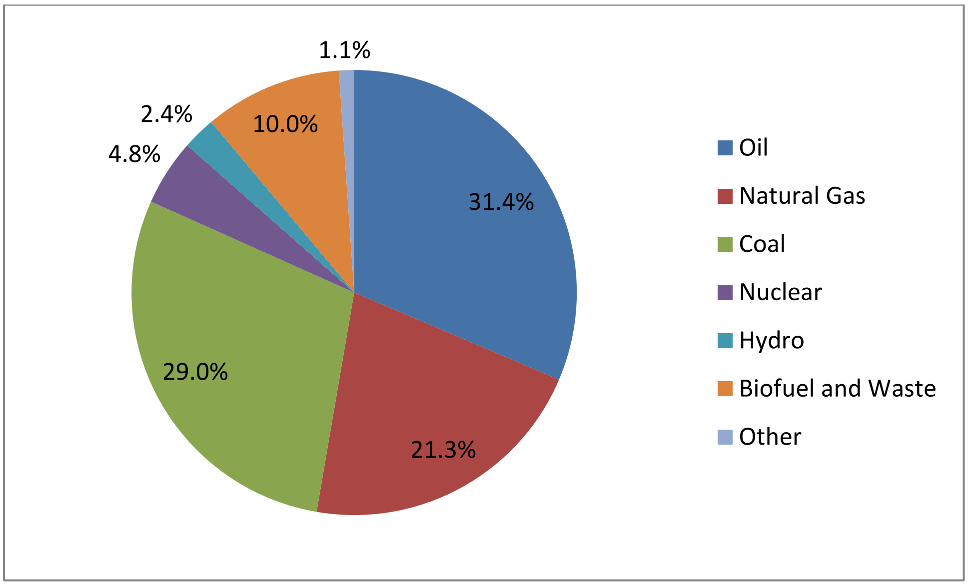


**Figure 1.1: Global primary energy supply by source (IEA, 2014)**

Global energy consumption by sector has been indicated in figure 1.2. According to that industrial sector consumes 52%, transportation sector consumes 26%, domestic sector consumes 14% and also commercial sector consume 8% out of the total energy consumption (Annual Energy Outlook 2014, 2014).



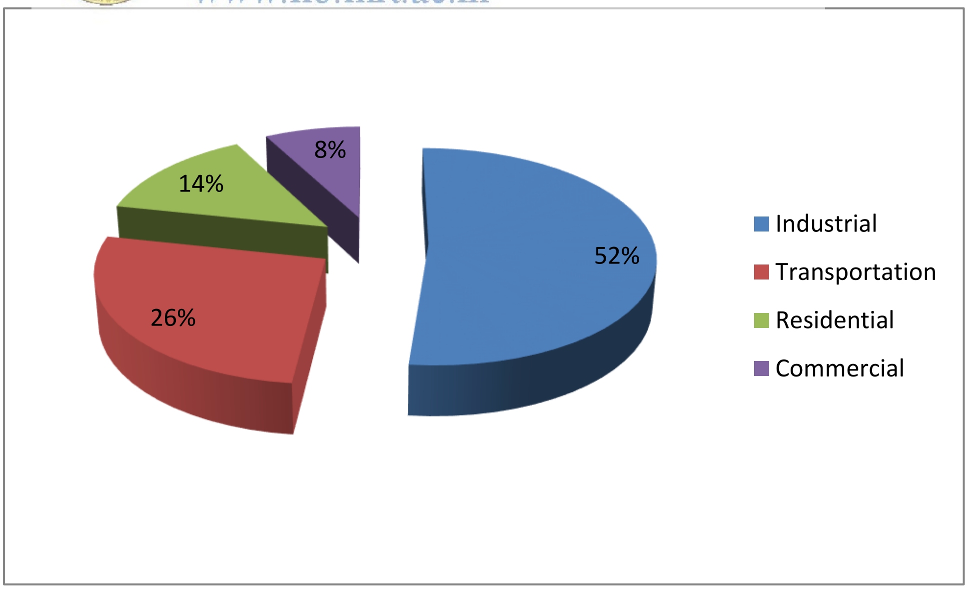


**Figure 1.2: Global energy consumption by sector (IEA, 2014)**

According to the Current consumption rate of fossil fuels, oil will run out on 2053, Gas will run out on 2059 and coal will run out 2088 as indicated figure 1.3.

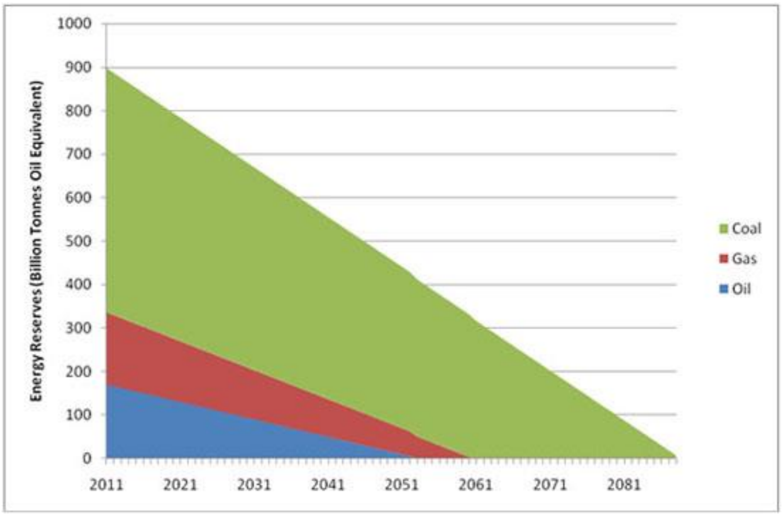


**Figure 1.3: Rate of Fossil Fuel Consumption (Gore)**

Lot of countries has taken actions to increase the usage of renewable energies to compensate for the fossil fuel as a solution for the decomposition of the fossil fuel and also in order to minimize the GHGs emission. International Renewable Energy Agency is the one of main organizations which has been formed for the development of renewable energy sector in the world.



So it is very essential to increase the usage of renewable energy sources to furnish the global energy demand and also to reduce the adding of greenhouse gases to the environment by the same time as solution for the global warming.

### 1.3 Global Electricity Generation and Consumption

Electricity is the main secondary energy source which is used in the world. As an energy source, it is very easy and convenient way to use in all sectors comparatively other energy sources biomass, LP gas, etc…. So it is important to take a look on electricity generation also.

### 1.3.1 Global electricity generation by source

The contribution for the global electricity generation by source has been indicated in figure 1.4 and according to that 67% of them are from fossil fuels, 17% of them are from Hydro and 5% of them are from other renewable sources.

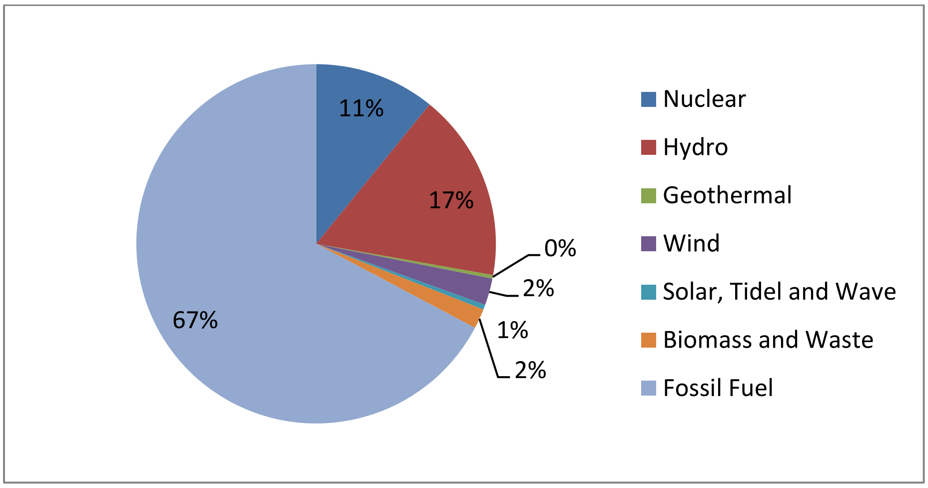


**Figure 1.4 : Global Electricity Generation by Source (IEA, 2014)**

Contribution for the global electricity generation from renewable energy sources has been increased rapidly as indicated figure 1.5. According to that renewable energy sources have generated electricity 3750 Billons kWh in 2008 and 4720 Billion kWh in 2012.



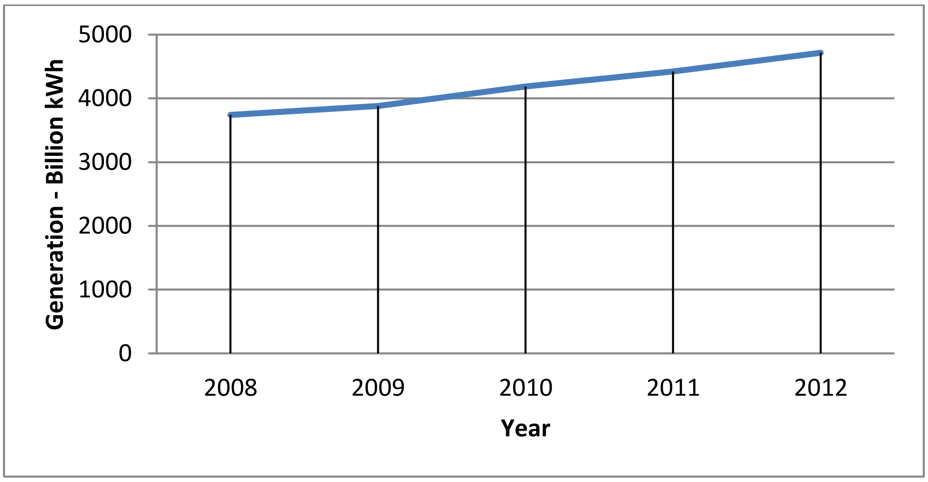


**Figure 1.5: Electricity Generation by Renewables (IEA, 2014)**

So it can be seen that the trend of using renewable energies has been increased specially due to the environmental issues with the fossil fuels and also as a solution for the fossil fuel degradation.

In the figure 1.6, it has been indicated that the growth of the contribution of each energy source to global power generation. There is a huge trend for solar photovoltaic and it is 69% and for the wind power generation growth rate is 25% and biofuels growth rate is 17.6%. In this figure also, it can be seen that the trend of the using renewable energy usage for the power generation is very high comparatively fossil fuels.

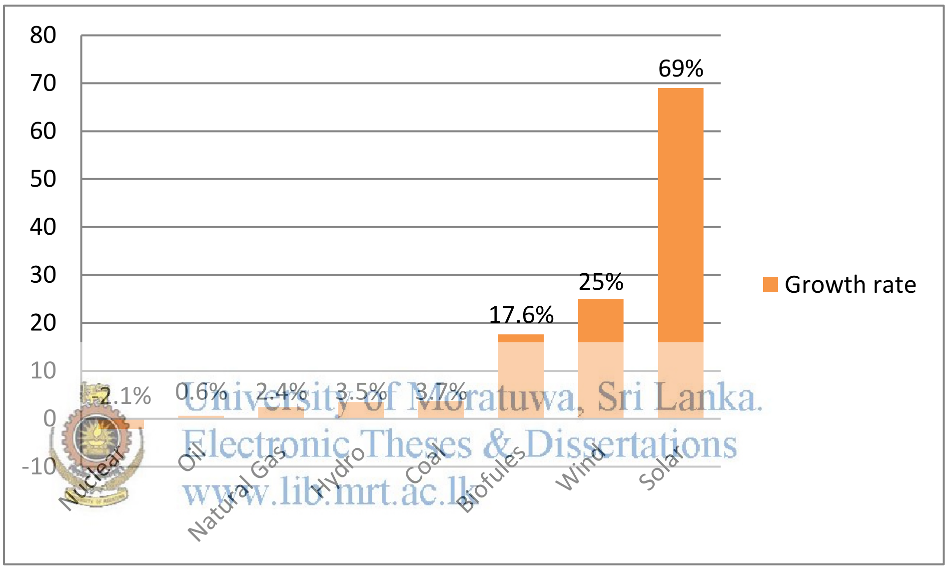




**Figure 1.6: Global Growth Rate of Energy Consumption by Source (IEA, 2014)**

### 1.4 Primary Energy Supply and Consumption in Sri Lanka

In connection with primary energy supply in Sri Lanka, it can be noticed that the primary energy supply from the renewable energy sources has increased gradually from 0.1% to 1.6% from the year of 2000 to 2012 (SLSEA, 2012) as indicated in figure 1.7 and table 1.1.

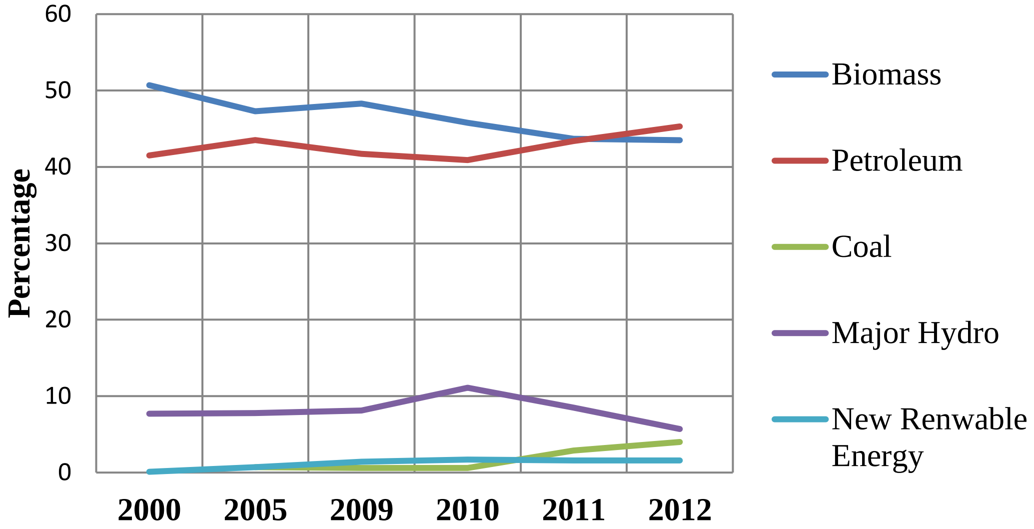


**Figure 1.7: Energy Supply by Source (SLSEA, 2012)**

Biomass usage has decreased by 7.2% while petroleum and coal usage has increased by 4.2% and 3.3%.

**Table 1.1: Primary Energy Supply by Source (SLSEA, 2012)**

| ktoe | 2000 | 2005 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| Biomass | 4,469.80 | 4,668.30 | 4,786.20 | 4,954 | 4,944.40 | 5,014.00 |
| Petroleum | 3,656.10 | 4,289.70 | 4,130.90 | 4,420.50 | 4,914.80 | 5,219.60 |
| Coal | - | 64.9 | 58.7 | 59.9 | 324 | 455.9 |
| Major Hydro | 675.1 | 773.4 | 805.3 | 1197.2 | 964.2 | 654.4 |
| New Renewable energy | 13.2 | 71 | 136.5 | 179.7 | 178.4 | 180.6 |
| Total | 8,814.10 | 9,867.30 | 9,917.70 | 10,811.40 | 11,325.80 | 11,524.60 |
| **PJ** | | | | | | |
| Biomass | 187.1 | 195.5 | 200.4 | 207.4 | 207 | 209.9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Petroleum | 153.1 | 179.6 | 173 | 185.1 | 205.8 | 218.5 |
| Coal | - | 2.7 | 2.5 | 2.5 | 13.6 | 19.1 |
| Major Hydro | 28.3 | 32.4 | 33.7 | 50.1 | 40.4 | 27.4 |
| New Renewable energy | 0.6 | 3 | 5.7 | 7.5 | 7.5 | 7.6 |
| Total | 369 | 413.1 | 415.2 | 452.7 | 474.2 | 482.5 |
| **Percentage(%)** | | | | | | |
| Biomass | 50.7 | 47.3 | 48.3 | 45.8 | 43.7 | 43.5 |
| Petroleum | 41.5 | 43.5 | 41.7 | 40.9 | 43.4 | 45.3 |
| Coal | - | 0.7 | 0.6 | 0.6 | 2.9 | 4 |
| Major Hydro | 7.7 | 7.8 | 8.1 | 11.1 | 8.5 | 5.7 |
| New Renewable energy | 0.1 | 0.7 | 1.4 | 1.7 | 1.6 | 1.6 |



Primary energy consumption in all sectors in year 2012 in Sri Lanka has been indicated in figure 1.8.

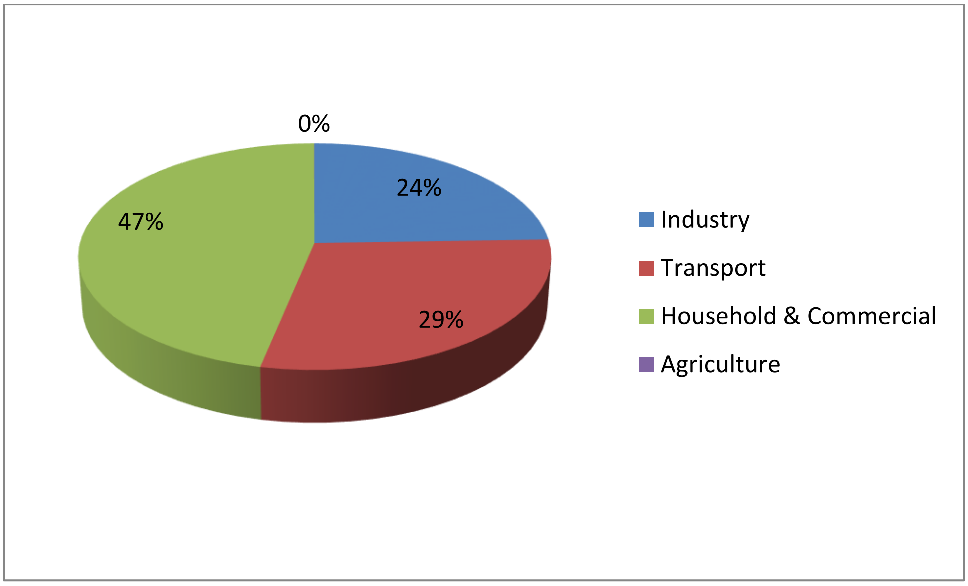


**Figure 1.8: Energy consumption by sector (SLSEA, 2012)**

According to this figure, it can be seen that the household and commercial sector consume 47% out of total energy consumption. Data could not found separate energy consumption for domestic sector only.



## 1.5 Electricity Generation and Consumption in Sri Lanka

### 1.5.1 Electricity Generation

Electricity generation from the year of 2000 to 2012 is indicated in table1.2. According to that generation form Thermal source (Oil & Coal) is the highest contribution for the total generation. Renewable generation has increased year by year.

**Table 1.2: Electricity Generation by Source**

| GWh | 2000 | 2005 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| Major hydro | 2,812.80 | 3,222.50 | 3,355.60 | 4,988.50 | 4,017.50 | 2,726.70 |
| Thermal (Oil) | 3,512.40 | 5,339.30 | 6,062.50 | 5,063.30 | 5,857.50 | 7,012.70 |
| Thermal (Coal) | - | - | - | - | 1,038.10 | 1,403.70 |
| CEB wind | 3.4 | 2.4 | 3.5 | 3 | 2.7 | 2.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| New Renewable Energy | 43.3 | 279.7 | 548.5 | 728.5 | 722.3 | 733.3 |
| Gross Generation to CEB Grid | 6,371.80 | 8,844.00 | 9,970.10 | 10,783.20 | 11,627.80 | 11,878.80 |

(SLSEA, 2012)

The growth of the contribution from renewable energy for electrical generation in Sri Lanka has been depicted in the figure 1.7. According to that it has increased rapidly from year 2000 to 2010 and after that it has increased slightly in 2012.

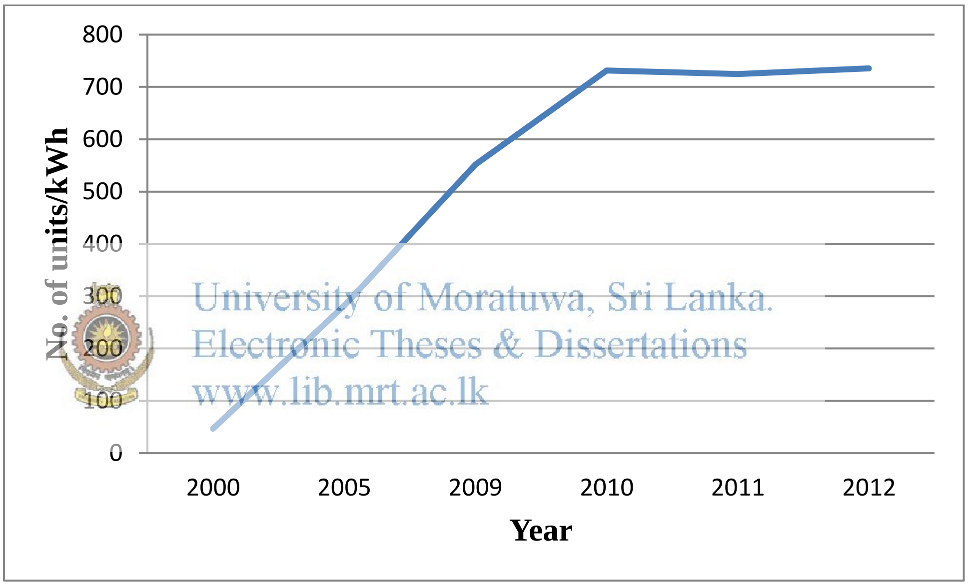



**Figure 1.9: Electricity generations from renewables (SLSEA, 2012)**

### 1.5.2 Electricity Consumption

According to the Figure 1.7, the largest sector of the electricity consumption in Sri Lanka is domestic sector and it is 38% out of the total electricity consumption. Commercial sector consumes 26% while industrial sector consumes 34%. Religious sector and Street lighting consume 2% out of total electricity consumption.

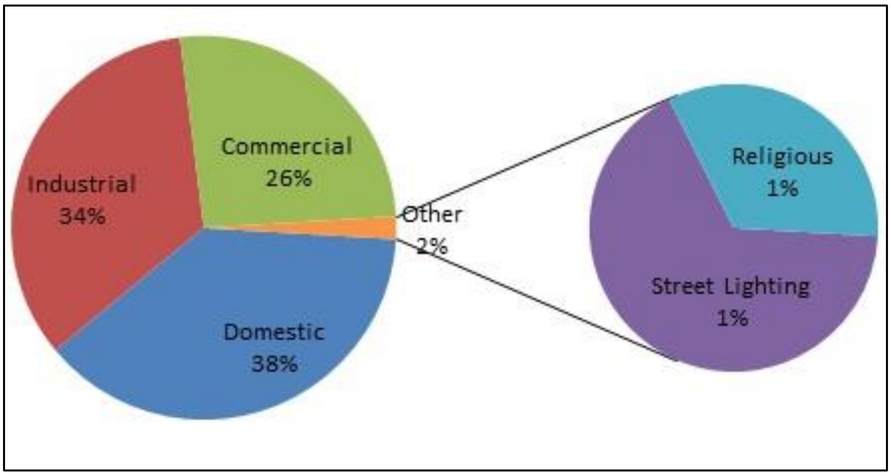


**Figure 1.10: Electricity Consumption by Sector (SLSEA, 2012)**

In connection with the Sri Lanka, total numbers of houses is 2,813,844 (Census, 2012). Among these houses, 511,810 houses are in urban sector and 2,084,841 houses are in rural sector while 217,193 houses are in lane. Among above houses, 87% is used the electricity from the national grid for their day to day energy requirement. From the urban sector houses, 96.8 houses are using electricity, among rural sector, 85.2% houses are using electricity while 79.9% houses are using electricity among the other sector houses.



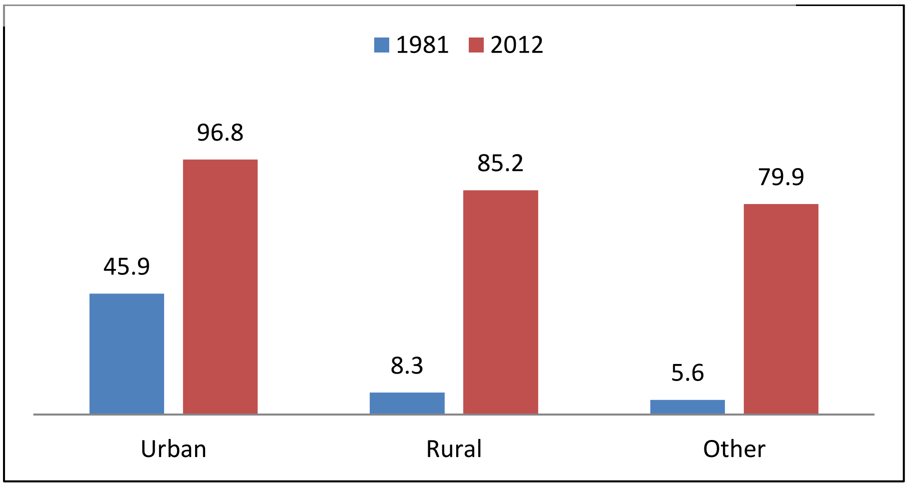


**Figure 1.11: Domestic Electricity Usage from national grid (Census, 2012)**

### 1.6 Problem Identification

According to the above statistics, household and commercial sector energy consumption is 47% out of total energy consumption. Energy consumption only in domestic sector cannot be found.

Main energy consumption methods are electricity and LP gas in Sri Lankan Urban sector. Total electricity consumption in Sri Lanka by domestic sector is 38%. If this electricity consumption can be produced by using existing renewable energy sources at the home, it will be a remarkable solution for current energy cost which is spent for fossil fuels and also to reduce the GHGs emission. It is not an easy task. There should be a proper plan for the building envelop also from the stage of the construction of the building and also good coordination in between Architects, Engineers and consultants.

Even this NZEH concept is being practiced in many countries in the world such as UK, USA, Canada, Korea, etc…., there is no any action plan or national goal or even a guide line in Sri Lanka to implement this concept upto now. There is a guide line called "code of practice" for energy efficient building which has been published by the sustainable energy authority(SEA) but it is not for the NZEH concept.



So it is very essential to introduce a this type of concept to Sri Lanka in order to minimize the energy consumption from national grid and reach to net zero targets through the domestic electricity and LP gas consumption. In this thesis, only urban sector has been considered.

### 1.7 Aim

The aim of this thesis is to identify the potential of NZEH in Sri Lankan urban sector and how far it is practicable in connection with environment, energy and cost.

### 1.8 Objectives

Objectives of this thesis are to study the energy consumption pattern in Sri Lanka and to identify the potential of developing NZEH for Sri Lankan urban sector. And also guidelines which will be supportive for NZEH design will be proposed.

### 1.9 Methodology

- Discuss the current energy consumption statistics in Sri Lanka and in the world.

- Identify the literature available for NZE homes and gather the required information from them.
- Data collection from residencies in urban areas in the country and analyze the energy consumption pattern of them and recognize the shortcomings of the existing houses in connection with the energy efficiency, building envelop and renewable energy generation trend.
- Identify the architectural concerns in order to minimize the space heating and increase the day lighting and natural ventilation.
- Identify the basic energy usage methods in domestic sector and propose the current available technologies and methods to minimize the energy consumption.
- Identify the potential to produce the required energy consumption by using site-based renewable energy systems.

## 1.10 Introduction to the chapters

This thesis has been divided into six chapters as introduction, literature review, methodology, discussions, guidelines to NZEH and conclusion.

At the introduction chapter, global and Sri Lankan energy supply and consumption, problem identification, objectives of the thesis and methodology have been discussed. Literature and definitions available for NZEH will be discussed at the chapter of literature review. Next chapter is methodology and in this chapter all the collected data has been summarized and descriptive analysis has been done. Next chapter is discussions. At this chapter all the outcomes of data analysis will be discussed broadly. Next chapter is guidelines for NZEH and it will describe the basic guidelines to achieve NZEH. Final chapter is the conclusion.

# 2 LITERATURE REVIEW

This chapter will describes the literature available in connection with the NZEHs in the world and the global trend, current regulations, action plans which have been implemented by several countries to achieve the NZEHs. As well the current definitions available for the NZEHs have been discussed briefly.

## 2.1 Background

It can be found lot of ongoing projects, action plans to achieve NZEHs in the world and few of them have been discussed below.

According to the literature available, the first country which required the NZE for both residential and commercial buildings was the United Kingdom. Its Energy Efficiency Action Plan of 2007 stated that in the household sector, they will continue to raise energy performance standards for new homes in England and Wales through Part L of the Building Regulations with the aim of delivering net zero energy homes by 2016. The Code for Sustainable Homes will support this ambition and drive wider environmental improvements in new homes.



By the same time, the Welsh Assembly Government implemented the target that all new buildings, not just housing, must be zero energy in relation to space heating, hot water and lighting by 2011. The UK government has meanwhile announced to be conducting feasibility studies to enforce the NZEB target also for non-residential buildings.

As well in USA, California Energy Commission (CEC) and California Public Utility Commission (CPUC) has published an action plan called California Energy Efficiency Action Plan to achieve the NZEHs in 2020. This has been published in 2008 and has been updated in 2011. It has outlined goals and strategies for key market sectors such as commercial, residential, industrial, and agricultural and crosscutting initiatives such as heating, ventilation, and air conditioning (HVAC), codes and standards, research and technology in order to reduce the barriers to the adoption of energy efficiency measures.

Other NZEB implementation examples are in France, where all new buildings should be energy positive by 2020 (EU, 2009) and Hungary, which has set the target of achieving zero emissions for all new buildings by 2020 (Kapsalaki, 2012).

Ireland has planned to have net zero energy buildings by 2013 and in the Netherlands there is a voluntary agreement with industry to have energy zero buildings in 2020 (EU, 2009).
Furthermore Sweden has proposed a strategy for all public buildings to be zero energy 2019 extending to all buildings by 2021 (Almeida, 2012). Finally, in Norway zero energy buildings are expected by 2027.

Rest parts of the World; South Korea has included residential NZEBs by 2025 as part of a Green Building Policy Package (Benn, 2011) to fulfill the objective of low carbon green growth.

## 2.2 Definitions of Net Zero Energy Concept

There are several definitions for net zero energy concepts commonly for both domestic and commercial building sector. It can be defined in several ways, depending on boundary and the metric. Most common definitions are Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Costs and Net Zero Energy Emissions (VU, 2010) as described below.

### 2.2.1 Net Zero Site Energy (NZSE)



A Site NZEB produces at least as much energy as it uses in a year, when accounted for at the site. For the generation, roof mounted PV system, roof mounted small wind turbine, parking lot mounted PV system can be used. Disadvantage of the site ZEB definition is that the values of various fuels at the source are not considered.

### 2.2.2 Net Zero Source Energy (NZSE)

A Source ZEB produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building’s total sources the appropriate site-to-source conversion multipliers are used to calculate the imported energy and exported energy.

### 2.2.3 Net Zero Energy Costs (NZEC)

In a Cost ZEB, the amount of money the utility pays the building owner for the energy that the building exports to the grid is at least equal to the amount the owner pays to the utility for the energy services and energy used over the year.

### 2.2.4 Net Zero Energy Emissions (NZEE)

A Net-zero emissions building produces at least as much emissions free renewable energy as it uses from emissions-producing energy sources. For the generation they can use the possible renewable energies within the building foot print and at the site. If they take all electrical requirement in the building from off-site renewable electricity generation system such as hydro, nuclear or wind, it is already zero emissions and no need to generate on-site any renewable energy to offset emissions.

Summary of the most common NZEBs definitions has indicated below in table 2.1 with the advantages and disadvantages and the issues of each definition.

**Table 2.1: Summary of common NZEBs Definitions**

| Definition | Pluses | Minuses | Issues |
|---|---|---|---|
| Site ZEB | • Easy to implement.<br>• Verifiable through on-site measurements.<br>• Conservative approach to achieving ZEB.<br>• No externalities affect performance, can track success over time.<br>• Easy for the building community to understand and communicate.<br>• Encourages energy-efficient building designs. | • Requires more PV export to offset natural gas.<br>• Does not consider all utility costs (can have a low load factor).<br>• Not able to equate fuel types.<br>• Does not account for nonenergy differences between fuel types (supply availability, pollution). | |

| | | | |
|---|---|---|---|
| Source ZEB | • Able to equate energy value of fuel types used at the site.<br>• Better model for impact on national energy system.<br>• Easier ZEB to reach. | • Does not account for nonenergy differences between fuel types (supply availability, pollution).<br>• Source calculations too broad (do not account for regional or daily variations in electricity generation heat rates).<br>• Source energy use accounting and fuel switching can have a larger impact than efficiency technologies.<br>• Does not consider all energy costs (can have a low load factor). | • Need to develop site to source conversion factors, which require significant amounts of information to define. |
| Cost ZEB | • Easy to implement and measure.<br>• Market forces result in a good balance between fuel types.<br>• Allows for demand-responsive control.<br>• Verifiable from utility bills. | • May not reflect impact to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid.<br>• Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges. | • Offsetting monthly service and infrastructure charges require going beyond ZEB.<br>• Net metering is not well established, often with capacity limits and at buyback |

| | | | |
|---|---|---|---|
| | | • Highly volatile energy rates make for difficult tracking over time | rates lower than retail rates. |
| Emissions ZEB | • Better model for green power.<br>• Accounts for non-energy differences between fuel types (pollution, greenhouse gases).<br>• Easier ZEB to reach. | | • Need appropriate emission factors. |

In addition to the above definitions, the International Energy Agency (IEA) defines NZEBs are as buildings that do not use fossil fuels but get their entire energy requirement from solar energy and other renewable energy sources (Lausts, 2008). It suggests the following variants.



- Zero Net Energy Buildings are buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. They don't need any fossil fuel for heating, cooling, lighting or any other energy uses although they sometimes draw energy from the grid.
- Zero Stand Alone Buildings are buildings that do not require connection to the grid or do so only as a backup. Stand-alone buildings can independently produce the required energy for their usage as they have the capacity to store the energy for night time or wintertime usage.
- Plus Energy Buildings are buildings that deliver more energy to the grid than they use. These buildings produce more energy than they consume over a year.
- Zero Carbon Buildings are buildings that over a year do not use energy that involves carbon dioxide emission. Over the year, these buildings are carbon neutral or positive in term that they produce enough CO2-free energy to supply themselves.

## 2.3 Net Zero Energy Home Overview

Concept of the net-zero energy is that buildings could generate enough on-site energy to balance-out or exceed their annual energy consumption. The “NET” means the building may use energy from the utility grid during some times of the day but supplies renewable energy back to the grid during other times, in a balance that equals out over the course of a year.

A grid connected NZEH normally uses the conventional energy sources from the utility grid when on-site energy production is not enough to meet the demand. When the on-site generation is greater than the demand, excess electricity is exported to the utility grid. By using the grid to account for the energy balance, excess production can offset later energy use. It is almost impossible to offset building energy demand without being connected to grid with the current technologies. As well reliability of an off-grid home is not acceptable for people live in urban areas due to wide range of uncertainty in power availability and off-grid buildings cannot feed their excess energy production back onto the grid to offset other energy uses.



A pathway to NZEH can be depicted in below figure 2.1. Initially Demand is very high and on-site electricity generation is zero. Once the NZEH system is implemented, demand will gradually decrease and the generation from renewables will gradually increase. The point of crossing these both demand line and generation line is the Net Zero Energy point. From this point, both demand and generation should be maintained equally to survive as a NZEH.

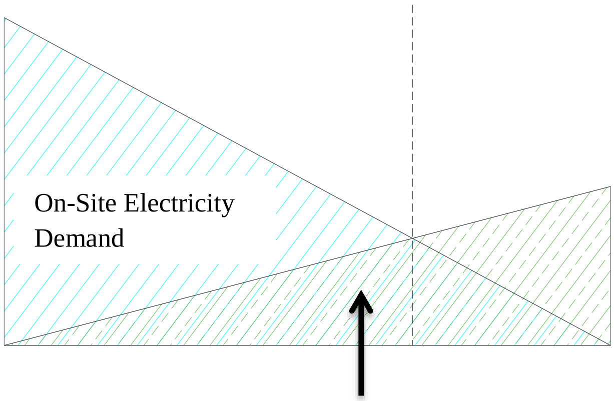


**Figure 2. 1: A Pathway to Net Zero Energy Home** (California Energy Commission, 2013)

Generally, NZEBs can be seen as an extension from the concept of solar or passive buildings which had been developed since the 1970's, and many demonstration buildings have been built around the World.



### 2.3.1 Self-Sufficient Solar House in Freiburg

In 1992, the Fraunhofer Institute for solar energy systems set the operation of the self-sufficient solar house in Freiburg (Freiburg, 2015) as indicated in figure 2.6. This can be considered as the first NZE Residential Building. For three years 1992 to 1995, the house was occupied by a family of two adults and one child and demonstrated that the sun can provide a house with all the required energy that it needs, even in the Central European climate where the solar radiation available is moderate. During that period, the home was not connected to the grid and there was no other external supply of non-solar energy. The success of the project was based on solar generated hydrogen as the energy storage form for electricity & heat and a fuel cell as a miniature cogeneration power plant. Nowadays, the building is used as a research platform.

**Figure 2. 2: Self-Sufficient Solar House in Freiburg**

### 2.3.2 Residential Building in Lakeland, Florida

Another example for a NZEB is the house which was constructed in Lakeland, Florida in 1998. It is an experimental residential building called ‘PVRES’, constructed together with a conventional one (both had the same floor plan) which played the role of the project control. The ‘PVRES’ home (Figure 2.7) had higher levels of thermal insulation, a white reflective roof system, solar water heating and efficient interior appliances and lighting, a high efficiency heat pump and a PV system. Even though the project, did not reach zero energy annual balance. It showed that virtually zero net utility peak coincident demand was possible and became the flagship for the program of the U.S Department of Energy. Zero Energy Homes (Parker 2009).

**Figure 2. 3: Residential Building in Lakeland, Florida**

### 2.3.3 Net Zero Energy Home in Colarado

Another net zero energy home (NZEH) is a 426 m2 house designed and constructed by Eric Doub and his company Ecofutures Building in 2005 (Moore, 2005). It is located in Boulder, Colorado, U.S (Figure 2.8). The concept is a combination of active and passive solar design features with heavy thermal insulation, high performance glazing and windows and highly efficient equipment. All the appliances in the house are electric, with all its electricity needs covered from PV panels while space heating and domestic hot water is supplied by solar thermal flat-plate collectors. As well as it features extended engineered heat recovery ventilation system and a PVC pipe buried underground for seasonal thermal pre-warming and pre-cooling of the incoming fresh air.

**Figure 2. 4: Net Zero Energy Building Home, Colarado**

### 2.4 Net Zero Energy Home Design Process

Design a NZEH is not an easy task. It is an output of a contribution of various parties from design stage including the home owner. Total design process can be categorized into three major steps as indicated below Figure 2.9.



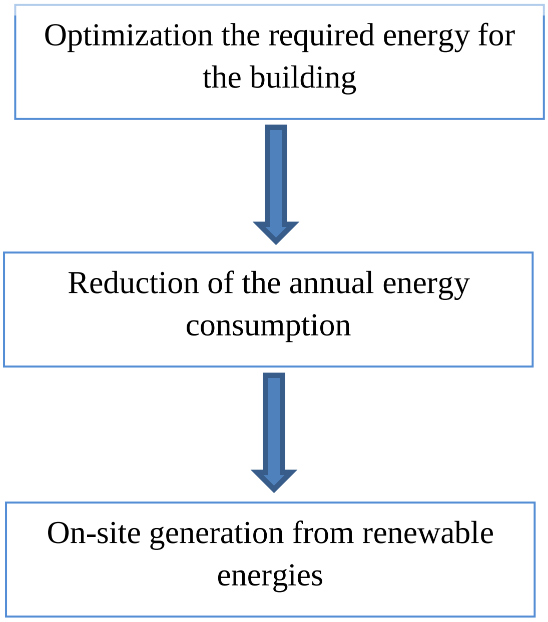


**Figure 2. 5: Three Major Steps of NZEH Design Process**

Building energy requirement reduction is the most important step throughout the design process. This is a comprehensive analysis and optimization process to reduce building energy need in steady-state condition. Reducing building energy demand by analytical analysis between performances, costs, and design will direct the project into a practical path toward the energy reduction.

Step one is performance analysis of building orientation and geometry in reducing energy demand as well as the thermal performance of building components and assemblies such as windows and shades, roof and wall assemblies to select the optimum design scenario. From an architectural view, the building design and siting are necessary considerations for net-zero energy. The overall form of the structure, the climate considerations, and its location and orientation to the sun in relation to the immediate surroundings will all affect the efficiency of the building. Optimization of building energy demand represents optimum architectural design energy performance of the building. Normally as thumb rule it says that the building energy demand can be reduced with proper design and affordable materials and technologies by 30% annually.

After reducing demand side energy requirement, next step is the optimization of energy consumption and it is a less complex process. Building mechanical and electrical systems can be selected and sized based on optimized building energy need. Sensitive factors in this process are energy efficiency, costs, and size of the systems. System selection depends on location, climate zone and availability of systems in the project's region. Scenario analysis indicates how much savings can be achieved based on efficiency and system types and the results of these analyses will led to selection of optimum building systems.



The majority of net-zero buildings are grid-connected consumers of utility energy because the current generation of energy storage technologies is limited. In some cases, renewable energy supply can be directly purchased from the grid. In case of limitation or unavailability of green power, on-site renewable energy production should offset building's annual energy production. One of the benefits of on-site energy generation is reversing buildings strain on utility infrastructure, especially during peak-time periods. In this phase of project, designer should analyze different possibilities of generating energy on-site based on a home's estimated annual energy consumption and other important factors. The study's approach recommends usage of the simplest, widely available technologies to minimize initial costs of systems and maintenance cost of systems during its service time.

### 2.5 Case Study

Four case studies will be discussed under this sub chapter. There are several case studies which have been carried out in various countries and more important case studies have been discussed here.

#### 2.5.1 Net Zero Energy Home in Maryland

This house has been built by National Institute of Standard and Technology (NIST) according to U.S. Green Building Council LEED Platinum standards which are the highest standards for sustainable structures in the country. Under these standards, the test house had been estimated to be 60% more efficient than houses built to meet the requirements of the 2012 International Energy Conservation Code which are the standards adopted for new constructions in Maryland. The floor area of the house is 2,700Sq.Ft and it is two storied one with 4 bed rooms, three bath rooms as indicated in figure 2.9.



**Figure 2. 6: Net Zero Energy Home in Maryland (Bello, 2014)**

The building was extremely well isolated, aiming to cut out air infiltration and heat loses through the walls and roof, including triple-paned windows. The most important difference between this home and a Maryland code-compliant home is the improvement in the thermal envelope, the insulation and air barrier. Apart of the insulation, the house got installed solar water heating and 32 solar panels in order to produce its own energy, and have been equipped with the most energy-efficient appliances.

In a typical year, a comparable size home in Maryland would consume an average of almost 27,000 kWh of energy. Starting the summer, the solar panels has produced more energy than the house used from July to October, but during the winter was much colder than previous ones and the snow has covered during 38 days the sun-powered system. The house has used 3,000 kWh more energy during the year of the study than it had been projected for the region's typical weather. In November, it has begun running negative numbers monthly and at the end of March, the energy shortage was 1,800 kWh. In April, the energy yield has increased again, and the house injected electric power to the grid on most of the days.

In total, the photovoltaic had produced 13,577 kWh of energy, while the house only had used 13,086 kWh in the whole year. The Net-Zero-Energy house from the NIST has showed to be 70% more efficient, instead of the 60% initially estimated, than houses meeting the standards adopted in Maryland. The NIST suggests that a Net-Zero-Energy home could be combined with the use of an electric car to make use of this energy surplus, enough to drive an electric-powered vehicle for about 1,440 miles.



Although the extra investment needed to improve the efficiency, compared to the price of a similar construction complying with Maryland's state building code, is calculated to be about $162,700, residents of these type of houses would save about $4,373 in electricity a year ($364 a month), and the improvements will not only increase the total value of the house, but it will also enhance the living comfort.

### 2.5.2 The Net Zero Energy House in Auckland

The location of this home is in Auckland, New Zealand just west of the Auckland city center with good access to local amenities, bus routes and cycle ways. Data of its annual energy usage is as indicated below.

Simulated/ Designed annual energy use : 3,217 kWh/yr

Actual Energy Use : 2,361 kWh/yr

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

A roof integrated PV array has been installed on the house to produce required energy. The tiles have been fixed to 45x45mm roofing battens, using 3 Nos. of self-tapping screws. The PV slates overlap each other with a soaker tray between adjacent tiles to form a waterproof roof that also doubles as a PV array. The array generates DC current at 396V, 10.45A at maximum power point operation.

The grid connected inverter has been installed in the garage adjacent to the switchboard for easy access. The DC current from the PV array is converted to the 230V AC single phase current to be supplied to the electrical board of the property. The grid tied inverter output is connected to the AC board on the load side of the utility meter. Energy generated by the PV array is first used in the loads before excess in exported to the grid. Excess generation which is exported to the grid is recorded by the net metering system. The utility meter measures import and export on separate registers for billing purpose. Two additional meters have been installed as part of the electricity metering and have been configured to ensure that the energy generation and usage can be directly determined.



### 2.5.3 The Equinox home in Urbana, Illinois

This house has been built in Urbana, Illinois and the owner of the house is Mr. Ty Newell who is a professor emeritus of mechanical engineering at University of Illinois. According to him this house required 12000 kWh of electricity to operate from December 2010 to November 2011 including electricity required for heating, air conditioning, hot water heating, cloths washing and drying, and all other appliances. In this house natural gas is not used.

**Figure 2. 7: Equinox House in Urbana, Illinois (Tom Theis & Jonathan Tomkin, 2012)**



During the first year, solar panels produced approximately 11000 kWh of electricity and so 1000 kWh of electricity have to be imported from the national grid. This has happen actually because of the less efficient heating system. Next year, more efficient heating system has been installed and then this house has produced surplus electricity. This surplus electricity has been used to power the electric car for the 8,000 miles of in town driving they do annually.

In conjunction with its solar panels, this house achieves net-zero energy use because it requires far less energy than even a well-built conventional home about one-fifth as much. It does so through the use of design and technology that did not add a significant burden to the cost of construction.

The walls and roof of this house have been constructed with twelve-inch thick structural insulated panels, which are four to five times more effective at preventing thermal transfer than the walls of a typical house. Great care has also been taken to minimize the leakage of air through the building envelope of the house.

This uses high performance, triple-pane windows, which also help to prevent thermal transfer. Beyond that, the windows are oriented to allow direct sunlight into living space for the heat it provides during the cooler half of the year and to exclude direct sunlight during the warmer half of the year when it would increase the load on the cooling system.

Ultimately, the demands of the Equinox House for heating, cooling, ventilation, and humidity control will all be met by a single, heat-pump based system, developed by Ty Newell and his son Ben through their company, Newell Instruments. Apart from the fact that it maintains a comfortable temperature and level of humidity in the house, this system also delivers a constant flow of fresh air from the outside, and it does that without the loss of conditioned air that occurs in a drafty house.

As well the Equinox House will be outfitted in other ways that emphasize conservation, including LED lighting, low-flow plumbing fixtures, etc. It even features a system for collecting rainwater that is designed to meet 80 percent of the annual water needs for a family of four.



When he talks about the Equinox House, Ty Newell emphasizes how well it works from an economic perspective, since the couple's average daily cost for energy is a mere $3.00. That's based on a twenty-year life for the solar array, which cost a net of $20,000 installed.

### 2.5.4 NZE Home in Seatle, Washington

This home is located in Seatle, Washington. There are 3 bed rooms, 2 bath rooms and the living space is around 1915 Sq.Ft. The front view of the home is as below indicated figure 2.12.

**Figure 2. 8: NZE Home in Seatle, Washington**

Construction details of the home are as below.



**Foundation** - Slab on grade, R-20 horizontal rigid foam insulation beneath, R-10 vertical rigid foam to footing at perimeter

**Walls** - 6 1/2" SIPs (Structural Insulated Panel), R-26 including siding and drywall

**Windows** -Vinyltek vinyl windows glazed with Cardinal 180/i81 triple glazing with low-e coatings and argon gas fill. Glazing specs (center-of-glass, not whole, window): 0.50 SHGC (Solar Heat Gain Coefficient) and U-factors from 0.15 to 0.20, depending on size, configuration and opening means.

**Space heating** - Air to water heat pump, 3-ton, 35,400 BTU/h capacity, 9.2 HSPF (Heating Seasonal Performance Factor). Space heat distribution: hydronic PEX (Cross-linked polyethylene. Specialized type of polyethylene plastic that is strengthened by chemical bonds formed in addition to the usual bonds in the polymerization process) tubing in first-floor slab. Hydronic heating system is supplemented by electric-resistance in-floor heating mats in upstairs bathroom.

**Domestic hot water** – Preheated by the air-source heat pump and brought up to temperature by electric resistance water heater.

**Appliances -** Energy Star rated appliances (where applicable), LG front-loading clothes washer and dryer set, Bosch dishwasher, Frigidaire refrigerator, Viking electric range.

**Energy –** PV System 6.4-kW rooftop PV array (28Nos. PV modules, each rated at 230 watts) and 6-kW inverter.

Space Heat Demand - 3.3 MMBtu/yr (1723 BTU/ft2/yr)

Annual Energy used on site – 6,064 kWh

Energy Produced on site – 7,903 kWh

Net energy Balance – 1,429 kWh surplus

**Water Efficiency -** Low-flow plumbing fixtures

Caroma combination sink and toilet, recycles hand-washing water



PEX and copper piping

All storm water handled on site via rain garden and recycled oak wine barrel cisterns

**Indoor Air Quality -**

No-VOC paints and finishes, hard wax coating on interior wood beams

Stained concrete slab flooring (first floor), reclaimed wide-plank fir flooring and stair treads with water-based finish (second floor), and tile (upstairs bathroom)

Balanced ventilation system provides fresh air to living spaces and bedrooms

Motion-sensor exhaust fan in upstairs bathroom

# 3 METHODOLOGY

This chapter will describe the methodology of the data collection and its analysis.

## 3.1 Data Collection

Available data for the domestic energy consumption was randomly collected from Colombo district basically in urban area such as Bambalapitiya, Nugegoda, Dehiwala, etc…. Data was collected from 60 Nos. of homes.

A format of the Questionnaire which was used to collect the data has been indicated in Anexure-01. Lot of questions has been included to get the maximum information from the selected homes. Questionnaire was prepared to collect the electricity consumption, LPG consumption and also to study the tendency of the consumers for saving electrical energy.

## 3.2 Summary of the Collected Data Samples

Summary of the collected samples has been indicated in Annexure - 02. Only most important parameters have been included such as monthly electricity consumption, LP Gas consumption and area of the building footprint. Since the objective of this thesis is to study the potential of the NZEH in Sri Lankan urban sector, important factors such as monthly consumption of electricity and LP gas have been summarized.



## 3.3 Data Analysis

According to the collected data, several analysis were carried out such as percentage of the consumers in the each consumption range, average electricity consumption by several categories, the electricity consumption rate with the building footprint, etc….

### 3.3.1 Percentage of Consumers in each Electricity Consumption Range

Electricity Consumers are divided into three categories according to the monthly electricity consumption as 90-120 Units/Month, 120-180 Units/Month and more than 180 Units/Month and percentage of consumers in each range has been depicted as the Figure 3.1.

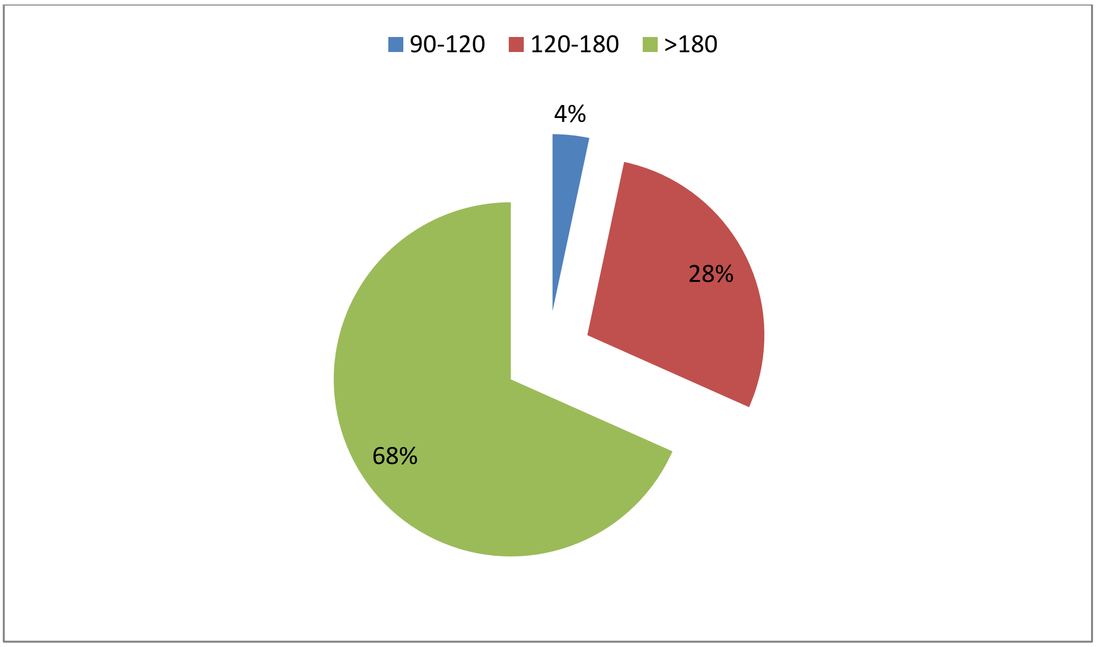


**Figure 3. 1: Percentage of consumers with the range of the units/month**

According to the figure 3.1, it can be noticed that the more percentage of the consumers is in more than 180 units consumption range and it is 68% while percentage of 120-180 range of units is 28%. Percentage of 90-120 units consumption per month is 4%.



### 3.3.2 Average Electricity Consumption by Several Categories

Electricity consumption is divided into several categories such as Lighting, Communication & Entertainments, Heating & Cooling, Cooking, MVAC, Washing and Other Equipment. Lighting is further divided into four categories such as Incandescent, LFL, CFL and LED. Percentage of average electricity consumption for each category is indicated in below figure 3.2.

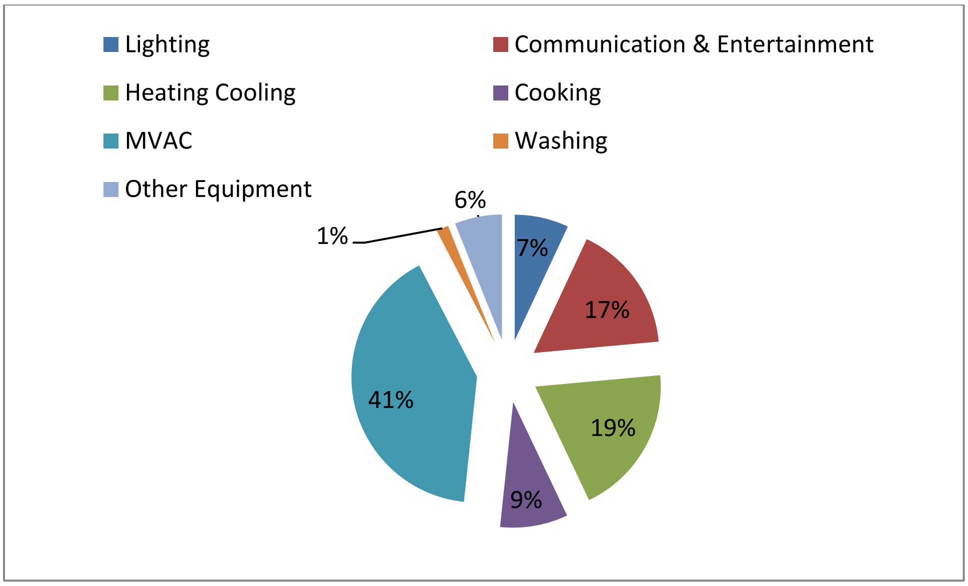


**Figure 3. 2: Average Electricity Consumption by each Category**

It can be noticed that the highest percentage of consumption is for the MVAC and its 41% from total consumption. Lowest consumption is for washing and it is 1%. Consumption for heating & cooling is 19% and for communication & entertainment is 17% while Consumption for lighting is 7% and 6% for other equipment.



One of the critical factor for the electricity consumption is the types of lights are used. Electricity consumption for the subcategories of lighting is indicated below figure 3.3.

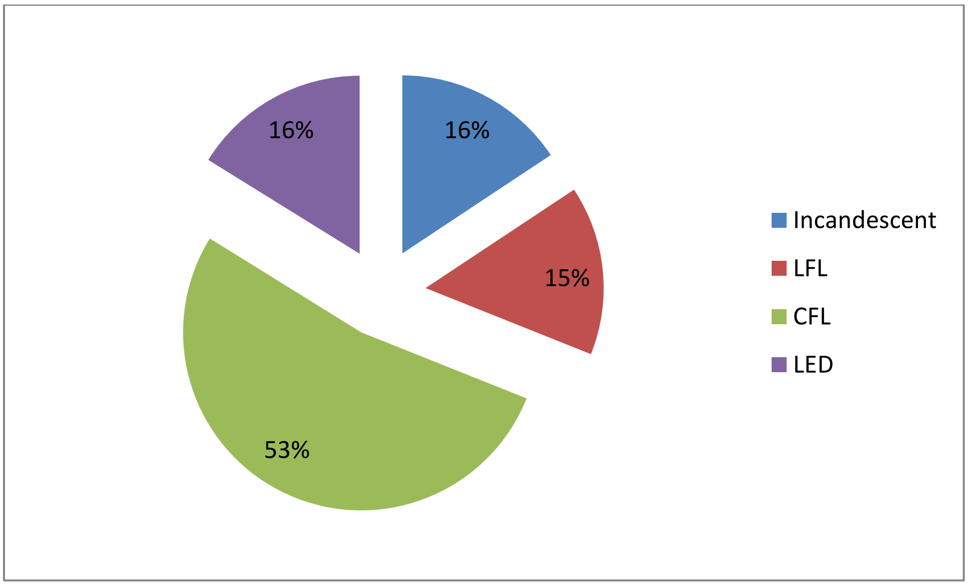


**Figure 3. 3: Average Electricity Consumption by type of Lighting**

53% of total lighting consumption is for CFL while 15% is for LFL lighting. As well, it is 16% for Incandescent and again 16% for LED lighting.

According collected data, as per the figure 3.4, 22 Nos. of houses out of 60 are using at least one incandescent bulb and it is 36.66% from the total houses. All houses are using CFL lights while using other lights also. 19 Nos. of houses are using LFL lights and it is 31.66% out of total houses. LED lights are used by 31Nos. of houses and it is 51.6% out of total sample houses.

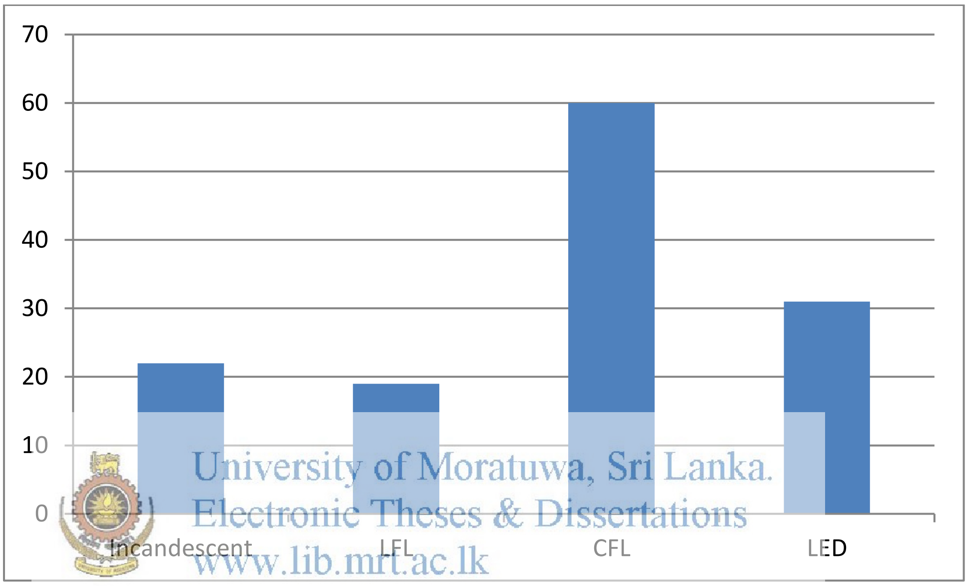



**Figure 3. 4: Numbers of Houses using various Light Types**

### 3.3.3 Electricity Consumption with the building footprint

Increasing of building footprint also may affect to increase the monthly consumption of the consumer since with the increasing of building foot print, usage of no. of bulbs increases and also other usage of electricity equipment such as TVs, MVAC, etc….also increase. The variation of the electricity consumption has been indicated figure 3.3.

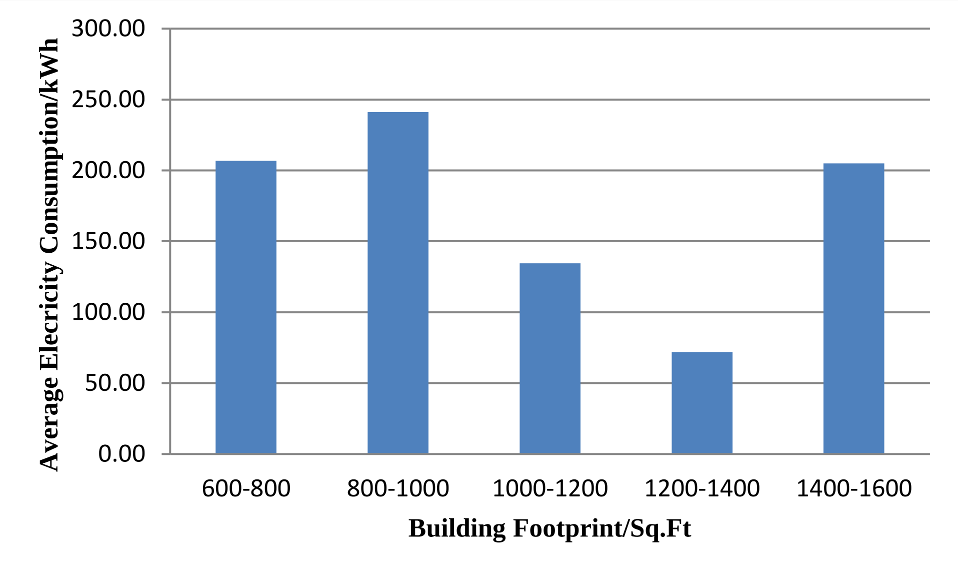


**Figure 3. 5: Electricity Consumption Variation with building footprint**

According to the above figure 3.5, it can be noticed that there is a higher average consumption among the consumers with the building footprint 800-1000Sq.ft. And also there is the least average consumption among the consumers with the building footprint 1200-1400Sq.ft. So it cannot be decided that the electricity consumption increases definitely with the increasing of the area of building footprint but some extent it is a factor for increasing of electricity consumption.



### 3.3.4 LP Gas Consumption

In addition to the electricity consumption, other main energy consumption method in domestic sector is the usage of LP gases. Basically LP Gases are used for cooking. Among the sample houses, LP gas consumption pattern is indicated below figure 3.6.

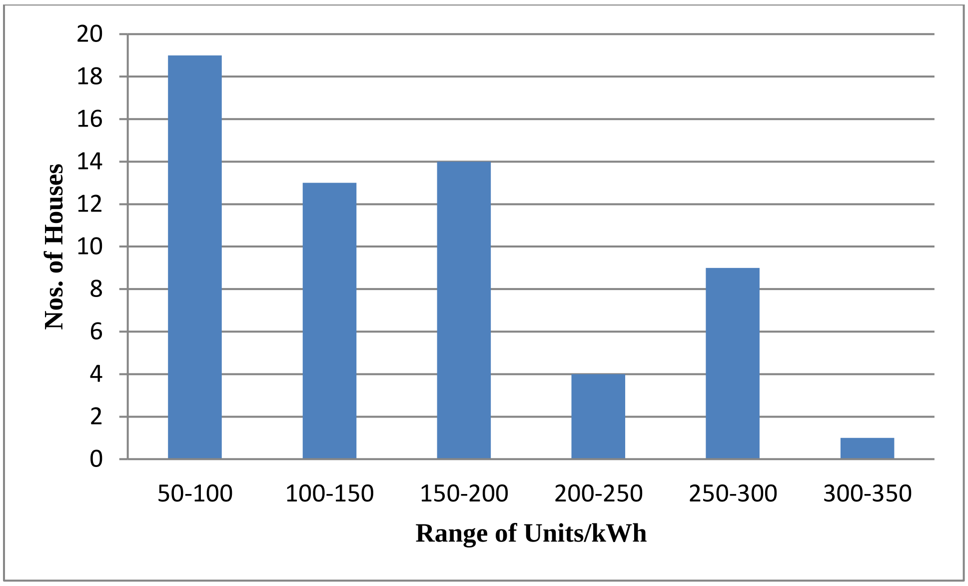


**Figure 3. 6: LP Gas Consumption Pattern**

Here the LP Gas consumption is indicated in kWh. There is a 13.6kWh of energy in one kg of LP Gas (Hahn, 2013).

19 Nos. of houses are using 50-100 units per month and it is a 32% as indicated in figure 3.7. Only there is one house which is using more than 300 Units per month. There are 13 Nos. of houses which use the units 100-150 and 14 Nos. houses which use 150-200 units. Percentage wise it is 22% and 23% respectively. There are only 4 Nos. of houses which use 200-250 units while 9 houses use units 250-300.



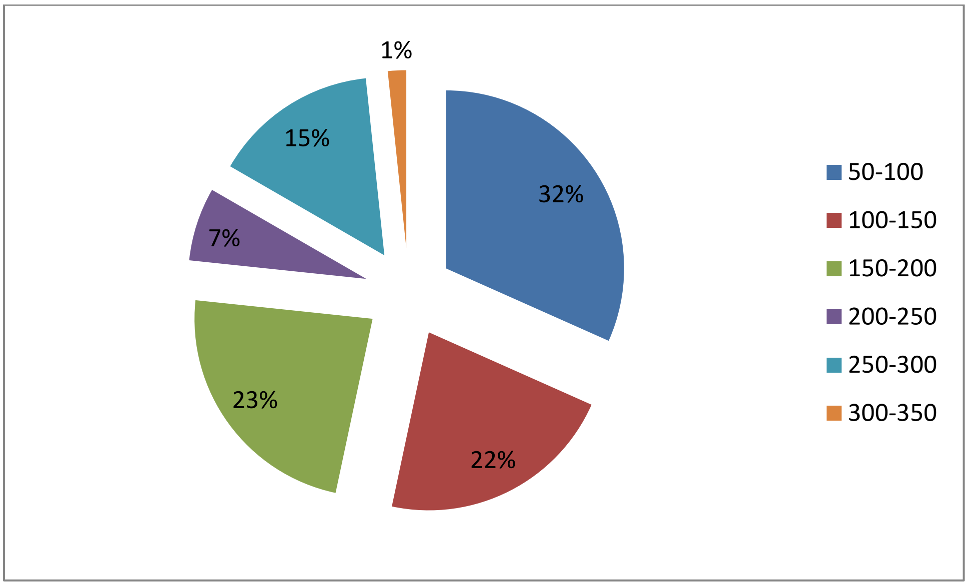


**Figure 3. 7: LP Gas Consumption Percentage with Units per month**

### 3.3.5 Renewable Energy Generation

**Electricity from Solar PV Systems**

PV Solar panels are used by only three consumers out of 60 houses as indicated below figure 3.8. Percentage wise it is 5% and comparatively very less. Out of these three houses, electric vehicles are used by two houses.

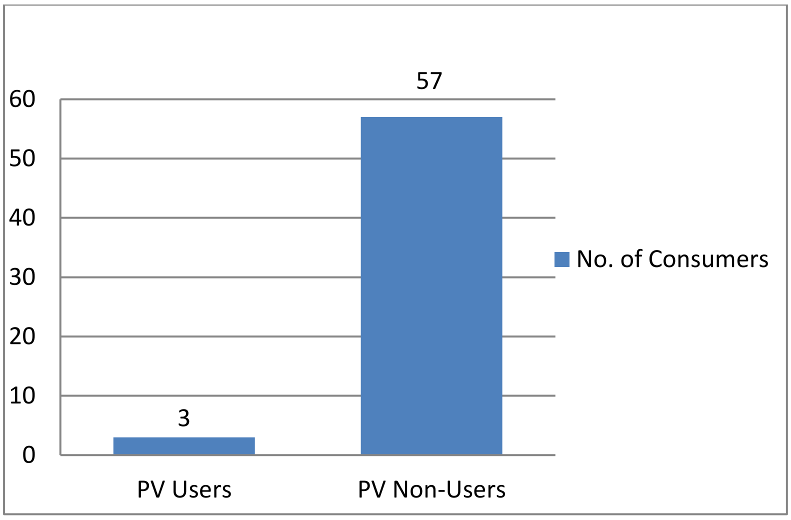


**Figure 3. 8: PV Usage as Renewable Energy Generation**



All three systems have been supplied by a same PV Panels manufacturer and the capacities of the systems are 1.8kW, 2.2kW and 2.4 kW.

**Solar Thermal Systems**

Solar thermal systems are used by 6 houses out of 60 samples as indicated below figure 3.9 and basically that is only for usage of bathing purposes and electrical heaters which are normally fixed in wash rooms have been avoided completely by using that. As a percentage, it is only 10%. Electrical heaters are used by 16 consumers but there were no clear indication about the duration about the usage time. It is depend upon the person.

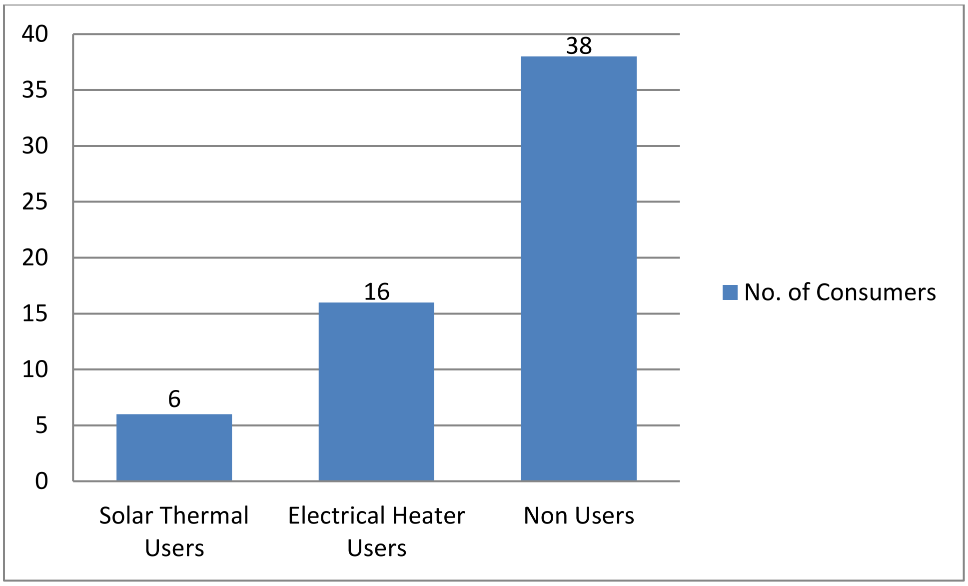


**Figure 3. 9: Hot water for bathing purposes**

# 4 DISCUSSIONS

This chapter describes the discussion of the research under the several important concerns which affect to the energy efficiency of the home.

## 4.1 Lighting Usage Pattern

When all the samples of data are considered, they all are using at least one CFL bulb. But there are 16% of houses which is using at least one incandescent bulb even though CFL and LED lights are more efficient than incandescent. At least 1 Nos. of CFL lights is used by all the homes while 11 Nos. of them are using only CFL lights.

But unfortunately only 31 Nos. of homes are using LED lights out of 60 samples. The LFL lights are used by 19 Nos. of houses out of 60 samples. It is obvious that the all homes have tended to use the CFL instead of incandescent. But the tendency for the usage of LED instead of CFL is minimum. So it is very important to create a trend among the home owners to use LED lighting wherever possible since it can be reduced the lighting load more than 25% compared to using of CFL as indicated below table 4.1.



**Table 4.1: Comparison of LED vs CFL and Incandescent Bulb**

| Cost Comparision of 40W incandescent Equivalent | LED | CFL | Incandescent |
|---|---|---|---|
| Light Bulb Projection Lifespan | 50,000 Hrs | 10,000 Hrs | 1,200 Hrs |
| Watts per Bulb | 8 | 11 | 40 |
| Cost per bulb | $9.97 | $1.25 | $0.66 |
| kWh electricity used over 50,000 hours | 400 | 550 | 2000 |
| Cost of Electricity (@0.11964 per kWh) | $48.00 | $66.00 | $239.00 |
| Bulbs needed for 50,000 Hrs of use | 1 | 5 | 42 |
| Bulb Expense | $9.97 | $6.25 | $27.57 |
| Total Cost for 50,000 Hrs | $58.00 | $72.00 | $267.00 |
| Cost Comparision of 75W incandescent Equivalent | LED | CFL | Incandescent |
| Light Bulb Projection Lifespan | 50,000 Hrs | 10,000 Hrs | 1,200 Hrs |
| Watts per Bulb | 14 | 19 | 75 |

| | | | |
|---|---|---|---|
| Cost per bulb | $25.00 | $2.50 | $0.66 |
| kWh electricity used over 50,000 hours | 700 | 950 | 3750 |
| Cost of Electricity (@0.11964 per kWh) | $84.00 | $114.00 | $449.00 |
| Bulbs needed for 50,000 Hrs of use | 1 | 5 | 42 |
| Bulb Expense | $6.50 | $12.50 | $27.57 |
| Total Cost for 50,000 Hrs | $90.00 | $126.00 | $476.00 |

(WCSEN)

## 4.2 Heating Applications

As the heating applications, electric kettles, heaters, rice cookers and electric irons are considered for the discussion.

### 4.2.2 Usage of Electric kettles and heaters

One of the most electricity consumption appliance in the domestic sector is usage the electric kettles and heaters. Only 35 homes are using electric kettles/heaters for hot water requirement and rest of them are using LP gas for the water boiling. If LP gas can be used for domestic hot water requirement, it will be effective both energy and cost wise.



### 4.2.3 Usage of electric rice cookers

48 homes are using electric rice cookers for cooking the rice while other homes are using pressure cooker for cooking the rice with LPG. Lots of electric cookers are in a range of 800W-1500W and average time is 60 minutes to operate the rice cooker daily. It means the rice cooker consume average 1 unit per day for the cooking process.

**Table 4.2: Summary of Energy Consumption for lighting and Appliances**

| Description | Using at least one Incandescent | Using at least one LED | Using at least one CFL | Using Rice Cooker | Using Pressure cooker for cooking rice | Using electric kettles and heaters | Using LP gas |
|---|---|---|---|---|---|---|---|
| No. of Homes | 22 | 31 | 60 | 48 | 12 | 35 | 60 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Percentage of Homes (%) | 36.7 | 51.6 | 100 | 80 | 20 | 58.33 | 100 |

According to the table 4.2, electric rice cooker is used by 48 houses while pressure cooker with LP Gas is used by 12 houses. And also 58.33% of them are using electric kettle or heater for required hot water supply while rest homes are using LP gas to fulfil the required hot water.

### 4.2.4 Usage of electric Iron

All homes are using the electric iron but usage time duration is different basically according to the no. of occupants. Since it is a very essential appliance, according to the sample of data 24 Nos. of homes out of 60 are using the electric iron once a week while others are using the electric iron daily even all of them know the benefits of using an electrical iron at once instead of using daily.

## 4.3 Usage of Renewable for Energy Generation

Only three homes use PV system for electricity generation. This is basically due to the initial higher investment and also lack of knowledge in connection with the renewable energy generation.



## 4.4 A Case Study on Actual Scenario

Among the samples of collected data, one house which is situated in Nugegoda area has been selected for the case study. Collected data for this particular house is as below.

Current average electricity consumption = 105 kWh (Units) per month
Current Average LP Gas consumption = 1 Nos. of 12.5kg Cylinder per month
Energy of LP gas consumption per month = 600 MJ
Total Floor Area of the Home = 81 $m^2$
Total Main Roof Area = 127$m^2$
Parking and Other roof area = 55$m^2$
Number of Occupants = 6 Nos.

### 4.4.1 Concerns related to energy consumption in the home

- Day Lighting arrangement in this home is very good. They don't use the artificial lights during the day time even in the bathroom. There are 6 windows all together and 5 Nos. of them are placed in north and south facade of the building. Only the window attached to the kitchen is placed in east facade of the house. So the solar heat gain is low.
- But all the windows have been furnished with the normal single glass without any tint or texture. So the comparatively U value is very high than the other window glazing methods such as single glass with tint, double glass, clear, etc….Figure 4.1 shows the variation of U-values with various window glazing types.

| GLAZING TYPE | U-FACTOR (Btu/hr-ft²-°F) Wood or Vinyl Frame (with insulated spacer) | Alum. Frame with thermal break (with conventional spacer) | Aluminum Frame without thermal break (with conventional spacer) |
|---|---|---|---|
| Single glass | ----- | 1.07 | 1.30 |
| Double glass, 1/2-inch air space | 0.48 | 0.62 | 0.81 |
| Double glass, e = 0.20*, 1/2-inch air space | 0.39 | 0.52 | 0.70 |
| Double glass, e = 0.10*, 1/2-inch air space | 0.37 | 0.49 | 0.67 |
| Double glass, e = 0.10*, 1/2-inch argon space | 0.34 | 0.46 | 0.64 |
| Triple glass, e = 0.10 on two panes*, 1/2-inch argon spaces | 0.23 | 0.36 | 0.53 |
| Quadruple glass, e = 0.10 on two panes*, 1/4-inch krypton spaces | 0.22 | ----- | ----- |



**Figure 4.1: : U-Values of window glazing (SWEE, 1997)**

- Except two windows which have been placed in south facade, all other windows have been shaded with the set of Amano sheet roof which has been installed in north, east and west facade of the building. So 4 nos. of windows have got shaded automatically due to this set of roofs.
- No incandescent bulbs are used at all in this home. So it has been reduced the large power consumption which accounts from incandescent bulbs to total lighting load.
- They had used a refrigerator which has been rated the power output as 110W and defrosting power as 165W. Because of this, they had to consume approximately 2 units per day only for the refrigerator. But finally they have replaced a new refrigerator with 80kW output without defrosting heater. Then they could have saved half of the electricity they have consumed earlier when they had the old refrigerator.
- Pressure cooker with LP Gas is used for cooking rice twice per day. So more than 10 units have been saved per month than using an electric rice cooker with 1200w. Cooking time was 40 minutes twice per day when electric rice cooker was used. Now the time duration of rice cooking is 8 Minutes and twice per day. Net saving can be calculated as below.



| | |
|---|---|
| Energy 12.5Kg of LP Gas Cylinder | = 600 MJ |
| Medium Burner Consumption | = 9 MJ/h |
| Energy Consumption per day | = 2.4 MJ |
| Energy Consumption per month | = 72 MJ |
| Energy Consumption per month in kWh | = 20 kWh |

If rice cooker is used,

| | |
|---|---|
| Electricity Consumption per day | = 1.6 kWh |
| Electricity Consumption per month | = 48 kWh |
| So the electrical energy saving | = 28 kWh (28 Units) |

### 4.4.2 Simulation of the Load

For the simulation process, software called “eQUEST” is used. Simulation was done for the existing building. The model of the existing building is as below figure 4.2.

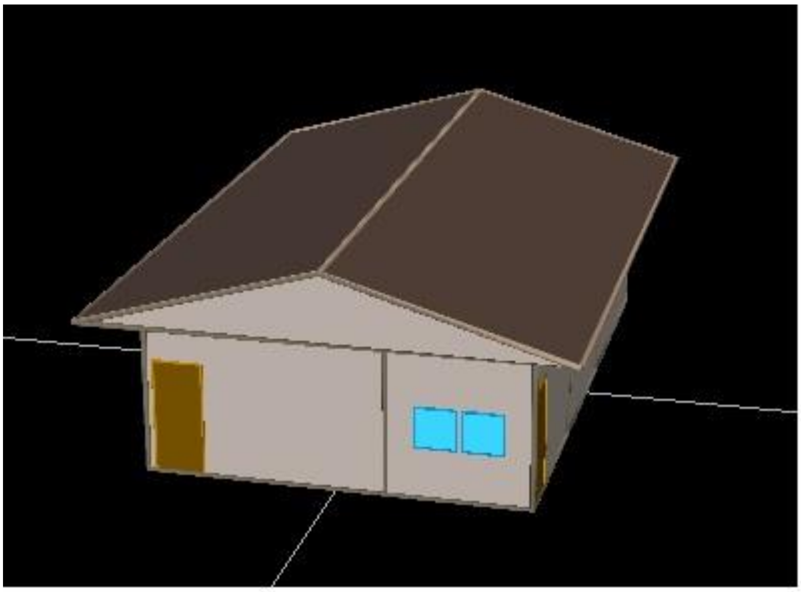

**Figure 4.2: Model of Existing Home**

After the simulation, Results report given from the eQUEST software has been indicated in figure 4.3 and table 4.3.

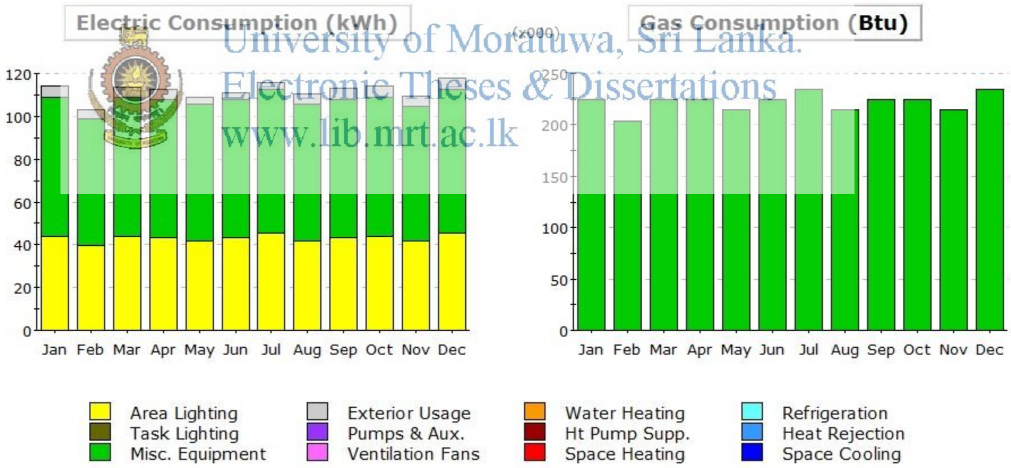




**Figure 4.3: Electricity and Gas Consumption Report**

**Table 4.3: Electricity Consumption During the year**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Space Cool | | | | | | | | | | | | | |
| Heat Reject. | | | | | | | | | | | | | |
| Refrigeration | | | | | | | | | | | | | |
| Space Heat | | | | | | | | | | | | | |
| HP Supp. | | | | | | | | | | | | | |
| Hot Water | | | | | | | | | | | | | |
| Vent. Fans | | | | | | | | | | | | | |
| Pumps & Aux. | | | | | | | | | | | | | |
| Ext. Usage | 5.40 | 4.10 | 4.60 | 4.40 | 3.20 | 3.00 | 3.20 | 5.10 | 5.00 | 5.10 | 5.20 | 5.40 | **53.60** |
| Misc. Equip. | 65.30 | 59.20 | 65.30 | 64.40 | 63.60 | 64.40 | 66.90 | 63.70 | 64.40 | 65.20 | 62.70 | 67.00 | **772.00** |
| Task Lights | | | | | | | | | | | | | |
| Area Lights | 43.70 | 39.70 | 43.80 | 43.60 | 41.90 | 43.60 | 45.50 | 41.90 | 43.60 | 43.70 | 41.80 | 45.50 | **518.20** |
| **Total** | **114.4** | **103** | **113.7** | **112.4** | **108.7** | **111** | **115.6** | **110.7** | **113** | **114** | **109.7** | **117.9** | **1343.8** |

According to that Monthly electricity consumption is in between 103-118kWh. Actual average electricity consumption is 110kWh and Actual average LP gas consumption is 600MJ that means 167kWh.

So go for a NZEH achievement, 277kWh of energy should be produced by using on-site renewable generation.



### 4.4.3 Cost and payback period analysis with renewable energy generation

As a compensation for the above import energy, energy should be generated by using available possible low cost renewable energies. Most possible and easy way to produce renewable energy is the solar PV technology. Other possible sources for on-site renewable energy generation is roof mounted or mini wind turbine and biogas but it is very limited and difficult to implement compared to PV specially in urban sector. Only solar PV technology is assumed to be used for the generation of required energy of the home.

**Case 01 – PV system to offset imported electricity and LP GAS**

Since the average total energy consumption is 277kWh per month, only PV system can be arranged to generate the 277kWh (Units) per month. Then annual renewable energy generation should be at least 3324 units to become NZE.

According to the manufacture's specifications, available models for PV systems can be selected from below Table 4.4. This is only a reference and it will be different with the manufacturer.

According to that 2.2kWp PV System can be used to generate the required electricity for electricity consumption of the home and for compensation for LP gas usage. Size of the PV system will be 11m2. Since the total roof area of the home is 127m2 and the PV system can be installed easily on the roof.

Total cost for the PV System = Rs. 850,000.00

Total monthly Cost for Electricity and LP Gas = Rs. 3300.00

**Then the Pay Back Period = 21.5 Years**

**Table 4.4: Available PV Panel Sets from Sunway Solar Brand**

| Rating/KW | No. of Panels 300w | Inverter | Units Generation per Month(kWh) | Pay Back (Years) |
|---|---|---|---|---|
| 1.8 | 6 | M XS 2200 TL | 200-250 | 4.8 |
| 2.2 | 7 | M XS 3000 TL | 260-300 | 4.5 |
| 3 | 10 | M XS 3800 TL | 370-400 | 3.9 |
| 4 | 13 | M XS 4600 TL | 480-540 | 3.2 |
| 4.5 | 15 | M XS 4600 TL | 550-620 | 3.1 |
| 5 | 17 | M XS 5000 TL | 630-720 | 2.8 |
| 6 | 20 | M XS 6000 TL | 730-800 | 2.8 |
| 7 | 23 | M XS 7500 TL | 900-950 | 2.5 |
| 8 | 27 | M XS 9000 TL | 1050-1100 | 2.2 |
| 9 | 30 | M XS 9000 TL | 1200-1240 | 2.0 |
| 10 | 33 | M XS 12000 TL | 1300-1375 | 2.1 |
| 11 | 37 | M XS 12000 TL | 1450-1500 | 1.9 |
| 12 | 40 | M XS 12000 TL | 1600-1650 | 1.8 |



(Solar Power System, 2012)

When net metering system is considered, all the exported energy to the grid by the consumer will be supplied back to customer by the CEB free of charge. For every month home can export around 180 units to the grid and this energy can obtain from the CEB in the future.

**Case 02 – Fuel wood can be used instead of LP gas**

If fuel wood is used for instead of LP gas, then only electricity is going to be offset by renewable energies, then 1kw Solar PV system is enough.

Then,

Total cost for 1kw PV system = Rs. 330,000.00

Total cost for electricity bill = Rs. 1800.00

Payback period = 15 Years.

Only Drawback of this option is, in urban sector, it is very difficult to find fuel wood for cooking process and also it is not practical.

**Case 03 – Electricity can be used for cooking process instead of LP Gas**

If electricity is used for cooking process, monthly electrical energy consumption will be 277kWh.

Then total cost for electricity = Rs. 8430.00/month

Cost for 2 kW PV system = Rs. 850,000.00

Payback period = 8.4 Years



That means if electrical cooking appliances are used instead of LP gas, then the payback period of PV system can be reduced and it is 8.4 Years.

## 4.5 Summary of the payback periods for each case

Payback period was calculated for three cases and summary of them for each case are as below table 4.5.

**Table 4. 5: Summary of Payback Periods**

| Case | Description | Initial Cost | Payback Period |
|---|---|---|---|
| 1 | PV system to offset imported electricity and LP gas | Rs. 850,000.00 | 21.5 Years |
| 2 | PV system to offset imported electricity and fuel wood instead of LP gas | Rs. 330,000.00 | 15.0 Years |
| 3 | PV system to offset imported electricity and electricity for cooking also instead of LP gas. | Rs. 850,000.00 | 8.4 Years |

According to table 4.4, there is a minimum payback period in case 3 which is assumed to be used PV system to offset imported electricity while electricity is used for cooking instead of LP gas.

### 4.6 Sensitivity Analysis

According to the below table 4.6 (Feldman, et al., 2015), price of solar PV module has decreased significantly.

**Table 4. 6: Price Variation of Solar PV Module**

| Year | $/Watt | Percentage of Price Reduction |
|---|---|---|
| 2011 | 1.41 | |
| 2012 | 0.84 | 40.43 |
| 2013 | 0.66 | 21.43 |
| 2014 | 0.63 | 4.55 |
| 2015 | 0.6 | 4.76 |
| 2016 | 0.54 | 10.00 |
| 2017 | 0.49 | 9.26 |
| 2018 | 0.46 | 6.12 |

(Feldman, et al., 2015)



It has decreased by 40% in 2012 compared to 2011, and 21.43% in 2013 compared to 2012. Finally it has decreased by 4.76% in 2015 compared to 2014. According to the Prediction for the price reduction in 2016, 2017, 2018, solar PV module price will decrease by 10%, 9.26% and 6.12 respectively.

So for sensitivity analysis of next 15 years, it is assumed that the average price reduction of solar PV module is 5% per annum. As well according to the past data of electrical tariff, most of the time, the cost for the electricity has increased. Actually it is very difficult to predict according to the past data also. It is assumed 2% price increment for electricity per annum in order to implement the sensitivity analysis.

According to the analysis for all three cases, it can be found that there is a considerable reduction of payback periods of each case as indicated in table 4.7. After 10 years, in 2025, Payback period for case 01 will be 10.5 years and it is 7.5 for case 2. As well the payback period for case 03 is 4.1 years.

**Table 4. 7: Variation of payback period during next twenty years**

| No. of Years | Case-01 | | | Case -02 | | | Case - 03 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cost for Soalr PV(LKR) | Cost for Electricity (LKR) | Payback Period (Years) | Cost for Soalr PV(LKR) | Cost for Electricity (LKR) | Payback Period (Years) | Cost for Soalr PV(LKR) | Cost for Electricity (LKR) | Payback Period (Years) |
| 2015 | 850,000 | 3,300 | 21.5 | 330,000 | 1,800 | 15.3 | 850,000 | 8,430 | 8.4 |
| 2016 | 807,500 | 3,366 | 20.0 | 313,500 | 1,836 | 14.2 | 807,500 | 8,599 | 7.8 |
| 2017 | 767,125 | 3,433 | 18.6 | 297,825 | 1,873 | 13.3 | 767,125 | 8,771 | 7.3 |
| 2018 | 728,769 | 3,502 | 17.3 | 282,934 | 1,910 | 12.3 | 728,769 | 8,946 | 6.8 |
| 2019 | 692,330 | 3,572 | 16.2 | 268,787 | 1,948 | 11.5 | 692,330 | 9,125 | 6.3 |
| 2020 | 657,714 | 3,643 | 15.0 | 255,348 | 1,987 | 10.7 | 657,714 | 9,307 | 5.9 |
| 2021 | 624,828 | 3,716 | 14.0 | 242,580 | 2,027 | 10.0 | 624,828 | 9,494 | 5.5 |
| 2022 | 593,587 | 3,791 | 13.0 | 230,451 | 2,068 | 9.3 | 593,587 | 9,683 | 5.1 |
| 2023 | 563,907 | 3,866 | 12.2 | 218,929 | 2,109 | 8.7 | 563,907 | 9,877 | 4.8 |
| 2024 | 535,712 | 3,944 | 11.3 | 207,982 | 2,151 | 8.1 | 535,712 | 10,075 | 4.4 |
| 2025 | 508,926 | 4,023 | 10.5 | 197,583 | 2,194 | 7.5 | 508,926 | 10,276 | 4.1 |
| 2026 | 483,480 | 4,103 | 9.8 | 187,704 | 2,238 | 7.0 | 483,480 | 10,482 | 3.8 |
| 2027 | 459,306 | 4,185 | 9.1 | 178,319 | 2,283 | 6.5 | 459,306 | 10,691 | 3.6 |
| 2028 | 436,341 | 4,269 | 8.5 | 169,403 | 2,328 | 6.1 | 436,341 | 10,905 | 3.3 |
| 2029 | 414,524 | 4,354 | 7.9 | 160,933 | 2,375 | 5.6 | 414,524 | 11,123 | 3.1 |
| 2030 | 393,798 | 4,441 | 7.4 | 152,886 | 2,423 | 5.3 | 393,798 | 11,346 | 2.9 |
| 2031 | 374,108 | 4,530 | 6.9 | 145,242 | 2,471 | 4.9 | 374,108 | 11,573 | 2.7 |
| 2032 | 355,402 | 4,621 | 6.4 | 137,980 | 2,520 | 4.6 | 355,402 | 11,804 | 2.5 |
| 2033 | 337,632 | 4,713 | 6.0 | 131,081 | 2,571 | 4.2 | 337,632 | 12,040 | 2.3 |
| 2034 | 320,751 | 4,807 | 5.6 | 124,527 | 2,622 | 4.0 | 320,751 | 12,281 | 2.2 |



Annual variations of all three cases during next twenty years have been depicted in below figure 4.4.

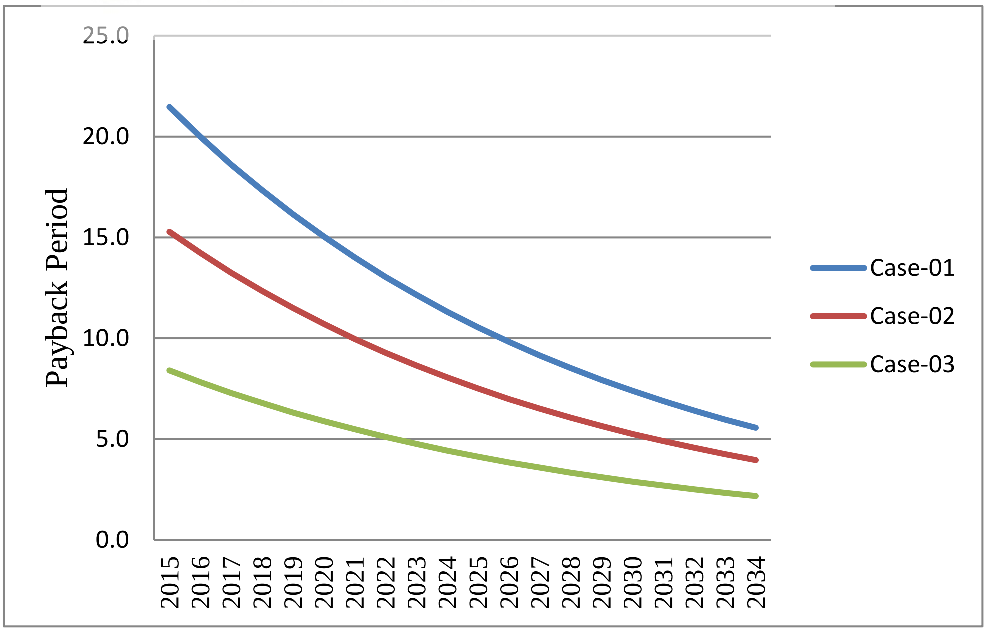


**Figure 4. 4: Annual variation of payback periods**

# 5 GUIDELINES TO NZEH

This chapter will describe the main guidelines from the design stage upto the operating stage for the residential buildings to achieve the NZE target. In comparison with a more conventional residential design process, this would involve more people and time and would increase significantly the cost and the time also of the design. An effective and user-friendly simulation tool can support architects to analyze energy performance of the project. The requirement is the broad knowledge of building science and construction to facilitate the designer to perform energy analysis in parallel with architectural design to reduce the design time process and also cost. On the hand, residential buildings have a very limited budget for design and construction compared with commercial buildings. Architects who want to be involved in designing NZE homes must have proper training in energy performance analysis and simulation process.

Successful design processes, need a step-by-step general strategy to achieve net-zero status. However some of these steps can be re-evaluated many times during the course of design, or they can be applied with combination of other steps. Re-examination of the case study project verified results of simulations and created some design indicators to support efficient design process. As an example, artificial tree planting analysis is not a necessary analysis for a residential project in many cases but general results can support designers to make better design decisions.



The design process highlighting in this study is mainly focused on energy side of architectural and construction practice and discussions are limited to subjects that would matter to reduce energy consumption.

## 5.1 Design Stage Guide Line

At the design stage, several concerns should be taken into consideration for a proper design in order to achieve the NZE target. One by one has been indicated below under this sub chapter.

### 5.1.1 Site Analysis

This phase of design is the earliest step of the total design process and also it is a comprehensive study of the existing condition, surrounding environment, climate analysis, building orientation assessments, solar radiation assessment, and landscaping design and strategies to support building loads reduction.

A tree plan survey identifies the size, location, and families of trees in a property's boundary. In addition, we need to have the approximate heights and diameters of trees to enable designers to study their shading effects on the site and proposed building. This data needs to be added to site survey documents. In addition, preparation of an urban scale site plan is recommended to identify surrounding building locations, and dimensions to support analysis of their shading effects on the building with respect to the building energy consumption (interior effects) and daylighting availability.

Designers should make some key design decisions from the survey plans to support their future design. For example, which trees are going to stay, and the site design strategy concerning slope.

### 5.1.2 Wind and Shading

Energy modeling tools are now widely available and can be used to support site plan wind and shading affects analysis. Wind effects analysis is not recommended for low-rise residential buildings for multiple reasons unless project is located in an area with severe wind pressure categories.



Knowing seasonal wind patterns of a project may not be affective on heating load but it can help in supporting the design of operable windows in favor of natural ventilation.

Sri Lanka has two basic wind patterns as northeast monsoon and southwest monsoon. Considering these two basic wind patterns, Architects can design the natural ventilation systems in order to minimize the mechanical ventilation systems which should be used the electricity and this will help to reduce the total building annual energy consumption by a small fraction which is important to net zero energy goal.

Shading analysis is an important assessment toward reduction of building energy requirement. In urban areas, adjacent buildings can have a significant effect on reducing solar radiation. This reduction is sometimes beneficial and in some cases can reduce free solar gain. Before starting the schematic design phase, it is important to study these factors. Shading from adjacent buildings can improve thermal comfort and reduce cooling loads but also can eliminate free solar heat. Energy efficiency analyzing software can be used to analyze this. The best method to approach is to create a 3D model of the building site with surrounding buildings and place a cubical building with approximate dimensions as proposed project. With this model, designers can easily study the solar movement around the building during the year and study the shading effect of adjacent buildings on their proposed building.

### 5.1.3 Energy Impacts of Artificial Tree Planting

Energy focused landscaping design strategies will reduce building energy consumption by some fraction. Simulations indicated that in cold climates, a 30% of uniform increase in urban tree cover can reduce winter heating bills in urban areas by 10% and in rural areas by 20% by reducing the ambient temperature and the wind speed.

Trees affect energy use in buildings through both direct and indirect processes. The direct effects are,

- Reducing solar heat gain through windows, walls, and roofs by shading.
- Reducing the radiant heat gain from the surroundings by shading.

The indirect effects are,

- Reducing the outside air infiltration rate by lowering local wind speed.
- Reducing the heat gain into the buildings by lowering ambient temperatures.

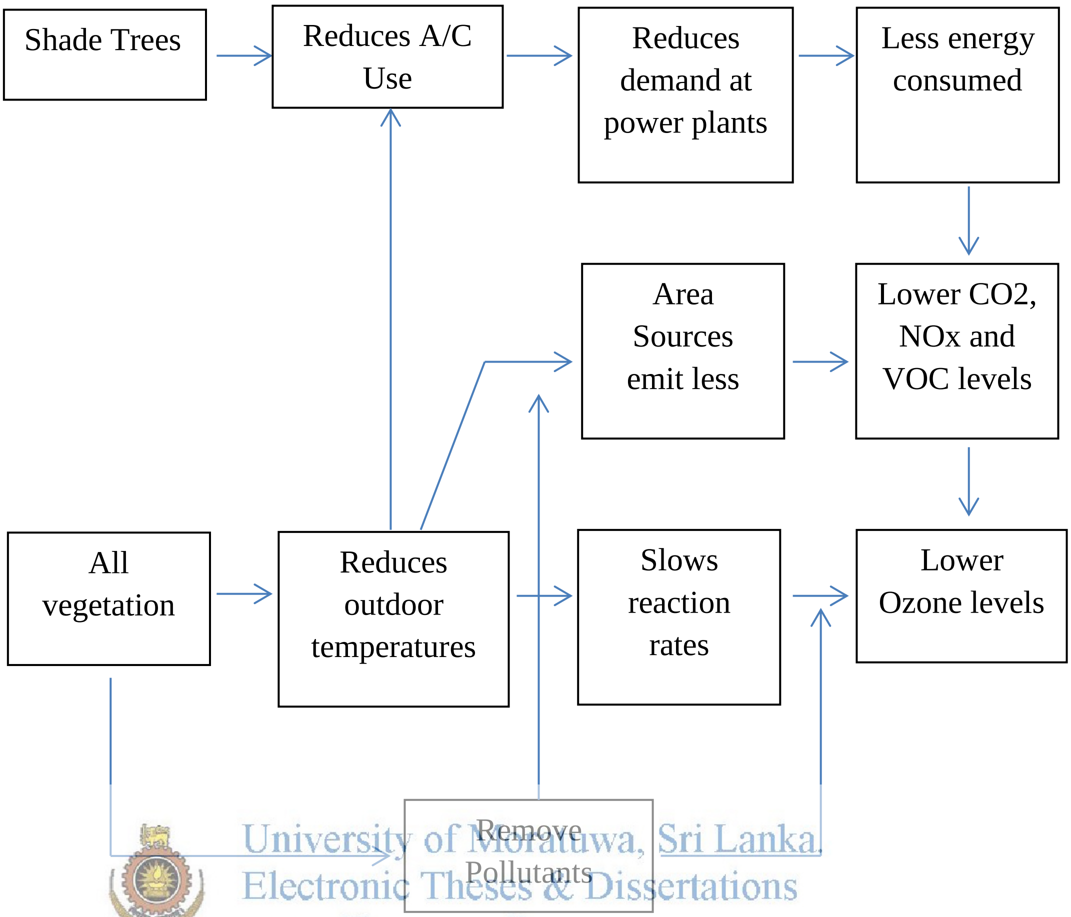




**Figure 5. 1: Direct and Indirect Effects of Trees on Energy and Air Quality**

### 5.1.4 Natural Lighting

Natural lighting is one of the most important factors at the building design process in many ways. Usage of daylight into the space of the house will reduce the consumption of artificial lights during day time. Specially when bathrooms are used during day time, more than 90% houses use artificial lights due to unavailability of day lighting. So it is very important to use day lighting wherever possible in the house to decrease the power consumption as well as for architecturally attractive design.

However usage of the day lighting should be optimized because more day lighting will be a problem for the cooling load of the home. Following strategies will help for the home owners to maximize the day lighting while maintaining the cooling load minimum.

- Main living spaces in a home such as Sitting, Kitchen can be placed in the south face of the building with sufficient glazing area. From a day lighting standpoint, this is desirable because direct solar radiation received by the south façade is easier to control to prevent excess solar gain, is relatively uniform, and is necessary for solar heating strategies.

- External overhangs, canopies, concealed balconies and light shelves can be used to control the day lighting, direct sun radiation, glare and uniform distribution into space for south facing spaces.

- Bedrooms can face north to avoid morning radiation. The nearly constant diffuse skylight availability on the north face is advantageous for uniform and soft day lighting.

- Bathrooms, staircases, storage spaces, laundry room and the areas that occupants don't spend a lot of time can be designed with no or small window systems and can be placed in the west and east side of building. This strategy can reduce the heating-cooling load of the building.



- All of these recommendations are considered for an ideal case and cannot be practically achieved in all cases together. The building orientation, shape and microclimate may change all of these suggestions. In large-scale residential projects day lighting simulation analysis will be the best strategy to achieve desired natural light and view for each space.

### 5.1.5 Windows Glazing

Windows are used in buildings for day lighting and also ventilation. Many studies have even shown that health, comfort, and productivity are improved due to well-ventilated indoor environments and access to natural light. However, windows also represent a major source of unwanted heat loss, discomfort, and condensation problems.

In recent years, windows have undergone a technological revolution. High-performance, energy-efficient window and glazing systems are now available that can dramatically cut down the energy consumption and pollution sources. They have lower heat loss, less air leakage, and warmer window surfaces that improve comfort and minimize condensation. These high-performance windows feature double or triple glazing specialized transparent coatings, insulating gas sandwiched between panes, and improved frames. All of these features reduce heat transfer, thereby cutting the energy lost through windows.

When selecting a glass, generally three factors should be considered. Those are U-value of the glass, Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (Tvis-glass). The meaning of these each factor has been briefed below.

- U-value indicates the rate of heat flow due to conduction, convection, and radiation through a window as a result of a temperature difference between the inside and outside. The higher the U-factor the more heat is transferred (lost) through the window. The unit of U-value is Btus per hour per square foot per °F (Btu/hr.ft$^2$.°F). U-factors usually range from a high of 1.3 (for a typical aluminum frame single glazed window) to a low of around 0.2 (for a multi-paned, high-performance window with low-emissivity coatings and insulated frames).

- SHGC indicates how much of the sun's energy striking the window is transmitted through the window as heat. As the SHGC increases, the solar gain potential through a given window increases. The SHGC is a ratio between 0 and 1. SHGC is equal to 0 means none of the incident solar gain is transmitted through the window as heat and SHGC is equal to 1 means all of the incident solar energy is transmitted through the window as heat.
  So it is desirable to select window glazing with low SHGC values since our country doesn't have cool climate to get passive solar heating.



### 5.1.6 Natural Ventilation

Implementation of natural ventilation into building energy consumption cannot be easily applied with the available current tools. It may not be desirable for small-scale residential projects. The level of uncertainty and unpredictability of wind pressure during the day and the wind direction make this natural free energy an unreliable resource to be considered as part of energy simulation analysis. This statement can be interoperated in a different way for regions with steady wind pressure during cooling period. Natural ventilation could become an important renewable energy source and drastically reduce building cooling load and support net-zero homes initiatives.

In Sri Lanka, there is a minimum usage of AC system in domestic sector and but however this natural ventilation will decrease the usage of ceiling and table fans during the day.

### 5.2 Reduction the Energy Consumption

Energy consumption can be reduced and optimized in various ways. Once the building envelop is built in an energy efficient manner, this is the next challenge to go for a NZEH. There are lots of practical methods which can be used to reduce the energy consumption as described below.

#### 5.2.1 Using Energy Star Appliances

Energy stared appliances, lights, etc….can be used as much as possible. Star rating decides its efficiency. If higher energy stared appliances are used, energy efficiency will be higher and so energy consumption will be less.

#### 5.2.2 Eliminate the Phantom Loads



Even energy star appliances are used, habits of the home owners will directly impact to the energy consumption in case of phantom loads. Lot of electronic devises and appliances that are plugged into electrical outlets continue to consume the energy even they are turned off. This occurs because the device or appliance is not actually “off” but in a standby mode that is still drawing the energy to remain in its idle state. TV’s, DVD players, cable receivers, microwaves, alarm clocks, printers, computers, stereos, and phone chargers, along with all standard appliances are examples of these devices that consume energy 24-hours a day. So every time the power supply for these appliances should be switched off from the electrical outlet in order to eliminate the phantom loads.

#### 5.2.3 Replace LED for incandescent, CFL and LFL lights

It is necessary to use LED lights instead of conventional incandescent, fluorescent and CFL lights. This is one of the main concerns which can be practiced for the reduction of electricity consumption. It can be noticed that according to the table 4.1.

### 5.2.4 Utilization of day lighting

Usage of artificial lighting can be reduced as much as possible during the day time. Day lighting can be utilized wherever possible in order to minimize energy consumption.

### 5.2.5 Use LP Gas for water heating

Lot of homes uses electric kettles and heaters for water heating. But it is also one of major electricity consuming appliance such as electric rice cooker and electric iron. So it is advisable to use LP gas for water heating.

### 5.2.6 Using Electric Iron

It is advisable to use electric iron once a week without using it daily for ironing purpose as much as possible.

### 5.2.7 Refrigerator Usage Pattern

Opening and closing of the door of refrigerator should be minimized as much as possible. As well it is better to practice to use small refrigerators instead of using large refrigerators. And also inverter type refrigerators can be used in order to minimize the electricity consumption.



### 5.2.8 Mechanical Ventilation

Usage of electrical fans can be minimized by utilizing natural ventilation. Table or Stand fans can be used instead of ceiling fans.

### 5.2.9 Replace Pressure Cooker for Electric Rice Cooker

Pressure cooker is a very effective appliance among the appliances which are used in domestic sector compared to the electric rice cooker. Energy saving is more than twice if pressure cooker can be replaced for the electrical rice cooker. It can be seen from the practical example which has been elaborated in section.

## 5.3 Renewable Energy Generation

For renewable energy generation, basically most affordable option is solar PV for urban sector. Biogas and micro wind energies is very difficult to use in urban sector due to the space issues.

### 5.3.3 Solar PV System

One of the main renewable energy which can be used for the generation of electricity is solar PV system. Sri Lanka is situated close to the equator and it is in between 6° & 10° of North Latitude and 80° & 82° of east longitude. As a tropical country, Sri Lanka doesn't have seasonal variations such as other part of the world and receives an abundant supply of solar radiation during the year. Even there is no considerable seasonal variation of solar radiation over the island. It is observed that there is a spatial differentiation between the lowlands and mountains regions.

The average temperature range in the lowlands up to and altitude of 100m to 150m is in between 26.5 °C -28.5 °C with an annual temperature of 27.50 °C. In the highlands, temperature falls quickly as the altitude increases. Mean annual temperature in Nuwara Eliya, at 1800m sea level is 15.9 °C.

According to the solar resource map developed by the National Renewable Energy Laboratory of USA, most parts of the dry zone in the island receive 4.0-4.5kWh/m$^2$day. And also solar radiation remains as low as 2.0-3.5kWh/m$^2$day in high plains in Nuwara Eliya due to the significant cloud cover during the day.



Selection of PV systems depends on various factors such as system efficiency, economics and costs, and durability of systems. There are three basic types of PV panels. Mono-crystalline cells are slices from a single crystal of silicon. These are the most efficient and the most expensive to produce. Polycrystalline cells are a slice cut from a block of silicon consisting of a large number of crystals. These cells are slightly less efficient and slightly less expensive than mono-crystalline cells and again need to be mounted in a rigid frame. Amorphous cells are manufactured by placing a thin film of amorphous (non-crystalline) silicon onto a wide choice of surfaces. These are the least efficient and least expensive to produce of the three types. Any of these panels can be used for a residential project. Availability, costs and efficiency of systems are major factors to select the best system for each project.

In net-zero energy system, the annual energy consumption of the home is the key indicator to estimate the size of PV panels. In order to generate energy equal or greater than annual building energy consumption, available dedicated area to panels (roof), PV panels' efficiency, and orientation of panels are the main factors in calculation of on-site energy production.

The efficiency of the Solar PV is around 15%. It is maximum theoretical efficiency and it depends upon the solar irradiance during the day time. According to the available the manufacturer's data of solar PVs brand called Triana, electrical data at standard test conditions (STC) is indicated below table 4.6. Standard test conditions are irradiance 1000W/m2, Cell Temperature 25'C, Air Mass Am1.5 according to EN 60904-3 and typical efficiency reduction 0f 4.5% at 200W/m2 according to EN 60904-1.

**Table 5.1: Electrical Specifications of PV Panel at STC (Tan, 2016)**

| | | | | |
|---|---|---|---|---|
| Peak Power Watts-Pmax (Wp) | 245 | 250 | 255 | 260 |
| Power Output Tolerance-Pmax(%) | 0~+3 | | | |
| Maximum Power Voltage | 29.9 | 30.3 | 30.5 | 30.6 |
| Maximum Power Current | 8.2 | 8.27 | 8.37 | 8.5 |
| Open Circuit Voltage | 37.8 | 38 | 38.1 | 38.2 |
| Short Circuit Current | 8.75 | 8.79 | 8.88 | 9 |
| Module Efficiency | 15 | 15.3 | 15.6 | 15.9 |



And also the electrical data of the PV module at the condition of nominal operating cell temperature is indicated in below figure 5.2.

**Table 5.2: Electrical Specifications at NOCT (Tan, 2016)**

| | | | | |
|---|---|---|---|---|
| Maximum Power-Pmax(Wp) | 182 | 186 | 190 | 193 |
| Maximum Power Voltage(V) | 27.6 | 28 | 28.1 | 28.3 |
| Maximum Power Current(A) | 6.59 | 6.65 | 6.74 | 6.84 |
| Open Circuit Voltage-Voc(V) | 35.1 | 35.2 | 35.3 | 35.4 |
| Short Circuit Current - Isc(A) | 7.07 | 7.1 | 7.17 | 7.27 |

The general length and size of a PV module is as indicated in figure 5.3. These dimensions can vary brand by brand but there may be small differences.

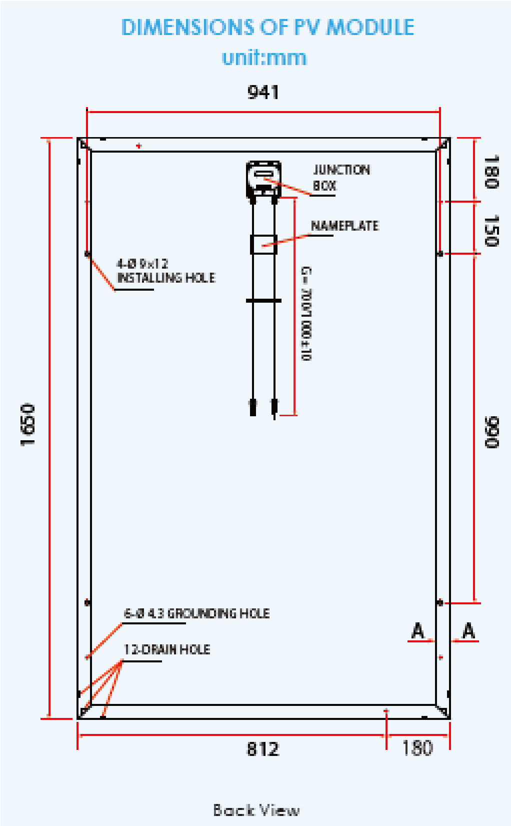


**Figure 5.2: General Dimensions of a PV module (Tan, 2016)**



According to the above data, it can be identified that the actual power which can be obtained from the PV module is around 75% of its rated power. It is called performance Ratio. The following factors can have influence to the value of the performance Ratio.

- Environmental factors (Tan, 2016)
  - ✓ Temperature of the PV Module.
  - ✓ Solar Irradiation and power dissipation.
  - ✓ The measuring gauge is in the shade or soiled.
  - ✓ PV module in the shade or soiled.
- Technical Factors (Tan, 2016)
  - ✓ Recording Period.
  - ✓ Conduction Losses.
  - ✓ Efficiency Factor of the PV modules.
  - ✓ Efficiency Factor of the Inverter.

- ✓ Differences in solar cell technologies of the measuring gauge and of the PV module.

So when the design is done this factor should be considered.

Mechanical data such as the length and width, etc….of the PV module has been indicated in below table 5.3.

**Table 5.3: Mechanical Data of PV Module (Tan, 2016)**

| | |
|---|---|
| Solar Cells | Multi-Crystalline 156x156 mm(6 Inches) |
| Cell Orientation | 60 cells (6x10) |
| Module Dimensions | 1650x992x35 mm |
| Weight | 18.6 kg |
| Glass | 3.2 mm, High transmission, AR Coated Tempered Glass |
| Backsheet | white |
| Frame | Silver Anodized Aluminum Alloy(PC05A), Black(PC05A,08) |
| J-Box | IP 65 or IP 67 rated |
| Cables | Photovoltaic Technology cable 4.0mm2, 700/1000 mm |
| Connector | MC4 or MC4 Compatible |



**Capacity Utilization Factor of PV Plant**

Capacity Utilization Factor (CUF) is defined as the ratio between the gross energy generation of a power plant and the maximum gross energy generation possible in the period under operation. Normally it is considered for a period of one year. This is also very important factor when the house is design for NZE by using Solar PVs. In connection with the CUF, any literature could not be found in Sri Lanka. But according to the manufacture's specifications, CUF is around 18%.

For an example if the electricity consumption of the house is 120kWh per month and 1440kWh per year, PV plant should be capable to supply the annual total energy equal to 8000kWh since the CUF is 18%.

### 5.3.4 Solar Thermal for hot water requirement

Solar thermal hot water can be used to get the hot water requirement in the domestic sector in order to avoid the usage of electric heaters. But in Sri Lanka, hot water is rarely is used for bathing purposes.

## 5.4 Barriers to Net Zero Energy Homes

Even there are enough strategies and modern technologies to build a NZEH, there are lot of barriers when it is built practically. Fault may be traditional way of designing homes and associated higher capital cost.

Many building designers still design their respective systems individually without giving considerations on how much their system affects other building systems. In the traditional building design process, the architectural team works with the owner to create a building program that specifies the needs for the building. The architect designs the building to satisfy the program requirements, and then the project engineers design the electrical and mechanical systems and evaluate compliance with energy codes and acceptable levels of environmental comfort. However, because many important architectural decisions are set at this point, few changes can be made that would improve energy performance.



In contrast to the traditional building process, the whole-building design process requires the team, including the architect, engineers (lighting, electrical, and mechanical), energy and other consultants, and the building's owner and occupants, to work together to set and understand the energy performance goals. The full design team focuses from the outset on energy and energy cost savings. The process relies heavily on energy simulation. To be effective, the process must continue through design, construction, and commissioning.

Despite the considerable benefits of reducing or eliminating energy costs, building owners finally ask how much of an investment must be made and what is the value of such an investment. The cost of such a project varies greatly depending on the strategy undertaken to reduce energy use and the climate in which the building is constructed.

## 6 CONCLUSION

As explained above there are three basic steps for NZE home target. First one is the minimizing the required energy for a particular home by optimizing the building envelops at the design stage. But in Sri Lankan urban sector housing, rarely that kind of improvements can be found rather than using slightly day lighting and natural ventilation in few cases. So lot of improvements should be done at the design stage of the housing in order to optimize the energy demand.

Second step of the NZE housing target is minimizing the energy consumption. Some house owners are strictly following the methods which will help to minimize the energy consumption but some houses owners don't follow as habits. So there should be some awareness programs to educate the house owners regarding the minimizing of energy consumption.

Third step is the generation of balance required energy demand by using renewable energy sources. Only option is using the solar PV modules for electricity generation and solar thermal systems for hot water requirement.



In connection with the electricity consumption in urban sector in Sri Lanka, 4% out of total users consume 90-120 Units per month. 28% percentages of consumers use 120-180 units per month. 68% percentages of consumers use more than 180 units per month.

Go for a NZEH target by using only solar PV, at least 1kWp PV panel system should be used. 1kW system can produce nearly 112 units per month. But if this system is installed, the payback period will be 15 Years according to the current market price of the PV systems. If 1.5kWp PV system is installed for consumers who use around 150-160 units per month, then the minimum payback period will be 11 years. For consumers who use more than 180 units per month, 1.8kWp PV system which generates 200-250 units per month should be used. Then the minimum payback period will be 7 years.

So Net Zero Energy Home concept is most suitable for urban sector which is used units more than 180. It is 68% percentage out of the total domestic consumers. If the Solar PV systems are installed for consumers who use below 180 units per month, the payback period will be in between 10-25 years. However GHGs emission will be zero even the payback period is very high. So environmentally this is ok but economically this is not viable for the customers who use less than 180 units per month due to this long payback period.

However according to the sensitivity analysis in 4.3 sections, it can be seen that the price of the solar PV module is decreasing significantly and summarized payback periods for a house which used around 110 units during next twenty years is as below table 6.1.

**Table 6. 1: Summary of the payback periods during next twenty years for a house with the consumption of 110 Unit per month**

| Year | Case-01 | Case-02 | Case-03 |
|---|---|---|---|
| 2015 | 21.5 | 15.3 | 8.4 |
| 2016 | 20.0 | 14.2 | 7.8 |
| 2017 | 18.6 | 13.3 | 7.3 |
| 2018 | 17.3 | 12.3 | 6.8 |
| 2019 | 16.2 | 11.5 | 6.3 |
| 2020 | 15.0 | 10.7 | 5.9 |
| 2021 | 14.0 | 10.0 | 5.5 |
| 2022 | 13.0 | 9.3 | 5.1 |
| 2023 | 12.2 | 8.7 | 4.8 |
| 2024 | 11.3 | 8.1 | 4.4 |
| 2025 | 10.5 | 7.5 | 4.1 |
| 2026 | 9.8 | 7.0 | 3.8 |
| 2027 | 9.1 | 6.5 | 3.6 |
| 2028 | 8.5 | 6.1 | 3.3 |
| 2029 | 7.9 | 5.6 | 3.1 |
| 2030 | 7.4 | 5.3 | 2.9 |
| 2031 | 6.9 | 4.9 | 2.7 |
| 2032 | 6.4 | 4.6 | 2.5 |
| 2033 | 6.0 | 4.2 | 2.3 |
| 2034 | 5.6 | 4.0 | 2.2 |



So it is obvious that with the time, payback periods will be very less compared to its current values even for monthly electricity consummation is around 120 Units. Even it is not economical for the electricity consumption range less than 180 Units at present, according to the sensitivity analysis it can be seen that in future NZEH concept is economical for all the consumers in urban sector.

Here AC systems are rarely used for cooling even in domestic urban sector. Fans are used for ventilation instead of AC systems. If AC systems are used then this PV system is worth to install since the AC systems normally consume more power than fans.

From this thesis energy consumption for transportation was not considered for the calculations. If transportation also considered, electric car can be used instead of fuel used car. Then Definitely PV system will be economical and also environmental friendly. Then GHGs emission occurring due to transportation also can be eliminated.

In connection with the electricity consumption in urban sector in Sri Lanka, 21% out of total users consume 0-30 Units per month. 28% percentages of consumers use 30-60 units per month. 27% percentages of consumers use 60-90 units per month. 12% percentages from total consumers use 90-120 units per month. 8% percentages of consumers use 120-180 units per month while 4% percentages of consumers use units more than 180.

So for the semi urban sector and rural sector it can be introduced Net Zero Energy Village concept. Then large PV system can be used to supply the energy for the homes in the village. Then the payback period will not be higher than five years.

Finally it can be seen that there is a significant potential for NZEH in Sri Lankan urban sector. It is achievable but only possible renewable energy which can be used is solar PV since other renewable energies are very difficult to adopt in urban sector. This NZEH concept will be very economical for the urban sector consumers who use more than 180 units of electrical consumption per month at present and with the price reduction of solar PV modules, it is economical all the domestic customers in Sri Lankan urban sector.

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**ANEXTURE – 01**

| Sample No. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Building Envelop** | | | | | | | | | | | | **Remarks** |
| Building Footprint (Sq.ft) | | | | | | | | | | | | |
| Type of Wall | | | | | | | | | | | | |
| Interior Wall Colour | | | | | | | | | | | | |
| **Windows Details** | | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 | |
| | Size (ft) | | | | | | | | | | | |
| | Area(Sq.ft) | | | | | | | | | | | |
| | Total Area(Sq.ft) | | | | | | | | | | | |
| Orientation of Windows | | | | | | | | | | | | |
| Nos. of East & South Face Windows | | | | | | | | | | | | |
| Window Glazing Type | | | | | | | | | | | | |
| Nos. of Double Glazing Windows | | | | | | | | | | | | |
| Window shading | | | | | | | | | | | | |
| Curtains for Windows | | | | | | | | | | | | |
| **Roof Details** | | **Remarks** | | | | | | | | | | |
| Type of Roof | Clay Tiles | | | | | | | | | | | |
| Insulation for roof | N/A | | | | | | | | | | | |
| Ceiling type | Wood | | | | | | | | | | | |
| **Electricity Consumption** | | | | | | | | | | | | |
| **Type of usage** | **Wattage (W)** | **Total Nos.** | **Duration /day (hrs)** | | | | | | | | **Usage (kWh/M)** | |
| | | | **N.1** | **N.2** | **N.3** | **N.4** | **N.5** | **N.6** | **N.7** | **N.8** | | |

| **Lighting** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Incandescent | 25 | | | | | | | | | | | |
| | 40 | | | | | | | | | | | |
| | 60 | | | | | | | | | | | |
| | 75 | | | | | | | | | | | |
| | 100 | | | | | | | | | | | |
| Sub Total-Incandescent | | | | | | | | | | | | |
| LFL | 15 | | | | | | | | | | | |
| | 18 | | | | | | | | | | | |
| | 30 | | | | | | | | | | | |
| | 36 | | | | | | | | | | | |
| | 58 | | | | | | | | | | | |
| | 70 | | | | | | | | | | | |
| Sub Total - LFL | | | | | | | | | | | | |
| CFL | 3 | | | | | | | | | | | |
| | 5 | | | | | | | | | | | |
| | 7 | | | | | | | | | | | |
| | 8 | | | | | | | | | | | |
| | 11 | | | | | | | | | | | |
| | 12 | | | | | | | | | | | |
| | 14 | | | | | | | | | | | |
| | 15 | | | | | | | | | | | |
| | 18 | | | | | | | | | | | |
| | 20 | | | | | | | | | | | |
| | 23 | | | | | | | | | | | |
| | 24 | | | | | | | | | | | |
| Sub Total - CFL | | | | | | | | | | | | |
| LED | 2.5 | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | | | | | | | | | | | |
| | 5 | | | | | | | | | | | |
| | 7 | | | | | | | | | | | |
| | 7.5 | | | | | | | | | | | |
| | 9 | | | | | | | | | | | |
| | 9.5 | | | | | | | | | | | |
| | 10 | | | | | | | | | | | |
| | 10.5 | | | | | | | | | | | |
| | 12 | | | | | | | | | | | |
| Sub Total - LED | | | | | | | | | | | | |
| Total for Lighting | | | | | | | | | | | | |
| **Communication / Entertainment** | | | | | | | | | | | | |
| Television(Plasma) | | | | | | | | | | | | |
| Television (LED) | | | | | | | | | | | | |
| Television (LCD) | | | | | | | | | | | | |
| Television (CRT) | | | | | | | | | | | | |
| DVD Player | | | | | | | | | | | | |
| Stereo Systems | | | | | | | | | | | | |
| Laptops | | | | | | | | | | | | |
| PCs | | | | | | | | | | | | |
| Cell Phone Chargers | | | | | | | | | | | | |
| Sub Total - Comm/Entertainment | | | | | | | | | | | | |
| **Heating & Cooling** | | | | | | | | | | | | |
| Electric Kettle | | | | | | | | | | | | |
| Electric Heater | | | | | | | | | | | | |
| Electric Iron | | | | | | | | | | | | |
| Electric Hair Dryer | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refrigerator | | | | | | | | | | | | |
| Sub Total - Heating&Cooling | | | | | | | | | | | | |
| **Cooking** | | | | | | | | | | | | |
| Rice Cooker | | | | | | | | | | | | |
| Electric Stoves | | | | | | | | | | | | |
| Blender/Grinder | | | | | | | | | | | | |
| Hot Plate | | | | | | | | | | | | |
| Electric Oven | | | | | | | | | | | | |
| Microwave Oven | | | | | | | | | | | | |
| Toaster | | | | | | | | | | | | |
| Electric Fryers | | | | | | | | | | | | |
| Sub Total - Cooking | | | | | | | | | | | | |
| **MVAC** | | | | | | | | | | | | |
| Ceiling Fans | | | | | | | | | | | | |
| Stand Fans | | | | | | | | | | | | |
| Table Fans | | | | | | | | | | | | |
| Air Conditioning | | | | | | | | | | | | |
| Sub Total - MVAC | | | | | | | | | | | | |
| **Washing & Cleaning** | | | | | | | | | | | | |
| Washing Machine | | | | | | | | | | | | |
| Vacuum Cleaner | | | | | | | | | | | | |
| Floor Polisher | | | | | | | | | | | | |
| Sub Total - Washing&Cleaning | | | | | | | | | | | | |
| **Other Equipment** | | | | | | | | | | | | |
| Water Pumps | | | | | | | | | | | | |
| Electric Vehicle | | | | | | | | | | | | |
| Sub Total - Other Equipment | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of Units per Month (kWh) | | | | | | | | | | | | |
| Average Actual Electricity Consumption | | | | | | | | | | | | |

| **LPG Consumption** | | | | | |
|---|---|---|---|---|---|
| **Type of the Cylinder** | **Capacity of the Cylinder(kg)** | **Nos. of Days per Cylinder** | **Energy-kWh/kg** | **Average Monthly Consumption(kWh/Month)** | |
| Large | 12.5 | | 13.6 | | |
| Medium | 5.0 | | 13.6 | | |
| Small | 2.5 | | 13.6 | | |
| Total - LP Gas Energy | | | | | |

| **On-Site Energy Renewables** | | | | | | |
|---|---|---|---|---|---|---|
| **System** | **Detail of Capacity** | **Brand** | **Type** | **Size** | **Average Monthly Energy Generation** | |
| Solar PV Systems | | | | | | |
| Solar Water Heaters | | | | | | |
| Domestic Wind Systems | | | | | | |

**ANEXTURE – 02**

| | Building Foot Print | Lighting | | | | | Communication & entertainment | Heating Cooling | Cooking | MVAC | Washing | Other Equipment | No. of Units | Actual No. of Units | LP Gas Consumption |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Incandescent | LFL | CFL | LED | Total | | | | | | | | | |
| S-01 | 1400 | 0.00 | 0.00 | 6.15 | 1.62 | 7.77 | 26.22 | 70.20 | 18.00 | 16.74 | 6.64 | 0.00 | 145.57 | 120.00 | 113.33 |
| S-02 | 1200 | 5.40 | 13.50 | 6.24 | 0.21 | 25.35 | 46.20 | 36.34 | 18.75 | 43.80 | 12.86 | 0.00 | 183.30 | 165.00 | 170.00 |
| S-03 | 1200 | 13.95 | 5.40 | 9.99 | 2.00 | 31.34 | 72.84 | 62.57 | 42.00 | 63.45 | 3.00 | 0.00 | 275.20 | 240.00 | 127.50 |
| S-04 | 1600 | 13.50 | 0.00 | 9.24 | 0.00 | 22.74 | 32.88 | 82.29 | 30.00 | 84.30 | 3.86 | 0.00 | 256.06 | 235.00 | 255.00 |
| S-05 | 1100 | 12.00 | 5.40 | 11.78 | 0.00 | 29.18 | 46.14 | 51.77 | 18.00 | 27.30 | 10.29 | 2.40 | 185.07 | 180.00 | 113.33 |
| S-06 | 1360 | 9.00 | 0.00 | 9.81 | 0.00 | 18.81 | 34.32 | 22.85 | 22.80 | 61.80 | 0.00 | 0.00 | 160.58 | 140.00 | 85.00 |
| S-07 | 1900 | 0.00 | 16.20 | 9.48 | 3.02 | 28.70 | 33.63 | 48.69 | 47.91 | 42.60 | 9.43 | 0.00 | 210.95 | 180.00 | 68.00 |
| S-08 | 1400 | 0.00 | 0.00 | 12.17 | 0.00 | 12.17 | 50.10 | 36.34 | 18.75 | 89.85 | 6.00 | 0.00 | 213.21 | 200.00 | 170.00 |
| S-09 | 850 | 6.75 | 0.00 | 5.45 | 0.00 | 12.20 | 49.74 | 29.83 | 9.00 | 45.00 | 0.00 | 0.00 | 145.76 | 150.00 | 170.00 |
| S-10 | 1000 | 0.00 | 4.32 | 20.73 | 0.00 | 25.05 | 94.92 | 126.00 | 48.00 | 313.50 | 0.00 | 0.00 | 607.47 | 530.00 | 340.00 |
| S-11 | 1600 | 0.00 | 0.00 | 7.95 | 14.00 | 17.60 | 57.30 | 49.63 | 57.00 | 75.60 | 18.00 | 0.00 | 275.12 | 250.00 | 255.00 |
| S-12 | 600 | 8.10 | 6.48 | 7.95 | 0.00 | 22.53 | 28.47 | 47.49 | 1.50 | 30.60 | 5.79 | 0.00 | 136.37 | 150.00 | 68.00 |
| S-13 | 900 | 0.00 | 0.00 | 3.78 | 7.86 | 11.64 | 33.54 | 30.86 | 5.50 | 28.20 | 2.57 | 120.0 | 232.31 | 225.00 | 170.00 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-14 | 800 | 11.25 | 0.00 | 7.92 | 0.00 | 19.17 | 1.08 | 55.14 | 18.00 | 41.40 | 3.43 | 0.00 | 138.22 | 130.00 | 68.00 |
| S-15 | 1400 | 0.00 | 0.00 | 12.06 | 6.48 | 18.54 | 61.86 | 63.43 | 2.00 | 60.15 | 3.86 | 0.00 | 209.84 | 180.00 | 255.00 |
| S-16 | 700 | 0.00 | 11.88 | 12.21 | 0.00 | 24.09 | 8.16 | 65.49 | 20.25 | 48.00 | 0.00 | 0.00 | 165.99 | 160.00 | 127.50 |
| S-17 | 1000 | 0.00 | 0.00 | 6.15 | 0.00 | 6.15 | 34.56 | 24.34 | 13.50 | 45.60 | 0.00 | 0.00 | 124.15 | 130.00 | 68.00 |
| S-18 | 1400 | 0.00 | 0.00 | 5.76 | 0.00 | 5.76 | 32.28 | 72.60 | 0.00 | 882.00 | 0.00 | 0.00 | 992.64 | 825.00 | 42.50 |
| S-19 | 1100 | 0.00 | 0.00 | 1.32 | 5.43 | 6.75 | 21.48 | 44.57 | 4.00 | 136.50 | 7.71 | 2.40 | 223.42 | 200.00 | 113.33 |
| S-20 | 1600 | 0.00 | 0.00 | 10.74 | 1.80 | 12.54 | 35.04 | 47.83 | 19.43 | 228.30 | 2.57 | 0.00 | 345.71 | 325.00 | 51.00 |
| S-21 | 1600 | 0.00 | 0.00 | 3.42 | 7.20 | 10.62 | 42.60 | 42.69 | 55.25 | 302.40 | 20.64 | 0.00 | 474.20 | 425.00 | 113.33 |
| S-22 | 850 | 0.00 | 0.00 | 11.72 | 0.21 | 11.93 | 18.72 | 70.29 | 23.50 | 46.80 | 0.00 | 0.00 | 171.23 | 150.00 | 85.00 |
| S-23 | 1000 | 0.00 | 12.96 | 17.88 | 0.00 | 30.84 | 67.44 | 53.49 | 37.00 | 66.00 | 0.00 | 96.00 | 350.77 | 300.00 | 255.00 |
| S-24 | 900 | 0.00 | 0.00 | 1.62 | 0.00 | 13.77 | 29.25 | 33.56 | 14.11 | 66.15 | 7.29 | 0.00 | 164.12 | 175.00 | 170.00 |
| S-25 | 750 | 6.75 | 13.50 | 14.22 | 0.63 | 35.10 | 46.20 | 60.06 | 55.54 | 45.00 | 7.71 | 0.00 | 249.61 | 220.00 | 127.50 |
| S-26 | 1400 | 0.00 | 0.00 | 17.04 | 3.15 | 20.19 | 50.88 | 51.34 | 45.00 | 60.00 | 0.00 | 0.00 | 227.41 | 185.00 | 170.00 |
| S-27 | 1000 | 5.40 | 13.50 | 5.40 | 0.21 | 24.51 | 50.88 | 51.26 | 26.36 | 457.80 | 8.57 | 0.00 | 619.38 | 550.00 | 255.00 |
| S-28 | 800 | 0.00 | 0.00 | 3.20 | 7.20 | 10.40 | 58.62 | 71.57 | 60.14 | 339.00 | 0.00 | 0.00 | 539.73 | 500.00 | 204.00 |
| S-29 | 1000 | 6.00 | 10.80 | 5.22 | 6.60 | 28.62 | 68.94 | 81.77 | 32.14 | 69.75 | 3.86 | 0.00 | 285.08 | 300.00 | 170.00 |
| S-30 | 800 | 4.50 | 0.00 | 10.32 | 0.81 | 15.63 | 39.78 | 23.83 | 13.50 | 40.50 | 2.57 | 0.00 | 135.81 | 110.00 | 68.00 |
| S-31 | 1200 | 0.00 | 0.00 | 1.80 | 6.93 | 8.73 | 91.08 | 53.49 | 6.43 | 164.10 | 0.00 | 0.00 | 323.82 | 300.00 | 204.00 |
| S-32 | 800 | 0.00 | 0.00 | 0.00 | 17.84 | 17.84 | 100.20 | 111.43 | 25.00 | 426.00 | 0.00 | 0.00 | 680.46 | 620.00 | 255.00 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-33 | 650 | 6.00 | 0.00 | 15.21 | 0.00 | 21.21 | 28.02 | 56.20 | 32.57 | 56.10 | 2.57 | 120.0 | 316.67 | 325.00 | 113.33 |
| S-34 | 850 | 0.00 | 0.00 | 18.63 | 0.00 | 18.63 | 70.50 | 72.34 | 60.00 | 72.00 | 6.43 | 0.00 | 299.90 | 260.00 | 204.00 |
| S-35 | 1200 | 0.00 | 0.00 | 2.25 | 10.50 | 12.75 | 59.70 | 63.77 | 14.14 | 49.20 | 2.57 | 0.00 | 202.14 | 200.00 | 85.00 |
| S-36 | 1000 | 10.35 | 6.48 | 7.56 | 0.00 | 24.39 | 27.60 | 37.34 | 1.63 | 28.80 | 0.00 | 0.00 | 119.76 | 125.00 | 68.00 |
| S-37 | 800 | 0.00 | 0.00 | 10.17 | 2.16 | 12.33 | 36.12 | 35.91 | 6.75 | 16.80 | 0.00 | 0.00 | 107.91 | 110.00 | 170.00 |
| S-38 | 1100 | 0.00 | 0.00 | 12.21 | 0.00 | 12.21 | 13.20 | 53.49 | 45.00 | 30.00 | 0.00 | 0.00 | 153.90 | 140.00 | 85.00 |
| S-39 | 700 | 0.00 | 0.00 | 20.58 | 0.00 | 20.58 | 49.92 | 53.14 | 15.00 | 63.00 | 7.71 | 240.0 | 449.36 | 475.00 | 113.33 |
| S-40 | 1000 | 3.60 | 0.00 | 8.40 | 11.34 | 23.34 | 64.14 | 92.29 | 26.00 | 307.50 | 5.14 | 0.00 | 518.41 | 550.00 | 85.00 |
| S-41 | 800 | 0.00 | 15.12 | 2.64 | 9.45 | 27.21 | 30.24 | 65.14 | 13.50 | 45.00 | 7.71 | 0.00 | 188.81 | 165.00 | 85.00 |
| S-42 | 1400 | 12.15 | 0.00 | 7.26 | 0.00 | 19.41 | 18.96 | 21.34 | 43.57 | 45.00 | 2.57 | 0.00 | 150.86 | 150.00 | 68.00 |
| S-43 | 700 | 9.00 | 0.00 | 16.35 | 0.00 | 25.35 | 73.74 | 44.91 | 46.43 | 99.00 | 9.43 | 0.00 | 298.86 | 275.00 | 255.00 |
| S-44 | 1000 | 10.80 | 0.00 | 12.18 | 0.00 | 22.98 | 21.96 | 53.34 | 18.75 | 43.50 | 0.00 | 0.00 | 160.53 | 150.00 | 51.00 |
| S-45 | 800 | 0.00 | 6.48 | 10.95 | 0.00 | 17.43 | 44.76 | 29.49 | 26.08 | 171.00 | 1.71 | 0.00 | 290.47 | 300.00 | 68.00 |
| S-46 | 900 | 4.50 | 0.00 | 14.22 | 0.00 | 18.72 | 19.32 | 40.34 | 21.21 | 40.50 | 2.57 | 240.0 | 382.67 | 410.00 | 170.00 |
| S-47 | 1000 | 0.00 | 0.00 | 9.18 | 8.19 | 17.37 | 78.30 | 56.06 | 2.00 | 261.00 | 5.14 | 0.00 | 419.87 | 400.00 | 170.00 |
| S-48 | 1000 | 0.00 | 0.00 | 21.45 | 0.00 | 21.45 | 54.78 | 58.14 | 32.00 | 41.10 | 0.00 | 0.00 | 207.47 | 200.00 | 85.00 |
| S-49 | 1000 | 0.00 | 0.00 | 4.62 | 14.39 | 19.01 | 58.74 | 102.86 | 48.00 | 73.80 | 7.71 | 0.00 | 310.12 | 325.00 | 255.00 |
| S-50 | 800 | 0.00 | 0.00 | 19.26 | 0.00 | 19.26 | 40.80 | 43.20 | 4.00 | 60.84 | 5.31 | 0.00 | 173.41 | 160.00 | 113.33 |
| S-51 | 700 | 0.00 | 0.00 | 18.60 | 0.00 | 19.01 | 58.74 | 50.06 | 32.00 | 51.00 | 7.71 | 5.00 | 235.59 | 215.00 | 255.00 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-52 | 1400 | 9.60 | 0.00 | 19.80 | 0.00 | 29.40 | 62.52 | 63.14 | 49.20 | 59.40 | 5.14 | 0.00 | 268.81 | 290.00 | 170.00 |
| S-53 | 650 | 0.00 | 4.32 | 8.91 | 5.04 | 18.27 | 44.04 | 23.49 | 21.00 | 64.50 | 5.14 | 0.00 | 176.44 | 150.00 | 113.33 |
| S-54 | 1000 | 0.00 | 0.00 | 2.25 | 12.12 | 14.37 | 23.70 | 68.14 | 2.57 | 39.60 | 3.86 | 0.00 | 152.24 | 150.00 | 113.33 |
| S-55 | 600 | 0.00 | 5.40 | 4.50 | 6.72 | 16.62 | 45.90 | 46.63 | 6.50 | 159.60 | 7.71 | 0.00 | 282.96 | 250.00 | 170.00 |
| S-56 | 1200 | 0.00 | 0.00 | 8.55 | 4.23 | 12.78 | 47.52 | 66.77 | 12.00 | 47.25 | 7.71 | 0.00 | 194.04 | 200.00 | 85.00 |
| S-57 | 1200 | 6.75 | 4.32 | 15.33 | 0.00 | 26.40 | 57.12 | 60.57 | 6.57 | 181.35 | 0.08 | 5.00 | 337.09 | 325.00 | 204.00 |
| S-58 | 1000 | 0.00 | 3.24 | 17.10 | 2.70 | 23.04 | 49.26 | 32.06 | 13.00 | 39.75 | 3.86 | 0.00 | 160.96 | 145.00 | 170.00 |
| S-59 | 1000 | 4.80 | 0.00 | 19.74 | 0.00 | 24.54 | 52.14 | 43.20 | 26.46 | 46.80 | 3.99 | 180.0 | 377.13 | 400.00 | 170.00 |
| S-60 | 1100 | 0.00 | 17.28 | 9.72 | 5.70 | 32.70 | 63.54 | 39.54 | 16.60 | 209.10 | 0.00 | 0.00 | 361.48 | 325.00 | 127.50 |