PRELIMINARY STANDARD FOR ENERGY EFFICIENT DOMESTIC BUILDINGS IN SRI LANKA

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Degree of Master of Engineering

Department of Mechanical Engineering

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DECLARATION

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ABSTRACT

In Sri Lanka the total electricity consumption of domestic units is 40% of the total electricity generated in the country. Especially in the Western province electricity usage is high, compared to other parts of Sri Lanka. By controlling building energy and implementing operational strategies to domestic units, it would provide a great opportunity to reduce domestic consumption. The saved energy could be utilized for industries to develop the nation. The current code of practice published by the SLSEA for energy efficient buildings in Sri Lanka has focused on multistory buildings with higher energy consumption. The specified criterion in the standard does not satisfy domestic units. The increase in demand for domestic energy is a major issue for supply side management. It is vital to study possible approaches to save energy in domestic units and standardization of a code of practice for energy efficient systems for domestic units in Sri Lanka. Mainly the use of electricity of a domestic unit can be categorized into different aspects namely, lighting, ventilation & air conditioning, water heating, etc. A survey was conducted and data was collected from domestic consumers, (sample size: n=50) located in Colombo district. These data were analyzed using SPSS tool to identify significant variables to electricity consumption of domestic units. Use of air conditioners is a trend which is becoming more common in domestic units in Colombo district. Hence, it is desirable to standardize and introduce a code of practice for domestic units at the current stage as a solution for the increasing electricity demand. The conclusions of the analysis reflect that domestic units located in Colombo district can be classified into two main models such as 'High Income Model and 'Middle Income Model'. Using Autodesk Revit, Building Information Modeling software, developed two designs. Revit Architecture, Revit MEP are the BIM related software which are used to design an intelligent 3D model with bi-directional associative feature for energy analysis. These models A and B are designed with suitable lighting levels and comfort levels for each defined space. This will reduce the waste of energy of the unit and could be used as a preliminary guide line for energy efficient domestic unit. International energy efficient domestic codes of India and USA are discussed in this paper. This research could be used as a preliminary document for reference and to develop a guideline for practicing authorities to implement energy efficiency in domestic units in Sri Lanka.

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating Refrigerating and Air conditioning Engineers
BEE	Bureau of Energy Efficiency
BS	British Standard
CEB	Ceylon Electricity Board
CEN	Committee for European Standardisation
CIBSE	Chartered Institution of Building services Engineers
COC	Certificate of Conformity
CIE	International Commission of Illumination
DSM	Demand Side Management
ESD	Energy Services Delivery
EE	Energy Efficiency
EPRI	Electric Power Research Institute
EMCS	Energy Management Control System
GDP	Gross Domestic Product
IES	Illuminating Engineering Society
LECO	Lanka Electricity Company
LEED	Leadership in Energy and Environmental Design
LM	Load Management
LOR	Light Output Ratio
LPD	Lighting Power Density
PUCSL	Public Utilities Commission of Sri Lanka
RSE	Relative System Efficiency
RERED	Renewable Energy for Rural Economic Development
SLSEA	Sri Lanka Sustainable Energy Authority
SPP	Simple Payback Period
UDA	Urban Development Authority

LIST OF APPENDICES

CHAPTER 1. INTRODUCTION

This chapter aims to introduce the background of the present domestic energy consumption pattern and identify limitations of the current code of practice for energy efficient buildings in Sri Lanka.

1.1 Background

Sri Lanka energy balance compiled by Sustainable Energy Authority shows that the housing sector of Sri Lanka consumes 38% of the total energy while industry, commercial and other sectors consume only 34%, 26% and 2% respectively in year 2013 [1]. In year 2014 these figures revised as 40%, 34%, 24% and 2% for each consumer category [2]. Sri Lanka Census 2012 records indicate that nearly 4.5 million houses out of 5.16 million are lit up by electricity from the national grid. [3]. However, Ceylon Electricity Board statistics 2013 state that 96% of households are electrified by the national grid and the average electricity consumption per capita is 519kWh/person [4]. Further these figures have been increased to 98% and 535kWh per person in 2014, which shows a 3.19% and 2.5% growth rate respectively [5]. Particularly in Colombo city of Western province of Sri Lanka, the percentage of electricity consumption is 11.7% of the total electricity sales and the average per capita consumption is 634kwh in 2014 [6], which shows a higher value compared to the average consumption per person of Sri Lanka. This causes high usage of lighting, air conditioning and electrical appliances in Colombo district domestic units, compared to other parts of Sri Lanka. Further CEB statistics highlights that nearly 4.77 million account holders are domestic consumers, which holds 88.1% of the total accounts. Therefore, study of energy demand patterns and forecasting models for domestic buildings are essential to control and save energy to utilize for the development of the country.

According to the housing and town improvement ordinance, local authorities issue Certificate of Conformity (CoC) [7] to the domestic user confirming that the construction has been completed in conformity with the regulations in place accordance with the approved building plan and the building permit. It is desirable to introduce energy efficient system regulations for evaluation process of CoC and promote people to implement energy efficient systems for their domestic building designs. Conducting energy audits, it is possible to identify the energy waste in existing domestic units and the energy manager appointed by authorities can propose an energy efficient system to minimize the energy waste of the domestic unit to comply with requirements of CoC. At present there are no such procedures for evaluating domestic units in Sri Lanka for energy concern; however other countries practice these by introducing different strategies.

In September 2000, Demand-side Management Branch of Ceylon Electricity Board has published the first Energy Efficient Building Code for Commercial Buildings in Sri Lanka with the support of the World Bank. By reviewing and amending this code, Sri Lanka Sustainable Energy Authority has (SLSEA) published the Code of Practice for Energy Efficient Buildings in Sri Lanka - 2008 under Clause 36 (g) of Sri Lanka Sustainable Energy Authority Act [8].

The extensive application of this code of practice will lead to reduced energy consumption and reduced electricity demand in the country, and will also support a cleaner environment through the reduction of waste. Code of Practice for Energy Efficient Buildings in Sri Lanka-2008 is applicable for commercial buildings, Industrial facilities and large scale housing developments which satisfy the criteria mentioned below.

a. Four or more stories
b. Floor Area of 500 m^2 or more
c. Electrical power demand of 100 kVA or more
d. Air-Conditioning cooling capacity of 350 kW (Output) or more

This code of practice covers only the energy performance aspects of a given building considering the following building elements:

a. Building Envelope
b. Ventilation & Air Conditioning
c. Lighting

d. Electrical Power and Distribution
e. Service Water Heating

However there are domestic units, medium industries and small and medium scale commercial buildings that may not come under the specified criteria. Medium scale commercial buildings with two or three floors, where floor area is less than 500m^2 are found in cities and these buildings consume electrical power for air conditioning, lighting and other office equipment. Sites where power demand is less than 100kVA and air-conditioning cooling capacity is less than 350 kW (Output) do not benefit from the current code. Considering the domestic sector, this code applies only for large scale housing developments and not for individual domestic units, which fall below the criteria. As mentioned above 40% of the total electricity utilization of Sri Lanka in year 2014 is consumed by domestic buildings [2]. Hence, it is vital to develop a national action plan for energy efficient domestic buildings for the country. Energy codes for domestic units can be mainly classified as new and existing buildings. Existing buildings may need to undergo major renovations to meet the minimum requirements for energy efficiency.

1.2 Problem Identification

Very importantly energy efficiency measures have to be incorporated in domestic buildings at the design stage to achieve better outcomes. Hence, authorities have to encourage designers in energy efficiency designs exceeding minimum standards. For that there should be a guide line or a specified code of practice for energy efficient domestic buildings. The present energy efficient building code of Sri Lanka has specified criteria’s and limitations for building applications. However individual domestic units do not lie in this limitations. Hence there is a key requirement of developing an energy efficient code for domestic units. This can be developed by adapting the current energy efficient building code to suits for domestic buildings or as an integral part of the current code considering special areas related to domestic concern such as lighting and air conditioning. As the highest domestic electricity consumers are in Colombo district, it is vital to conduct a survey and analyse the electricity consumption of domestic buildings in Colombo district

1.3 Aim

The aim of this research is to develop a preliminary standard for energy efficient domestic units that do not fall under the given building categories of the 2008 energy efficient code for buildings developed by the SLSEA.

1.4 Objectives

1. To explore the current state of electricity consumption of domestic units in Sri Lanka.
2. To investigate different categories of electricity consumption and its pattern in domestic units in Colombo district.
3. To identify parameters to include in a preliminary standard for Energy Efficient Domestic Buildings in Sri Lanka.

1.5 Methodology

1. Literature review on current state of electricity consumption of domestic units in Sri Lanka.
2. Data collection by survey domestic units located in Colombo district as a case study.
3. Analyze data and identify correlation between different variables.
4. Discuss results and formulate a set of recommendations.
5. Evaluate the developed recommendations based on expert judgment and literatures.

1.6 Outline of the Thesis

Chapter one describes the background of the research and the present code of practice for Energy Efficient Buildings in Sri Lanka. However identifies the problem of this research as limitations of the current code in application to domestic buildings. The objectives of this research paper is listed in point form where followed by the methodology to achieve the scope. Study of the current energy scenario of Sri Lanka, electricity demand, present energy efficient building code 2008, basic concepts of energy efficient lighting and HVAC systems are discussed under the literature review in chapter two. Climate of Colombo and International standards for domestic units are also discussed in this chapter. Chapter three consists of data collection from fifty domestic users located in Colombo district. These data were analyzed preliminary by MS excel. Further the collected data were fed into SPSS statistics tool for detailed analysis. The results of the study are discussed in chapter four. Further, discussed about Identified significant variables to electricity consumption of domestic units in Colombo district. Chapter five is the final chapter, which discuss the conclusion and recommendation based on the analysis

CHAPTER 2. REVIEW OF LITERATURE

A study of the present energy scenario of Sri Lanka and current code of practice for energy efficient building in Sri Lanka are mainly reviewed in this chapter. Understanding of climate change of Colombo and available International codes for energy efficient domestic buildings are discussed in the later part of this chapter.

2.1 Present Energy Scenario of Sri Lanka

This section reviews fundamentals of energy characteristics, understanding of billing unit of electricity, current energy demand, Energy-Economy Indicators, electricity consumption of domestic sector, growth of population and statistics related to domestic units from latest census report.

2.1.1 Energy Characteristics

Energy is an indirectly observed quantity which comes in many forms. It can be classified into two types of energy namely kinetic energy and potential energy. However, it is clear that energy is always an indispensable prerequisite for performing mechanical work, thermal (heat), electrical and chemical. The basic units in which energy is measured are those used for mechanical work equivalent to a unit of force multiplied by a unit of length. Other equivalent units for energy are mass units multiplied by velocity units squared. The customary measurements of Energy are Watts (W). The kilowatt hour, or kilowatt-hour, (kWh) is a unit of energy equal to 1000 watt hours or 3.6 Mega Joules. Petajoule is equal to one quadrillion (1015) joules. For constant power, energy in watt hours is the product of power in watts and time in hours. The kilowatt hour is most commonly known as a billing unit for energy delivered to consumers by electric utilities. The tonne of oil equivalent (toe) is a unit of energy defined as the amount of energy released by burning one tonne of crude oil. It is approximately 42 gigajoules, although different crude oils have different calorific values, the exact value is defined by convention; several slightly different definitions exist. The toe is sometimes used for large amounts of energy. Multiples of the toe are used, in particular the kilo toe (ktoe), mega toe (Mtoe, one million toe) and the gigatoe

(Gtoe, one billion toe). A smaller unit of kilogram of oil equivalent (kgoe) is also sometimes used denoting 1/1000 toe.

2.1.2 Energy Demand in Sri Lanka

Energy balance 2014 reports that the total energy demand of Sri Lanka for the year 2014 is 9,133.5 ktoe, (382.5PJ) [9]. Out of this the largest share of 44.7% accounted by household, commercial and other sectors. The total energy demand by each category are summarized in Table 2.1 and Figure 2.1 illustrates an area graph, which shows the increment of total energy usage from year 1977 to 2014 period. These data and graphs clearly shows that domestic sector consume a higher portion compared to industry & transport.

Table 2.1: Total Energy demand by sector

Ktoe	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**
Industry	1,679.0	2,011.1	2,072.0	2,175.7	2,272.3	2,261.3	2,362.8
Transport	1,689.6	2,115.8	2,397.9	2,459.7	2,670.2	2,565.7	2,686.1
Household, Comm & Others	3,855.7	3,918.2	4,312.9	4,284.9	4,179.2	4,075.5	4,084.5
Total	7,224.4	8,045.0	8,782.8	8,927.2	9,122.2	8,902.5	9,133.5
PJ							
Industry	70.3	84.2	86.8	91.1	95.2	94.7	98.9
Transport	70.7	88.6	100.4	103.0	111.8	107.4	112.5
Household, Comm & Others	161.4	164.0	180.6	179.4	175.0	170.6	171.0
Total	302.5	336.8	367.7	373.5	381.9	372.7	382.5
%							
Industry	23.2	25.0	23.6	24.4	24.9	25.4	25.9
Transport	23.4	26.3	27.3	27.6	29.3	28.8	29.4
Household, Comm & Others	53.4	48.7	49.1	48.0	45.8	45.8	44.7

(Source: Sri Lanka Sustainable Energy Authority, Energy Balance 2014)

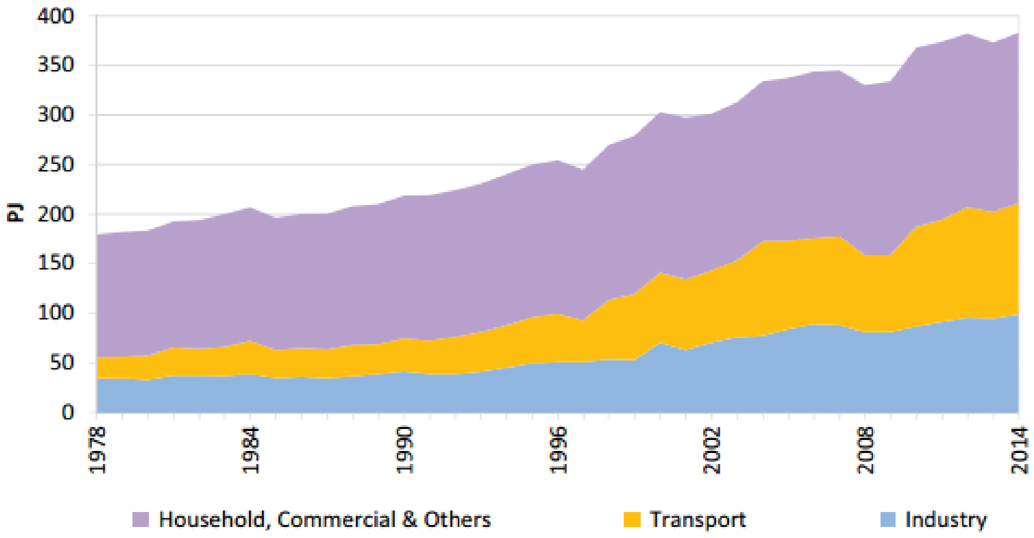


Figure 2.1: Total Energy demand by sector

(Source: SLSEA Energy Balance 2014)

The sustainable Energy Authority, Energy balance for the year 2014 provided in Table 2.2 shows the total energy demand by household units, commercial and other sectors. Biomass approximately accounts for 76.8% of the total demand. However electricity usage shows a continuous increment since year 2000 making double for a decade from 7.2% to 15.2% in 2014 [9].

Table 2.2: Total Energy demand in household sector by Energy Source

Ktoe	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**
Biomass	3,173.1	3,167.8	3,435.0	3,340.6	3,215.0	3,147.7	3,138.9
Petroleum	404.0	361.6	356.7	375.8	372.5	328.9	324.1
Electricity	278.7	388.8	521.2	568.5	591.6	598.9	621.5
Total	3,855.7	3,918.2	4,312.9	4,284.9	4,179.2	4,075.5	4,084.5
PJ							
Biomass	132.8	132.6	143.8	139.9	134.6	131.8	131.4
Petroleum	16.9	15.1	14.9	15.7	15.6	13.8	13.6
Electricity	11.7	16.3	21.8	23.8	24.8	25.1	26.1
Total	161.4	164.0	180.6	179.4	175.0	170.6	171.1
%							
Biomass	82.3	80.8	79.6	78.0	76.9	77.2	76.8
Petroleum	10.5	9.2	8.3	8.8	8.9	8.1	7.9
Electricity	7.2	9.9	12.1	13.3	14.2	14.7	15.2

(Source: Sri Lanka Sustainable Energy Authority, Energy Balance 2014)

The energy balance in Figure 2.2 illustrates the energy supply, conversion, losses and consumption for year 2013 and 2014 in PJ. The energy demands of the household sector are 170.6 PJ and 171.1 PJ, which is 45.8% and 44.7% respectively of the total demand. In this sector 77.2% was sourced by biomass in 2013 reduced to 76.8% in 2014. However electricity demand has increased from 14.7% to 15.3%. in last two years. The total energy demand in the industrial sector in 2013 is 94.7 PJ of where biomass accounted for 69.1 PJ, petroleum for 10.5 PJ, coal for 2.2 PJ and electricity accounted for 12.9 PJ. Electricity demand in industrial sector has decreased from 14% to 13.7% from 2013 to 2014. The entire demand of the transport sector was sourced by petroleum.

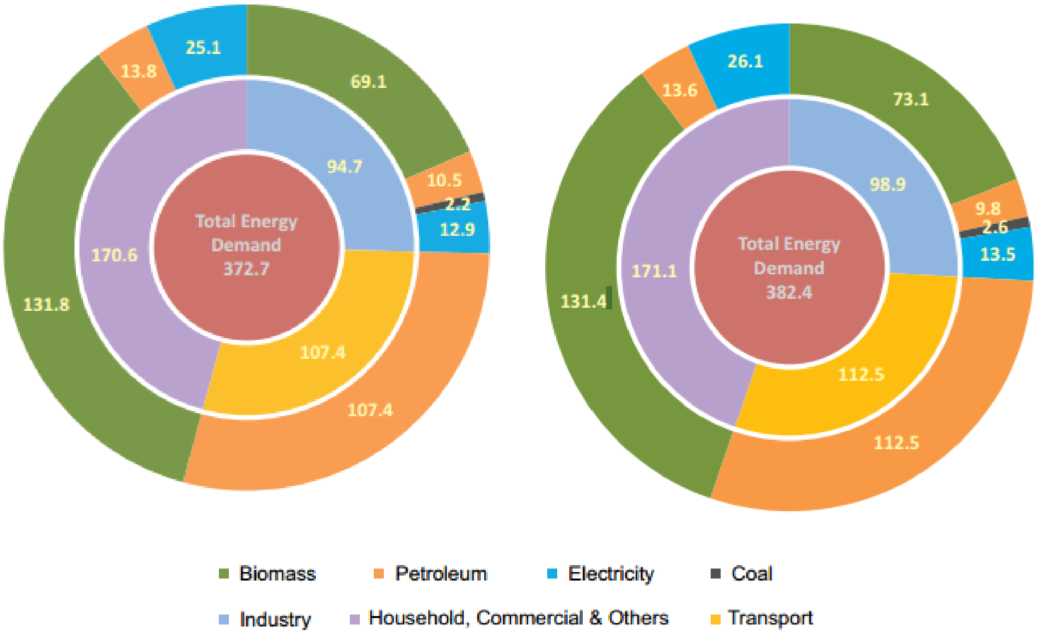


Figure 2.2: Energy Balance 2013 and 2014 in PJ
(Source: SLSEA Energy Balance 2013/2014)

Biomass is the most significant primary energy supply source in the country. Biomass has a widespread demand for both commercial and domestic applications. However, the informal nature of supply, mainly through users' own supply chains, has prevented accurate and comprehensive usage data being compiled for biomass. Therefore, estimation methods are used to develop reasonable information based on available data. The mid-year population data and LPG consumption are used to estimate household firewood consumption. Meanwhile, industrial biomass consumption is estimated based on the industrial production data and surveys. Table 2.3 shows the total usage of fuel wood in different sectors.

Table 2.3: Sectorial Consumption of Fuel wood

Consumer	2008	2009	2010	2011	2012	2013
Industries	3398.5	3519	3788.5	4040.9	4158.1	4139.2
Household & Commercial	8671.8	8888.5	9039.5	8791.0	8460.6	8283.4

(Source: Sri Lanka Sustainable Energy Authority)

2.1.3 Electricity Demand in Sri Lanka

In Sri Lanka there are two identified aspects to fulfill the national electricity demand. They are cumulative electrical energy requirement and the peak demand. The national demand profile has an evening peak, the capability of the supply system in meeting the demand during the evening is important. However the generating systems needs to be able to meet both aspects. Figure 2.3 shows the hourly demand profile of 8 April, 2013, the day the system recorded the annual peak. There is a notable loss of demand due to a line tripping at 02:30 hrs on this day. The lost demand was added to the load profile after statistically clearing the lost demand of 170 MW [1].

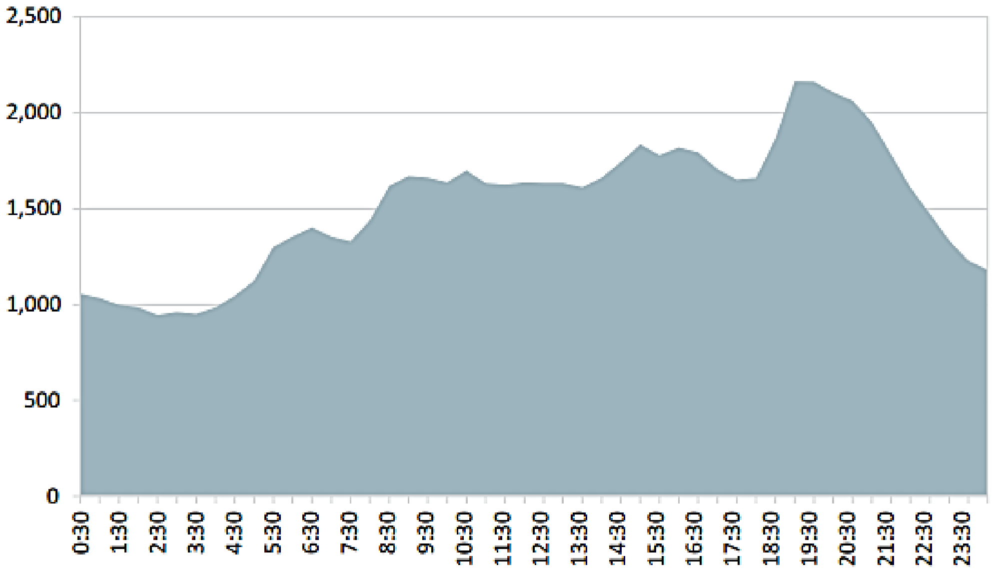


Figure 2.3: System Demand Profile in MW
(Source: SLSEA Energy Balance 2013)

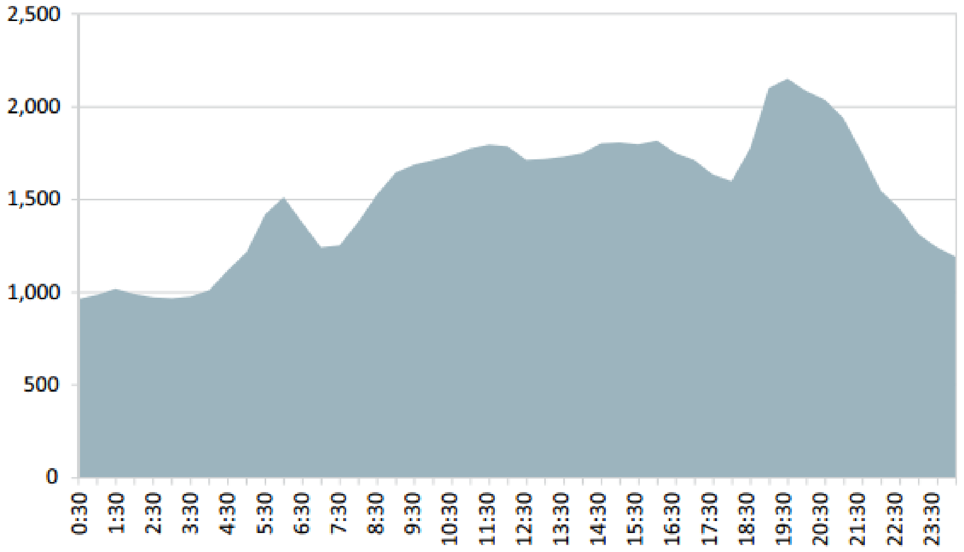


Figure 2.4: System Demand Profile in MW
(Source: SLSEA Energy Balance 2014)

Figure 2.4 shows the load profile of the highest recorded annual peak in year 2014, 19th May and Figure 2.5 depicts the historic growth of the load curve since 2005 to 2014 [2].

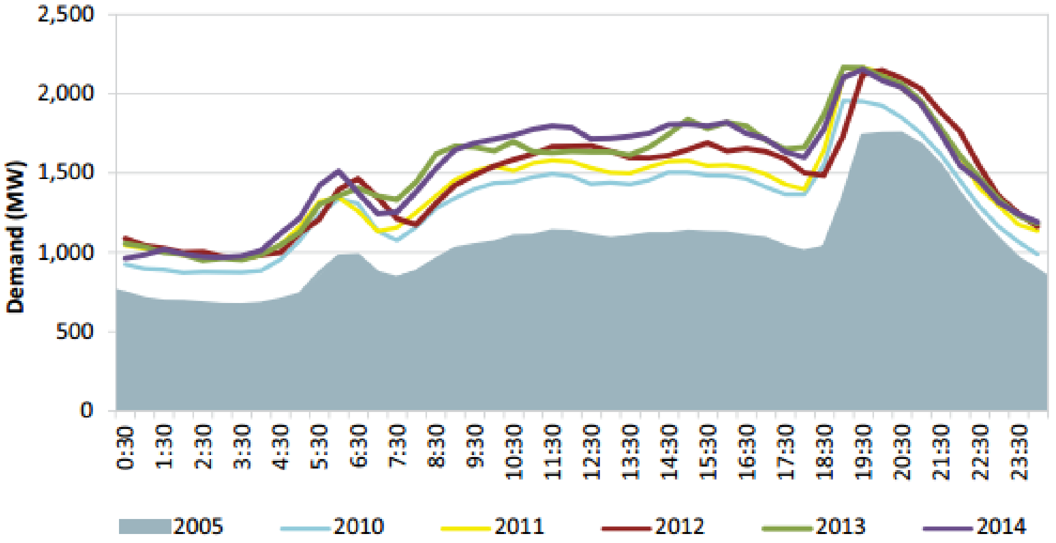


Figure 2.5: Historic Growth of the Load Curve
(Source: SLSEA Energy Balance 2014)

Table 2.4 shows the maximum demand of electricity in year 2014 as 2,151 MW. Further the system load factor and system reserve margin percentages are 68% and 88% respectively.

Table 2.4: The Growth in System Capacity & Demand

System Parameters	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**
Total Gross Gen (GWh)	6629	8897	10800	11646	11897	12024	12849
Total Grid Conn Cap (MW)	1,838	2,420	2,817	3,140	3,368	3,290	4043
Maximum Demand (MW)	1,404	1,748	1,954	2,163	2,146	2,164	2151
Reserve Capacity	433.5	672.6	862.9	977.6	1,222	1,126	1892
System Load Factor	51%	57%	63%	61%	63%	63%	68%
System Reserve Margin	31%	37%	44%	45%	56%	52%	88%

(Source: Sri Lanka Sustainable Energy Authority, Energy Balance 2014)

Figure 2.6 depicts the development of the system load factor, reserve margin and peak demand from 1978 to present. The system load factors are in the range of 55%-65% are typical of a customer mix dominated by households with a high demand for electricity used for lighting in the evening.

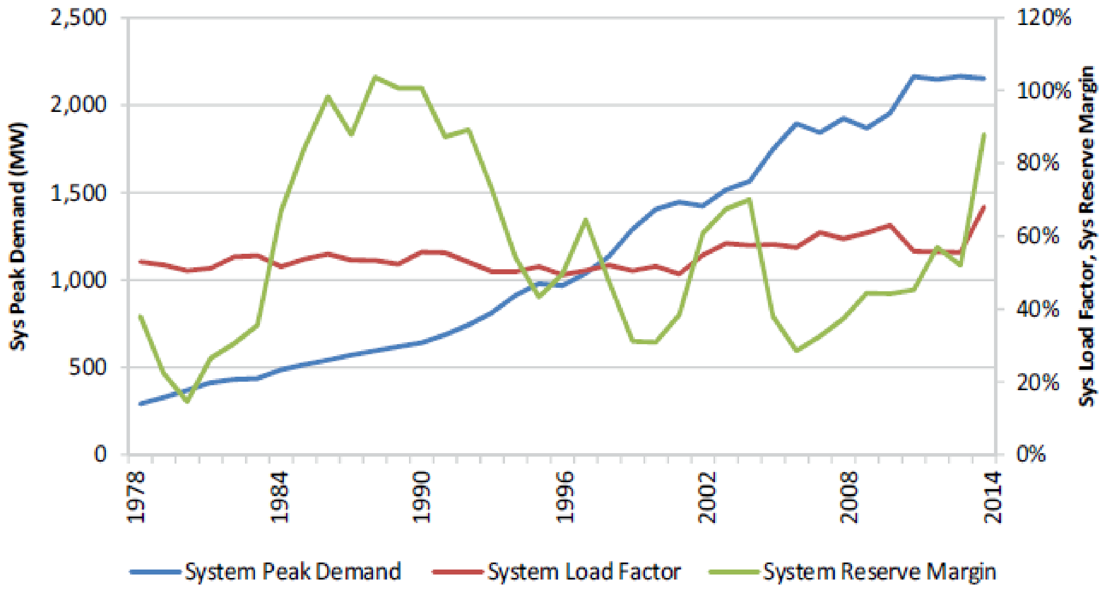


Figure 2.6: Peak Demand, Load Factor and System Reserve Margin

(Source: SLSEA Energy Balance 2014)

2.1.4 Demand Side management

One of the key objectives of the Public Utilities Commission of Sri Lanka in terms of Sri Lanka Electricity Act, No. 20 of 2009 to encourage consumers to amend their electricity consumption pattern both with respect to timing and level of electricity demand for efficient use of energy [10]. Actions are taking in three aspects such as corporate objectives, load shape objectives and non-load Shape objectives. Corporate Objectives are improving distribution network system, collection efficiency, power quality, reliability, upgrading sub-stations and customer service. Also focusing to minimize losses at all points. Figure 2.7 illustrated several load shape objectives including load management (LM), energy efficiency (EE) and electrification. DSM uses one of the following specific load shape objectives as cost effective options.

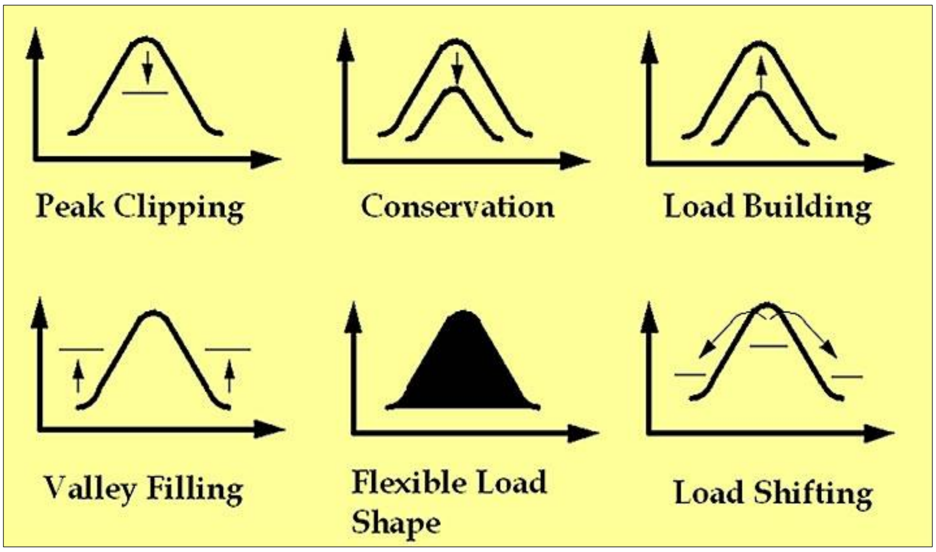


Figure 2.7: Load shape objectives of DSM (Source: CEB, DSM)

Peak clipping is the reduction of utility load during the period of peak demand. This is the most suitable option for Sri Lanka to control the “Night Peak” which starts at 7pm in the night. Improvement of system load factor by building load in off-peak periods is called valley-filling. Load shifting can be done by reducing utility loads during periods of peak demand and while at the same time building load in off-peak periods. Conservation is the reduction of utility loads, more or less equally, during all or most hours of the day, when load building increases the utility loads, more or less equally.

2.1.5 Electricity Consumption in Domestic units

Sri Lanka Sustainable Energy Authority published the latest energy balance for different consumer account numbers for different categories as shown in Table 2.5 from year 2008 to 2014.

Table 2.5: Electricity Consumers (Nos) served by the Grid

Category	2008	2009	2010	2011	2012	2013	2014
Domestic	3992071	4179278	4363324	4578596	4810595	5024077	5205453
Religious	26355	27692	29050	30645	32369	34068	35640
Industrial	43797	45936	48461	50885	54017	56638	57945
Commercial	471808	492816	514292	543535	577050	611785	638700
Street Light	2934	3142	2931	3803	3622	4651	3504
Total	**4536965**	**4748864**	**4958058**	**5207464**	**5477653**	**5731219**	**5941242**

(Source: Sri Lanka Sustainable Energy Authority, Energy Balance 2014)

Energy balance 2014 statistics shows that domestic category has the highest number of consumers served by the National grid compared to all other sectors. The number of accounts served by the grid has increased by 4% in the year 2013 when compared with year 2012. The growth rate has reduced to 3.7% in 2014 with respective to 2013.

Using Table 2.5 for electrified consumer population of Sri Lanka by category in numbers has been converted to percentage format and developed the Table 2.6 for comparison purpose.

Table 2.6: Electrified consumer population (%) in Sri Lanka by category

Category	2008	2009	2010	2011	2012	2013	2014
Domestic	88.0%	88.0%	88.0%	87.9%	87.8%	87.7%	87.6%
Religious	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
Industrial	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Commercial	10.4%	10.4%	10.4%	10.4%	10.5%	10.7%	10.8%
Street Light	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%

(Source: Sri Lanka Sustainable Energy Authority)

However domestic consumer’s population is 87.6% of the total electrified consumers in Sri Lanka in 2014. Figure 2.8 signifies that the major potion occupied by domestic category due to dramatic increase of types of energy consuming equipment in use and expansion of rural electricity distribution in Sri Lanka during last few decades.

Population growth, distribution of domestic units and increase of energy use by per capita are other main factors for increase in electricity consumption.

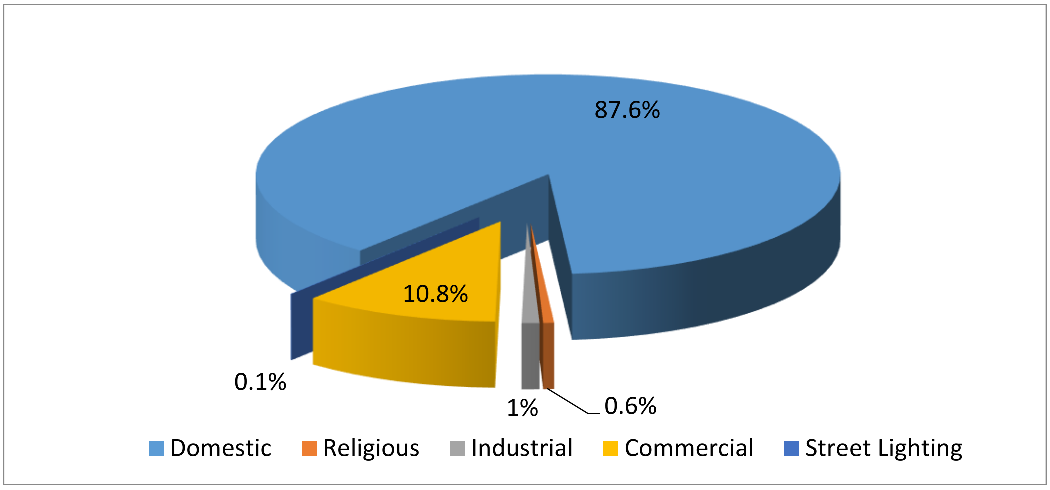


Figure 2.8: Consumer Accounts by Category in year 2014

Amounts of electricity used by different customer categories in GWh are given in Table 2.7, which also includes off-grid electricity generation using conventional and non-conventional sources. The electrical energy demands of different end users are established by using electricity sales data.

Table 2.7: Sri Lanka Total Electricity Use (CEB+LECO+Self+Off Grid) in GWh

Category	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Domestic	3239.23	3373.2	3651.4	3928.43	4064.7	4012.95
Religious	48.64	50.7	55.0	59.12	63.3	66.58
Industrial	2956.94	2772.5	3148.1	3379.31	3528.0	3590.19
Commercial	1985.79	2059.1	2224.0	2490.15	2614.1	2752.11
Street Lighting	135.12	133.2	130.0	132.93	139.1	132.64
Tot Electricity Requirement	8365.72	8388.73	9208.48	9989.94	10409.23	10554.47

(Source: Sri Lanka Sustainable Energy Authority)

Figure 2.9 illustrates the increment of household electrification rate had reached 98.4% by 2014 [2]. Due to the different approaches taken by the CEB and the Department of Census in defining a housing unit, the rate of electrification reported by the CEB and result of Census 2011 differs.

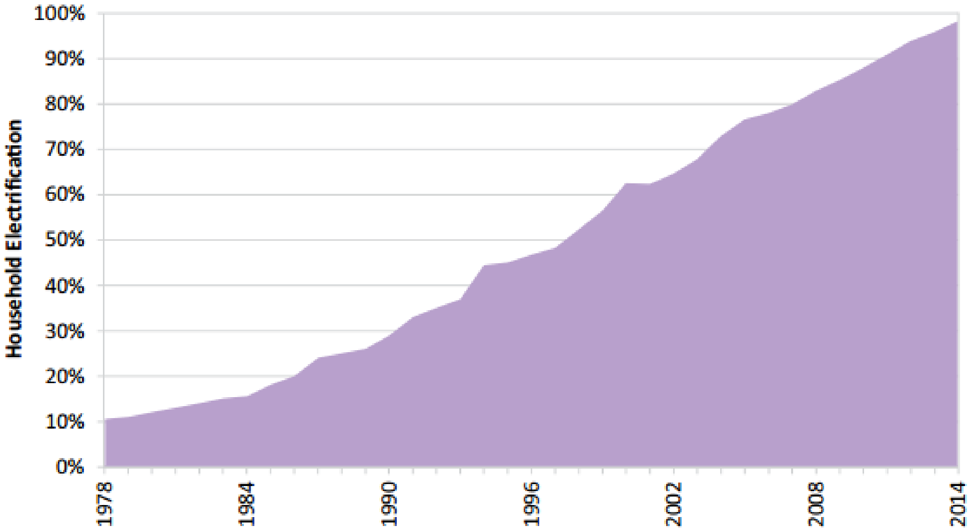


Figure 2.9: Household Electrification Rate

(Source: SLSEA Energy Balance 2014)

The national average selling price of electricity is given in Table 2.8 and the growth of the price is depicted in Figure 2.10. The average selling price of electricity per kWh depends on the tariff structure and the sales to different consumer categories.

Table 2.8: National Average Selling Price of Electricity

	2000	2005	2010	2011	1012	1013	2014
Average Selling Price (LKR/kWh)	4.86	8.04	13.03	13.63	15.71	18.01	18.54

(Source: Sri Lanka Sustainable Energy Authority)

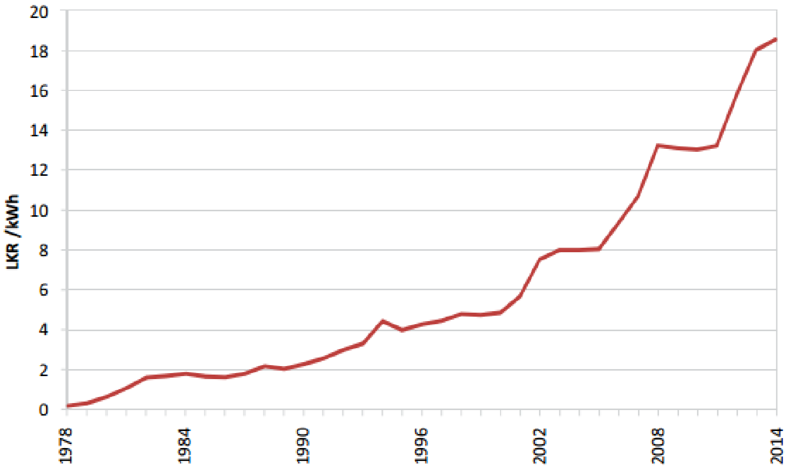


Figure 2.10: National Average Selling Price of Electricity
(Source: SLSEA Energy Balance 2014)

As illustrated in Figure 2.9, the average selling price of an electricity unit in Sri Lanka increased over time. The tariff was revised on April 20, 2013 and Table 2.9 indicates the electricity pricing in the year 2013 only for domestic concern.

Table 2.9: Electricity Prices in Year 2013

Domestic Consumption	**Unit Rate (LKR/Unit)**	**Fixed Charge (LKR/month)**
Block 1 – 0 - 30 Units	5.00	30.00
Block 2 –0 - 60 Units	6.00	60.00
Block 3 – 0 – 90 Units	8.50	90.00
Block 4 – 0 – 120 Units	15.00	315.00
Block 5 – 0 – 180 Units	20.00	315.00
Block 6 – 0 – 210 Units	24.00	315.00
Block 7 – 0 – 300 Units	26.00	315.00
Block 8 – 0 - >300 Units	32.00	315.00

(Source: Sri Lanka Sustainable Energy Authority)

Referring Table 2.10, it has been reported that 96% of household units were electrified by the national grid by the year 2013. At that time the mid-year population was 20.48 million. Table 2.11 specifies the electricity consumption per capita in kWh from 2008 to 2013.

Table 2.10: Household Electrified by the National Grid

	2008	**2009**	**2010**	**2011**	**2012**	**2013**
Percentage of Household Electrification (%)	83	85.4	88	91	94	96
Mid-year Population (million)	20.22	20.45	20.65	20.86	20.33	20.48

(Source: Sri Lanka Sustainable Energy Authority)

Table 2.11: Electricity Consumption Per Capita (kWh/Person)

	2008	**2009**	**2010**	**2011**	**2012**	**2013**
Gross Generation: Grid + Off Grid	494.7	488.3	523.0	556.1	585.2	586.9
Sales: Grid+Off Grid	413.7	410.2	445.9	478.9	512.0	515.4

(Source: Sri Lanka Sustainable Energy Authority)

Sri Lanka Energy Balance 2013 indicates that the percentage of households that used kerosene for lighting was 11.5% of the total population. The distribution network of LPG expanded, realising an increased penetration of LPG, displacing a portion of biomass used in the domestic sector for cooking. The percentage that uses LP gas for cooking in urban households is 55.5%, while the percentage that uses fuel wood for cooking in the urban sector is 35.2% **[1]**.

Table 2.12: Energy usage per person in Sri Lanka

Energy use per person	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Energy use (toe/person)	390.05	389.09	425.75	427.77	448.85	434.78
Commercial Energy Use (toe/person)	156.84	153.49	184.01	188.24	207.36	198.01
Electricity Sold (kWh/person)	414.14	409.21	445.87	478.7	512.06	515.28
Petroleum Sold (kg/person)	176.99	184.59	180.44	198.62	214.21	177.35

(Source: Sri Lanka Sustainable Energy Authority)

2.1.6 Energy-Economy Indicators

Commercial energy intensity is an indicator of a country’s energy utilization with respect to the national output, measured in terms of Gross Domestic Product (GDP). The commercial energy intensity marginally decreased to 0.39 TJ/GDP million LKR in the year 2013 from the previous year’s figure of 0.44 TJ/GDP million LKR as shown in Figure 2.11. The success of policies and action taken by the relevant authorities as well as the energy consumers in making their energy consumption more productive than ever, combined with the structural change of the economy where growth is largely in the services sector is presumed to have warranted this trend.

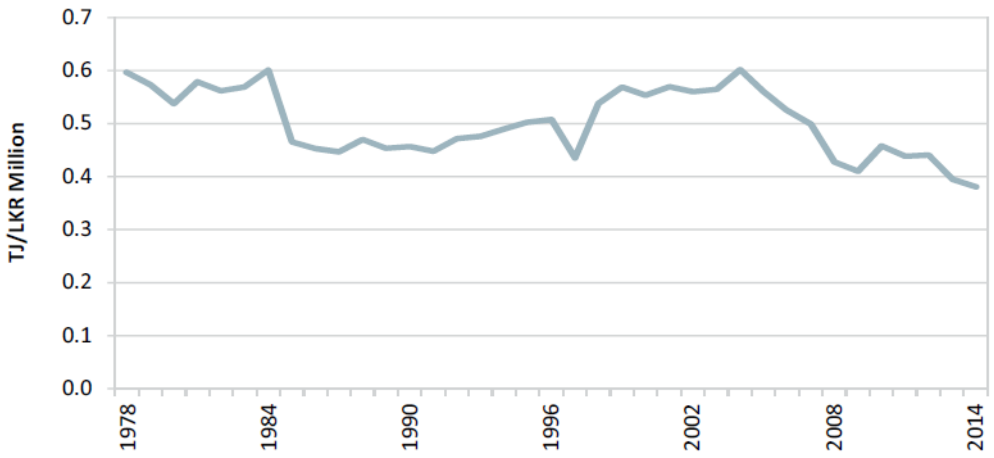


Figure 2.11: Commercial Energy Intensity

(Source: SLSEA Energy Balance 2014)

2.1.7 Population Growth and Domestic Units in Sri Lanka

The 14th National Census conducted in Sri Lanka was carried out during 27th February and 21st March in 2012. It is reported in the Census of Population and Housing 2011, the population of the entire country after a lapse of 30 years as 20,277,597. The average annual population growth rate between 1981 and 2012 stood at 1.0 per cent, while the same between the intercensal period of 2001 and 2012 was reported as 0.7 per cent [3]. It can therefore be concluded that the population of Sri Lanka is still growing as Illustrated in Figure 2.12, which tends to increase number of domestic units respectively.

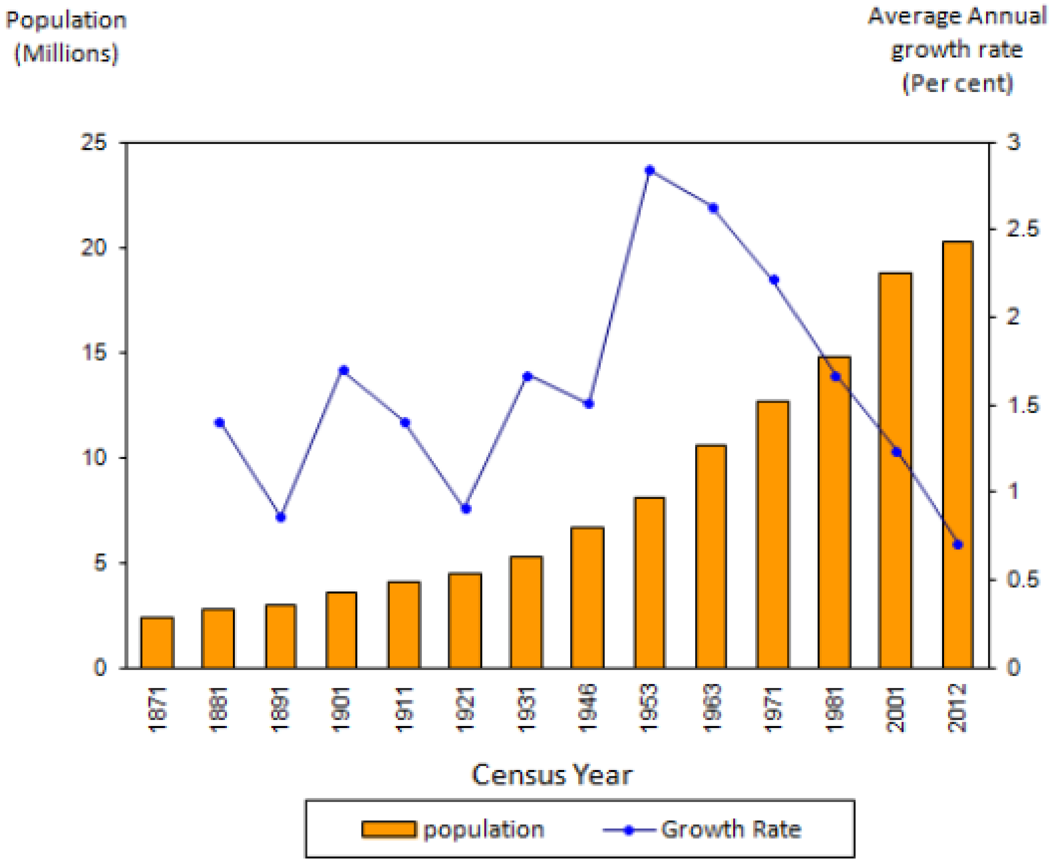


Figure 2.12: Annual Growth Rate 1871- 2012

(Source: Census of Population and Housing 2011)

According to a district-wise analysis of the population, Colombo district continues to record as the most populous district of the country with a population of 2,323,826 (Appendix 1). This is followed by the adjoining district of Gampaha, which records a population of 2,298,588. A major share of 28.8 per cent of the population lives in the Western province out of the 25 districts. The Western Province accounts for more than one fourth of the total residents (28.8 per cent) in Sri Lanka. This is followed by the Central Province (12.6 per cent), Southern Province (12.2 per cent) and the North Western Province (11.7 per cent) respectively.

Population density, defined as the number of persons in a unit area, could be used as the most appropriate measure for this purpose. In other words, it is important to calculate the number of persons in a square kilometer for this purpose. The population density in the country, in general, has increased in keeping with the increase in population. Reports say that the population density of 230 persons per square kilometer in 1981 had increased to 300 in 2001, which continued to increase to 323 according to the 2012 census report. According to the current Census, the highest level of population density is prevalent in the Colombo District. The population density in the Colombo District, which stood at 2,605 persons per square kilometer in 1981, had increased to 3,330 persons per square kilometer in 2001, and it has further increased to 3438 as illustrated in Figure 2.13.

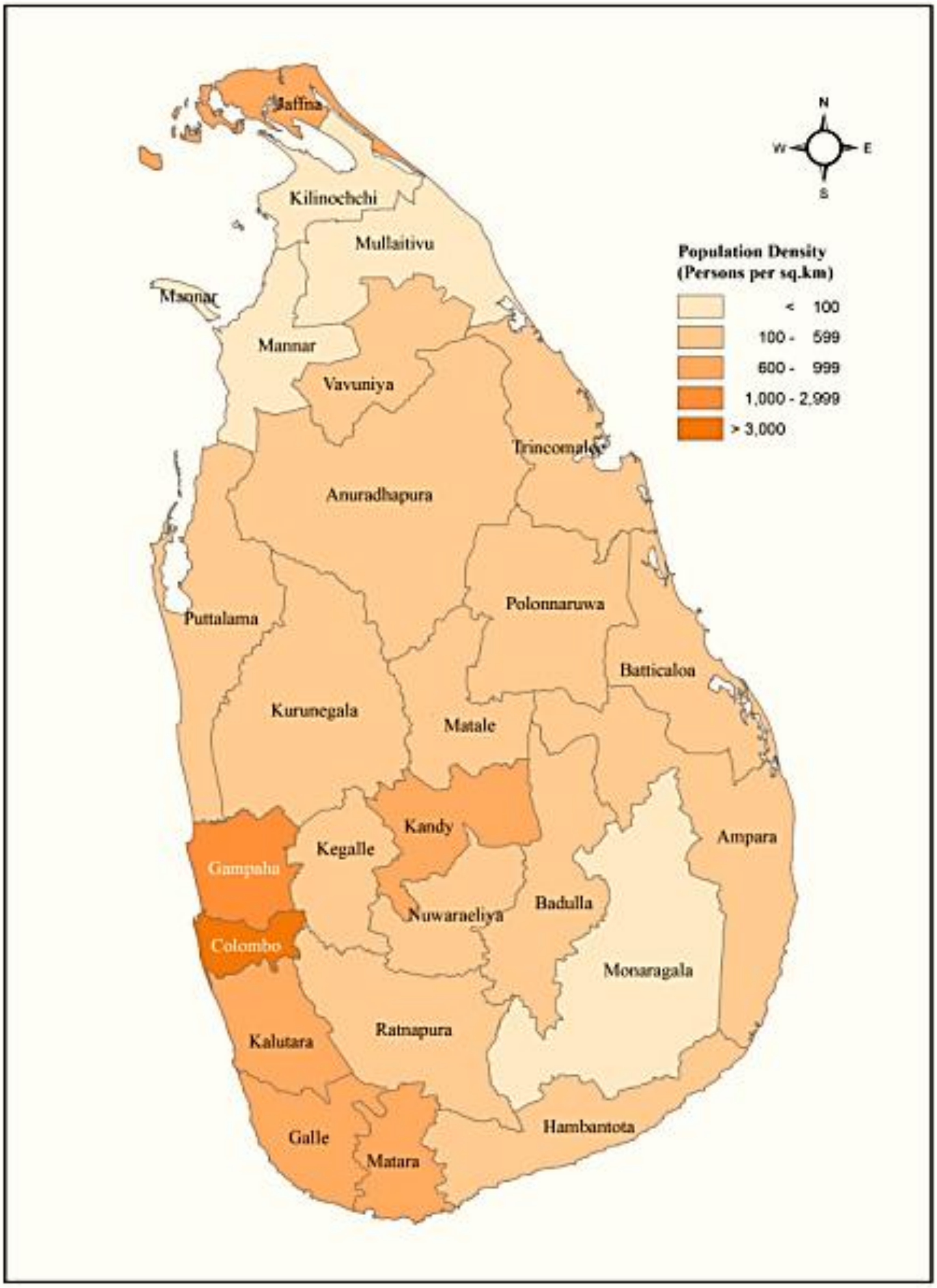


Figure 2.13: Population Density by District, 2012

(Source: Census of Population and Housing 2011)

Table 2.13 is an abstract from Appendix 2: Households in occupied housing units by districts and the principal type of lighting, latest census report of 2012 which indicates the no of housing units in selected area for discussion.

Table 2.13: Principal type of lighting usage by domestic units in year 2012

District	Number of Households	**Principle Type of Lighting**					
		Electricity		Other			
		Electricity from National Grid	Electricity from rural hydro power project	Kerosene	Solar power	Bio gas	Other
Sri Lanka	5,188,047	4,514,182	36,904	597,360	34,315	840	4,446
	100.0	87.0 %	0.7 %	11.5 %	0.7%	0.6%	0.1%
Colombo	558,755	545,784	904	11,370	150	44	503
	100.0	97.7	0.2	2.0	0.0	0.0	0.1
Gampaha	593,317	573,100	0	19,505	232	34	446
	100.0	83.2	10.00	0.6	1.3	0.2	-
Kalutara	300,402	281,075	1,416	16,853	657	36	365
	100.0	93.6	0.5	5.6	0.2	0.0	0.1
Kandy	344,681	318,184	2,405	23,283	633	27	149
	100.0	93.6	0.7	6.8	0.2	0.0	0.0
Galle	269,740	251,367	2,451	15,370	315	37	200
	100.0	93.2	0.9	5.7	0.1	0.0	0.1
Matara	204,194	191,079	1,057	11,706	24	15	123
	100.0	93.6	0.5	5.7	0.1	0.0	0.1

(Source: Census of Population and Housing 2011)

2.2 Code of Practice for Energy Efficient Buildings in Sri Lanka

On 30th June 2009 Sustainable Energy Authority published the latest Code of Practice for Energy Efficient Buildings in Sri Lanka under Clause 36 (g) of Sri Lanka Sustainable Energy Authority Act.

This code sets the requirements for design and/or retrofit of commercial buildings and industrial installations. This practice covers only the energy performance aspects of a given building considering the following building elements: [11]

a. Building Envelope
b. Ventilation & Air Conditioning
c. Lighting
d. Electrical Power and Distribution
e. Service Water Heating

This practice is to be implemented by Urban Development Authority (UDA), Provincial Councils and Local Authorities. All new buildings with one or more features stated above are expected to conform to the building code regulations. SLSEA provide necessary assistance to the Local Authorities to evaluate sections regarding energy efficiency aspects in the CODE in all building applications as necessary. SLSEA is the responsible agency for the implementation of CODE and UDA, Provincial Councils and Local Authorities (Municipal Councils, Urban Councils and Pradeshiya Sabha) are the implementing partners of the CODE.

The code in the present form is basically to be used for commercial buildings. Industrial buildings, hotels and large apartment complexes are to be brought in subsequently.

The mechanism for the implementation of this code is fully controlled by the Implementing Authorities mentioned above and it introduces an additional compliance requirement as an integral part of the building plan approval procedure. The relevant section of the building permit application, with the relevant drawings and the submittals will be forwarded to a special code compliance certifying body specifically set up for the purpose. The code compliance certifying body will be established by the SLSEA and it comprises of two committees as monitoring and approval. This committee will be assisted by the technical evaluation committee, which after carefully studying the submittals; will submit their recommendations to the monitoring and approval committee. The monitoring and approval committee will consist of senior specialists in the relevant fields covering the entire code. They will be selected and appointed by the SLSEA. The technical evaluation committee will consist of technically qualified persons having adequate experience in the specialty areas coming under the code and who have been trained in the implementation procedure of the provisions of the code. This committee will process the submittals and make their recommendations to the monitoring and approval committee. The SLSEA will obtain the services of the existing professional associations and bodies to obtain their services as partners or obtain their assistance in selecting suitable persons for the technical evaluation committee. The monitoring and approval committee will make the final recommendation to the responsible agency (SLSEA). The SLSEA will issue a letter of compliance to the relevant agency for eligible projects, considering the recommendations of the monitoring and approval committee. It will be the code compliance approval for the project. The inspection of the building on completion will be carried out either by the technical evaluation committee or any other organization or committee appointed by the SLSEA. Certificate of Conformity will be issued for the projects, which shall be successful at this stage of evaluation. Certificate of Conformity will be the final document expressing the compliance of the certified building to the code. The compliance certificate will be issued for a specific period of time (3 – 5 years). The certificate needs to be revalidated subsequent to an inspection thereafter. The buildings complying with the code will be given a ‘Star Rating’ depending on the level of compliance.

Sri Lanka’s energy consumption is rapidly increasing compared to the last decade and in future this will become the most significant issue. As engineers we have to be ready to control and reduce energy waste by introducing energy efficiency in all aspects. The extensive application of the current code of practice will lead to reduced energy consumption and reduced electricity demand in the country, and will also support a cleaner environment through the reduction of waste. Hence it is vital to develop a similar code or an amendment to the current code of practice including the category of domestic buildings where it holds a major part of the total consumption.

2.2.1 General Principles of Energy Efficient Lighting Practice

It can be observed from previous sections that lighting is the single largest consumer of energy (kilowatt hours) in a domestic building. It also contributes largely towards increasing of cooling loads in buildings in tropical climates, as lighting generates heat, which in turn results in higher consumption of energy for air conditioning requirements. Today there are a number of technologies available, that can significantly reduce this component but it has to be done with utmost care as it needs to be accepted by the occupants who actually experience the lighting installation. Further, latest research has revealed that qualitative aspects of lighting can bring about increase in productivity and therefore, it is a matter of arriving at solutions, without compromising the qualitative aspects, to reduce energy. This also calls for creativity on the part of lighting designers, for instance, to maximise the use of daylight and apply dynamic lighting solutions and colours in a sensible way, without compromising safety aspects. The current code sets the maximum allowable loads for building lighting systems as well as lower limits for the acceptable efficiencies for commonly used lighting components (lamps and ballasts). The Lighting Designer therefore is to face the challenge of using this code as a minimum energy performance standard to develop lighting systems that balance appealing and effective visual environments with minimal energy usage.

The objective of the current code is to use minimal electrical energy to provide lighting to the quantity and quality of standards. It is however necessary to evaluate the equipment, techniques and services available for both existing and proposed installations in order to meet these requirements.

Following are six basic rules for achieving energy efficiency in lighting.

1. Use the most efficient but suitable light source
2. Ensure efficient usage of lamp light output

3. Ensure proper maintenance of lighting equipment
4. Use well-designed energy efficient lighting schemes
5. Establish controlled switching operations and maximise use of daylight
6. Consider appropriate interior décor: use light-colours whenever possible.

Two main factors involved in the energy efficient lighting systems are the lamp wattage and the duration of its operation. Both these factors are equally important and could be made to contribute to energy efficiency through 'Lighting Controls' such as area controls and automatic lighting controls.

2.2.2 Area Controls

The simplest way to improve lighting efficiency is to turn off lights when they are not in use. All lighting systems must have switching or control capabilities to allow lights to be turned off when they are not required. All spaces enclosed by walls or ceiling height partitions shall be provided with one manually operated on/off lighting control (switch) for each space. Each space must have its own switching; gang switching of several spaces is not permitted. All manually operated switching devices must be located in such a way that it is visible to the operational personnel handling the switches.

2.2.3 Automatic Lighting Controls

Photo electric sensor and timer controls with manual override option can be used for the lighting in external areas of the buildings including road ways, car parks… etc. This may be applicable to all the areas where lighting needs are predictable and predetermined.

Occupancy based controls are best suited to spaces that have highly variable and unpredictable occupancy patterns. Occupancy or motion sensors are used to detect occupant motion, lighting the space only when it is occupied.

Daylight control Use of day lighting shall be maintained in all buildings. This may be achieved either manually through separate dedicated switching provided for day-lit areas or by using automatic controls. Further, Designers shall be encouraged to maintain a minimum average daylight factor of 2% – 5% in which case it can be supplemented with electric lighting [12].

Average Daylight Factor and Limiting Depth Criteria can be calculated with following equations 2.1 and 2.2.

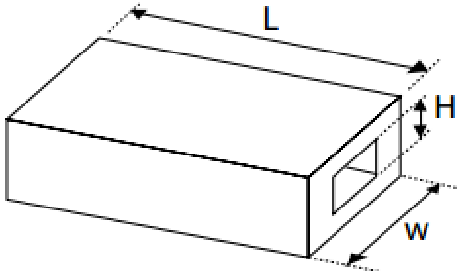


Figure 2.14: Criteria's for Average Daylight Factor

$$\mathbf{D = W/A * (T\,r/\,(1-R^2))\ldots\ldots\ldots\ldots\ldots\quad (2.1)}$$

Where;

D = average daylight factor

W=window area in m^2 (Ref Figure: 2.14)

A= area of all surfaces of the room in m^2 (floor, ceiling, walls including windows)

T = glass transmittance

r = visible sky angle, in degrees

R = average reflectance of area A

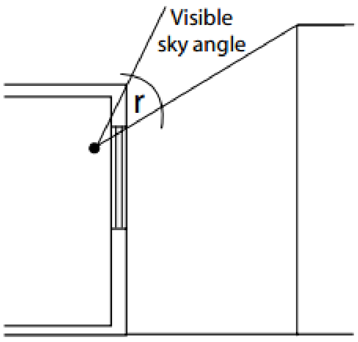


Figure 2.15: Visible Sky Angle

To be successfully day-lit from one side, the depth (L) of the room should be limited to meet the following condition:

$$\mathbf{L/w + L/h \le 2 / (1-R_b)} \ldots\ldots.(2.2)$$

L =depth of room from window to back wall
w =width of the room measured across the window wall
h =height of the window head above the floor
R_b= area weighted average reflectance in the back half of the room (the value for a typical office is likely to be around 0.5) [13].

2.2.4 Daylight and Skylight

All daylight comes from the sun, whether we see it as sunbeams or as the light from a clouded sky. However, for the purpose of calculating the light available for illuminating our work during the day, the source used is the overcast sky. This is now termed skylight not daylight as before. Controlled daylight can replace up to 80% of lighting energy consumption during daytime hours [14]. The internationally accepted standards developed by CIE (International Commission of Illumination) used as a base for skylight studies as overcast sky. This sky is three times as bright as the zenith (overhead) as at the horizon, and no brighter than to the south than to the north. It is assumed that its minimum illumination is 5000 lux outdoors.

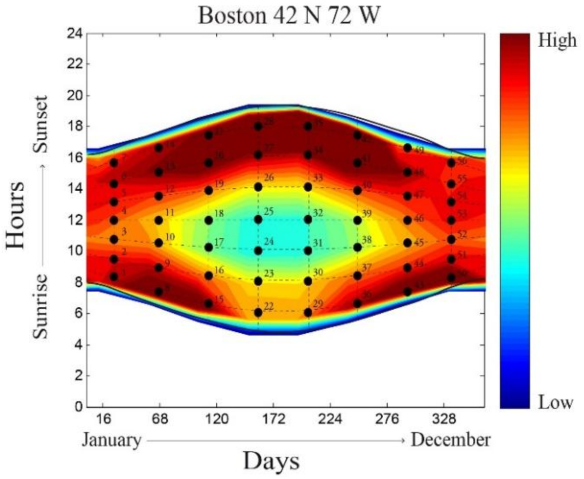


Figure 2.16: Day Light Illumination

(Source: CIBSE Day Light)

As daylight levels vary over a large range even on an overcast day, illuminance indoors coming from skylight is, in practice, measured as a ratio. This ratio (daylight factor) is the illuminance at a point indoors, usually on the working plane, expressed as a percentage of the illuminance outdoors. So if the illuminance outdoors is 5000 lux, that of a dull overcast sky, a daylight factor of 2% at a point indoors will give an illuminance of 100 lux at that point (2% of 5000 lux = 100 lux).

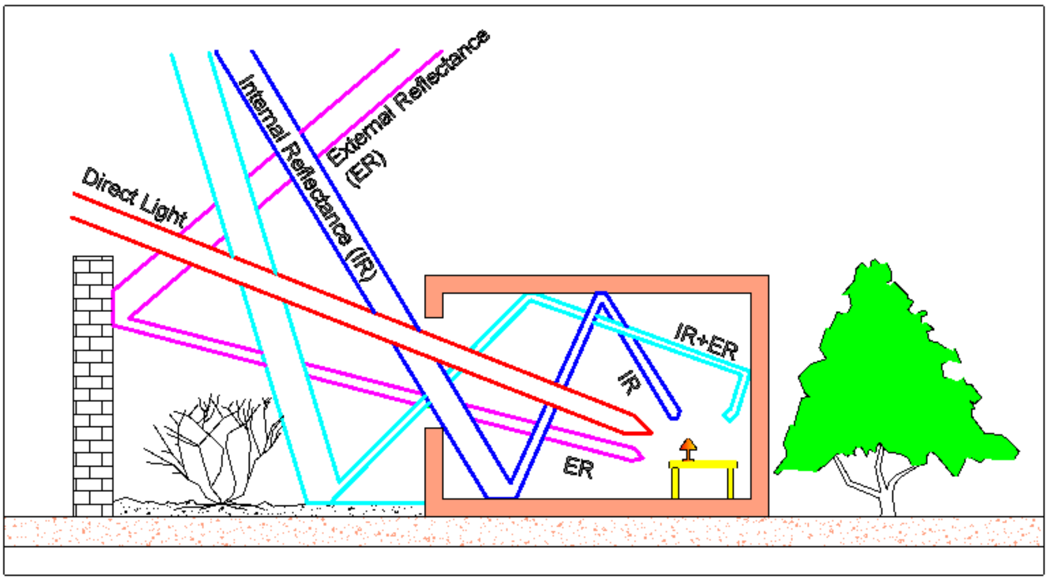


Figure 2.17: Main Components of skylight

Figure 2:17 shows the main components of the skylight which reaches a desk at the back of the room. First there is the direct light from any part of the sky which is visible from the desk. All other light which reaches the desk is reflected, either outside or inside or both.

Reflected light makes a significant contribution to the working light indoors, the proportion increasing as one move further from the window. As the ceiling and walls form a large part of the internal surface of a room, using light colours can greatly increase reflected light. A light floor finish close to the window can also help, as it reflects direct light from high sky. The amount of light reflected depends on the reflectance of the surfaces, and some typical values are given in Table 2.14. For calculating the average daylight factor, use R=0.5 for a room with light surfaces, and R=0.3 for a room with darker surfaces. BS Daylight code 2.p 27 has to be referred for other cases [13].

Table 2.14: Typical Surface Reflectance

Surface Type	R
White ceilings	0.7
Pale walls	0.5
Floors and furniture	0.3
The ground outside	0.1

Obstructions such as buildings are usually assumed to be 20% as bright as the sky behind them. Values for interior surfaces need to be further reduced to allow for deterioration with age and dirt. Deterioration factor for an office in a clean location may be 0.9 and the deterioration factor for dirty work in a dirty location may be as low as 0.6 [15].

2.2.5 Maximum Allowable Power for Illumination Systems

Lighting Power Density (LPD) is calculated by dividing the total connected load for all lighting systems in the building by the gross lighted floor area of the building. SLSEA has defined maximum lighting power density (LPD), values for building lighting systems and related types for domestic units have been highlighted in Table 2.17.

Table 2.15: Lighting Power Density

Building Area Type	LPD (W/m^2)	Building Area Type	LPD (W/m^2)
Automotive Facility	9.7	Multifamily	7.5
Convention Centre	12.9	Museum	11.8
Dining: Bar Lounge/Leisure	14.0	Office	10.8
Dining: Cafeteria/Fast Food	15.1	Parking Garage	3.2
Dining: Family	17.2	Arts Theatre	17.2
Dormitory/Hostel	10.8	Police/Fire Station	10.8
Gymnasium	11.8	Post Office/Town Hall	11.8
Healthcare Clinic	10.8	Places of Worship	14.0
Hospital/Health Care	12.9	Retail/Mail	16.1
Hotel	10.8	School/University	12.9
Library	14.0	Sports Arena	11.8
Manufacturing Facility	14.0	Transportation	10.8
Motel	10.8	Warehouse	8.6
Motion Picture Theatre	12.9	Workshop	15.1

(Source: Sri Lanka Sustainable Energy Authority)

Table 2.16 shows the lighting requirements for Interior Lighting as per the CIBSE. The recommended design maintained Illuminance over the task area in any room where house work is carried out is generally in the range of 100 to 300 lux.

Table 2.16: Lighting Levels for Domestic units as CIBSE.

Area	Illuminance (lux)	Limiting Glare Rating	Minimum colour rendering (Ra)
Lounge	100 - 300	19	80
Kitchens	150 - 300	-	80
Bathrooms	150	-	80
Toilets	100	-	80

(Source: CIBSE)

Code instructs to use the most efficient luminaries or fixtures for lighting applications and defines the Light Output Ratio (LOR) as the ratio of the lumens from the luminaries to the sum of the individual lumen values of the lamps inside the luminaries. For general-purpose lighting systems, the minimum figure for LOR has mentioned as 0.50.

Table 2.17: Electrical power equivalents for differing lamps

Minimum light output (lumens)	Electrical Power consumption (Watts)		
	Incandescent	CFL	LED
450	40	9-13	4-9
800	60	13-15	10-15
1,100	75	18-25	17
1,600	100	23-30	22
2,600	150	30-52	Not available

Above Table 2.17 clearly shows that replacing of incandescent lamps with CFLs reduces the heat production significantly. Use of CFL’s for indoor space where air conditioning systems have installed reduce the load on the cooling system when compared to the use of incandescent lamps, resulting in savings in electricity in addition to the energy efficiency savings of the lamps themselves.

2.2.6 Light Source Selection

There may be situations in a lighting installation where the maximum required light level does not need to be maintained throughout the area. In such situations, the lighting designer may focus on providing 'Design Maintained Illuminance' for the task areas while maintaining 'Standard Maintained Illuminance' in the surrounding areas. Depending on the concept, this may be achieved by using localized lighting to supplement the general lighting that could be maintained at a minimum.

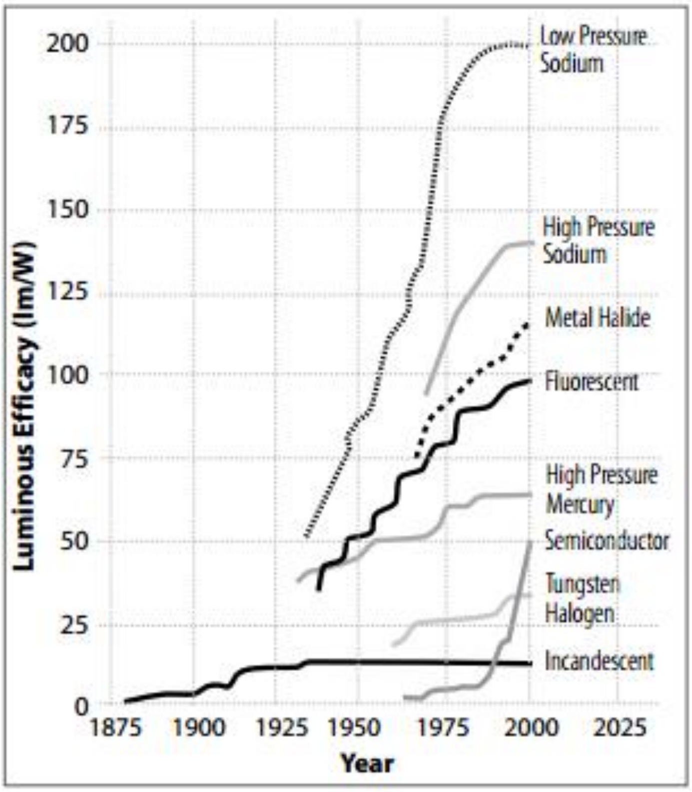


Figure 2.18: Comparison of Lamp Efficiencies

(Source: SLSEA, Energy Efficient Building Code 2008)

The use of incandescent or tungsten halogen lamps for general lighting should be discouraged unless the application specifically requires so. Wherever applicable, general lighting should be provided with fluorescent lamps of appropriate colour. Although incandescent and tungsten halogen light sources are the least expensive to install, they are less energy efficient compared to sources such as fluorescent lighting or other discharge lamps.

Use of compact fluorescent lamps in ‘downlights’ in ceiling under 4m and use of high pressure sodium vapour or metal halide lamps for ‘high bay’ applications (ceiling over 4 m) are generally recommended.

The lamp efficacy is calculated by dividing the lamp’s rated light output (in lumens) by the rated lamp power (watts) and does not include the ballast losses. But in system lighting power density (LPD) calculation, both lamp and ballast losses are considered.

Table 2.18: Lamp Efficacy of Linear Fluorescent Lamps

Lamp Length (mm)	Lamp Power (W)	Diameter (mm)	Minimum lamp Efficacy (lm/W)
600	18	26	55
1200	36	26	66
1500	58	26	66

(Source: Sri Lanka Sustainable Energy Authority)

Lamp efficacy for Linear Fluorescent, Integral type CFL, Modular type CFL and Incandescent Lamps are listed in Table 2.18 and 2.19. However it is clearly shows that the highest efficacy has in modular type CFL relative to other types.

Table 2.19: Lamp Efficacy for Integral and Modular Type CFL

Type	Lamp Power (W)	Minimum Lamp Efficacy (lm/W)
Integral type CFL	09	42
	11	52
	15	57
	20	57
	23	62
Modular type CFL	7	54
	10	57
	11	78
	13	66
	18	63

Incandescent Lamps	40	10.6
	60	12.0
	75	12.7
	100	13.6

(Source: Sri Lanka Sustainable Energy Authority)

2.2.7 Codes of Practices for Lighting Design

It is the responsibility of the lighting designer to select the illumination level required for any given task. The Standard Maintained Illuminance values are tabulated in Table 2.10 Annexure 1 and these values shall be the starting point for any lighting design. "Code of Interior Lighting– 1994", published by the Chartered Institution of Building services Engineers (CIBSE), UK provides information on 'Standard Maintained Illuminance' [15]

For many years, the Illuminating Engineering Society (IES) Code for Lighting was the existing standard for lighting provision in the United Kingdom. However, in 2002, the Committee for European Standardisation (CEN) took on the task of providing lighting recommendations, and, since then the British Standards Institution has adopted the CEN recommendations for use in the United Kingdom. As a result, there are now a range of British Standards that specify the quantitative lighting requirements for a wide range of applications. Consequently, the role of the SLL Code for Lighting has shifted from being the only source for quantitative lighting recommendations to being a guide on how to interpret the British Standard recommendations and how to implement them in practice.

SLL Code for Lighting takes the changes in lighting guidance a step further by a process of separation and concentration. The separation involves moving the details of vision, lighting technology and lighting applications into another publication called the SLL lighting handbook. The concentration occurs because this SLL code for lighting provides information on three fundamental matters of relevance to lighting practice. These matters are a summary of what is known about the effects of lighting on task performance, behaviour, safety, perception and health as well as its financial and environmental costs. This compilation covers recommendations for both interior and exterior lighting in normal conditions. The SLL lighting handbook covers the balance of lighting, indoor workplaces, outdoor workplaces, road lighting, daylight, simple guidance for energy efficient lighting, construction (design and management) regulations, basic energy and light, luminous flux, intensity, illuminance, luminance and their interrelationships, direct lighting, indirect lighting, photometric datasheets, indoor lighting calculations, outdoor lighting calculations, measurement of lighting installations and interpreting the results, colors, daylight calculations and predicting maintenance factors.

2.2.8 Ventilation and Air Conditioning Systems

Code of practice for Energy Efficient Buildings Sri Lanka 2008 specifies to follow the ASHRAE Handbook 2004 or equal standard for the system design for cooling load calculations. For the purpose of sizing systems and selecting equipment it is required to consider Sri Lanka climate for indoor and outdoor design conditions. The code specifies that indoor design conditions of an air-conditioned space has to design for a dry bulb temperature of 25°C ± 1.5°C and relative humidity of 55% ± 5% [16]. The combination of suitable high temperatures and humidity may be used within the comfort zone for energy saving purposes, provided that the conditions maintained herein are agreeable to the occupants. For outdoor design conditions dry bulb temperatures of 31°C and wet bulb temperatures of 27°C could be used. ASHRAE Thermal comfort zone is shaded in Figure 2.19: Thermal Comfort Zone with activity of 1.0 metabolic rate, clothing 0.5 and velocity <0.2 for $-0.5<PMV<+0.5$.

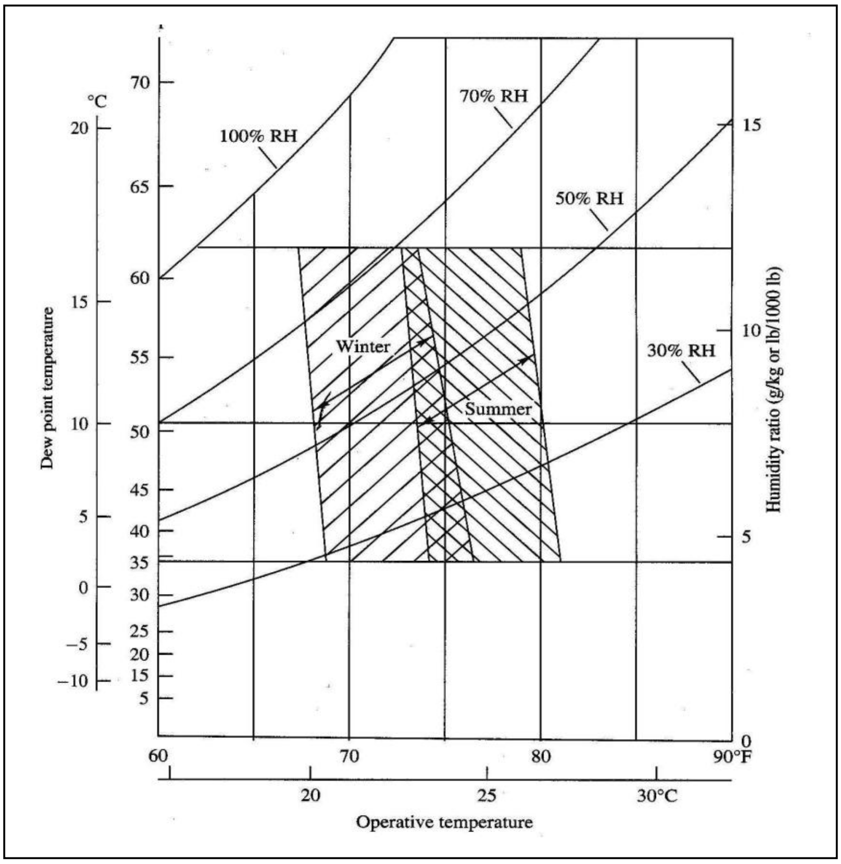


Figure 2.19: Thermal Comfort Zone

(Source: ASHRAE, Hand book 2004)

2.2.9 ASHRAE Standard for Energy Efficient Buildings

American Society of Heating, Refrigerating and Air Conditioning Engineers, founded in 1894, is a building technology society with more than 50,000 members worldwide. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry. The ASHRAE handbook is a four-volume resource of HVAC&R including Fundamentals, HVAC Applications, HVAC Systems and Equipment, and Refrigeration where one of the four volumes is updated each year.

ASHRAE also publishes a well-recognized series of standards and guidelines relating to HVAC systems and issues. These standards are often referenced in building codes, and are considered useful standards for use by consulting engineers, mechanical contractors, architects, and government agencies. These are legally unenforceable, except when referenced as mandatory provisions in building codes, but are commonly accepted standards for architects and engineers. [16]

Following are some of the ASHRAE Standards used in the industry.

Standard 34 – Designation and Safety Classification of Refrigerants

Standard 55 – Thermal Environmental Conditions for Human Occupancy

Standard 62.1 – Ventilation for Acceptable Indoor Air Quality

Standard 62.2 – Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

Standard 90.1 – Energy Standard for Buildings except Low-Rise Residential Buildings – The IESNA is a joint sponsor of this standard.

Standard 135 – BACnet - A Data Communication Protocol for Building Automation and Control Networks

Standard 189.1 – Standard for the Design of High Performance, Green Buildings except Low-Rise Residential Buildings

ASHRAE Standard 55 and 62.2 are discussed in this paper, which are the most related codes of practices to refer in designing residential buildings for ventilation and indoor air quality management.

2.2.10 AC System Design and Equipment Selection

To maintain the comfort in a consistent way, AC Systems and Equipment shall be sized with available equipment capacity. Multiple units of the same equipment type, such as multiple chillers, with combined capacities exceeding the design load may be specified to operate concurrently only if controls are provided in sequence, or otherwise, the operation of each unit should be optimally controlled based on the load. The code denotes the capacity of any individual unit shall not be less than 20 kW (output), excepting backup units for specified areas.

The code recommends, when selecting equipment for A/C Systems, the pressure drops in chilled water cooling coils, water cooled condensers and evaporator coils should be kept below 6 m of water pressure loss, across the coil. Systems with total fan motor power less than or equal to 4 kW are exempted by the current code.

For fan systems that provide a constant air volume whenever the fans are operating, there shall be a requirement of at least 590 l/s of supply air volume per kW of total input power for motors to provide the combined fan system at design conditions. Variable Air Volume (VAV) Fan Systems that are able to vary system air volume automatically as a function of load, there shall be a requirement of at least 420 l/s of supply air volume per kW of total input power for the motors to provide the combined fan system at designed conditions.

The energy demand of a pumping system is defined as the sum of the demand of all pumps operating at designed conditions to supply fluid from the cooling source to the conditioned spaces or to heat transfer devices and to the source in return. Piping systems shall be designed at friction pressure loss rate of 100 to 400 Pa per meter of equivalent pipe length subject to the velocity in the system pipe lines not exceeding 2.5 m/s. Lower friction rates may be required for proper noise or corrosion control. The following aspects of pumping systems should be designed to minimise life-cycle system costs. Pipe size, components and layout should be optimised to reduce system pressure drops, thus reducing the pump and motor sizes required. Once the operating flow and pressure are established, the pump should be carefully selected for maximum efficiency, and not less than 70%. The flow rate should never exceed 110% of designed flow. Once the pump shaft power requirement is determined, the motor with the highest efficiency at the design load. Reasons for dissatisfaction due to local effects are summarized with percentages in the Table 2.20. This shows the draft effect is high compared to other factors for an occupant in a building.

Table 2.20: Percentage Dissatisfied due to local discomfort

PD Due to Draft	PD Due to Vertical Air Temp Difference	PD Due to Warm of Cool Floors	PD Due to Radiant Asymmetry
< 20%	< 5%	< 10%	< 5%

(Source: SLSEA, Energy Efficient Building Code 2008)

Table 2.21 Indicate the radiant temperature asymmetry effect from different elements of a building. Allowable temperature for walls is less than 23 ^{0}C, where warm ceiling allows only less than 5 ^{0}C.

Table 2.21: Allowable radiant temperature asymmetry

Warm Ceiling	Cool Wall	Cool Ceiling	Warm Wall
$< 5^0$ (9.0)	$< 10^0$ (18.0)	$< 14^0$ (25.2)	$< 23^0$ (41.4)

2.2.11 ASHRAE Standard 62.2

ASHRAE Standard 62.2 developed in year 2003 for Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, as the first national ventilation and indoor air quality (IAQ) standard for residential buildings with three or less stories.

The standard follows the mechanical ventilation rates have been increased to reflect the elimination of the default assumption of a leakage rate of 2 cfm per 100 ft^2. Houses and apartments are being built tighter for both energy and code reasons. Therefore, the 2013 standard assumes that there is no reasonable expectation of leakage in multifamily buildings and only single-family homes must be measured for leakage with a blower door to estimate the amount of leakage that can be deducted from the calculated mechanical ventilation rate. The base assumption is now 7.5 cfm per person plus 0.03 cfm per square foot. Other significant new changes include weather data for estimating annual leakage based on a blower door test [17].

There are three primary sets of requirements and a number of secondary ones. The three primary sets involve whole-building ventilation, local demand-controlled exhaust, and source control. Whole-building ventilation is intended to dilute the unavoidable contaminant emissions from people, from materials, and from background processes. Local demand controlled exhaust is intended to remove contaminants from those specific rooms that, because of their design function, are expected to contain sources of contaminants (e.g., kitchens and bathrooms). Other source control measures are included to deal with those sources that can be reasonably anticipated to be found in a residence. The standard’s secondary requirements focus on properties of specific items that are needed to achieve the main objectives of the standard. Examples of this include sound and flow ratings for fans and labeling requirements.

This standard defines the roles of and minimum requirements for mechanical and natural ventilation systems and the building envelope intended to provide acceptable indoor air quality (IAQ) in low-rise residential buildings.

Following equations are used to calculate the required total ventilation rate for domestic buildings as specified by the standard. The total required ventilation rate (Q_{tot}) shall be as specified in Table 2.22 or, alternatively, calculated using Equation 2.3 or Equation 2.4 as per the imperial and metric units.

$$\mathbf{Qtot = 0.03Afloor + 7.5(Nbr + 1)} \text{ ……….. (IP) (2.3)}$$

Where;

Qtot = total required ventilation rate, cfm

Afloor = floor area of residence, ft^2

Nbr= number of bedrooms (not to be less than 1)

$$\mathbf{Qtot = 0.15Afloor + 3.5(Nbr+1)} \text{ …………. (SI) (2.4)}$$

Where;

Qtot= total required ventilation rate, L/s

Afloor = floor area of residence, m^2

Nbr= number of bedrooms (not to be less than 1)

Table 2.22: Ventilation Air Requirements (SI) (L/s)

Floor Area	Bedrooms				
m^2	1	2	3	4	5
< 47	14	18	21	25	28
47-93	21	24	28	31	35
93-139	28	31	35	38	42
140-186	35	38	42	45	49
186-232	42	45	49	52	56
232-279	49	52	56	59	63
279-325	56	59	63	66	70
325-372	63	66	70	73	77
372-418	70	73	77	80	84
418-465	77	80	84	87	91

(Source: SLSEA, Energy Efficient Building Code 2008)

2.2.12 ASHRAE Standard 55-2004

ASHRAE Standard 55 specifies the combination of indoor thermal environmental factors and personal factors that produces thermal environmental conditions acceptable to a majority of occupants. Thermal comfort is the condition in mind which expresses satisfaction with the thermal environment. Hence primary factors involved are metabolic rate, clothing insulation, air temperature, and radiant temperature, air speed and humidity level of the space.

As general requirements of the standard the design will apply to a specific space & its occupants, where occupants have resided more than 15 minutes in that space. Activity & clothing of occupants must be considered and if any deviations present that should be considered. But standard may not be able to cover all occupants in the space due to individual differences. Following are the conditions for thermal comfort as per ASHRAE Standard 55.

Standards specify the required thermal environmental conditions for human Occupancy as specified space, weather occupants have resided more than 15 minutes in that space, activity and clothing condition. But it not may be possible to cover all occupants in the space due to individual differences.

Primary factors are at steady state, prior to exposure are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity level of the space. There are three techniques to determine the acceptable thermal comfort. They are mathematical model, graphical method and computational method.

Mathematical Model for Thermal Comfort calculate by equation

$$t_o = (t_a + t_r)/2 \qquad \text{............} \quad (2.5)$$

t_o - Operative Temperature

t_a - Weighted average of air temperature

t_r - Mean radiant temperature

Graphical method for Thermal comfort is to be applied to spaces where the occupants have activity range 1.0 – 1.3 Met (Appendix A) and clothing 0.5 – 1.0 clo (Appendix B). In this 80% satisfied, 10% total satidfied and local dissatisfied where air speed is less than 0.2 m/s.

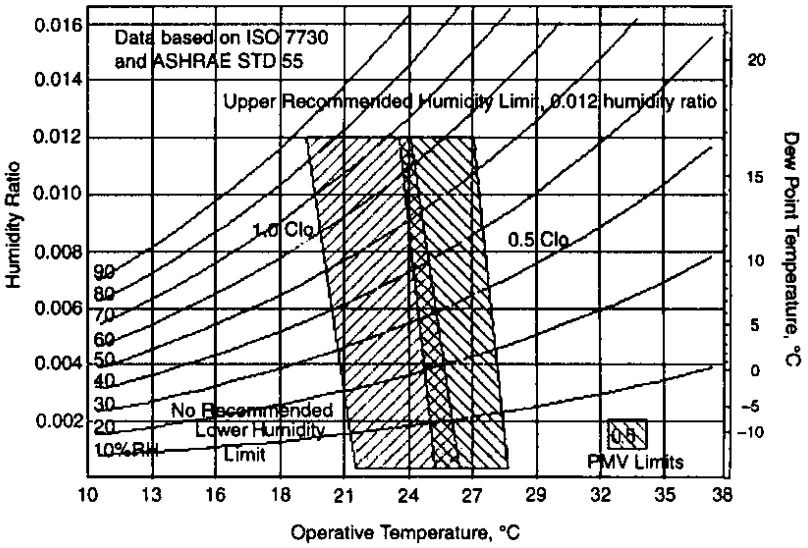


Figure 2.20: Predicted Mean Vote (PMV)

(Source: ASHRAE Standard 55)

Computational Method is the third method which is applicable for spaces where activity and clothing conditions have activity in the range of 1.0 – 2.0 Met and clothing up to 1.5 clo.

In this method ASHRAE’s 7 point sensation scale is use, Predicted Mean Vote (PMV) uses heat balance principles to relate 06 key factors and Predicted Percentage Dissatisfied (PPD) is related to PMV

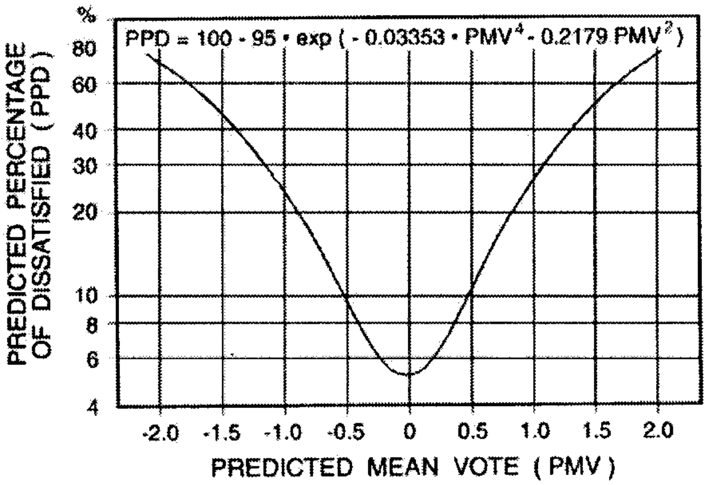


Figure 2.21: PPD Vs PMV

(Source: ASHRAE Standard 55)

The acceptable general thermal comfort is PPD < 10%, -0.5 < PMV < +0.5. This is also the basis for graphical method and PMV model is calculated air temp, mean radiant temp, metabolic, clothing, air speed, and humidity. The calculated PMV value is checked to be related to the parameters in the comfort zone where PMV model is limited to 0.2 m/s. Standard also gives provision for higher velocities, however the recommended Elevated Air Speed is only up to 0.8 m/s and increase of 3°C.

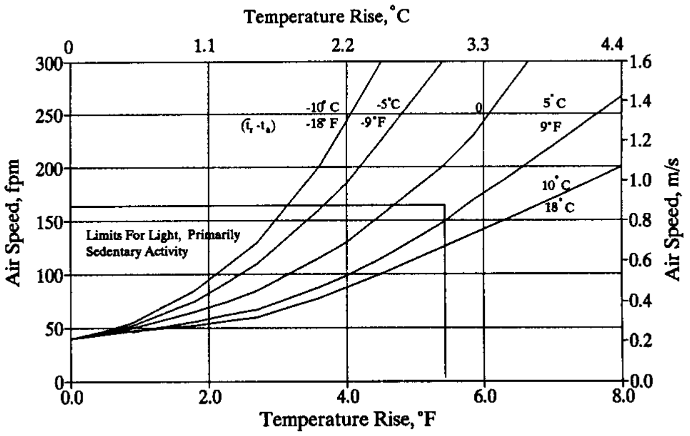


Figure 2.22: Air Speed

(Source: ASHRAE Standard 55)

2.3 Climate of Colombo

During night time specially Colombo area domestic consumers use fans and ACs for their comfort and it is reasonable to study the climate of Colombo area. Colombo features a tropical monsoon climate under the Köppen climate classification. Colombo's climate is fairly temperate throughout the year. As shown in Table 2.23 from March to April the temperature averages around 31.8 degrees Celsius maximum. The only major change in the Colombo weather occurs during the monsoon seasons from May to August and October to January. This is the time of year where heavy rains can be expected. Colombo sees little relative diurnal range of temperature, although this is more marked in the drier winter months, where minimum temperatures average 22 degrees Celsius. During these months the humidity level is noted as 71% and 75%, where beyond the range of thermal comfort zone according to the ASHREA standard.

Table 2.23: Climate data for Colombo, Sri Lanka

Monnth	Jan	Feb	Mar	Apr
Record high ^{o}C	35.2	35.6	38	35.2
Average high ^{o}C	30.9	31.2	31.7	31.8
Daily Mean ^{o}C	26.6	26.9	27.7	28.2
Average low ^{o}C	22.3	22.6	23.7	24.6
Record low ^{o}C	16.4	18.9	17.7	21.2
Precipitation mm	58.2	72.7	128.0	245.6
Avg. Precipitation days	5	5	9	14
% Humidity	69	69	71	75
Mean monthly sunshine hours	248.0	248.0	275.9	234.0

2.4 Energy efficient building codes in other countries.

Building energy codes provide range of energy, environmental, and economic benefits to the country. Energy benefits of building codes include saving on energy bills, reducing peak energy demand, and improving system reliability. Many countries such as USA, India have been using building codes for nearly three decades, and confirm it’s a cost effective model to implement as a solution for energy saving purpose for buildings.

2.4.1 Energy Scenario of USA

Energy consumption in buildings in US has been growing in aggregate over time. The services demanded of buildings are for lighting, warmth in the winter, cooling in the summer, water heating, electronic entertainment, computing, refrigeration and cooking. The total energy use is about 40 quadrillion Btu per year and 40 percent of this is consumed by 114 million households and 4.7 million commercial buildings which is higher than the energy consumption of transportation or industry sector [18].

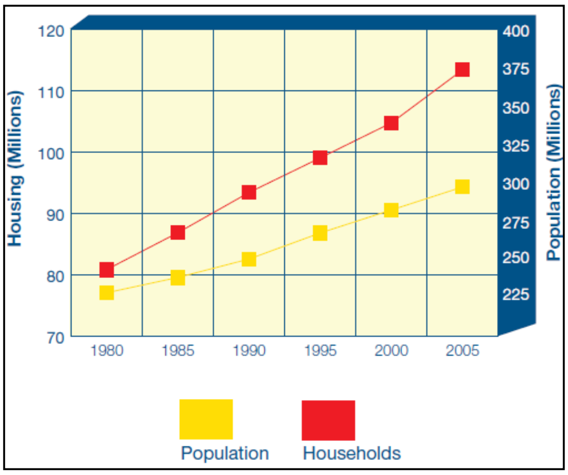


Figure 2.24: Population Growth in USA

(Source: Department of Energy, US)

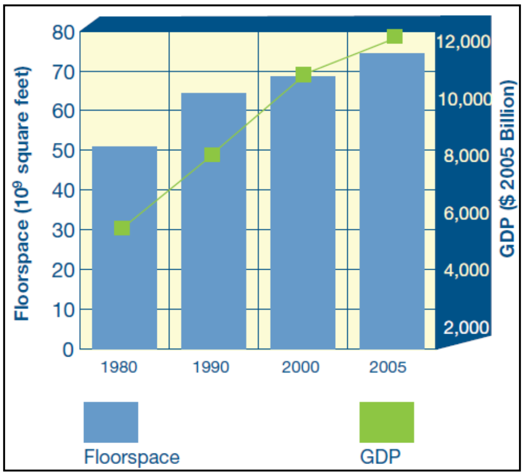


Figure 2.25: Economic Growth in USA

(Source: Department of Energy, US)

Major reasons identified are growing population as shown in Figure 2.24 which drives increase in number of homes, schools, and other community buildings, Economic growth (real GDP) as shown in Figure 2.25, which is a major driver of new floor space in offices and retail buildings, increasing of service demands such as lighting and space conditioning, electronics, process loads etc. helps to breakdown information in US and it shows buildings account for roughly 40% of all US energy use. Or stated with more particularity, residential buildings account for 22% of all US energy use which is higher than the commercial buildings account 18% of all US energy use.

Residential Energy Use:

- 1% – Computers
- 5% – Cooking
- 5% – Wet clean
- 7% – Electronics
- 8% – Refrigeration
- 11% – Lights
- 12% – Cooling
- 12% – Water heat
- 31% – Heating

Commercial Energy Use:

- 2% – Cooking
- 3% – Computers
- 4% – Refrigeration
- 6% – Office equipment
- 6% – Ventilation
- 7% – Water heat
- 13% – Cooling
- 14% – Heating
- 26% – Lighting

Improvements in technologies and practices over the past three decades in lighting fixtures, windows, insulation, building controls, and appliances, as well as whole-building design and construction have made it possible to deliver many building services with lower energy intensity.

Building energy codes have been a factor in the rise of residential energy efficiency. In addition, more new homes are being constructed to meet the targets of energy efficiency programs, and 46 percent of new home buyers cite energy efficiency as a primary consideration in their purchasing decisions. Many programs exist to address efficiency in homes: Building America, ENERGY STAR, Masco’s Environments for Living™, and the newly-launched Leadership in Energy and Environmental Design (LEED) for homes. It is possible to design and construct new houses that are 30% to 40% lower in energy intensity than a typical house, at little or no additional cost.

USA statistics shows that they saved 30 to 40 percent energy by implementing appliance standards with well-designed energy codes at the time of building construction compared to standard practices [18].

At the building level, the “payback period” on any increase in upfront costs is typically short. A Nevada study estimated that upgrading the energy efficiency of commercial buildings to comply with the code would cost about $1.60 per square foot but would result in $0.68 per square foot of energy bill savings per year, meaning a simple payback of about 2.4 years [19]. Similarly, it is estimated that Building Energy Codes typically specify requirements for thermal resistance” in the building shell and windows, minimum air leakage, and minimum efficiency re heating and cooling equipment.

These measures can help eliminate inefficient construction practices and technologies with only modest increases in up-front project costs. New construction and major renovation represent cost-effective times to incorporate energy-efficiency measures into buildings because these improvements save energy throughout the life of those buildings and can be expensive to adopt later.

Building energy codes are typically developed at the national level, adopted at the state level, and implemented and enforced by local governments.

2.4.2 Energy Scenario of India

India ranks sixth in the world in terms of energy demand accounting for 3.5 % of world commercial energy demand in 2001. With a GDP growth rate of 8 % set for the Tenth Five-Year Plan (2001 – 2006), the energy demand is expected to grow at 5.2 %. Still, at 479 kg of oil equivalent (kgoe), annual per capita energy consumption is low even compared to other developing countries.

The need of developing countries to improve living standards and reduce poverty is well understood and energy is the prime resource for development. Though, the total energy use, which one of the major sources of emissions is increasing in developing countries, their per capita energy consumption still remains far below then that of developed countries.

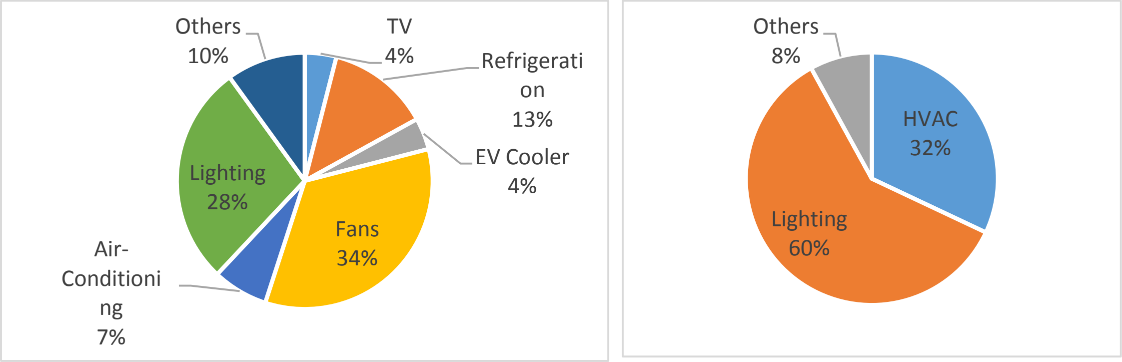


Figure 2.25: Energy Consumption in India

(Source: Country Profile 2013, Trends, Earth)

The building sector plays an important role in the energy expansion where the Indian residential sector consumes about 201,000 MTOE (million tons of oil equivalent), which is about 11% of world's energy consumption in residential sector [19]. In Indian households energy is mainly used for cooking, heating & cooling and lighting. Only the latter two relate to buildings. Cooking and lighting are almost independent, whereas other demands are region specific and climate dependent. According to the 2001 census of India, only 43.5% of rural households have an electricity connection and more than 85% of electrified rural households use it for lighting purpose only. The Indian urban sector which accounts for 28.4% of the country's population is consuming a proportionate share of energy (close to 25%) but around 87% of the urban population has access to electricity for meeting their energy demand. The urban sector is therefore highly dependent on clean energies like electricity and LPG gas. With growth in the economy of the country, the per capita income is increasing and thus the purchasing power for a more sophisticated lifestyle with extensive usage of electricity is rising. It shows the breakdown for Residential Buildings and Commercial Building sector with Annual Consumption of 116 TWh and 33 TWh respectively [19].

Launching the Bureau of Energy Efficiency action plan for promoting energy efficiency in the country, Prime Minister Vajpayee announced in 2002 that all the Government Organizations should bring down their energy consumption by 30% and Private organizations by 20% over a period of 5 years. Improvement in the building sector is one of the agenda in the BEE's Action Plan.

Simulations were carried out on six cities representing one climatic zone each for ascertain the amount of possible savings in different climatic zones. In hot & dry with double glazed, double glazed Low-E and triple glazed energy efficient windows, savings of 5% to 27% were observed for 10% and 20% glazing area respectively. These simulation results are on the basis of 24 hours usage of the building and can fit well for the residential sector.

The need of developing countries to improve living standards and reduce poverty is well understood and energy is the prime resource for development. Though, the total energy use, which one of the major sources of emissions is increasing in developing countries, their per capita energy consumption still remains far below then that of developed countries.

By implementing energy codes, it can reduce the load growth and the need for new energy generation capacity of the country. Further, it’s limiting the air pollution and greenhouse gas emissions.

Building energy codes can also help to grow the country’s economy, by introducing new job opportunities to technical people in installing equipment and monitoring building compliance.

2.5 Summary

Chapter two of this research paper has covered following areas.

1. Identified the limitations of the current code of practice for energy efficiency in Sri Lanka for domestic units.
2. Referring to recorded statistics observed that 40% of electricity has been utilized by household sector.
3. Studied the lighting principles and energy efficient lighting systems which can be implemented for domestic buildings.
4. Identified the required lighting levels for a domestic unit, use of daylight and selection of suitable lamps for energy efficient lighting systems.
5. Studied the aspects of ventilation and air conditioning systems in energy scenario with reference to ASHRAE standards.
6. Identified ASHRAE 62.2 for Ventilation and Acceptable Indoor Air Quality is the most suitable standard for Low-Rice Residential Buildings.
7. Studied the climate condition of Colombo District which can be related with the energy survey data for the purpose of analysis.
8. Reviewed case studies implemented in USA and India for energy efficient models conducted in policy level to minimize the waste of energy of the country.

CHAPTER 3. DATA COLLECTION AND ANALYSIS

3.1 Electricity Survey of Domestic Units in Colombo District

A list of criteria prepared to select domestic units from Colombo district for the electricity survey. Used criteria to identify the sample for the survey are as follows:

District and location : Colombo District

Age range of the house : 5– 25 yrs

No of floors : 2 floors

Total floor area : 1500 – 4000 sq ft (230-560m^2)

No of Occupants : 2-4 Adults with 2-4 children

Income Range : LKR. 50,000/- to 250,000/- per month

Based on above criteria, 50 domestic units were selected from Colombo District and a questionnaire for electricity usage as shown in Table 3.1 was forwarded to the house owner. This questioner prepared under eight different electricity utilization types such as Lighting, Communication/Entertainment, Water Heating, Cooking, Food Storage Medium, Ventilation, Washing and Ironing and Other Equipment. Data collected from the selected user/consumer of their equipment, Wattage, quantities and the usage in hours per day. These data were collected for a period of three months, commencing from February 2014 to April 2014.

General information related to occupancy and construction technology of domestic units are also collected as following variables and fed into the spreadsheet.

Occupant details

- Ownership of the Domestic Unit : Own/Rent
- Salary Scale : <150,000 or >150,000.00
- No of Occupants : 1 to 6

Space Details

- Land Area (p)
- Age of the Building (years)
- Building Floor Area (sq ft)
- Comfort : AC or Fan
- Window Area (sq ft)
- Window state (full open/ partially open)
- Roof Material
- Roof insulation state
- Distance to the adjoining building (m)
- Shade Level

Description of domestic unit sample 1:

Two storied domestic unit powered by the National Grid, located in Dehiwala area in Colombo district has been selected as the first sample for this energy audit where satisfy all selection criteria's. This domestic unit is occupied by a single family of four (4) members, parents and two schooling children aged 8 and 13 years old with a low income less than Rs. 150,000/-. This domestic unit is located in 14 perches extend and the next closest building is located in 6m away. Opening area is about 20% of the total exterior walls. This two storied house has a floor area of 2,900 ft^2 built in year 2007, consists of 3 bed rooms, with 1 bath room and 2 toilets. A concrete structure, Tiled flooring, 9" thick brick masonry wall and pitched type roof with asbestos roofing without any insulation. Incandescent lamps, florescent lamps and CFL lamps are been used for lighting and fans are used for human comfort. Shades are very low in this land and plug in electricity used for water pumping, water heating, washing, ironing, computing and refrigerator for food storage.

Table 3.1: Data sheet of the first sample in February 2014

Type of usage	**Wattage (W)**	**Nos.**	**Duration /day (hrs)**	**Usage (kWh/month)**
Total Consumption				**308.4**
Lighting (12.5%)				**38.7**
Incandescent	75	3	4	27
Tube Light	40	2	3	7.2
CFL	15	2	5	4.5
LED	0	0	0	0
Communication / Entertainment (6.6%)				**20.49**
Television (CRT)	100	1	5	15
Television (LCD)	0	0	0	0
Television (LED)	0	0	0	0
Satellite Dish	0	0	0	0
DVD Player	12	1	1/4	0.1
Stereo System	30	1	1	0.9
Personal Computer	150	1	1	4.5
Laptop	0	0	0	0
Electric Organ	0	0	0	0
Water Heating (7.3%)				**22.5**
Electric Kettle	1500	1	1/2	22.5
Geezer	0	0	0	0
Electric Heater	0	0	0	0
Cooking (6.2%)				**19.1**
Blender/Grinder	250	1	1/4	1.9
Hot Plate	0	0	0	0
Electric Oven	0	0	0	0
Microwave Oven	0	0	0	0

Rice Cooker	600	1	1/2	9
Toaster	1100	1	1/4	8.25
Food Storage medium (22.8%)				**116.1**
Refrigerator	130	1	18	70.2
Deep Freezer	0	0	0	0
Ventilation Systems (16.3%)				**50.4**
Ceiling Fan	75	2	8	36
Pedestal Fans	60	1	8	14.4
Table Fans	0	0	0	0
AC (Window Type)	0	0	0	0
AC (Split Type)	0	0	0	0
Washing & Ironing (7.3%)				**22.5**
Washing Machine	1500	1	1/4	11.3
Dryer	500	1	1/4	3.8
Electric Iron	750	1	1/3	7.5
Other Equipment (20.9%)				**64.5**
Cell Phone Re Charges	4	3	2	0.72
Hair Dryers	0	0	0	0
Vacuum Cleaner	0	0	0	0
Floor Polisher	500	1	1/4	3.8
Domestic Water Pump	500	1	4	60.0

Collected data from 50 domestic units for three months are entered into the Microsoft Excel spread sheet and summarized data are attached in the Appendix D.

3.2 Method of Analysis

Collected data from 50 domestic units are fed into Microsoft Excel spread sheet and calculate the total electricity consumption of each domestic unit for three months period. Total electricity consumption of each category such as Lighting, Communication/Entertainment, Water Heating, Cooking, Food Storage Medium, Ventilation, Washing and Ironing and Other Equipment are also calculated. Then data are exported to the SPSS statistical software to obtain significant relationships between variables. Identified parameters such as income level, occupancy data, plug in consumption, comfort level, lighting consumption are analysed with the total consumption of a domestic unit. Finally, observed significant parameters for total energy consumption of a domestic unit. Then approaching to energy efficiency measures calculated the possible energy saving in a domestic unit for a month for lighting usage. The total energy saving was calculated for a year for all domestic units in Sri Lanka and estimated the total saving for Sri Lanka for a year.

3.2.1 Preliminary Analysis of Domestic Electricity Consumption

Total electricity utilization of domestic units are summarized in Table 3.2 and calculated its percentages. Finding the total consumption calculated the average consumption per person. Considering Sri Lanka climate and with reasonable assumptions it is desirable to calculate the total electricity of domestic units in Sri Lanka, compare and contrast with collected information from literature review.

Table 3.2: Electricity consumption of sample 1 in February 2014

Type of Electricity Usage	Consumption (kWh)	Percentage (%)
Electricity usage for Lighting	38.7	12.5%
Electricity for Communication /Entertainment	20.49	6.6%
Electricity for Water Heating	22.5	7.3%
Electricity for Cooking	19.1	6.2%
Electricity for Food Storage Medium	70.2	22.8%
Electricity for Ventilation Systems	50.4	16.3%
Electricity for Washing & Ironing	22.5	7.3%
Electricity for Other Equipment	64.5	20.9%
Total usage for the Domestic Unit for 4 members	308.4	100%
Average usage per person	77.1	

Above table shows that sample 1 utilization distributes among few major categories such as food storage medium, equipment, ventilation systems and lighting. As per the above results, electricity breakdown will be as shown in Figure 3.1.

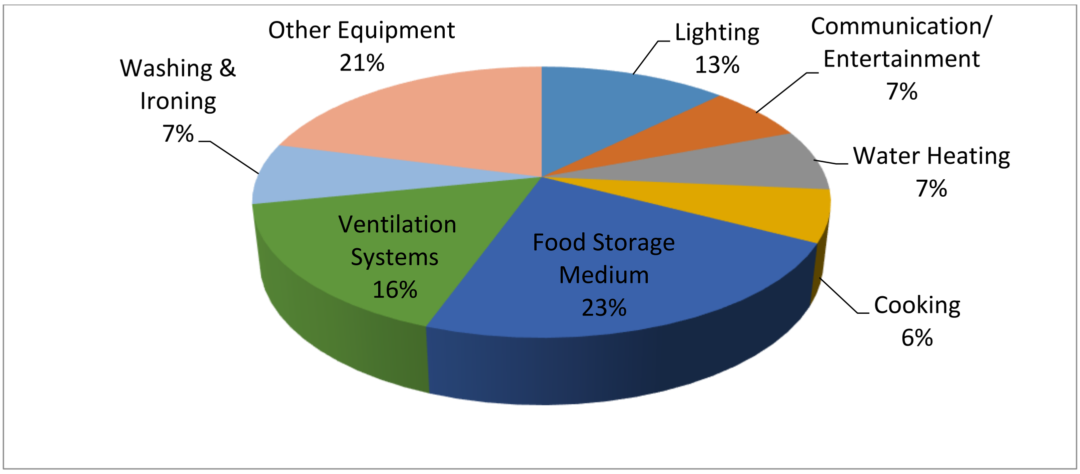


Figure 3.1: Electricity breakdown of Sample 1 for February 2014

Same analysis was carried out for months March and April and electricity breakdowns are given in Figure 3.2 and Figure 3.3.

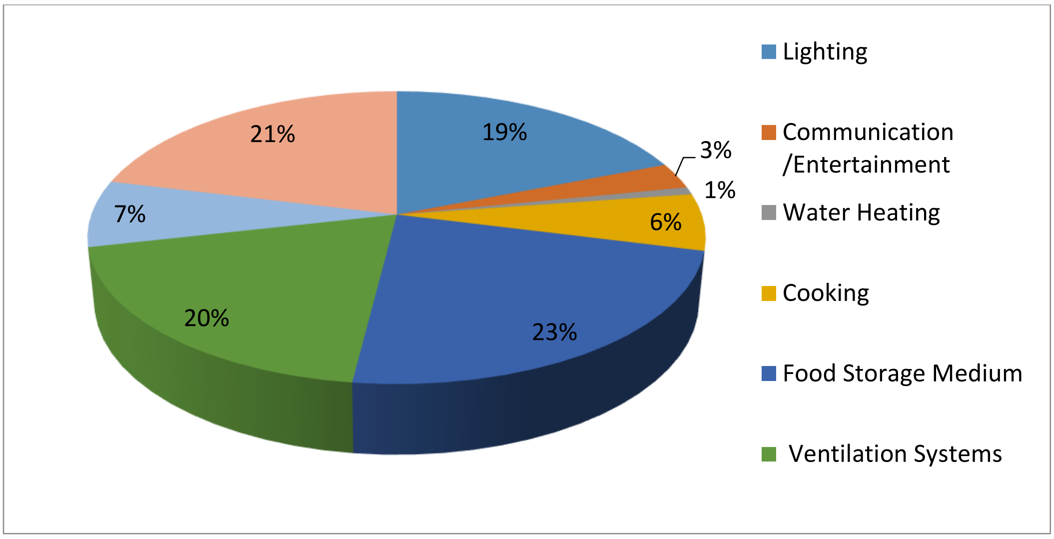


Figure 3.2: Electricity breakdown of Sample 1 for March 2014

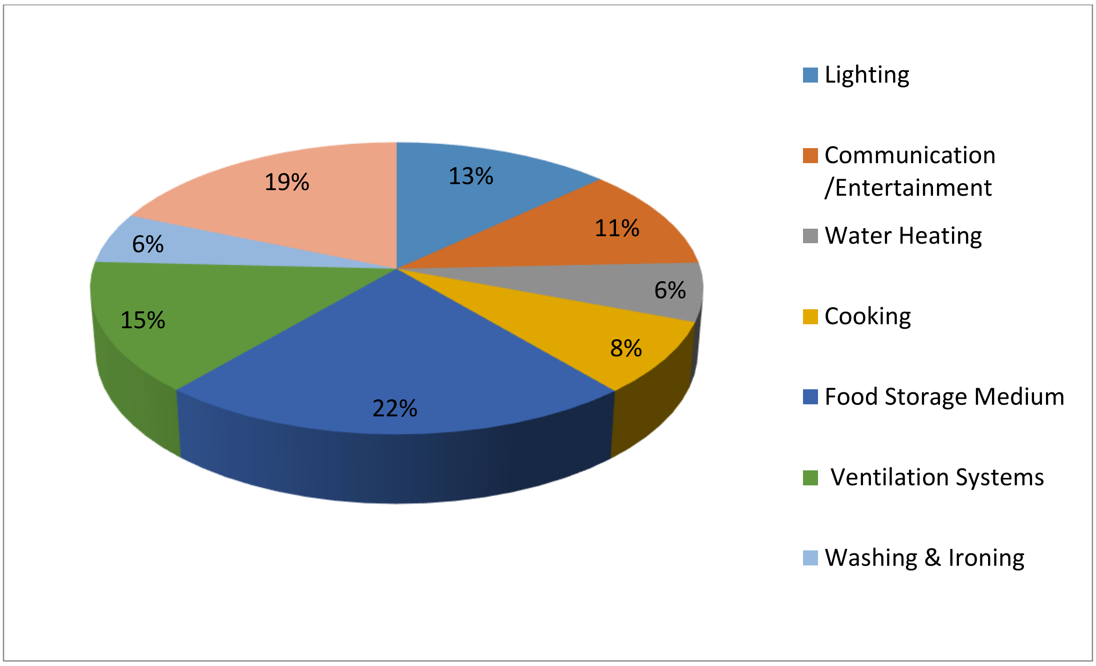


Figure 3.3: Electricity breakdown of Sample 1 for April 2014

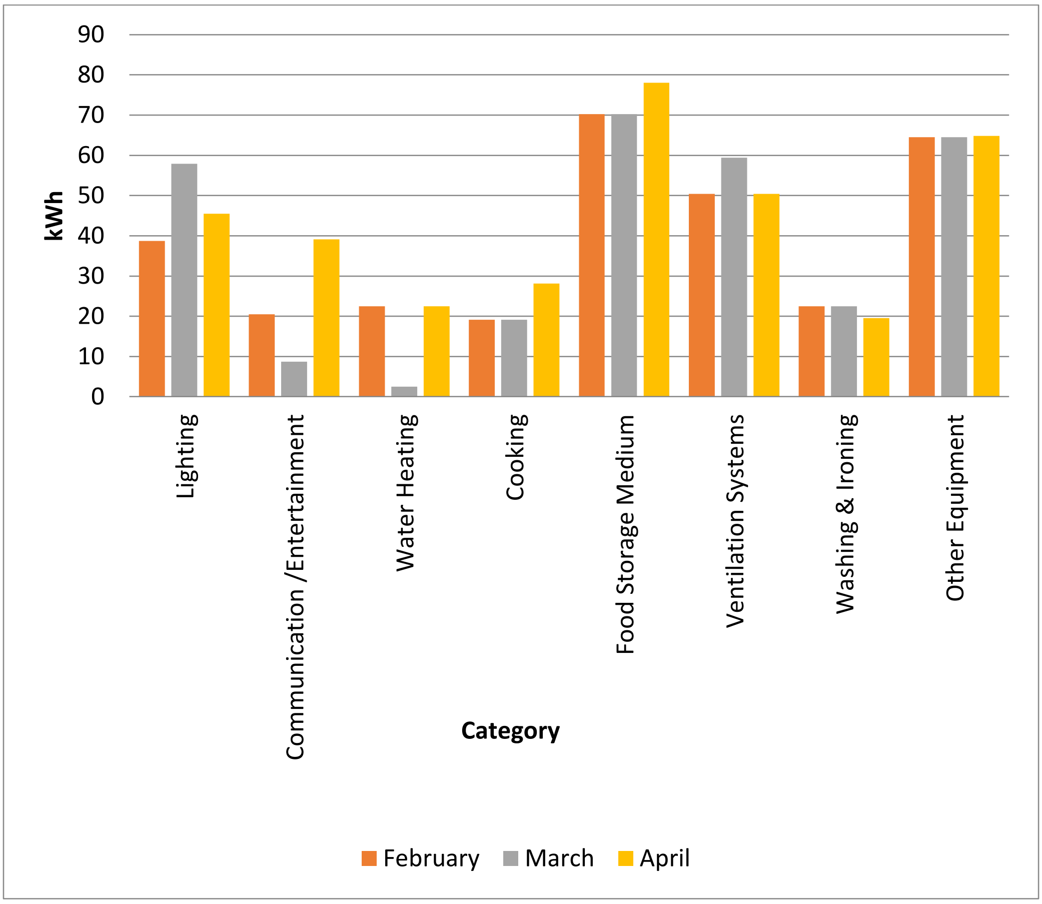


Figure 3.4: Electricity breakdown of Sample 1 in February, March and April.

Figure 3.4 shows the variation between three months period of sample 1 in all categories. It is observed that electricity usage is independent with month as Sri Lanka has only slight changes in the temperature and other climate conditions. But above data indicates a drastic increase in the entertainment utilization category due to April school holidays where more hours of occupancy at home.

Following table 3.3 shows monthly electricity consumption of each sample (n=50) for February, March and April 2014. The Average electricity consumption calculated for each unit and calculated the average consumption of a domestic unit in Colombo district for further discussion.

Table 3.3: Electricity consumption of 50 samples in Colombo district for three months

Sample	February	March	April	Average
1	308.4	324.8	347.9	327.0
2	679.1	680.7	758.4	706.1
3	597.9	599.1	633.6	610.2
4	440.4	440.3	490.9	457.2
5	262.1	263.1	289.9	271.7
6	1007.0	974.6	1001.7	994.4
7	599.3	667.4	686.3	651.0
8	406.3	399.8	419.5	408.5
9	901.0	897.4	998.2	932.2
10	755.7	795.1	883.4	811.4
11	625.0	657.1	669.3	650.5
12	560.0	586.7	632.7	593.2
13	654.1	672.7	694.8	673.8
14	366.8	393.9	427.1	395.9
15	523.6	632.0	704.6	620.1
16	361.2	375.3	487.2	407.9
17	420.3	396.3	504.8	440.4
18	375.2	373.9	432.5	393.9
19	359.4	355.6	373.5	362.8
20	643.3	340.9	448.1	477.4
21	340.0	548.3	633.6	507.3
22	659.5	548.3	633.6	613.8
23	636.0	597.9	716.6	650.2
24	513.1	538.2	586.1	545.8
25	420.3	525.5	719.6	555.1
26	619.2	581.8	658.2	619.7

27	500.8	536.7	559.2	532.2
28	645.5	552.8	660.0	619.4
29	233.1	251.0	271.9	252.0
30	285.2	283.8	310.2	293.1
31	429.6	384.9	489.1	434.5
32	766.4	641.2	744.9	717.5
33	168.4	166.5	197.0	177.3
34	428.5	439.4	471.0	446.3
35	724.5	613.8	593.0	643.7
36	384.8	291.9	314.5	330.4
37	722.5	640.4	687.8	683.6
38	575.5	542.2	529.9	549.2
39	549.7	608.5	646.6	601.6
40	606.2	523.3	571.2	566.9
41	601.9	513.6	579.3	564.9
42	696.1	698.8	852.5	749.1
43	327.9	330.5	370.0	342.8
44	543.0	591.3	549.8	561.4
45	417.2	402.9	387.5	402.5
46	354.0	316.6	329.4	333.3
47	441.6	443.0	439.2	441.3
48	744.7	590.6	682.7	672.6
49	658.2	748.2	734.4	713.6
50	667.3	659.7	728.8	685.3
Average Electricity Consumption of a Domestic Unit (kWh)				539.8

Table 3.3 provides monthly total consumption for each domestic Unit (n=50) in kWh. It has calculated the average electricity consumption of each unit and for 50 units average is 539.8kWh for a month. As per Table 2.15, total no of domestic units in Colombo is 558,755. Hence average electricity consumption in domestic units in Colombo district can be estimated is 302GWh. Figure 3.5 shows the variation of electricity consumption for three months for 50 samples. It is observed all samples have a similar pattern throughout the period except few units. Further observed this variance is due to the occupancy style

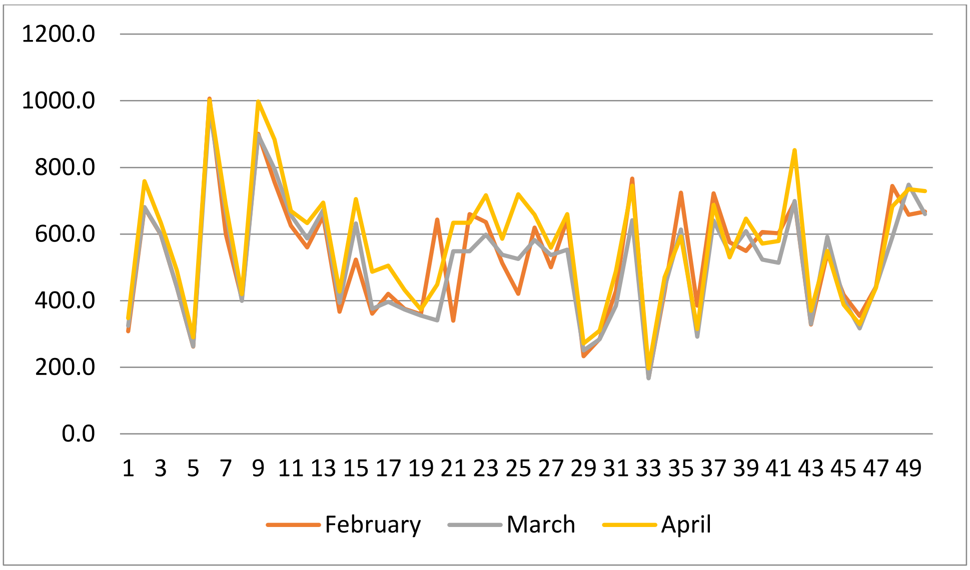


Figure 3.5: Electricity Consumption of 50 Samples for three months

It is useful to make out the percentage of electricity users of domestic units in Colombo district of electricity consumption (kWh) in blocks for a single month. Figure 3.6 shows that 60% users are either consume very less or very high where, balance 40% users consume in the middle ranges.

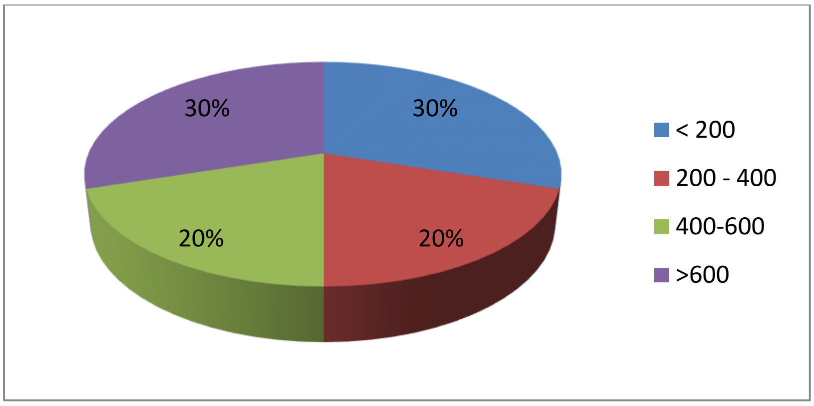
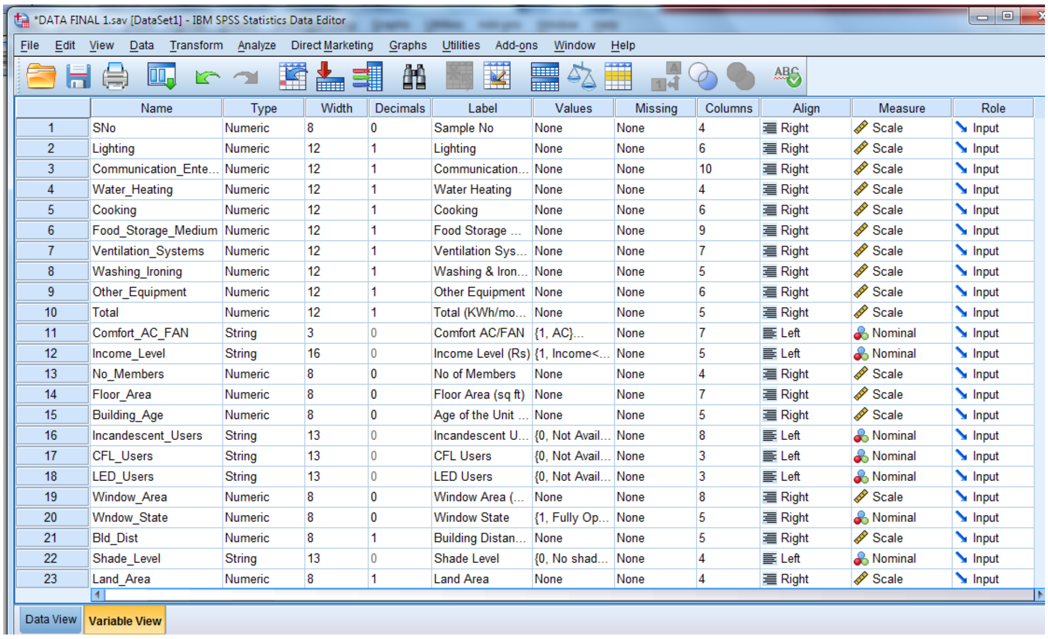


Figure 3.6: Average Consumption in Blocks

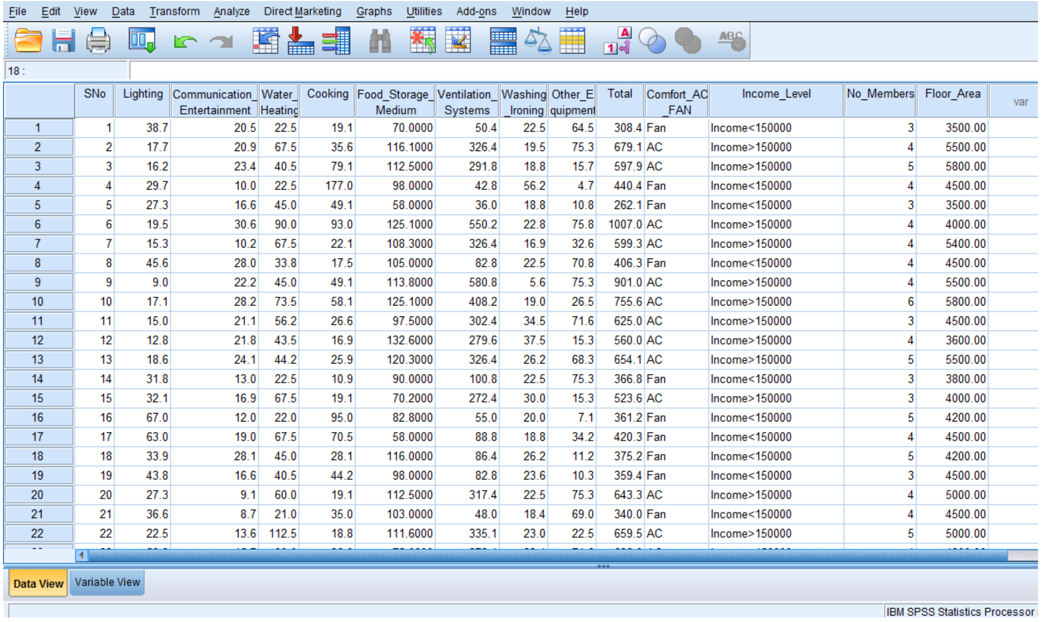
3.3 Statistical Analysis

Data collected from the survey according to the given criteria's in the section 3.2.1 were imported to SPSS data editor from MS excel spread sheet. Other than electricity data, occupancy data and space data entered to the SPSS as variables. 22 independent variables and one dependent variable, monthly electricity consumption of the domestic unit data are entered into the software tool. Out of these 22 independent variables 15 are scaled variables and 7 are Nominal variables. Figure 3.7 shows the variable view of the SPSS tool with 23 variables and data view shows in Figure 3.8



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	SNo	Numeric	8	0	Sample No	None	None	4	Right	Scale	Input
2	Lighting	Numeric	12	1	Lighting	None	None	6	Right	Scale	Input
3	Communication_Ente...	Numeric	12	1	Communication...	None	None	10	Right	Scale	Input
4	Water_Heating	Numeric	12	1	Water Heating	None	None	4	Right	Scale	Input
5	Cooking	Numeric	12	1	Cooking	None	None	6	Right	Scale	Input
6	Food_Storage_Medium	Numeric	12	1	Food Storage ...	None	None	9	Right	Scale	Input
7	Ventilation_Systems	Numeric	12	1	Ventilation Sys...	None	None	7	Right	Scale	Input
8	Washing_Ironing	Numeric	12	1	Washing & Iron...	None	None	5	Right	Scale	Input
9	Other_Equipment	Numeric	12	1	Other Equipment	None	None	6	Right	Scale	Input
10	Total	Numeric	12	1	Total (KWh/mo...	None	None	5	Right	Scale	Input
11	Comfort_AC_FAN	String	3	0	Comfort AC/FAN	{1, AC}...	None	7	Left	Nominal	Input
12	Income_Level	String	16	0	Income Level (Rs)	{1, Income<...	None	5	Left	Nominal	Input
13	No_Members	Numeric	8	0	No of Members	None	None	4	Right	Scale	Input
14	Floor_Area	Numeric	8	0	Floor Area (sq ft)	None	None	7	Right	Scale	Input
15	Building_Age	Numeric	8	0	Age of the Unit ...	None	None	5	Right	Scale	Input
16	Incandescent_Users	String	13	0	Incandescent U...	{0, Not Avail...	None	8	Left	Nominal	Input
17	CFL_Users	String	13	0	CFL Users	{0, Not Avail...	None	3	Left	Nominal	Input
18	LED_Users	String	13	0	LED Users	{0, Not Avail...	None	3	Left	Nominal	Input
19	Window_Area	Numeric	8	0	Window Area (...	None	None	8	Right	Scale	Input
20	Wndow_State	Numeric	8	0	Window State	{1, Fully Op...	None	5	Right	Nominal	Input
21	Bld_Dist	Numeric	8	1	Building Distan...	None	None	5	Right	Scale	Input
22	Shade_Level	String	13	0	Shade Level	{0, No shad...	None	4	Left	Nominal	Input
23	Land_Area	Numeric	8	1	Land Area	None	None	4	Right	Scale	Input

Figure 3.7: Variable View of SPSS



	SNo	Lighting	Communication_Entertainment	Water_Heating	Cooking	Food_Storage_Medium	Ventilation_Systems	Washing_Ironing	Other_Equipment	Total	Comfort_AC_FAN	Income_Level	No_Members	Floor_Area	var
1	1	38.7	20.5	22.5	19.1	70.0000	50.4	22.5	64.5	308.4	Fan	Income<150000	3	3500.00	
2	2	17.7	20.9	67.5	35.6	116.1000	326.4	19.5	75.3	679.1	AC	Income>150000	4	5500.00	
3	3	16.2	23.4	40.5	79.1	112.5000	291.8	18.8	15.7	597.9	AC	Income>150000	5	5800.00	
4	4	29.7	10.0	22.5	177.0	98.0000	42.8	56.2	4.7	440.4	Fan	Income<150000	4	4500.00	
5	5	27.3	16.6	45.0	49.1	58.0000	36.0	18.8	10.8	262.1	Fan	Income<150000	3	3500.00	
6	6	19.5	30.6	90.0	93.0	125.1000	550.2	22.8	75.8	1007.0	AC	Income>150000	4	4000.00	
7	7	15.3	10.2	67.5	22.1	108.3000	326.4	16.9	32.6	599.3	AC	Income>150000	4	5400.00	
8	8	45.6	28.0	33.8	17.5	105.0000	82.8	22.5	70.8	406.3	Fan	Income<150000	4	4500.00	
9	9	9.0	22.2	45.0	49.1	113.8000	580.8	5.6	75.3	901.0	AC	Income>150000	4	5500.00	
10	10	17.1	28.2	73.5	58.1	125.1000	408.2	19.0	26.5	755.6	AC	Income>150000	6	5800.00	
11	11	15.0	21.1	56.2	26.6	97.5000	302.4	34.5	71.6	625.0	AC	Income>150000	3	4500.00	
12	12	12.8	21.8	43.5	16.9	132.6000	279.6	37.5	15.3	560.0	AC	Income>150000	4	3600.00	
13	13	18.6	24.1	44.2	25.9	120.3000	326.4	26.2	68.3	654.1	AC	Income>150000	5	5500.00	
14	14	31.8	13.0	22.5	10.9	90.0000	100.8	22.5	75.3	366.8	Fan	Income<150000	3	3800.00	
15	15	32.1	16.9	67.5	19.1	70.2000	272.4	30.0	15.3	523.6	AC	Income>150000	3	4000.00	
16	16	67.0	12.0	22.0	95.0	82.8000	55.0	20.0	7.1	361.2	Fan	Income<150000	5	4200.00	
17	17	63.0	19.0	67.5	70.5	58.0000	88.8	18.8	34.2	420.3	Fan	Income<150000	4	4500.00	
18	18	33.9	28.1	45.0	28.1	116.0000	86.4	26.2	11.2	375.2	Fan	Income<150000	5	4200.00	
19	19	43.8	16.6	40.5	44.2	98.0000	82.8	23.6	10.3	359.4	Fan	Income<150000	3	4500.00	
20	20	27.3	9.1	60.0	19.1	112.5000	317.4	22.5	75.3	643.3	AC	Income>150000	4	5000.00	
21	21	36.6	8.7	21.0	35.0	103.0000	48.0	18.4	69.0	340.0	Fan	Income<150000	4	4500.00	
22	22	22.5	13.6	112.5	18.8	111.6000	335.1	23.0	22.5	659.5	AC	Income>150000	5	5000.00	

Figure 3.8: Data View of SPSS

Selected parameters suits for analysis are summarized in Table 3.4 considering entire data collection from fifty domestic units in Colombo District.

3.3.1 Selection of analytical tools

Analytical tools such as correlation coefficient and chi-square coefficient were selected to identify the between selected variables. In this analysis there are scaled variables and nominal variables use as input variables [19].

3.3.2 Analysis of continuous variables

This analysis was conducted with 15 continuous variables and the objective is to see whether these independent variables have any correlation with electricity consumption of the domestic unit. In correlation analysis, we determine the correlation coefficient of each independent variable in relation with the particular dependent variable of concern. Further it is checked whether these coefficients are significant; 5% or 1%. Accordingly the calculated correlation coefficients for monthly electricity consumption are given in Table 3.4. The SPSS analyzing tool provides three different correlation coefficients such as Pearson coefficient, Kendall’s tau-b coefficient and Spearman coefficient. Detailed output of the correlation calculation is given in Appendix F.

Table 3.4: Correlation coefficients for monthly electricity consumption

Independent variable	Pearson coefficient	Kendall's tau-b coefficient	Spearman’s rho coefficient
Lighting (kWh)	-.527**	-.413**	-.602**
Communication_Entertainment (kWh)	.411**	.249*	.360*
Water_Heating (kWh)	.578**	.467**	.623**
Cooking (kWh)	.047	.127	.180
Food_Storage_Medium (kWh)	.592**	.404**	.581**
Ventilation_Systems (kWh)	.931**	.703**	.877**
Washing_Ironing (kWh)	.126	.164	.225
Other_Equipment (kWh)	.427**	.367**	.509**
No_Members (Nos)	.406**	.335**	.434**
Floor_Area (sq ft)	.520**	.427**	.567**
Building_Age (Years)	-.178	-.082	-.140
Window_Area (sq ft)	.364**	.265**	.370**
Bld_Dist (ft)	.186	.137	.130
Land_Area (perches)	.303*	.221*	.316*
** Correlation is significant at the 0.01 level and * Correlation is significant at the 0.05 level.			

3.3.3 Analysis of nominal variables

Nominal variables are prepared as Table 3.5 in the data sheet of SPSS before subjected to analysis.

Table 3.5: Data Values for Nominal Variables

Variable	Values		
Comfort	“1-AC”	“2-FAN”	
Income Level	“1-Income<150000”	“2- Income>150000”	
Incandescent Users	“1- Available”	“0- Not Available”	
CFL Users	“1- Available”	“0- Not Available”	
LED Users	“1- Available”	“0- Not Available”	
Window State	“1-Fully Open”	“2-Partially Open”	
Shade Level	“0- No shade”	“1-Partial shade”	“2-Fully shade”

After providing values to nominal variables, Pearson correlation coefficient was calculated taking electricity consumption as column and independent variables as rows. Output of the calculation is given in Appendix D and results for significant variables are summarized in Table 3.6.

Table 3.6: Persons Correlation coefficients of general data to electricity consumption

		Total (KWh/month)	Comfort AC/FAN	Income Level (Rs)	Incandescent Users	CFL Users	LED Users
Total (KWh/month)	Correlation	1	-.838**	.838**	-.661**	.090	.540**
	Sig. (2-tailed)		.000	.000	.000	.534	.000
Comfort AC/FAN	Pearson Correlation	-.838**	1	-1.000**	.736**	-.168	-.632**
	Sig. (2-tailed)	.000		.000	.000	.244	.000
Income Level (Rs)	Pearson Correlation	.838**	-1.000**	1	-.736**	.168	.632**
	Sig. (2-tailed)	.000	.000		.000	.244	.000
Incandescent Users	Pearson Correlation	-.661**	.736**	-.736**	1	-.137	-.487**
	Sig. (2-tailed)	.000	.000	.000		.342	.000
LED Users	Pearson Correlation	.540**	-.632**	.632**	-.487**	.208	1
	Sig. (2-tailed)	.000	.000	.000	.000	.147	

*. Correlation is significant at the 0.01 level (2-tailed).

Kendall’s and Spearman's correlation also calculated for checking the significance for nominal variables. Referring below Table 3.7 identified significant parameters for electricity consumption for general and space variables. These significant figures were highlighted and subjected to graphical representation in the next section.

Table 3.7: Kendall’s & Spearman's Correlation coefficients of general data to electricity consumption

			Total (KWh/ month)	Comfort AC/FAN	Income Level (Rs)	Incandescent Users	CFL Users	LED Users	Window State	Shade Level
Kendall's tau_b	Total (KWh/month)	Correlation Coefficient	1.000	$-.705^{**}$	$.705^{**}$	$-.565^{**}$	.073	$.444^{**}$	.185	.116
		Sig. (2-tailed)	.	.000	.000	.000	.533	.000	.116	.307
		N	50	50	50	50	50	50	50	50
	Comfort AC/FAN	Correlation Coefficient	$-.705^{**}$	1.000	-1.00^{**}	$.736^{**}$	-.168	$-.632^{**}$	-.183	-.031
		Sig. (2-tailed)	.000	.	.	.000	.240	.000	.201	.822
		N	50	50	50	50	50	50	50	50
	Income Level (Rs)	Correlation Coefficient	$.705^{**}$	-1.00^{**}	1.000	$-.736^{**}$	.168	$.632^{**}$	.183	.031
		Sig. (2-tailed)	.000	.	.	.000	.240	.000	.201	.822
		N	50	50	50	50	50	50	50	50
	Incandescent Users	Correlation Coefficient	$-.565^{**}$	$.736^{**}$	$-.736^{**}$	1.000	-.137	$-.487^{**}$	-.035	.055
		Sig. (2-tailed)	.000	.000	.000	.	.337	.001	.804	.689
		N	50	50	50	50	50	50	50	50
	CFL Users	Correlation Coefficient	.073	-.168	.168	-.137	1.00	.208	.127	-.197
		Sig. (2-tailed)	.533	.240	.240	.337	.	.145	.375	.153
		N	50	50	50	50	50	50	50	50
	LED Users	Correlation Coefficient	$.444^{**}$	$-.632^{**}$	$.632^{**}$	$-.487^{**}$	.208	1.000	.176	-.092
		Sig. (2-tailed)	.000	.000	.000	.001	.145	.	.217	.504
		N	50	50	50	50	50	50	50	50
	Window State	Correlation Coefficient	.185	-.183	.183	-.035	.127	.176	1.000	.092
		Sig. (2-tailed)	.116	.201	.201	.804	.375	.217	.	.501

		N	50	50	50	50	50	50	50	50
	Shade Level	Correlation Coefficient	.116	-.031	.031	.055	-.197	-.092	.092	1.00
		Sig. (2-tailed)	.307	.822	.822	.689	.153	.504	.501	.
		N	50	50	50	50	50	50	50	50
Spearman's rho	Total (KWh/month)	Correlation Coefficient	1.000	-.855**	.855**	-.685**	.089	.538**	.225	.144
		Sig. (2-tailed)	.	.000	.000	.000	.538	.000	.117	.320
		N	50	50	50	50	50	50	50	50
	Comfort AC/FAN	Correlation Coefficient	-.855**	1.000	-1.00**	.736**	-.168	-.632**	-.183	-.032
		Sig. (2-tailed)	.000	.	.	.000	.244	.000	.204	.824
		N	50	50	50	50	50	50	50	50
	Income Level (Rs)	Correlation Coefficient	.855**	-1.00**	1.000	-.736**	.168	.632**	.183	.032
		Sig. (2-tailed)	.000	.	.	.000	.244	.000	.204	.824
		N	50	50	50	50	50	50	50	50
	Incandescent Users	Correlation Coefficient	-.685**	.736**	-.736**	1.000	-.137	-.487**	-.035	.057
		Sig. (2-tailed)	.000	.000	.000		.342	.000	.807	.693
		N	50	50	50	50	50	50	50	50
	CFL Users	Correlation Coefficient	.089	-.168	.168	-.137	1.00	.208	.127	-.204
		Sig. (2-tailed)	.538	.244	.244	.342	.	.147	.381	.155
		N	50	50	50	50	50	50	50	50
	LED Users	Correlation Coefficient	.538**	-.632**	.632**	-.487**	.208	1.000	.176	-.095
		Sig. (2-tailed)	.000	.000	.000	.000	.147	.	.221	.510
		N	50	50	50	50	50	50	50	50
	Window State	Correlation Coefficient	.225	-.183	.183	-.035	.127	.176	1.00	.096
		Sig. (2-tailed)	.117	.204	.204	.807	.381	.221	.	.507
		N	50	50	50	50	50	50	50	50
	Shade Level	Correlation Coefficient	.144	-.032	.032	.057	-.204	-.095	.096	1.00
		Sig. (2-tailed)	.320	.824	.824	.693	.155	.510	.507	.
		N	50	50	50	50	50	50	50	50

**. Correlation is significant at the 0.01 level (2-tailed).

Analyzing independent variables, obtained important correlations between parameters which are significant each other. According to results following tables 3.8, 3.9, 3.10 and 3.11 extracted for significance levels.

Table 3.8: Correlation of Window Area to Ventilation Systems

		Ventilation Systems
Window Area (sq ft)	Pearson Correlation	.386**
	Sig. (2-tailed)	.006
	N	50

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3.9: Correlation of No of Members to Electricity Consumption for Communication & Entertainment

		No of Members	Communication / Entertainment
No of Members	Pearson Correlation	1	.337*
	Sig. (2-tailed)		.017
	N	50	50

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3.10: Correlation of No of Members to Electricity Consumption for Water Heating

		No of Members	Water Heating
No of Members	Pearson Correlation	1	.339*
	Sig. (2-tailed)		.016
	N	50	50

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3.11: Correlation of Income Level to Ventilation System

		Income Level (Rs)	Ventilation Systems
Income Level (Rs)	Pearson Correlation	1	.908**
	Sig. (2-tailed)		.000
	N	50	50

**. Correlation is significant at the 0.01 level (2-tailed).

3.4 Summary

Chapter three of this research paper has covered following areas.

1. Gathered and structured, electricity consumption data from 50 domestic units located in Colombo district for three months.
2. Gathered occupant data and space data of domestic consumers.
3. Identified electrical usage pattern under different categories such as lighting, ventilation, water heating, Equipment.
4. Identified significant variables for electricity consumption from the SPSS analysis tool for discussion.
5. Identified important correlations between independent variables from the analysis.

Processed data obtained from the analysis will be subjected for discussion in following chapters to obtain a more significant result for this research.

CHAPTER 4. RESULTS AND DISCUSSION

This chapter includes the result obtained from the analysis. Identified significant parameters were graphically represented and discussed for recommendations.

4.1 Results Related to Electricity Consumption of Domestic Units

Results obtained from the previous section have been summarized in Table 4.1, providing significant coefficients for all correlations for Pearson's, Kendall's and Spearman's. The most significant coefficient has been highlighted in this table for further discussion. According to the analysis, there are two significant levels 1% and 5%, which shows the strength of relationship between these parameters.

Table 4.1: Significant Variables for Electricity Consumption

Independent variable	**Pearson's**	**Kendall's**	**Spearman's**
1% Significant Variables			
Usage for Lighting (kWh)	-.527	-.413**	-.602 (6)
Usage for Comm / Entertainment (kWh)	.411 (12)	.249*	.360*
Usage for Water Heating (kWh)	.578**	.467**	.623 (5)
Usage for Food Storage Medium (kWh)	.592 (7)	.404**	.581**
Usage for Ventilation Systems (kWh)	.931 (1)	.703**	.877**
Usage of Other Equipment (kWh)	.427**	.367**	.509 (10)
No of Members (Nos)	.406**	.335**	.434 (11)
Floor Area (sq ft)	.520**	.427**	.567 (8)
Window Area (sq ft)	.364**	.265**	.370 (13)
Comfort (AC/FAN)	-.838**	-.705**	-.855 (2)
Income Level (Rs)	.838**	.705**	.855 (3)
Incandescent Users	-.661**	-.565**	-.685 (4)
LED Users	.540**	-.444**	.538 (9)
5% Significant variables			
Land Area (perches)	.303*	.221*	.316 (14)

4.2 Correlation between parameters

Results obtained from the statistical analysis are illustrated graphically and evaluated with consideration to literature. Accordingly the parameters which were found to be significantly related with energy consumption are discussed separately in following sub sections according to the order of significance.

4.2.1 Ventilation System

The identified highest significant variable from the output for electricity consumption is ventilation system. As given in Table 4.1, correlation between ventilation system and electricity consumption is 0.931 at 1% significance level. Relationship between those two variables can further be studied by the graph shown in Figure 4.1. It shows that there are two specific groups for electricity consumption for ventilation systems. Referring to the graph these two groups represents fans and air conditioning systems use for human comfort. Subjected to this information, it may be judged that all fan user's are in the range below 500 kWh total consumption per month and that of AC user's consumption is greater than 500kWh. This confirms by the Figure 4.2 and it clearly shows that 500kWh is the marginal figure for these samples.

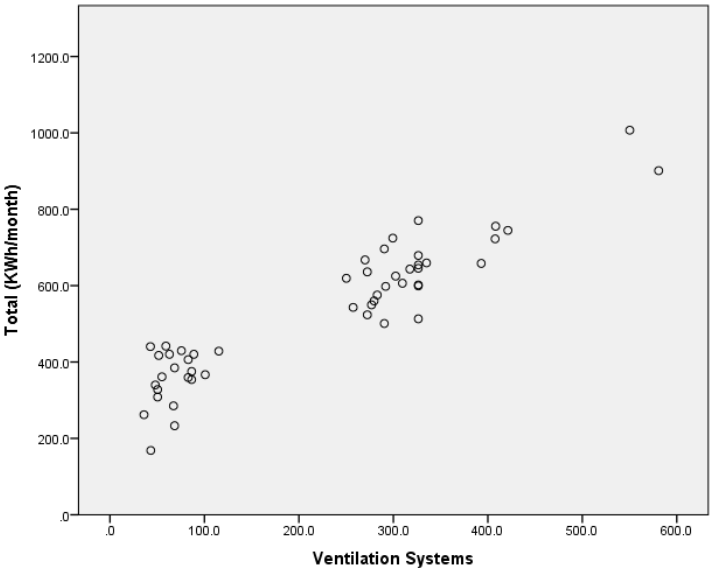


Figure 4.1: Variation of electricity consumption against ventilation systems

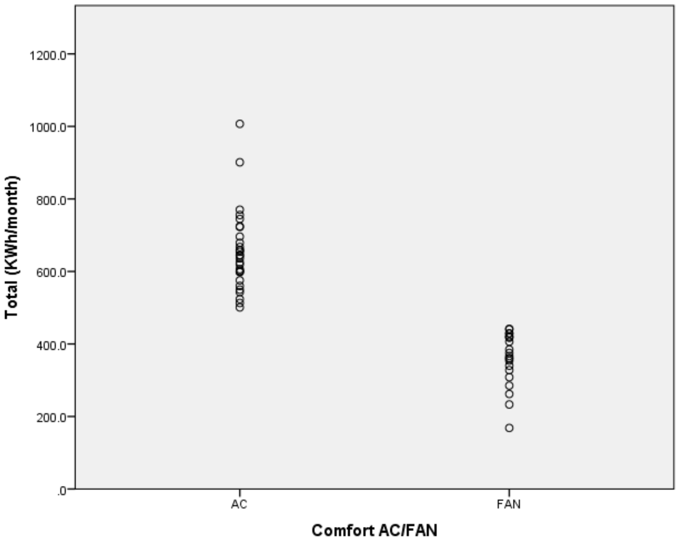


Figure 4.2: Variation of energy consumption against Comfort

4.2.2 Income Level

Statistical analysis shows that Income level is significant to the electricity consumption of a domestic unit with a value of .855 of 1% significance level. Figure 4.3 is similar to the Figure 4.2 where the consumer's use fans for their comfort has less electricity consumption and less salary scale. Whereas, consumers who get high salary are concerning to use AC systems for their comfort. It can be judged that most of the consumers in Colombo district prefer AC systems for their comfort than use of fans.

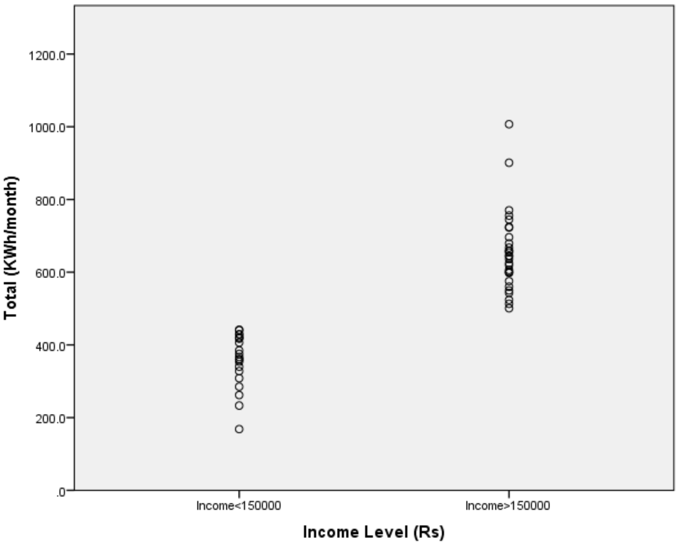


Figure 4.3: Variation of electricity consumption against Income level

4.2.3 Lighting

Lighting is a major component of the total consumption of a domestic unit and it confirms by the results given by the statistical analysis. Out of three types of lighting systems Incandescent lamps are the most significant to the total consumption with a value of 0.685 for 1% significant level. CFL has no significance and LED usage is significant with a value of .538 for 1% significant level. Figure 4.4 shows that the variation of the total electricity consumption with the lighting usage. According to the Table 4.1 usage of lighting has a Spearman's value of -.602 for 1% significant level.

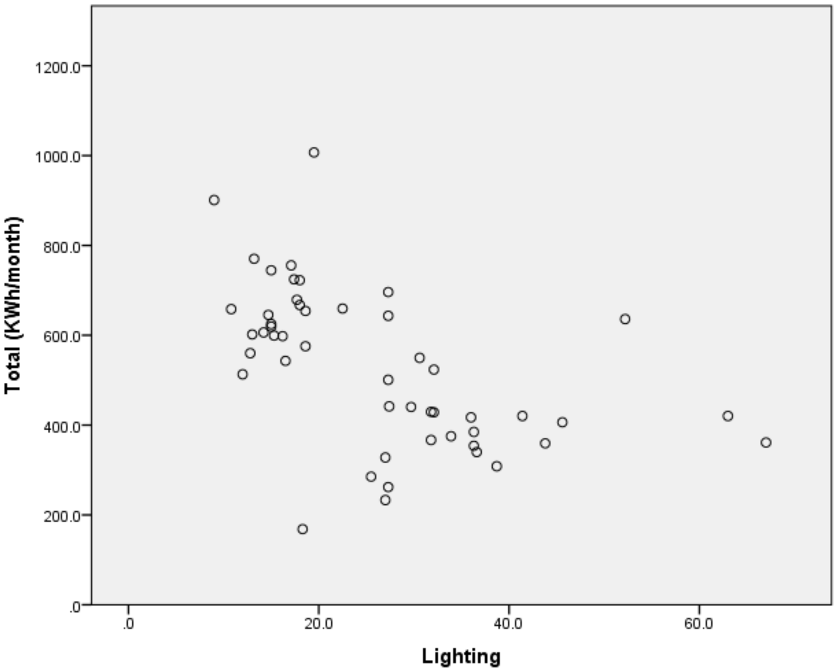


Figure 4.4: Variation of electricity consumption against lighting usage

4.2.4 Water Heating

Spearman significance for water heating usage for electricity consumption is .623 of 1% significance level. Figure 4.5 shows that most of these users are spread in the range of 25kWh to 75kWh. Very few units have consumed high capacities more than 75kWh.

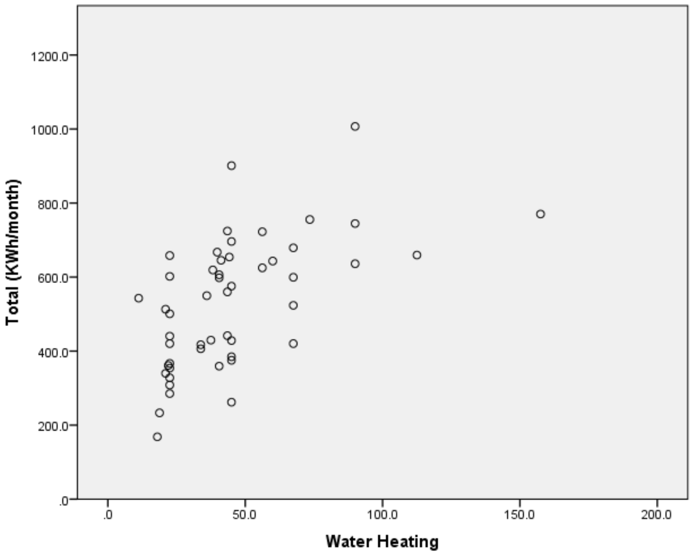


Figure 4.5: Variation of electricity consumption against water heating usage

4.2.5 Food Storage Medium

As given in Table 4.1, correlation between Food Storage Medium and total electricity consumption of a domestic unit has a .592 value for 1% significance. Figure 4.6 show that these parameters have clear relationship where increase of food storage media increases the total electricity consumption. Hence it can be identified as a key parameter.

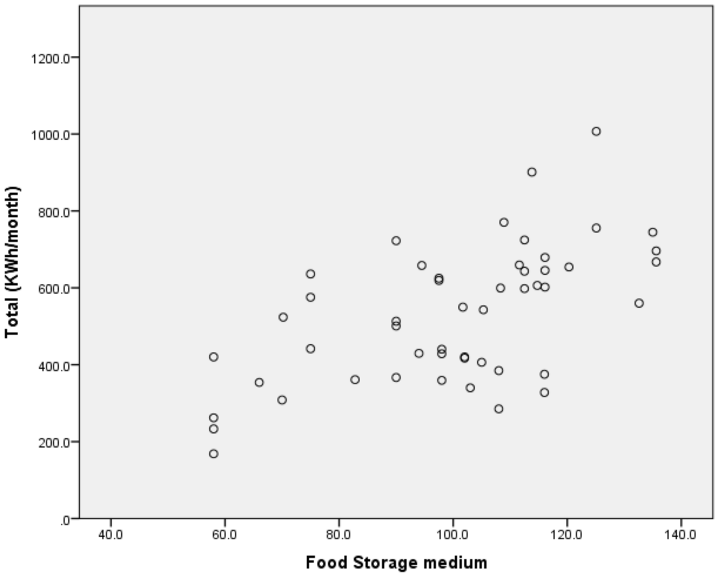


Figure 4.6: Variation of electricity consumption against food storage usage

4.2.6 Floor Area

As given in Table 4.1, correlation between floor area and electricity consumption is 0.567 at 1% significance level. Relationship between those two variables can further be studied by the graph shown in Figure 4.7. The trend line drawn in the graph shows the linear relationship between these two parameters. Hence floor area can be identified as a key parameter related to electricity consumption.

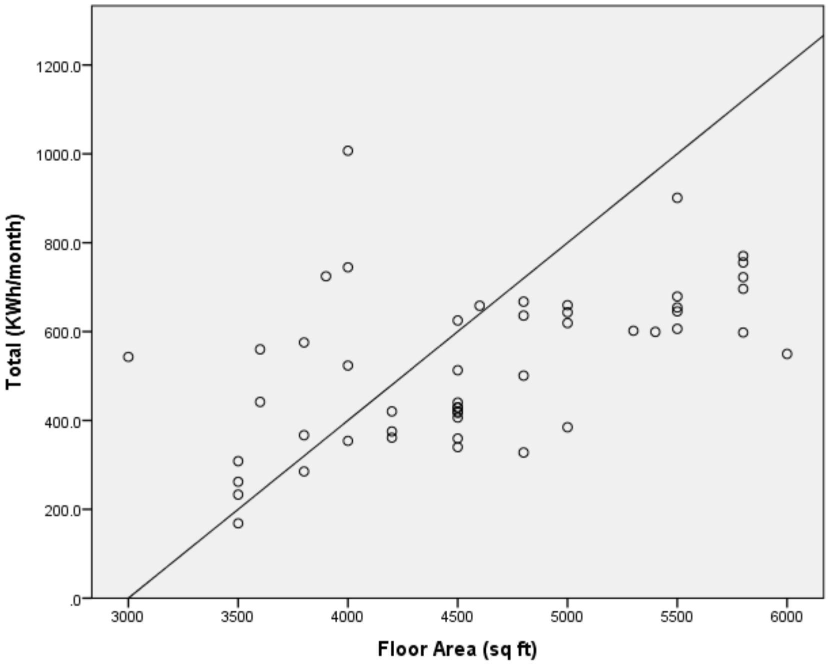


Figure 4.7: Variation of electricity consumption against Floor Area

4.2.7 Window Area

Window area of a domestic unit has been compared in two aspects. Table 4.1 indicates that the variation of electricity consumption to window area is significant with .370 of 1% significance level. According to Figure 4.8 there is a slight relationship between these two parameters. Figure 4.9 shows the variation of window area against floor area. This graph is also similar to the Figure 4.8, which shows a slight relationship between variables. But basically we can understand window area could be increased with the floor area of the domestic unit. Results obtained have a general pattern and this could be kept for future work to develop a model to identify the most accurate relationship between them.

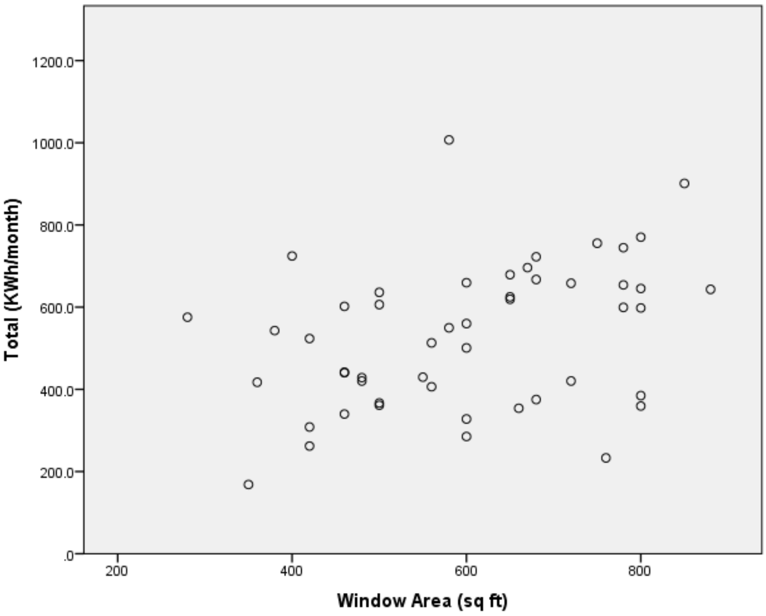


Figure 4.8: Variation of electricity consumption against window area

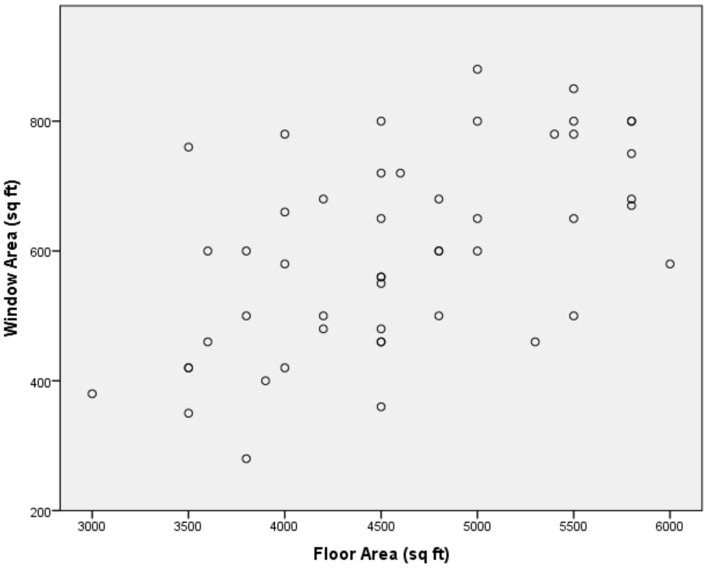


Figure 4.9: Variation of window area against floor area

4.2.8 Communication & Entertainment Usage

Table 4.1 indicates communication/entertainment usage is significant to electricity consumption with a .411 significant level of persons 1% level. Figure 4.10 shows the variation between these two variables.

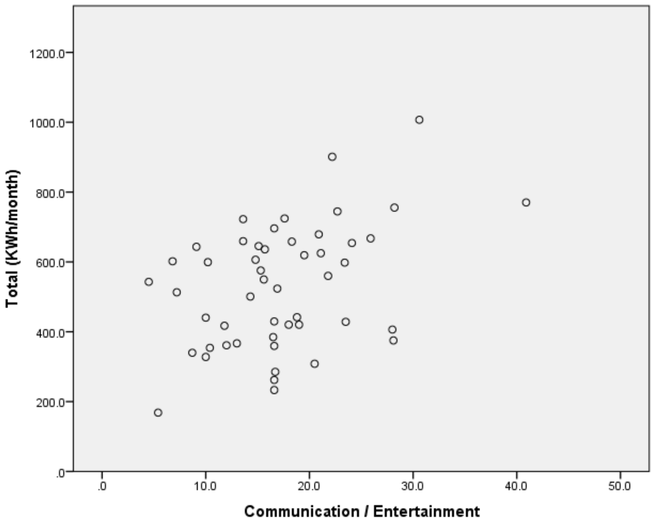


Figure 4.10: Variation of electricity against communication/entertainment usage

4.2.9 Land Area

According to the Table 4.1 the only variable which has 5% significant is land area with a value of .316 of spearman's correlation. Figure 4.11 shows the graphical representation between these two parameters and could not observe any clear relationship.

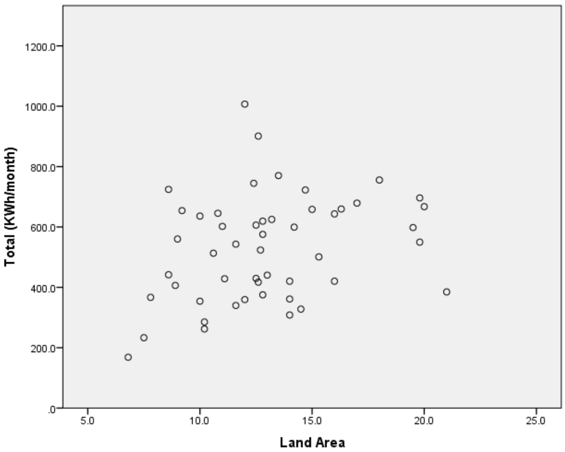


Figure 4.11: Variation of total electricity consumption against land area

4.3 Correlation between independent parameters

Table 4.2 has been prepared only for significant parameters of general data with reference to the Table 3.7 from the previous section. This short listed table provides significant values for correlation between each independent parameters under Kendall’s and Spearman's coefficients for 1% and 5% significant levels in blue and pink colours respectively.

Table 4.2: Correlation between independent parameters

Kendall's/ Spearman's		Comfort AC/FAN	Income Level (Rs)	Incandescent Users	LED Users	Window Area	Ventilation System	No of Members	Water Heating	Comm/ Entertainment
Parameters	Comfort AC/FAN	1.000	-1.00	.736 (2)	-.632 (3)	-.266	-.908 (1)	-.229	-.416 (9)	-.151
	Income Level (Rs)	-1.00	1.000	-.736 (2)	.632 (3)	-.266	-.713 (4)	.229	-.416 (9)	.151
	Incandescent Users	.736	-.736	1.000	-.487 (7)	-.183	-.601 (5)	-.226	-.297	-.169
	LED Users	-.632	.632	-.487	1.000	.322	.599 (6)	.192	.181	.236
	Window Area	-.266	.266	-.183	.322	1.00	.386 (10)	,329	.338	.373
	Ventilation Systems	-.908	-.908	-.739	.599	.386	1.00	.270	.469 (8)	.272
	No of Members	-.229	.229	-.226	.192	.329	,329	1.00	.339	.337
	Water Heating	-.416	-.416	-.297	.181	.338	.469	.339	1.00	.569
	Communi/ Entertainment	-.151	.151	-.169	.236	.373	.272	.337	.569	1.00

4.3.1 Correlation between Income to other variables

It is observed that Income level is significant with comfort level and ventilation system. Further, we can observe that LED users are proportionately related to the Income level however Incandescent users are inversely related. According to the graphical representation as in Figure 4.12 its observed Income level is highly significant to AC users. Less earning domestic units are using fans for their comfort.

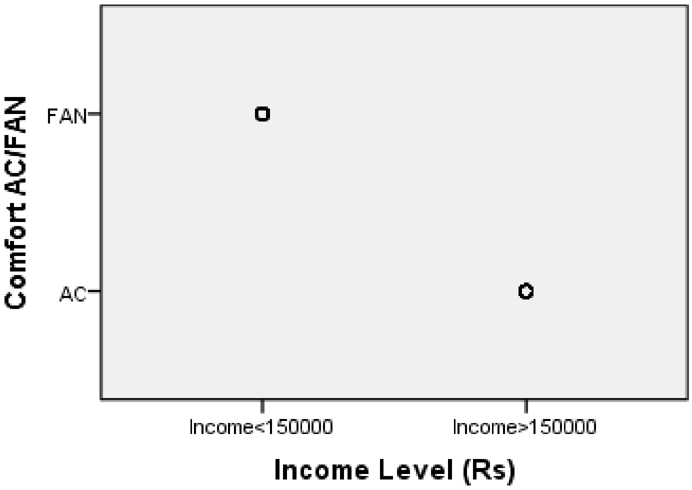


Figure 4.12: Variation of comfort against Income level

4.3.2 Correlation between occupants to other parameters

Figure 4.13 shows the variation of electricity consumption against number of members or occupants in a domestic unit. According to Table 4.1 the significant value for 5% is .434 for this correlation. Hence we can observe its significant to a certain extent.

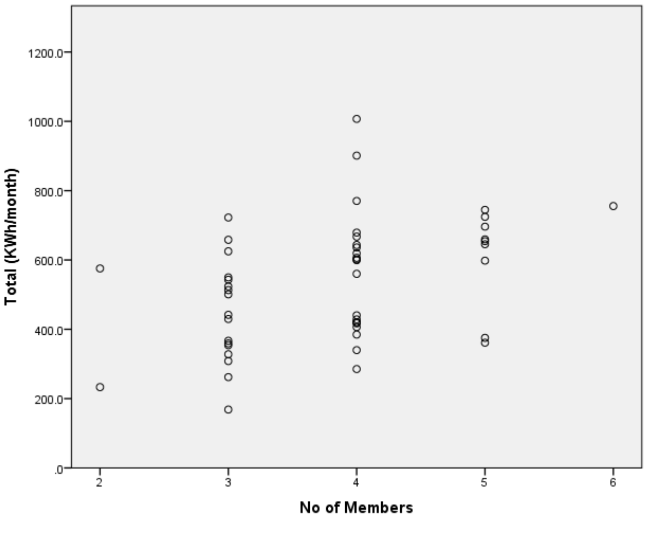


Figure 4.13: Variation of electricity consumption against occupants

4.4 Simple Payback Period (SPP)

With reference to the literature review in Chapter 2 use of LED lamps are more energy efficient than use of incandescent and CFL. However the initial cost of LED's are high, the following calculation confirms that the Simple Pay Back Period is effective.

A comparison of 15 Watt compact fluorescent lamp and a 75 Watt incandescent lamp energy usage and the cost incurred for lighting a domestic unit for average period of 4 hours per day per month (30days) can be analyzed as shown in Figure 4.14.

Each kWh is generated as Rs. 23.00 and the cost at the end of the month for both cases are Rs 41.40 and Rs.207.00 per bulb. The more the wattage of the lamp, energy bills are higher. Hence, Compact Florescent Lamp is an energy saving device use only 1/5th of incandescent lamps, saves up to 80 % of energy. CFLs have many advantages over incandescent lamps: Cost effective, high efficacy, longer lifetime, environmentally friendlier, for they last longer and need to be disposed less frequently. Not dangerous, if used as instructed where CFLs contain a small amount of mercury, less than that found in dental fillings and wrist watch batteries. CFLs are also available in a wide range of shapes, sizes and colours as per user requirement.

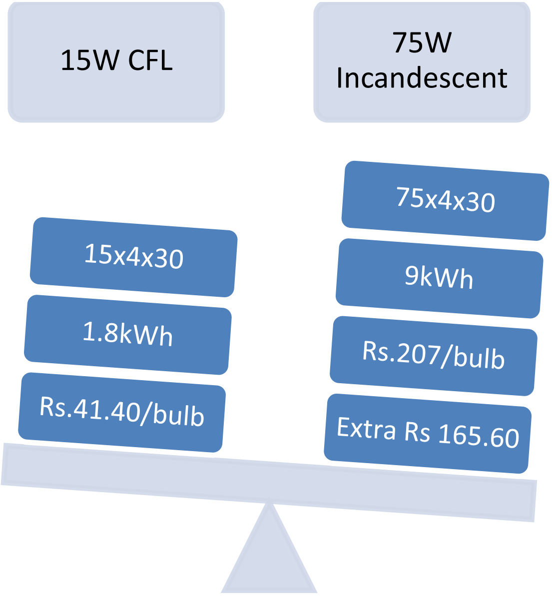


Figure 4.14: Comparison of a CFL to Incandescent lamp

Estimate of Simple Payback Period for replacing 4nos. of 75W incandescent lamps with 15W CFL lamps, if they operate 4 hours a day, seven days a week. Cost comparison of CFL with incandescent lamp when electricity tariff is Rs 32.0 /kWh.

	Incandescent	**CFL**
Costs (Rs)	75.00	500.00
Life (hours)	1000	8000
Energy savings per lamp	= (75-15)	= 60 W
Energy savings per day	= 60 x 4 x 4	= 0.96 kWh/day
Annual energy savings	= 0.96 x 365 x 23.00	= Rs 8,059.20
SPP	= (500 x4)/8,059.20	= 0.25 years

Simple Payback Period is 3 months

That is, the exploitation of energy saving technologies, in this instance the use of 'Energy Saving' Compact Florescent Lights (CFLs) in a well-intended way to address the national energy crisis. One clear fact is emerging; it is that as a nation we need to review our Power and Energy policies as a matter of priority. That would be the silver lining in the dark cloud. CFLs are capable of solving our energy crisis even as it stands today within day’s subject only to the availability of bulbs.

The national energy demand is greatest in the night with forty per cent being due to lighting of which ninety per cent of the bulbs are incandescent. It is at that time that by employing CFL bulbs, speedily and most cost efficiently, both the immediate and the medium term national energy crises can be solved.

As per the tariff structure for domestic buildings in Sri Lanka with the latest revised values as in Table 2.9 in the literature review section, announced by CEB, it is showing in blocks for unit charge and fixed charges are in Rs per month. The total electricity consumption of the first sample of the domestic unit from the survey as in Table 3.1 was 308.4kWh for the month of February. This falls to the tariff block of 0 to 300kWh and the cost calculates with a unit charge of Rs.32/kWh and a fixed charge of Rs. 315.00.

The total cost for February 2014 for Sample 1 = (308.4 x 32) + 315 = Rs. 10,183.80

Appendix B indicates that there are about 5,000,000 domestic consumers use electricity for lighting. The national energy consumption for lighting per consumer is 960Wh per day, spread over 4 hours, the rate of power consumption is 240W. If all the consumers were to replace the incandescent lamps with CFLs, the energy saved to the grid will be about 165 MW. In fact, at a realistic and a practical level in the short-term, if only two thirds of the national domestic lighting is converted to CFLs, the energy released to the grid will be equal to the combined capacities in the Private Power Purchase scheme and the hired thermal plant.

4.5 Summary

This chapter obtained results from the SPSS analysis tool for significant variables for the electricity consumption. Significant parameters are showed in graphical form for their correlation between variables. Identified significant parameters for electricity consumption in domestic units in Colombo district are listed below in order of significance for discussion and recommendations.

Table 4.3: Key Related Parameters to Electricity Consumption

Parameter	Results
Comfort Level	AC consumption is highly significant (0.931)
Income Level	Higher the income tend to use ACs (0.855)
Incandescent Users	Highly significant but has low efficacy (0.685)
Water Heating	Highly significant (0.623)
Food Storage Medium	Moderate significant (0.592)
Floor Area	Moderate significant (0.567)
LED Users	Moderate significant (0.538)
No of Members	Moderate significant (0.434)
Comm / Entertainment	Moderate significant (0.411)
Window Area	Low significance (0.370)
Land Area	Low significance (0.316)

These significant parameters can be used as information for further discussion when developing a guideline or a preliminary standard for energy efficient domestic units in Sri Lanka.

CHAPTER 5. CONCLUSION AND FUTURE WORK

The aim of this research paper is to develop a preliminary standard for energy efficient domestic units in Sri Lanka. Successfully conducting a survey in 50 domestic units in Colombo district for electricity consumption, data were collected and analyzed. Acquired results from the analysis were subjected to discussion in the previous chapter. It clearly shows that electricity consumption of domestic units can be classified into two main categories according to the income level. This key parameter is used as the main classification and developed two discrete models for each category. These models can be used as fundamental guide lines for energy efficient domestic units for Colombo district. Further, this model can be developed for the whole country for implementation process, associate with related authorities.

5.1 Conclusion

The most significant objective of this research paper is to identify parameters which effects domestic units for electricity usage. To reach this objective a survey was conducted in Colombo district. There were 22 parameters, classified under electricity consumption data, general data and space data. This energy audit was more towards an electricity audit which consists of major components related to electricity. Depending on the nature of data, the list of parameters was classified as 15 scaled variables and 7 nominal variables. Relation of those two types of parameters with electricity consumption was analyzed using software tool SPSS. All these parameters analyzed independently using three different correlation coefficients Pearson’s, Kendall’s and Spearman’s.

According to the results of the analysis, identified 14 directly related parameters to electricity consumption in domestic units. Some of the key parameters are lighting, ventilation, water heating, food storage medium, communication /entertainment and equipment usage. Floor area, window area, number of occupants, comfort level, income level, use of incandescent lamps, use of LED lamps and land area parameters were identified for significance from general and space data to electricity consumption.

These significant parameters were subjected into discussion and some of them were selected as directly related parameters with proper justification as given below.

Highest correlation with energy consumption was recorded in comfort level of the occupants. Further it was realized that comfort level to income ratio has a linear relationship. Hence Income level can be considered to be the key parameter related to energy consumption of domestic units in Colombo district.

Both Incandescent users and CFL users were found to be related to electricity consumption for domestic units. Since both parameters are indicating the lighting usage of the domestic unit, only the first one was selected as a key parameter related to high electricity consumption compared to the second. Further, use of LED lamps for lighting is the most recommended out of all three. Simple Payback Period for CFL is 3 months and could be recommended to replace all Incandescent with CFL. However, LED's have a longer SPP than CFL due to the higher investment, it's recommended to install for domestic units in a suitable way.

Water heating and food storage medium were also identified as key parameters for the domestic electricity consumption, but the relationship was exponential rather than linear. Floor area of the domestic unit and the window area of the domestic unit has a similar relation to the electricity consumption. In this scenario special cases could be found such as some domestic units window areas were high, but most of them were closed.

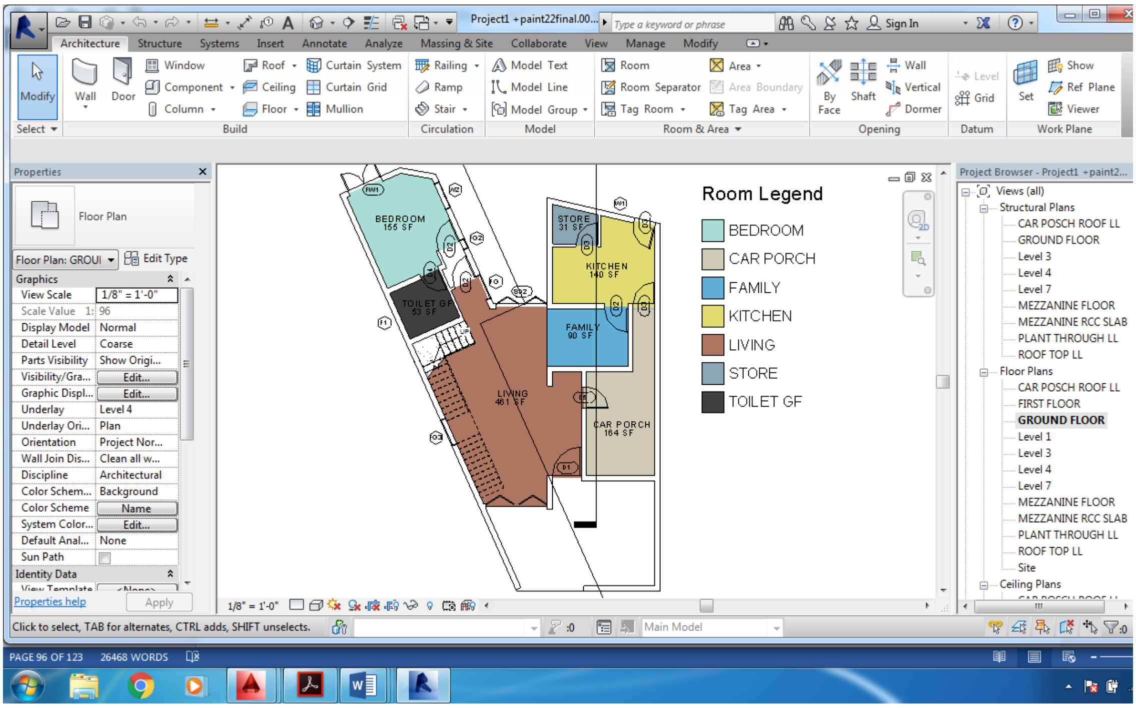
It should be noted that this analysis was based on a limited data of only 3 months. It is assumed that a better result could have been obtained if there was any chance to consider for a whole year with consideration of the climate of Colombo.

Above conclusions reflect that domestic units located in Colombo district can be classified into two main models such as 'High Income Model and 'Middle Income Model'. Designing and analyzing two discrete models for each category is important to develop a preliminary guide line for energy efficient domestic units for Sri Lanka.

5.2 Building Information Modelling

There are many software tools that can be used for designing and analyzing buildings for energy management. Latest BIM software developed by Autodesk Corporation, USA are Revit Architecture and Revit MEP. Revit is a whole building solution package which includes architectural designing, MEP designing, structural designing, which use intelligent Building Information Modeling (BIM) concept. This software has numerous tools to design 3D models in a realistic way within a short time. This includes building services such as lighting, HVAC and plumbing with real coordination in a 3D modeling interface. Further this software facilitates to locate the building on a geographical location and orientation to study the sun’s movements for day light saving option. Building envelops such as walls, roofs, windows also can be specified in this software in the design stage for analysis.

Following designs are initiated with Revit Architecture and systems such as Mechanical, Electrical and Plumbing designs integrated in Revit MEP software Tool. Two domestic units are identified from the sample set as A and B for ‘High Income Model’ and ‘Middle Income Model’. Floor plans of these Models A and B are shown in Figures 5.1 and 5.2 respectively.



Properties

Floor Plan

Floor Plan: GROUI

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Wall Join Dis...	Clean all w...
Discipline	Architectural
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Figure 5.1: 2D Plan for High Income Group Domestic Units

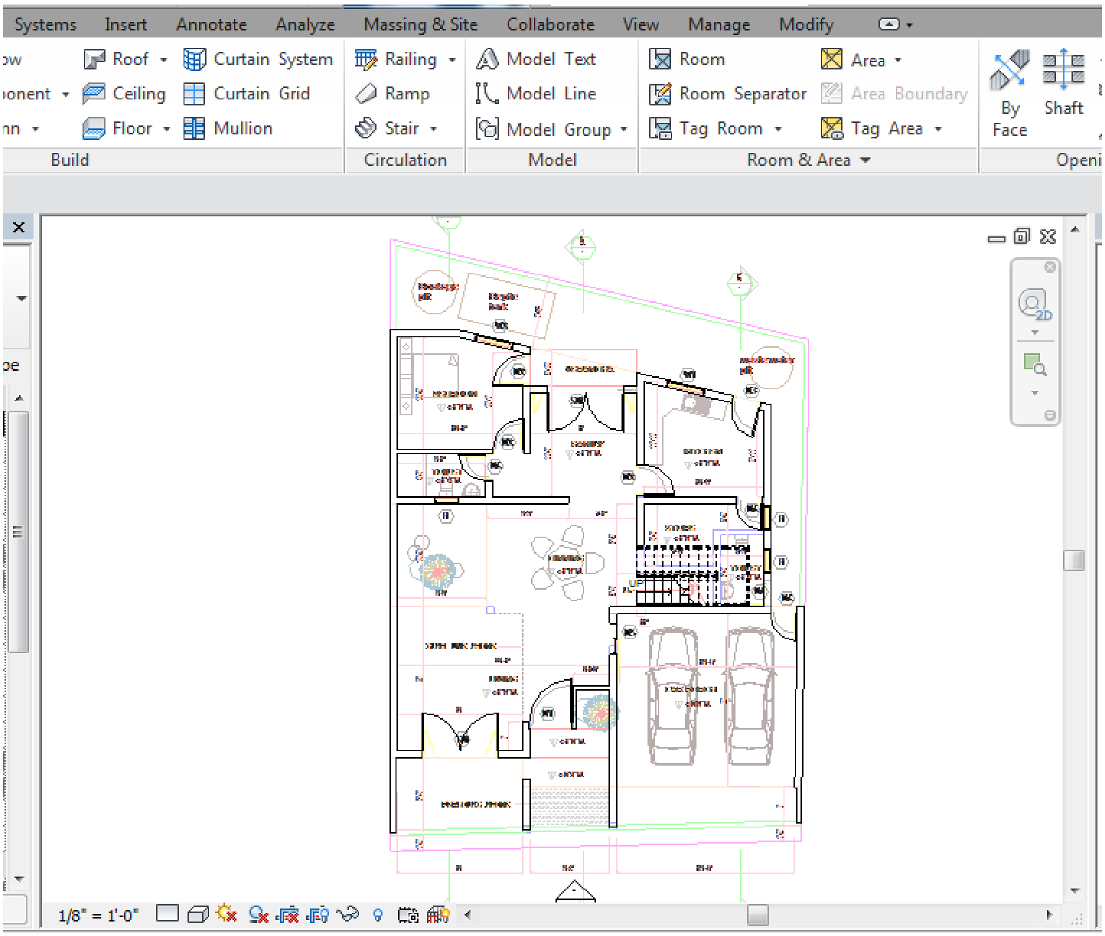

Figure 5.2: 2D Plan for Middle Income Group Domestic Units

Following figures 5.3 and 5.4 shows three dimensional models for above floor plans for each category. These models include lighting, ventilation and building envelope details during designing. Model A has more floor area with a complex architectural design, whereas model B is a basic design with less floor area with low comfort levels.

Compared to Model B, model A has more rooms, therefore floor area, window area, roof area are also high. Further, electricity consumption and number of occupancies are high in model A compared to model B. These models were subjected to analyze for energy efficiency and optimized individual zones for best performance for lighting and ventilation.

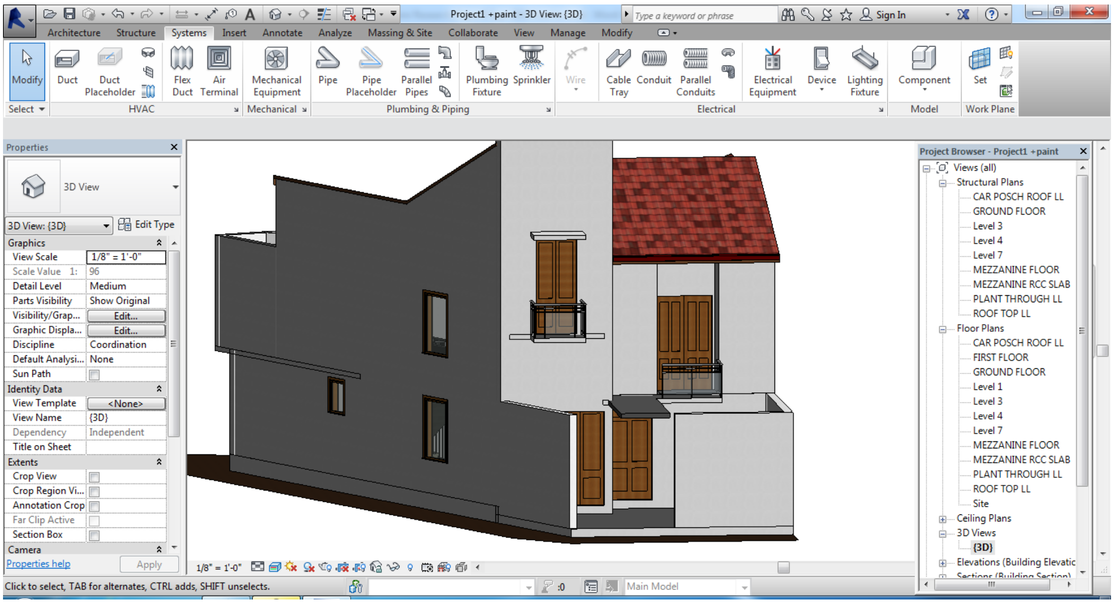

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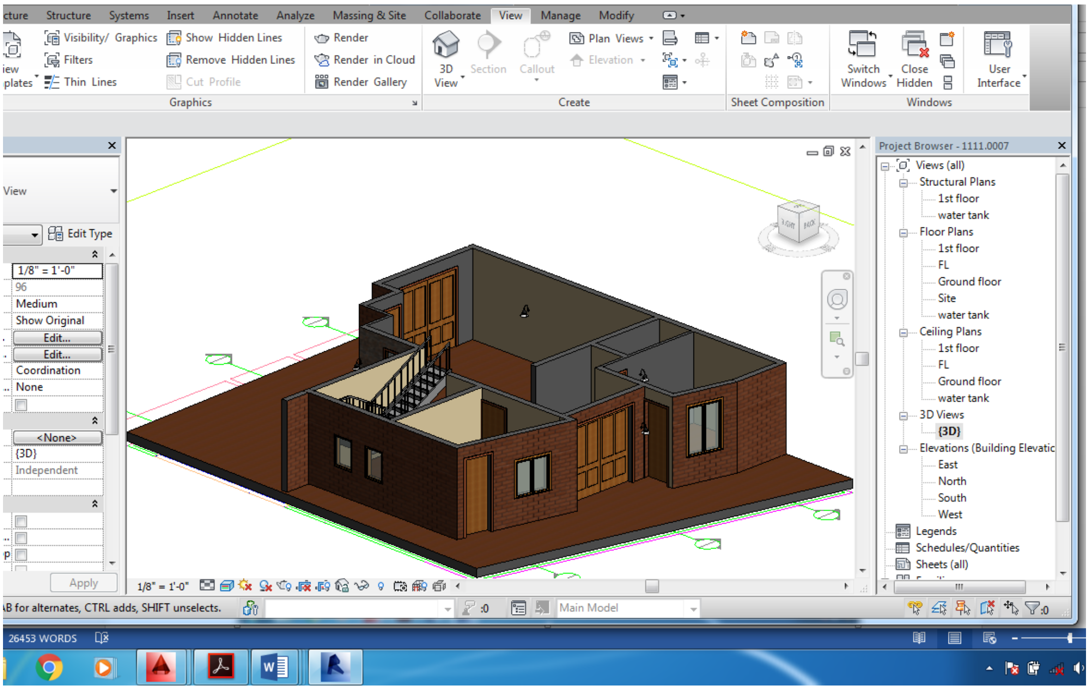
Figure 5.3: 3D Model for High Income Group Domestic Units



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B for alternates, CTRL adds, SHIFT unselects.

Figure 5.4: 3D Model for Middle Income Group Domestic Units

The completed 3D model was uploaded to the Revit MEP platform for energy analysis. In Revit MEP these models incorporated with the best solutions in lighting, ventilation and building envelops. With this modern technology it is very simple to design domestic units for higher performances in a short period of time.

Following are the main criteria's comprise with these models for energy efficient domestic units in Colombo District.

Table 5.1: Selection criteria for research models A and B

Parameter	Model A	Model B
Income level (LKR/month)	> 150,000/-	< 150,000/-
Electricity Consumption (kWh/Month)	> 500	< 500
Lighting Usage (kWh)	> 40	<40
Type of Human Comfort	Air Conditioning System	Fan Users
Comfort Level (kWh)	>50	< 50
Water Heating Capacity (kWh)	> 25	<25
Floor Area (sq ft)	> 1500	< 1500

Recommend to design and construct domestic units with following considerations to optimize energy efficiency of the building.

- Orientation: alignment of the building
- Building material specifications U Values for bricks, Roof Material, Glass
- Interior/ Exterior Wall finishes – Reflectance R=0.5 for light colours
- Introduce sky lights for roofing for Illumination
- Door, window arrangement for cross ventilation
- Day Light Usage: 80% day time
- Optimized Lighting Levels and Introduce switching systems
- Use of Inverter type equipment: Refrigerators, Air Conditioners
- Use of LED lamps
- Use LED Televisions
- Use of multi-level regulating fans to maintain comfort for

- Maintain minimum required distances from nearby buildings
- Apply Green building concepts
- Install Solar Panels for Nett metering

Software allows to perform detailed analysis of building design using energy simulation techniques. This can be used to create of a detailed building model and allows to automatically perform parametric simulations of design alternatives and provide with intuitive graphics that highlight the performance of proposed design alternatives all within a fraction of the time. Series of steps are to be followed to design a fully described model with principal energy-related features. The wizard then creates a detailed description of the proposed design in the format required by the simulation program.

The sequence of steps allows describing the building's architectural features and it's heating, ventilating, and air-conditioning (HVAC) equipment. The steps are organized so that the most general project information and more detailed architectural and HVAC information can be given step by step.

Once the simulation is completed, visualize the results through a number of graphical formats. Overall building estimated energy use can be seen on an annual or monthly basis. Detailed performance of individual building components may also be examined. Figure 5.5, for example, provides a pair of comparison graphics that show the monthly electrical and gas consumption for each of five building EEM simulations.

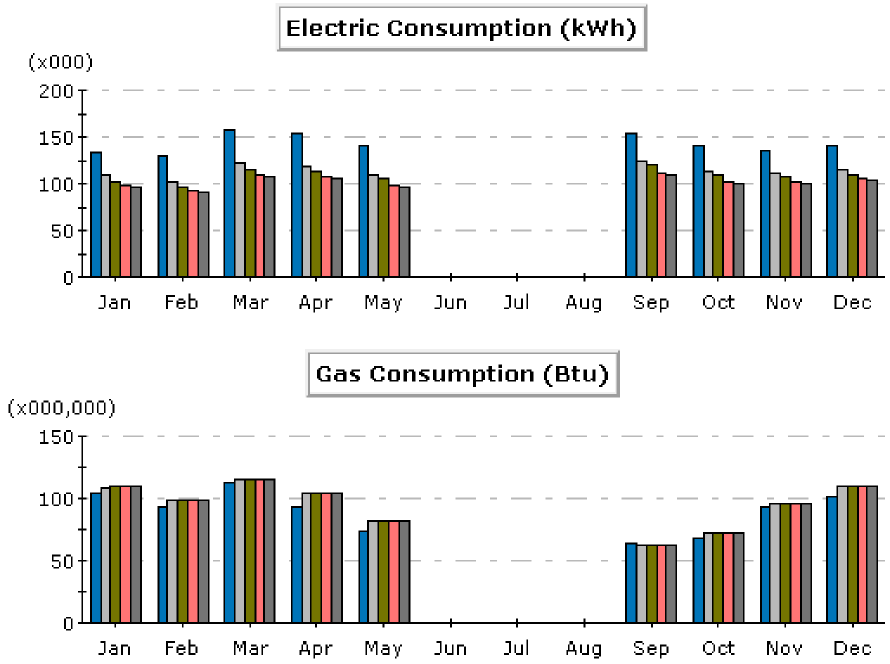

Figure 5.5: Results from Energy Analysis

5.3 Future Work

Technology is available to reduce the wastage of energy by a reasonable amount, but it has to be done with utmost care. Researches show that the quality aspects of lighting can have increase in productivity. Therefore, without compromising the qualitative aspects designers have to reduce energy using correct techniques. The designer therefore is to face the challenge of using a code as a minimum energy performance standard to develop systems that balance appealing and effective environments with minimal energy usage. Hence, it is however necessary to evaluate the equipment, techniques and services available for both existing and proposed installations in order to meet these requirements.

Hence it is a great need to develop an energy efficient domestic building code to Sri Lanka to minimize the waste and manage energy in an efficient way. Studying and associating existing standards and models used in other countries we can develop a preliminary code of practice for domestic units in Sri Lanka for energy efficient systems. This research paper could be used to identify key parameters for electricity consumption in Colombo district. Using domestic models A and B designed and analysed in this section could be used in a more general format for implementing in Sri

Lanka. These optimized models can be used as guide lines for domestic construction by contractors.

If domestic units are designed and constructed according to a given guide line related to energy efficiency, it will help to get a considerable amount of natural ventilation which would reduce the utilization of fans and AC's. And this is a reasonable option to cut down on the peak load at night. This option will help in peak clipping in DSM. Further replacing incandescent lamps with CFL or LED having low wattage will drastically reduce the energy consumption for lighting, and this could assist in the reduction of the peak load. Hence, introducing a building code for domestic use is essential for demand side management for clipping peak demand in Sri Lanka.

Performance grading is the index for evaluating energy performance of domestic units in many countries as discussed in Chapter 2. Performance grading comprises of lighting levels, comfort level, building envelopes and plug-in loads. Upon the value for the performance grading Star Ratings can be assigned to designers and building contractors. The higher the number of stars, the more energy efficient, and will promote to increase the bench mark of energy level to a higher level.

Some of the benefits identified from building energy to the consumer are money, reduce pollution and increase reliability, protect consumers and ensure health and safety. Further provide a quality and comfort to the customer and make a cost-effective investment and improve long-term sustainability.

This research could be used as a preliminary document for reference and to develop a guideline for practicing authorities to implement energy efficiency in domestic units in Sri Lanka.

References

[1] S. L. S. E. Authority, "Sri Lanka Energy Balance," 2013.

[2] S. L. S. E. Authority, Energy Balance statistics, 2014.

[3] D. o. C. a. S. S. Lanka, "Census of Population and Housing, Final Report," 2012.

[4] C. E. Board, "Statistical Digest," 2013.

[5] C. E. Board, "Summary Statistics," Colombo 00200, 2014.

[6] C. E. Board, "Electricity Sales by Province," 2014.

[7] H. a. T. I. Ordinance, "Part II Chapter 1, section 15".

[8] S. L. S. E. Authority, "Energy Efficient Building Code," 2008.

[9] S. L. S. E. Authority, "Energy Balance," 2014.

[10] P. U. C. o. S. Lanka, *Demand Side Management.*

[11] S. L. S. E. Authority, “Code of Practice for Energy Efficient Buildings,” 2008.

[12] J. B. a. W. Burt, *Designing Buildings for Daylight.*

[13] B. Standard, *Day light code 2.*

[14] C. D. Group, "Advances In Daylight Simulation".

[15] C. I. o. B. S. Engineers, “Code of Interior Lighting 1994, UK”.

[16] ASHRAE, " Standards Guidelines".

[17] A. S. 62.2, "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings," 2003.

[18] U. Department of Energy, "Energy Efficiency and Renewable Energy".

[19] P. a. P. Freedman, " Statistics, 4th ed.," New York: Norton, 2007.

[20] "en.wikipedia.org/wiki/File:Daylight_Factor_Study_Colour_plot.jpg,"

[21] "http://www.eere.energy.gov/basics/buildings/daylighting.html," [Online].

[22] http://upload.wikimedia.org/wikipedia/en/e/e9/American_Society_of_Heating%2C_Refrigerating_and_Air-Conditioning_Engineers_logo.jpg.

[23] A. M. Inderjeet Singh, CDM Potential through Energy Efficiency in Electricity Consumption, Indian Urban Building Sector, CDM, energy efficiency, India, 04

[24] "Compact_fluorescent_lamp#Energy_efficiency," [Online]. Available: http://en.wikipedia.org/wiki.

[25] Retail Tariff Proposal, Ceylon Electricity Board, March 2013.

[26] "Tariff-Proposal-Final," Ceylon Electricity Board, 2013.

[27] "World Meteorological Organization," Hong Kong Observatory.

[28] "Energy Efficiency Trends in Residential and Commercial Buildings," 2008.

[29] S. L. S. E. Authority, "Sri Lanka Energy Balance," Sri Lanka Sustainable Energy Authority, 2012.

[30] *CEB, Knowledge.*

[31] C. E. Board, "Demand Side Management".

[32] ASHRAE, "Standard 55".

[33] I. C. o. Illumination.

APPENDICES

Appendix A: Housing Units by Category in 2012

(Source: Sri Lanka Census and Statistics- Housing Units in Districts by sector)

District	No of Housing Units	Occupied Housing Units In Districts by Type of Housing Category 2012									
		Single house- single storied	Single house- two storied	Single house- more than two stories	Attache house/ Annex	Flat	Condominium/ Luxury/ Annex	Twin house	Row house/ Line rooms	Hut/ Shanty	Other
Sri Lanka	5,165,331	4,385,499	360,513	30,809	47,239	28,935	5,162	35,870	175,885	81,716	13,703
	100.0	84.9 %	7.0 %	0.6 %	0.9%	0.6%	0.1%	0.7 %	3.4 %	1.6 %	0.3 %
Colombo	555,926	349,145	119,040	13,302	19,841	23,461	4,645	3,047	14,193	7,979	1,273
	100.0	62.8	21.4	2.4	3.6	4.2	0.8	0.5	2.6	1.4	0.2
Gampaha	592,064	492,593	59,269	3,299	7,987	940	2	2,620	19,080	3,642	2,632
	100.0	83.2	10.00	0.6	1.3	0.2	-	0.4	3.2	0.6	0.4
Kalutara	299,321	263,581	22,948	1,233	2,407	614	-	1,786	5,453	1,117	182
	100.0	88.1	7.7	0.4	0.8	0.2	-	0.6	1.8	0.4	0.1
Kandy	342,255	278,032	33,423	3,782	4,088	1,335	174	2,551	17,085	1,476	309
	100.0	81.2	9.8	1.1	1.2	0.4	0.1	0.7	5.0	0.4	0.1
Matale	126,867	114,380	4,975	288	770	110	20	913	4,811	499	101
	100.0	90.2	3.9	0.2	0.6	0.1	-	0.7	3.8	0.4	0.1
Nuwara Eliya	176,495	96,560	9,007	1,305	3,101	-	-	9,649	52,491	3,813	569
	100.0	54.7	5.1	0.7	1.8	-	-	5.5	29.7	2.2	0.3
Galle	269,107	241,998	19,180	811	1,032	336	27	1,025	3,320	1,116	262
	100.0	89.9	7.1	0.3	0.4	0.1	-	0.4	1.2	0.4	0.1
Matara	203,570	183,012	13,358	831	1,096	259	-	1,211	3,041	683	79
	100.0	89.9	6.6	0.4	0.5	0.1	-	0.6	1.5	0.3	-
Hamban	154,980	149,005	4,393	188	255	124	47	118	160	615	75
	100.0	96.1	2.8	0.1	0.2	0.1	-	0.1	0.1	0.4	-
Jaffna	135,837	123,065	2,507	181	110	188	47	73	63	9,131	472
	100.0	90.6	1.8	0.1	0.1	0.1	-	0.1	-	6.7	0.3
Mannar	23,338	20,170	888	501	16	18	11	39	3	1,672	20
	100.0	86.4	3.8	2.1	0.1	0.1	-	0.2	-	7.2	0.1
Vavuniya	40,894	31,478	1,118	188	135	54	27	39	1,784	5,953	118
	100.0	77.0	2.7	0.5	0.3	0.1	0.1	0.1	4.4	14.6	0.3

Mullativu	24,278	12,983	250	35	6	-	-	-	-	10,577	427
	100.0	53.5	1.0	0.1	-	-	-	-	-	43.6	1.8
Kilinochchi	28,300	17,264	42	-	-	-	-	-	-	5,892	5,102
	100.0	61.0	0.1	-	-	-	-	-	-	20.8	18.0
Batticalo	132,999	118,906	3,397	437	132	-	-	97	21	9,698	311
	100.0	89.4	2.6	0.3	0.1	-	-	0.1	-	7.3	0.2
Ampara	162,224	150,830	5,000	185	333	976	-	1,706	278	2,872	44
	100.0	93.0	3.1	0.1	0.2	0.6	-	1.1	0.2	1.8	-
Trincomalee	95,213	88,092	2,341	279	159	-	-	1,077	793	2,184	288
	100.0	92.5	2.5	0.3	0.2	-	-	1.1	0.8	2.3	0.3
Kurunegala	437,931	416,921	14,657	527	689	5	4	631	1,667	2,449	381
	100	95.2	3.3	0.1	0.2	-	-	0.1	0.4	0.6	0.1
Puttalam	200,451	187,429	5,596	451	294	17	5	794	1,354	4,218	293
	100	93.5	2.8	0.1	-	-	-	0.4	0.7	21	0
Anuradpura	227,598	220,896	4,581	229	423	48	-	423	141	746	111
	100	97.1	2.0	0.1	0.2	-	-	0.2	0.1	0	-
Polonnaruwa	110,289	106,387	2,526	121	292	59	31	217	104	481	71
	100.0	96.5	2.3	0.1	0.3	0.1	-	0.2	0.1	0	0
Badulla	210,126	168,264	8,905	1,072	1,965	-	-	4,716	22,953	2,019	232
	100	80.1	4.2	0.5	0.9	-	-	2.2	10.9	1	0
Moneragala	117,812	113,304	1,647	115	273	109	29	192	1,428	637	78
	100.0	96.2	1.4	0.1	0.2	0.1	-	0.2	1	1	0
Ratnapura	280,243	248,438	10,012	703	1,558	257	93	1,880	16,334	1,239	129
	100	88.7	3.6	0.3	0.4	0.1	-	0.7	5.8	0	-
Kegalle	217,213	192,766	11,453	746	677	25	-	1,066	9,328	1,008	144
	100	88.7	5.3	0.3	0.3	-	-	0.5	4.3	1	0

Appendix B: Households in occupied housing Units by Districts and Principal type of lighting, 2012

(Source: Sri Lanka Census and Statistics- Housing Units in Districts by sector)

District	**Number of Households**	**Principle Type of Lighting**					
		Electricity		**Other**			
		Electricity from National Grid	**Electricity from rural hydro power project**	**Kerosene**	**Solar power**	**Bio gas**	**Other**
Sri Lanka	5,188,047	4,514,182	36,904	597,360	34,315	840	4,446
	100.0	87.0 %	0.7 %	11.5 %	0.7%	0.6%	0.1%
Colombo	558,755	545,784	904	11,370	150	44	503
	100.0	97.7	0.2	2.0	0.0	0.0	0.1
Gampaha	593,317	573,100	0	19,505	232	34	446
	100.0	83.2	10.00	0.6	1.3	0.2	-
Kalutara	300,402	281,075	1,416	16,853	657	36	365
	100.0	93.6	0.5	5.6	0.2	0.0	0.1
Kandy	344,681	318,184	2,405	23,283	633	27	149
	100.0	93.6	0.7	6.8	0.2	0.0	0.0
Matale	127,884	106,878	1,656	18,184	1,102	19	45
	100.0	83.6	1.3	14.2	0.9	0.0	0.0
Nuwara Eliya	177,420	155,301	2,466	18,961	545	52	95
	100.0	87.5	14	10.7	0.3	0	0.1
Galle	269,740	251,367	2,451	15,370	315	37	200
	100.0	93.2	0.9	5.7	0.1	0.0	0.1
Matara	204,194	191,079	1,057	11,706	24	15	123
	100	93.6	0.5	5.7	0.1	0.0	0.1
Hambantota	155,299	137,237	1,367	16,130	191	21	353
	100.0	88.4	0.9	10.4	0.1	0.0	0.2
Jaffna	137,503	99,576	1,283	36,056	452	12	124
	100	72.4	0.9	26.2	0.3	0.0	0.1
Mannar	23,783	13,810	1,378	8,131	407	8	49
	100.0	58.1	5.8	34.2	1.7	0.0	0.2
Vavuniya	41,214	28,692	564	11,431	514	3	10
	100	69.6	1.4	27.7	1.2	0.0	0.0
Mullativu	24,334	5,754	0	16,970	1,537	6	67
	100.0	23.6	0.0	69.7	6.3	0.0	0.3
Kilinochchi	28,304	2,874	0	22,310	3,057	6	67
	100.0	13.0	0	70.5	9.5	0.0	.4
Batticalo	133,795	90,314	0	42,803	622	6	50
	100.0	67.5	0.0	32.0	0.5	0.0	0.0

Appendix C1: Electricity consumption of Sample 1: Dehiwala in February 2014

Type of usage	**Wattage (W)**	**Nos.**	**Duration /day (hrs)**	**Usage (kWh/month)**
Total Consumption				**308.4**
Lighting				**38.7**
Incandescent	75	3	4	27
Tube Light	40	2	3	7.2
CFL	15	2	5	4.5
LED	0	0	0	0
Communication / Entertainment				**20.49**
Television (CRT)	100	1	5	15
Television (LCD)	0	0	0	0
Television (LED)	0	0	0	0
Satellite Dish	0	0	0	0
DVD Player	12	1	1/4	0.1
Stereo System	30	1	1	0.9
Personal Computer	150	1	1	4.5
Laptop	0	0	0	0
Electric Organ	0	0	0	0
Water Heating				**22.5**
Electric Kettle	1500	1	1/2	22.5
Geezer	0	0	0	0
Electric Heater	0	0	0	0
Cooking				**19.1**
Blender/Grinder	250	1	1/4	1.9
Hot Plate	0	0	0	0
Electric Oven	0	0	0	0
Microwave Oven	0	0	0	0
Rice Cooker	600	1	1/2	9
Toaster	1100	1	1/4	8.25
Food Storage medium				**70.2**
Refrigerator	130	1	18	70.2
Deep Freezer	0	0	0	0
Ventilation Systems				50.4
Ceiling Fan	75	2	8	36
Pedestal Fans	60	1	8	14.4
Table Fans	0	0	0	0
Air Conditioning (Window Type)	0	0	0	0
Air Conditioning (Split Type)	0	0	0	0
Washing & Ironing				**22.5**
Washing Machine	1500	1	1/4	11.3
Dryer	500	1	1/4	3.8
Electric Iron	750	1	1/3	7.5
Other Equipment				**64.5**
Cell Phone Re Charges	4	3	2	0.72
Hair Dryers	0	0	0	0
Vacuum Cleaner	0	0	0	0.0
Floor Polisher	500	1	1/4	3.8
Domestic Water Pump	500	1	4	60.0

Appendix C2: Electricity consumption of Sample 1: Dehiwala in March 2014

Type of usage	**Wattage (W)**	**Nos.**	**Duration /day (hrs)**	**Usage (kWh/month)**
Total Consumption				**310.8**
Lighting				**41.1**
Incandescent	75	3	4	27
Tube Light	40	2	4	9.6
CFL	15	2	5	4.5
LED	0	0	0	0
Communication / Entertainment				**20.49**
Television (CRT)	100	1	5	15
Television (LCD)	0	0	0	0
Television (LED)	0	0	0	0
Satellite Dish	0	0	0	0
DVD Player	12	1	1/4	0.1
Stereo System	30	1	1	0.9
Personal Computer	150	1	1	4.5
Laptop	0	0	0	0
Electric Organ	0	0	0	0
Water Heating				**22.5**
Electric Kettle	1500	1	1/2	22.5
Geezer	0	0	0	0
Electric Heater	0	0	0	0
Cooking				**19.1**
Blender/Grinder	250	1	1/4	1.9
Hot Plate	0	0	0	0
Electric Oven	0	0	0	0
Microwave Oven	0	0	0	0
Rice Cooker	600	1	1/2	9
Toaster	1100	1	1/4	8.25
Food Storage medium				**70.2**
Refrigerator	130	1	18	70.2
Deep Freezer	0	0	0	0
Ventilation Systems				50.4
Ceiling Fan	75	2	8	36
Pedestal Fans	60	1	8	14.4
Table Fans	0	0	0	0
Air Conditioning (Window Type)	0	0	8	0
Air Conditioning (Split Type)	0	0	0	0
Washing & Ironing				**22.5**
Washing Machine	1500	1	1/4	11.3
Dryer	500	1	1/4	3.8
Electric Iron	750	1	1/3	7.5
Other Equipment				**64.5**
Cell Phone Re Charges	4	3	2	0.72
Hair Dryers	0	0	0	0
Vacuum Cleaner	0	0	0	0.0
Floor Polisher	500	1	1/4	3.8
Domestic Water Pump	500	1	4	60.0

Appendix C3: Electricity consumption of Sample 1: Dehiwala in April 2014

Type of usage	**Wattage (W)**	**Nos.**	**Duration /day (hrs)**	**Usage (kWh/month)**
Total Consumption				**308.4**
Lighting				**38.7**
Incandescent	75	3	4	27
Tube Light	40	2	3	7.2
CFL	15	2	5	4.5
LED	0	0	0	0
Communication / Entertainment				**20.49**
Television (CRT)	100	1	5	15
Television (LCD)	0	0	0	0
Television (LED)	0	0	0	0
Satellite Dish	0	0	0	0
DVD Player	12	1	1/4	0.1
Stereo System	30	1	1	0.9
Personal Computer	150	1	1	4.5
Laptop	0	0	0	0
Electric Organ	0	0	0	0
Water Heating				**22.5**
Electric Kettle	1500	1	1/2	22.5
Geezer	0	0	0	0
Electric Heater	0	0	0	0
Cooking				**19.1**
Blender/Grinder	250	1	1/4	1.9
Hot Plate	0	0	0	0
Electric Oven	0	0	0	0
Microwave Oven	0	0	0	0
Rice Cooker	600	1	1/2	9
Toaster	1100	1	1/4	8.25
Food Storage medium				**70.2**
Refrigerator	130	1	18	70.2
Deep Freezer	0	0	0	0
Ventilation Systems				50.4
Ceiling Fan	75	2	8	36
Pedestal Fans	60	1	8	14.4
Table Fans	0	0	0	0
Air Conditioning (Window Type)	0	0	8	0
Air Conditioning (Split Type)	0	0	0	0
Washing & Ironing				**22.5**
Washing Machine	1500	1	1/4	11.3
Dryer	500	1	1/4	3.8
Electric Iron	750	1	1/3	7.5
Other Equipment				**64.5**
Cell Phone Re Charges	4	3	2	0.72
Hair Dryers	0	0	0	0
Vacuum Cleaner	0	0	0	0.0
Floor Polisher	500	1	1/4	3.8
Domestic Water Pump	500	1	4	60.0

Appendix D: Summary of Electricity consumption of 50 Samples in February 2014

Sample No	Lighting	Communication Entertainment	Water Heat	Cooking	Food Storage medium	Ventilation Systems	Washing & Ironing	Other Equipment	Total	Comfort	Income Level
1	38.7	20.49	22.5	19.125	70.2	50.4	22.5	64.47	308.38	Fan	<150000
2	17.7	20.94	67.5	35.625	116.1	326.4	19.5	75.345	679.11	AC	>150000
3	16.2	23.415	40.5	79.125	112.5	291.75	18.75	15.705	597.94	AC	>150000
4	29.7	9.99	22.5	177	97.5	42.75	56.25	4.71	440.4	Fan	<150000
5	27.3	16.59	45	49.125	58.5	36	18.75	10.845	262.11	Fan	<150000
6	19.5	30.615	90	93	125.1	550.2	22.8	75.825	1007.04	AC	>150000
7	15.3	10.215	67.5	22.125	108.3	326.4	16.87	32.595	599.31	AC	>150000
8	45.6	27.99	33.7	17.475	105.3	82.8	22.5	70.845	406.26	Fan	<150000
9	9	22.215	45	49.125	113.8	580.8	5.625	75.345	900.96	AC	>150000
10	17.1	28.215	73.5	58.125	125.1	408.15	19	26.46	755.65	AC	>150000
11	15	21.09	56.2	26.625	97.5	302.4	34.5	71.595	624.96	AC	>150000
12	12.7	21.84	43.5	16.875	132.6	279.6	37.5	15.345	560.01	AC	>150000
13	18.6	24.09	44.2	25.875	120.3	326.4	26.25	68.295	654.06	AC	>150000
14	31.8	12.99	22.5	10.875	90	100.8	22.5	75.345	366.81	Fan	<150000
15	32.1	16.89	67.5	19.125	70.2	272.4	30	15.345	523.56	AC	>150000
16	66.6	12.3	22.5	95.25	82.8	55.2	19.5	7.095	361.245	Fan	<150000
17	63	18.99	67.5	70.5	58.5	88.8	18.75	34.23	420.27	Fan	<150000
18	33.9	28.14	45	28.125	116.1	86.4	26.25	11.235	375.15	Fan	<150000
19	43.8	16.59	40.5	44.25	97.5	82.8	23.62	10.305	359.37	Fan	<150000
20	27.3	9.09	60	19.125	112.5	317.4	22.5	75.345	643.26	AC	>150000
21	36.6	8.7	21	35.025	103.3	48	18.37	68.97	340.02	Fan	<150000
22	22.5	13.59	112	18.75	111.6	335.1	23	22.47	659.51	AC	>150000
23	52.2	15.69	90	36	75	272.4	23.12	71.595	636.01	AC	>150000
24	12	7.2	21	28.125	90	326.4	21.75	6.615	513.09	AC	>150000
25	41.4	18	22.5	136.5	101.7	63	11.25	25.98	420.33	Fan	<150000
26	15	19.5	38.2	139.5	97.5	250.2	21.87	37.335	619.16	AC	>150000
27	27.3	14.34	22.5	25.875	90	290.4	23.25	7.095	500.76	AC	>150000
28	14.7	15.06	41.2	19.125	116.1	326.4	22.5	90.345	645.48	AC	>150000
29	27	16.59	18.7	19.875	58.5	68.4	16.87	7.095	233.085	Fan	<150000
30	25.5	16.68	22.5	18.375	108	67.2	22.5	4.47	285.225	Fan	<150000
31	31.8	16.59	37.5	144	94.5	75.6	18.75	10.845	429.585	Fan	<150000
32	13.2	40.92	157.	25.5	105	326.4	22.5	75.345	766.365	AC	>150000
33	18.3	5.4	18	10.5	58.5	43.2	11.25	3.27	168.42	Fan	<150000
34	32.1	23.49	45	25.875	97.5	115.2	18.75	70.605	428.52	Fan	<150000
35	17.4	17.64	43.5	139.05	112.5	299.4	19.87	75.105	724.47	AC	>150000
36	36.3	16.5	45	19.125	108	68.4	20.62	70.845	384.795	Fan	<150000

37	18	13.59	56.2	49.35	90	407.7	16.5	71.085	722.475	AC	>150000
38	18.6	15.315	45	40.875	75	282.9	22.5	75.345	575.535	AC	>150000
39	30.6	15.6	36	49.125	101.7	276.9	33	6.735	549.66	AC	>150000
40	14.2	14.79	40.5	49.35	114.7	309.6	20.62	42.315	606.18	AC	>150000
41	13.0	6.84	22.5	19.125	116.1	326.4	22.5	75.345	601.86	AC	>150000
42	27.3	16.59	45	57.375	135.6	290.4	37.5	86.355	696.12	AC	>150000
43	27	9.972	22.5	19.125	116.1	50.4	7.5	75.345	327.942	Fan	<150000
44	16.5	4.5	11.2	51	105.3	257.4	22	75.045	542.995	AC	>150000
45	36	11.79	33.7	153.37	102	51.6	16.87	11.835	417.225	Fan	<150000
46	36.3	10.44	22.5	64.125	66	86.4	7.5	60.72	353.985	Fan	<150000
47	27.4	18.75	43.5	137.1	75	59.25	30.37	50.19	441.615	Fan	<150000
48	15	22.74	90	26.625	135	421.2	22.5	11.595	744.66	AC	>150000
49	10.8	18.3	22.5	34.125	94.5	393	17.62	67.335	658.185	AC	>150000
50	18	25.86	39.7	34.5	135.6	270	41.25	102.31	667.275	AC	>150000

Appendix E: Summary of General Data of 50 Domestic Units in Colombo District

SN	AC/FAN	Income Level	No members	Floor Area	Building Age	Incandescent Users	CFL Use	LED Use	Window Area	Wndow State	Bld Dist	Shade Level	Land Area	Total Range
1	2	1	3	3500	10	1	1	0	420	1	10.0	2	14.0	1.00
2	1	2	4	5500	8	0	1	1	650	2	15.0	1	17.0	3.00
3	1	2	5	5700	23	0	1	1	800	1	13.0	2	19.5	2.00
4	2	1	4	4500	18	1	1	1	460	1	10.0	1	13.0	2.00
5	2	1	3	2800	15	1	1	1	420	1	12.0	0	10.2	1.00
6	1	2	4	4000	8	0	1	1	580	2	5.0	0	12.0	4.00
7	1	2	4	5400	5	0	1	1	780	2	8.0	1	14.2	2.00
8	2	1	4	4500	12	1	1	0	560	1	5.0	1	8.9	2.00
9	1	2	4	5500	6	0	1	1	850	1	8.0	1	12.6	4.00
10	1	2	6	5400	22	0	1	1	750	1	25.0	2	18.0	3.00
11	1	2	3	4500	4	0	1	1	650	2	10.0	1	13.2	3.00
12	1	2	4	3600	8	0	1	1	600	2	4.0	0	9.0	2.00
13	1	2	5	5500	10	0	1	1	780	1	2.0	2	9.2	3.00
14	2	1	3	3800	14	1	1	0	500	1	8.0	1	7.8	1.00
15	1	2	3	4000	16	1	1	1	420	2	11.0	1	12.7	2.00
16	2	1	5	4200	19	1	1	0	500	1	16.0	1	14.0	1.00
17	2	1	4	4500	13	1	1	0	720	2	24.0	2	16.0	2.00
18	2	1	5	4200	11	1	1	1	680	1	7.0	1	12.8	1.00
19	2	1	3	4500	17	1	1	1	800	2	5.0	1	12.0	1.00
20	1	2	4	5000	8	1	1	1	880	1	30.0	0	16.0	3.00
21	2	1	4	4500	12	1	1	0	460	1	6.0	1	11.6	1.00
22	1	2	5	5000	16	0	1	0	600	1	16.0	1	16.3	3.00

23	1	2	4	4800	6	1	1	0	500	2	8.0	2	10.0	3.00
24	1	2	3	4500	4	0	1	1	560	2	12.0	1	10.6	2.00
25	2	1	4	4200	15	1	0	0	480	1	12.0	2	14.0	2.00
26	1	2	4	5000	18	0	1	1	650	2	10.0	1	12.8	3.00
27	1	2	3	4800	25	1	1	1	600	1	16.0	2	15.3	2.00
28	1	2	5	5300	17	0	1	1	800	2	8.0	1	10.8	3.00
29	2	1	2	3000	26	1	1	0	760	1	6.0	0	7.5	1.00
30	2	1	4	3800	16	1	1	1	600	1	4.0	1	10.2	1.00
31	2	1	3	4500	5	1	1	0	550	2	6.0	1	12.5	2.00
32	1	2	4	5800	8	0	1	1	800	2	10.0	2	13.5	3.00
33	2	1	3	3500	10	0	1	0	350	1	.0	1	6.8	1.00
34	2	1	4	4500	16	1	1	1	480	2	6.0	1	11.1	2.00
35	1	2	5	3900	6	0	1	1	400	1	4.0	1	8.6	3.00
36	2	1	4	5000	21	1	1	1	800	2	20.0	2	21.0	1.00
37	1	2	3	5200	8	0	1	1	680	1	12.0	1	14.7	3.00
38	1	2	2	3800	4	0	1	1	280	1	16.0	1	12.8	2.00
39	1	2	3	6000	12	1	1	1	580	2	18.0	1	19.8	2.00
40	1	2	4	5500	18	0	1	1	500	2	10.0	1	12.5	3.00
41	1	2	4	5300	11	0	1	1	460	1	15.0	0	11.0	3.00
42	1	2	5	5800	21	1	1	1	670	2	16.0	2	19.8	3.00
43	2	1	3	4800	6	1	1	0	600	1	15.0	1	14.5	1.00
44	1	2	3	2600	4	0	1	1	380	1	12.0	1	11.6	2.00
45	2	1	4	4500	8	1	1	0	360	2	10.0	2	12.6	2.00
46	2	1	3	4000	2	1	1	0	660	1	6.0	1	10.0	1.00
47	2	1	3	2800	15	1	1	0	460	2	4.0	1	8.6	2.00
48	1	2	5	4000	12	0	1	1	780	2	8.0	2	12.4	3.00
49	1	2	3	4600	8	0	1	1	720	1	10.0	2	15.0	3.00
50	1	2	4	4800	22	0	1	1	680	1	20.0	1	20.0	3.00

Appendix F: Correlation of independent Variables of 50 Domestic Units in Colombo District

		Total KWh/month	Lighting	Communication/ Entertainment	Water Heating	Cooking	Food Store medm	Washing & Ironing	Ventilation Systems	Other Equipment	No of Members	Floor Area (sq ft)	Age of the Unit (yrs)	Land Area
Total (KWh/month)	Pearson	1	-.527**	.411**	.578**	.047	.592**	.126	.931**	.427**	.406**	.520**	-.178	.303*
	Sig.		.000	.003	.000	.743	.000	.383	.000	.002	.003	.000	.217	.032
Lighting	Pearson	-.527**	1	-.099	-.129	.173	-.439**	-.043	-.643**	-.194	-.012	-.228	.171	.019
	Sig.	.000		.495	.371	.229	.001	.766	.000	.178	.935	.111	.236	.895
Comm/ Entertainment	Pearson	.411**	-.099	1	.569**	-.026	.318*	.133	.272	.156	.337*	.210	.146	.153
	Sig.	.003	.495		.000	.855	.024	.358	.056	.280	.017	.144	.312	.288
Water Heating	Pearson	.578**	-.129	.569**	1	-.127	.225	.064	.469**	.135	.339*	.347*	-.109	.211
	Sig.	.000	.371	.000		.380	.116	.660	.001	.349	.016	.013	.450	.141
Cooking	Pearson	.047	.173	-.026	-.127	1	-.054	.134	-.186	-.219	.119	-.070	.029	.009
	Sig.	.743	.229	.855	.380		.711	.354	.195	.127	.409	.631	.842	.953
Food Storage	Pearson	.592**	-.439**	.318*	.225	-.054	1	.246	.495**	.281*	.635**	.467**	.054	.360*
	Sig.	.000	.001	.024	.116	.711		.085	.000	.048	.000	.001	.710	.010
Wash/ Ironing	Pearson	.126	-.043	.133	.064	.134	.246	1	.013	-.046	.106	.014	.265	.171
	Sig.	.383	.766	.358	.660	.354	.085		.926	.749	.464	.923	.063	.235
Ventilation Sys	Pearson	.931**	-.643**	.272	.469**	-.186	.495**	.013	1	.316*	.270	.481**	-.190	.234
	Sig.	.000	.000	.056	.001	.195	.000	.926		.025	.058	.000	.186	.102
Other Equipment	Pearson	.427**	-.194	.156	.135	-.219	.281*	-.046	.316*	1	.041	.219	-.277	.094
	Sig.	.002	.178	.280	.349	.127	.048	.749	.025		.776	.126	.052	.515
No of Mem	Pearson	.406**	-.012	.337*	.339*	.119	.635**	.106	.270	.041	1	.434**	.260	.274
	Sig.	.003	.935	.017	.016	.409	.000	.464	.058	.776		.002	.068	.054
Floor Area	Pearson	.520**	-.228	.210	.347*	-.070	.467**	.014	.481**	.219	.434**	1	.155	.591**
	Sig.	.000	.111	.144	.013	.631	.001	.923	.000	.126	.002		.283	.000
Age of the Unit	Pearson	-.178	.171	.146	-.109	.029	.054	.265	-.190	-.277	.260	.155	1	.309*
	Sig.	.217	.236	.312	.450	.842	.710	.063	.186	.052	.068	.283		.029
Land Area	Pearson	.303*	.019	.153	.211	.009	.360*	.171	.234	.094	.274	.591**	.309*	1
	Sig.	.032	.895	.288	.141	.953	.010	.235	.102	.515	.054	.000	.029	

Kendall's tau_b														
		Total (KWh/month)	Lighting	Communication / Entertainment	Water Heating	Cooking	Food Storage medium	Washing & Ironing	Ventilation Systems	Other Equipment	No of Members	Floor Area (sq ft)	Age of the Unit (yrs)	Land Area
Total (KWh/month)	Correlation	1.000	-.413**	.249*	.467**	.127	.404**	.164	.703**	.367**	.335**	.427**	-.082	.221*
	Sig.		.000	.011	.000	.197	.000	.101	.000	.000	.002	.000	.410	.024
Lighting	Correlation	-.413**	1.000	-.057	-.086	.084	-.285**	.016	-.468**	-.128	-.054	-.178	.139	.009
	Sig.	.000		.563	.395	.397	.004	.873	.000	.199	.623	.080	.166	.927
Communication / Entertainment	Correlation	.249*	-.057	1.000	.368**	.037	.203*	.168	.171	.121	.262*	.069	.104	.071
	Sig.	.011	.563		.000	.706	.041	.094	.084	.224	.018	.495	.301	.471
Water Heating	Correlation	.467**	-.086	.368**	1.000	-.006	.221*	.156	.417**	.228*	.305**	.274**	-.059	.214*
	Sig.	.000	.395	.000		.953	.030	.128	.000	.025	.007	.008	.565	.034
Cooking	Correlation	.127	.084	.037	-.006	1.000	-.049	-.098	-.050	-.068	.083	.065	-.003	.118
	Sig.	.197	.397	.706	.953		.626	.328	.614	.496	.457	.521	.980	.234
Food Storage medium	Correlation	.404**	-.28**	.203*	.221*	-.049	1.00	.175	.354**	.303**	.566**	.358**	.059	.171
	Sig.	.000	.004	.041	.030	.626		.083	.000	.002	.000	.000	.562	.084
Washing & Ironing	Correlation	.164	.016	.168	.156	-.098	.175	1.000	.073	.048	.098	-.007	.150	.028
	Sig.	.101	.873	.094	.128	.328	.083		.469	.637	.384	.946	.142	.781
Ventilation Systems	Correlation	.703**	-.468**	.171	.417**	-.050	.354**	.073	1.00	.273**	.238*	.385**	-.120	.147
	Sig.	.000	.000	.084	.000	.614	.000	.469		.006	.032	.000	.236	.138
Other Equipment	Correlation	.367**	-.128	.121	.228*	-.068	.303**	.048	.273**	1.000	.100	.207*	-.187	.079
	Sig.	.000	.199	.224	.025	.496	.002	.637	.006		.370	.043	.064	.425
No of Members	Correlation	.335**	-.054	.262*	.305**	.083	.566**	.098	.238*	.100	1.000	.341**	.254*	.156
	Sig.	.002	.623	.018	.007	.457	.000	.384	.032	.370		.003	.024	.160
Floor Area (sq ft)	Correlation	.427**	-.178	.069	.274**	.065	.358**	-.007	.385**	.207*	.341**	1.000	.122	.447**
	Sig.	.000	.080	.495	.008	.521	.000	.946	.000	.043	.003		.236	.000
Age of the Unit (yrs)	Correlation	-.082	.139	.104	-.059	-.003	.059	.150	-.120	-.187	.254*	.122	1.000	.176
	Sig.	.410	.166	.301	.565	.980	.562	.142	.236	.064	.024	.236		.080
Land Area	Correlation	.221*	.009	.071	.214*	.118	.171	.028	.147	.079	.156	.447**	.176	1.000
	Sig.	.024	.927	.471	.034	.234	.084	.781	.138	.425	.160	.000	.080	
Spearman's rho														
Total (KWh/month)	Correlation	1.000	-.60**	.360*	.623**	.180	.581**	.225	.877**	.509**	.434**	.567**	-.140	.316*
	Sig.		.000	.010	.000	.212	.000	.116	.000	.000	.002	.000	.331	.025
Lighting	Correlation	-.602**	1.000	-.092	-.121	.123	-.436**	.030	-.674**	-.216	-.091	-.281*	.204	.003
	Sig. (2-tailed	.000		.525	.401	.396	.002	.835	.000	.131	.531	.048	.156	.984
Communication	Correlation	.360*	-.092	1.000	.489**	.067	.314*	.231	.261	.151	.333*	.093	.173	.102

/ Entertainment	Sig. (2-tailed	.010	.525		.000	.641	.026	.107	.067	.296	.018	.520	.228	.479
Water Heating	Correlation	.623**	-.121	.489**	1.000	.010	.306*	.228	.546**	.315*	.376**	.362**	-.078	.303*
	Sig. (2-tailed	.000	.401	.000		.947	.030	.111	.000	.026	.007	.010	.592	.032
Cooking	Correlation	.180	.123	.067	.010	1.000	-.083	-.152	-.071	-.086	.108	.078	-.001	.171
	Sig. (2-tailed	.212	.396	.641	.947		.568	.292	.626	.551	.454	.592	.994	.236
Food Storage medium	Correlation	.581**	-.43**	.314*	.306*	-.083	1.000	.241	.500**	.409**	.680**	.466**	.075	.249
	Sig. (2-tailed	.000	.002	.026	.030	.568		.092	.000	.003	.000	.001	.603	.081
Washing & Ironing	Correlation	.225	.030	.231	.228	-.152	.241	1.000	.101	.048	.127	.006	.221	.044
	Sig. (2-tailed	.116	.835	.107	.111	.292	.092		.486	.741	.381	.968	.122	.764
Ventilation Systems	Correlation	.877**	-.67**	.261	.546**	-.071	.500**	.101	1.000	.386**	.309*	.538**	-.200	.228
	Sig. (2-tailed	.000	.000	.067	.000	.626	.000	.486		.006	.029	.000	.164	.112
Other Equipment	Correlation	.509**	-.216	.151	.315*	-.086	.409**	.048	.386**	1.000	.139	.288*	-.259	.121
	Sig. (2-tailed	.000	.131	.296	.026	.551	.003	.741	.006		.337	.042	.070	.401
No of Members	Correlation	.434**	-.091	.333*	.376**	.108	.680**	.127	.309*	.139	1.000	.412**	.304*	.202
	Sig. (2-tailed	.002	.531	.018	.007	.454	.000	.381	.029	.337		.003	.032	.159
Floor Area (sq ft)	Correlation	.567**	-.28*	.093	.362**	.078	.466**	.006	.538**	.288*	.412**	1.000	.159	.590**
	Sig. (2-tailed)	.000	.048	.520	.010	.592	.001	.968	.000	.042	.003		.270	.000
Age of the Unit (yrs)	Correlation	-.140	.204	.173	-.078	-.001	.075	.221	-.200	-.259	.304*	.159	1.000	.233
	Sig. (2-tailed)	.331	.156	.228	.592	.994	.603	.122	.164	.070	.032	.270		.104
Land Area	Correlation	.316*	.003	.102	.303*	.171	.249	.044	.228	.121	.202	.590**	.233	1.000
	Sig. (2-tailed)	.025	.984	.479	.032	.236	.081	.764	.112	.401	.159	.000	.104	

Appendix G: Correlation of General Data with Electricity Consumption for 50 Domestic Units in Colombo District

		Total (KWh/month)	Comfort AC/FAN	Income Level (Rs)	Incandescent Users	CFL Users	LED Users	Window State	Shade Level
Total (KWh/month)	Correlation	1	-.838**	.838**	-.661**	.090	.540**	.229	.078
	Sig. (2-tailed)		.000	.000	.000	.534	.000	.109	.590
	N	50	50	50	50	50	50	50	50
Comfort AC/FAN	Pearson Correlation	-.838**	1	-1.000**	.736**	-.168	-.632**	-.183	-.024
	Sig. (2-tailed)	.000		.000	.000	.244	.000	.204	.869
	N	50	50	50	50	50	50	50	50
Income Level (Rs)	Pearson Correlation	.838**	-1.000**	1	-.736**	.168	.632**	.183	.024
	Sig. (2-tailed)	.000	.000		.000	.244	.000	.204	.869
	N	50	50	50	50	50	50	50	50
Incandescent Users	Pearson Correlation	-.661**	.736**	-.736**	1	-.137	-.487**	-.035	.055
	Sig. (2-tailed)	.000	.000	.000		.342	.000	.807	.705
	N	50	50	50	50	50	50	50	50
CFL Users	Pearson Correlation	.090	-.168	.168	-.137	1	.208	.127	-.196
	Sig. (2-tailed)	.534	.244	.244	.342		.147	.381	.172
	N	50	50	50	50	50	50	50	50
LED Users	Pearson Correlation	.540**	-.632**	.632**	-.487**	.208	1	.176	-.101
	Sig. (2-tailed)	.000	.000	.000	.000	.147		.221	.486
	N	50	50	50	50	50	50	50	50
Window State	Pearson Correlation	.229	-.183	.183	-.035	.127	.176	1	.097
	Sig. (2-tailed)	.109	.204	.204	.807	.381	.221		.501
	N	50	50	50	50	50	50	50	50
Shade Level	Pearson Correlation	.078	-.024	.024	.055	-.196	-.101	.097	1
	Sig. (2-tailed)	.590	.869	.869	.705	.172	.486	.501	
	N	50	50	50	50	50	50	50	50

**. Correlation is significant at the 0.01 level (2-tailed).

			Total (KWh/month)	Comfort AC/FAN	Income Level (Rs)	Incandescent Users	CFL Users	LED Users	Window State	Shade Level
Kendall's tau_b	Total (KWh/month)	Correlation Coefficient	1.000	-.705**	.705**	-.565**	.073	.444**	.185	.116
		Sig. (2-tailed)	.	.000	.000	.000	.533	.000	.116	.307
		N	50	50	50	50	50	50	50	50
	Comfort AC/FAN	Correlation Coefficient	-.705**	1.000	-1.00**	.736**	-.168	-.632**	-.183	-.031
		Sig. (2-tailed)	.000	.	.	.000	.240	.000	.201	.822
		N	50	50	50	50	50	50	50	50
	Income Level (Rs)	Correlation Coefficient	.705**	-1.00**	1.000	-.736**	.168	.632**	.183	.031
		Sig. (2-tailed)	.000	.	.	.000	.240	.000	.201	.822
		N	50	50	50	50	50	50	50	50
	Incandescent Users	Correlation Coefficient	-.565**	.736**	-.736**	1.000	-.137	-.487**	-.035	.055
		Sig. (2-tailed)	.000	.000	.000	.	.337	.001	.804	.689
		N	50	50	50	50	50	50	50	50
	CFL Users	Correlation Coefficient	.073	-.168	.168	-.137	1.000	.208	.127	-.197
		Sig. (2-tailed)	.533	.240	.240	.337	.	.145	.375	.153
		N	50	50	50	50	50	50	50	50
	LED Users	Correlation Coefficient	.444**	-.632**	.632**	-.487**	.208	1.000	.176	-.092
		Sig. (2-tailed)	.000	.000	.000	.001	.145	.	.217	.504
		N	50	50	50	50	50	50	50	50
	Window State	Correlation Coefficient	.185	-.183	.183	-.035	.127	.176	1.000	.092
		Sig. (2-tailed)	.116	.201	.201	.804	.375	.217	.	.501
		N	50	50	50	50	50	50	50	50
	hade evel	Correlation Coefficient	.116	-.031	.031	.055	-.197	-.092	.092	1.00
		Sig. (2-tailed)	.307	.822	.822	.689	.153	.504	.501	.
		N	50	50	50	50	50	50	50	50
Spearman's rho	Total (KWh/month)	Correlation Coefficient	1.000	-.855**	.855**	-.685**	.089	.538**	.225	.144
		Sig. (2-tailed)	.	.000	.000	.000	.538	.000	.117	.320
		N	50	50	50	50	50	50	50	50
	Comfort AC/FAN	Correlation Coefficient	-.855**	1.000	-1.00**	.736**	-.168	-.632**	-.183	-.032

		Sig. (2-tailed)	.000	.	.	.000	.244	.000	.204	.824
		N	50	50	50	50	50	50	50	50
	Income Level (Rs)	Correlation Coefficient	.855**	-1.00**	1.000	-.736**	.168	.632**	.183	.032
		Sig. (2-tailed)	.000	.	.	.000	.244	.000	.204	.824
		N	50	50	50	50	50	50	50	50
	Incandescent Users	Correlation Coefficient	-.685**	.736**	-.736**	1.000	-.137	-.487**	-.035	.057
		Sig. (2-tailed)	.000	.000	.000	.	.342	.000	.807	.693
		N	50	50	50	50	50	50	50	50
	CFL Users	Correlation Coefficient	.089	-.168	.168	-.137	1.00	.208	.127	-.204
		Sig. (2-tailed)	.538	.244	.244	.342	.	.147	.381	.155
		N	50	50	50	50	50	50	50	50
	LED Users	Correlation Coefficient	.538**	-.632**	.632**	-.487**	.208	1.000	.176	-.095
		Sig. (2-tailed)	.000	.000	.000	.000	.147	.	.221	.510
		N	50	50	50	50	50	50	50	50
	Window State	Correlation Coefficient	.225	-.183	.183	-.035	.127	.176	1.00	.096
		Sig. (2-tailed)	.117	.204	.204	.807	.381	.221	.	.507
		N	50	50	50	50	50	50	50	50
	Shade Level	Correlation Coefficient	.144	-.032	.032	.057	-.204	-.095	.096	1.00
		Sig. (2-tailed)	.320	.824	.824	.693	.155	.510	.507	.
		N	50	50	50	50	50	50	50	50

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix H: Standard Maintained Illuminance; (Source: CIBSE: Code of Interior Lighting, 1994)

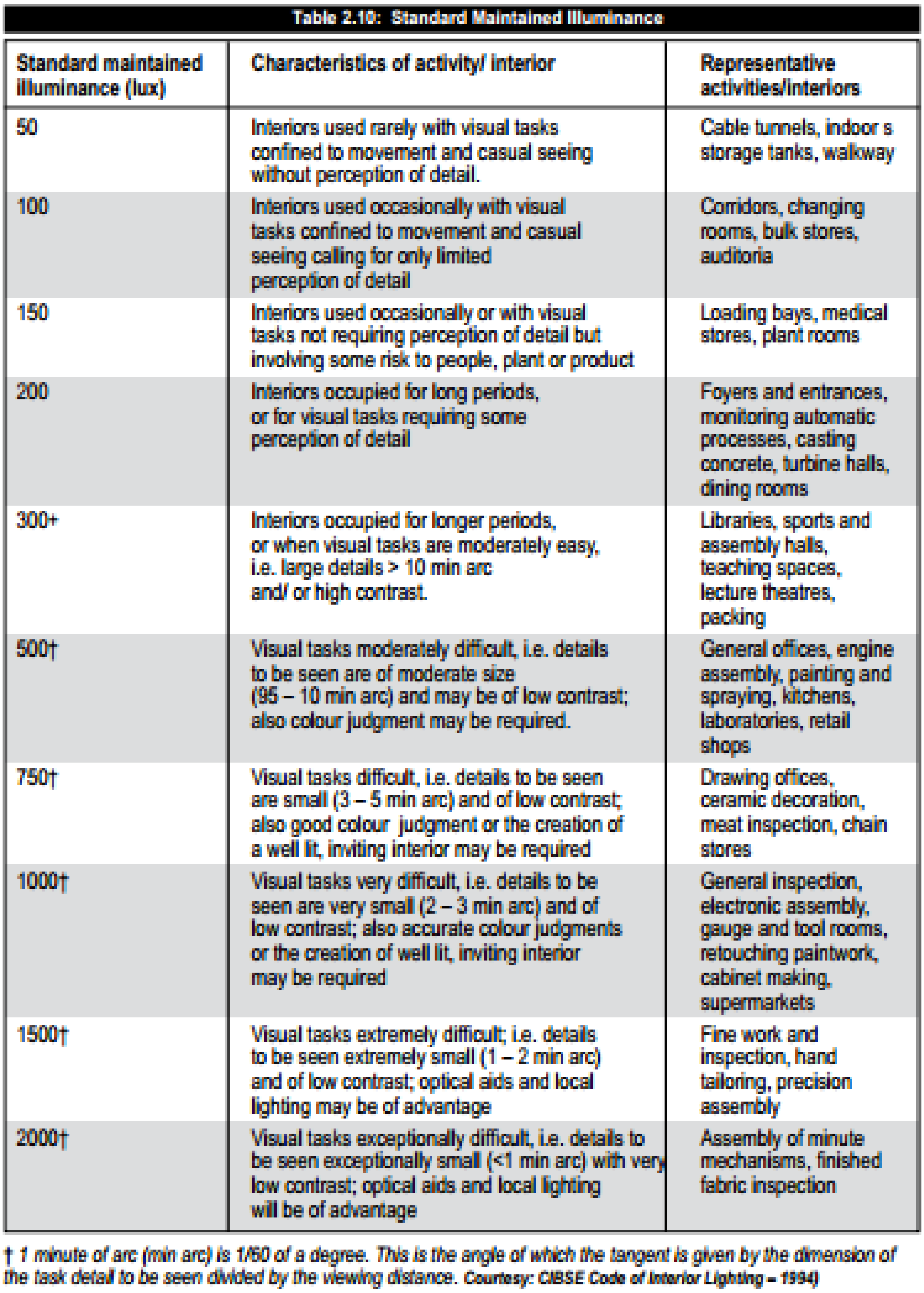

Table 2.10: Standard Maintained Illuminance

Standard maintained illuminance (lux)	Characteristics of activity/ interior	Representative activities/interiors
50	Interiors used rarely with visual tasks confined to movement and casual seeing without perception of detail.	Cable tunnels, indoor s storage tanks, walkway
100	Interiors used occasionally with visual tasks confined to movement and casual seeing calling for only limited perception of detail	Corridors, changing rooms, bulk stores, auditoria
150	Interiors used occasionally or with visual tasks not requiring perception of detail but involving some risk to people, plant or product	Loading bays, medical stores, plant rooms
200	Interiors occupied for long periods, or for visual tasks requiring some perception of detail	Foyers and entrances, monitoring automatic processes, casting concrete, turbine halls, dining rooms
300+	Interiors occupied for longer periods, or when visual tasks are moderately easy, i.e. large details > 10 min arc and/ or high contrast.	Libraries, sports and assembly halls, teaching spaces, lecture theatres, packing
500†	Visual tasks moderately difficult, i.e. details to be seen are of moderate size (95 – 10 min arc) and may be of low contrast; also colour judgment may be required.	General offices, engine assembly, painting and spraying, kitchens, laboratories, retail shops
750†	Visual tasks difficult, i.e. details to be seen are small (3 – 5 min arc) and of low contrast; also good colour judgment or the creation of a well lit, inviting interior may be required	Drawing offices, ceramic decoration, meat inspection, chain stores
1000†	Visual tasks very difficult, i.e. details to be seen are very small (2 – 3 min arc) and of low contrast; also accurate colour judgments or the creation of well lit, inviting interior may be required	General inspection, electronic assembly, gauge and tool rooms, retouching paintwork, cabinet making, supermarkets
1500†	Visual tasks extremely difficult; i.e. details to be seen extremely small (1 – 2 min arc) and of low contrast; optical aids and local lighting may be of advantage	Fine work and inspection, hand tailoring, precision assembly
2000†	Visual tasks exceptionally difficult, i.e. details to be seen exceptionally small (<1 min arc) with very low contrast; optical aids and local lighting will be of advantage	Assembly of minute mechanisms, finished fabric inspection

† 1 minute of arc (min arc) is 1/60 of a degree. This is the angle of which the tangent is given by the dimension of the task detail to be seen divided by the viewing distance. **Courtesy: CIBSE Code of Interior Lighting – 1994)**