A CASE BASED APPROACH TO BENCHMARK THE ENERGY AND WATER CONSUMPTION OF SUPERMARKETS IN SRI LANKA

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ABSTRACT

Buildings are responsible for about 40% of global energy consumption, 42% of global CO_2 emissions and about 30% of global fresh water consumption. Therefore, the importance of energy and water consumption benchmarking in buildings has become a major objective for governments and relevant authorities. Since energy and water consumption patterns depend upon various factors such as climate conditions, personal habits, hygiene practices and economic factors, it is most suitable to develop local benchmarks for countries/regions instead of using global benchmarks to compare the performance of the buildings. The main intention of this research is to analyse the major research gaps in energy and water benchmarking in Sri Lankan buildings, and to develop water and energy benchmarks to bridge those gaps. Energy consumption benchmarks in Sri Lankan context are available for commercial sector, hospitality industry, apparel industry and tea processing industry, which are established by Sri Lanka Sustainable Energy Authority (SLSEA). However, energy benchmarks are not available in local context for retail (supermarkets), educational, healthcare and residential building sectors. Moreover, it is identified that, water consumption benchmarking is a major research gap in Sri Lanka, as the water consumption benchmarks have been developed only for hospitality sector. The focus of this study is to establish the energy and water benchmarks for retail sector (supermarkets) in Sri Lanka.

During the study, electricity consumption data from 2008 to 2020, and water consumption data from 2018 to 2020 were collected from 101 supermarkets across the country. Annual electricity consumption, annual electricity cost and annual water consumption of these 101 supermarkets were analysed against the sales floor areas and total floor areas of the relevant supermarkets. According to the analysis, electricity consumption benchmarks for Sri Lankan supermarkets was estimated as 780 kWh/year/m^2 per sales floor area and 465 kWh/year/m^2 per total floor area. Moreover, the water consumption benchmarks was estimated for the Sri Lankan supermarkets as 247 L/year/ m^2 per sales floor area and 137 L/year/ m^2 per total floor area.

Keywords: Energy benchmarking, Water benchmarking, Energy consumption, Retail sector, Supermarket

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LIST OF ABBREVIATIONS

Abbreviation	Description
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BREEAM	Building Research Establishment Environmental Assessment Method
CCTV	Closed-Circuit Television
CIBSE	Chartered Institution of Building Services Engineers
CTC	Crush, Tear, Curl
ELV	Extra Low Voltage
EUI	Energy Use Intensity
FCU	Fan Coil Unit
GBCSL	Green Building Council Sri Lanka
HFO	Heavy Fuel Oil
HVAC	Heating, Ventilation and Air Conditioning
ICU	Intensive Care Unit
IHEI	International Hotels Environmental Initiative
LEED	Leadership in Energy and Environmental Design
LPG	Liquid Petroleum Gas
M&E	Mechanical & Electrical
MATV	Master Antenna Television
MVAC	Mechanical Ventilation and Air Conditioning
NWSDB	National Water Supply and Drainage Board
SFA	Sales Floor Area
SLSEA	Sri Lanka Sustainable Energy Authority
SLTDA	Sri Lanka Tourism Development Authority
SMV	Standard Minute Value
TFA	Total Floor Area
VRF	Variable Refrigerant Flow
WEI	Water Efficiency Index

CHAPTER 1

1.0 INTRODUCTION

During last 30 years, building operations have been identified as one of the most prominent ways of consuming energy and water around the globe. It has become a major concern for governments and various institutions to optimize building operations so that they consume less energy and water, and reduce the impact on global warming, climate change and resource depletion. Since more than 80% of the world energy usage are still covered by non-renewable sources [1], it is extremely important to optimize the energy consumption of buildings. Same scenario applies to water, since there is less than 1% of water usable to humans [2].

In order to analyse and optimize the building energy and water consumption, it is vital to evaluate the building performances with respect to the established benchmarks. Various authorities and institutions have developed many energy and water benchmarks for different types of buildings, which can be applied globally. However, it is important to develop benchmarks for building consumption in Sri Lankan context, as energy and water consumption patterns in buildings vary from region to region and country to country. In addition, these benchmarking figures need to be updated on yearly or other reasonable basis, as the global energy policies and standards are getting more and more stringent each year.

Although there are many studies have been carried out on building energy and water consumption benchmarking in Sri Lanka, there is no official body to monitor whether the buildings actually perform better or worse than the established benchmarks.

Therefore, following specific questions are needed to be addressed regarding the benchmarking of building consumptions.

1. What are the current benchmarks developed in Sri Lanka for Energy and Water consumption of different types of buildings?
2. What percentage of buildings perform better than the benchmarks?

3. What are the reasons for buildings to perform below than the benchmarks?
4. What are the measures that can be implemented to improve the poorly performing buildings?
5. What type of buildings do not have benchmarks?

Hence, this research work is designed to address the above research gaps in Energy and Water consumption patterns and benchmarks in various building types in Sri Lanka.

Chapter 2 of this thesis is dedicated to understand the current energy and water benchmarks in Sri Lanka and other regions around the world. First, buildings classification is discussed, as there are several major categories depending on building functional usage. then the energy and water consumption patterns and end-uses are discussed for each of these building types. In addition, currently available benchmarks for energy and water usage for these building types are discussed, and the local and international benchmarks were compared.

Chapter 3 explains the methodology of the research study, including data collection procedure, analysis of collected data and building energy modelling. Analyzed parameters include specific electricity consumption, specific electricity cost and specific water consumption.

Chapter 4 illustrates the results of the analysis done in the previous chapter. Results include the estimated electricity consumption benchmarks, electricity cost benchmarks and water consumption benchmarks. All these benchmarks were developed in terms of total floor area and sales floor area, as both these methods are used internationally. In addition, results include the outcomes of energy simulation, which was performed for a supermarket.

Chapter 5 discusses the results obtained in Chapter 4. Results of this research study are compared with the available international benchmarks that are being used in other countries. Moreover, simulated results are compared with the already established electricity consuming patterns. Similarities and differences of electricity consumption patterns between supermarkets in Sri Lanka and other countries are also discussed.

Chapter 6 discusses the major conclusions of the research.

1.1 Aim

To develop energy and water consumption benchmarks for retail supermarket buildings in Sri Lanka.

1.2 Objectives

1. To study the local and international energy and water consumption benchmarks for different types of buildings.
2. To quantify and establish the energy and water benchmarking in retail supermarket buildings in Sri Lanka.
3. To compare the established benchmarks with the international benchmarks for retail supermarkets.

1.3 Methodology

Objective 1:

- Identifying different energy and water consumption end-uses and usage patterns in different types of buildings.
- Identifying the available local and international energy and water benchmarks for different types of buildings.
- Studying the available benchmarking strategies for energy and water benchmarking.

Objective 2:

- Collection of energy and water consumption data of main retail supermarket operators in the country.
- Analysing the collected data.
- Performing a building energy simulation to analyse the electricity consumption breakdown of supermarkets.

Objective 3:

- Validating the energy simulation results by comparing with actual data.
- Developing benchmarks for energy and water consumption.
- Comparison of developed benchmarks with internationally established benchmarks.

CHAPTER 2

2. ENERGY AND WATER BENCHMARKING OF THE BUILDINGS

A literature review was carried out to review the local and international building energy and water benchmarks available for different types of buildings. Several major building types were identified during the literature review. Available local benchmarks for energy and water consumption were reviewed for each building type, and compared with the globally established benchmarks. In addition, different energy end-usage patterns and water end-usage patterns were also analyzed for the identified building types. This chapter outlines the major findings of the literature review.

2.1 Building Classification

Buildings are classified in to several types. It is also noteworthy that, some buildings fall into several categories instead of a specific type. Those buildings have been categorized into the best fit category, depending upon their functional usage.

2.1.1 Commercial Buildings

Commercial buildings are defined as buildings that are utilized for commercial purposes [3]. These commercial purposes can be either direct businesses or indirect type profit making businesses. According to this definition, the building types categorized as commercial buildings are office buildings, shops and shopping malls, fuel/gas stations, rented residential buildings, hotels, motels and restaurants.

In Sri Lankan context; shops, shopping malls, restaurants and fuel/gas stations are best categorized into the retail building category. Similarly, hotels and motels are best categorized into the hospitality building category. Therefore, in this study, only office buildings in Sri Lanka are considered under commercial building category.

2.1.2 Retail Buildings

Retail Store refers to individual stores used to conduct the retail sale of food or non-food consumer goods [3]. As mentioned above, most common and popular types of retail buildings in the country are shopping malls, restaurants and filling/fuel/gas stations. In section 2.4, energy and water usage patterns and benchmarking strategies are discussed for retail buildings.

2.1.3 Hospitality Buildings

Hospitality buildings are the buildings that facilitate hospitality industry, such as hotels, motels and other types of facilities, i.e. lodging, meals. Energy and Water consumption benchmarking in hospitality sector is extremely important as this sector is expected to compromise the efficiency and sustainability factors for enhanced guest comfort. However, there are ample opportunities in terms of energy efficiency, water efficiency and sustainability initiatives, as there are lots of energy and water consumption end-uses in these types of buildings. Sections 2.5 discusses how to identify these opportunities and develop benchmarks for energy and water consumption, so that these buildings can be compared with international standards.

2.1.4 Educational Buildings

Educational buildings can be defined as the buildings that are designed for various activities in a primary, secondary, or higher educational system and often including living areas for students, such as dormitories. In Sri Lankan context, Primary and Secondary schools may have a similar Energy and Water consumption patterns. Higher Educational Institutes (HEIs) may have higher consumptions compared to the other two, as they have larger laboratories, machineries, air-conditioned seminar rooms and student hostel facilities. Factors affecting energy and water consumptions of educational buildings were discussed in Section 2.6, along with the suitable benchmarking techniques.

2.1.5 Industrial Manufacturing Buildings

Industrial Manufacturing Buildings can be defined as buildings that are designed to facilitate the manufacturing process of products or components using various processes and machineries. Apparel manufacturing facilities, and Tea processing facilities can be considered as major industrial manufacturing processes in Sri Lanka. In addition, there are other industries such as rubber and coconut-based product manufacturing, spices and oils, food & beverages and jewelries manufacturing. This literature review was focused on Apparel and Tea industries, since those are the most prominent Energy and Water consuming industries in Sri Lanka.

2.1.6 Healthcare Buildings

Healthcare buildings have been designed to provide healthcare facilities to patients who are both external visitors and residents. Comparing with the other building types, healthcare buildings have the most complex operational requirements with many vital services such as oxygen supplies and precision air conditioning at ICUs'. Since healthcare industry is supposed to compromise sustainability for patient's health and wellbeing, benchmarking energy and water consumption can be very challenging. Section 2.9 has discussed the consumption patterns and benchmarking approaches of healthcare buildings.

2.1.7 Residential Buildings

Single Family Home refers to a standalone building with its own lot that provides living space for one household or family. Multifamily Housing refers to residential properties that contain two or more residential living units [3]. Rather than discussing the consumptions of individual households alone, it is more suitable to discuss the energy and water consumption of apartment sector, as high rise and mid-rise apartments are becoming much more popular in Sri Lanka. Section 2.10 has discussed the consumption patterns and benchmarking strategies for Energy and Water usage of apartment sector.

2.2 Benchmarking Techniques

There are four major techniques for benchmarking which are "Statistical analysis benchmarking", "Points-based rating systems", "Simulation model-based benchmarking" and "Hierarchical and end-use metrics" [4].

2.2.1 Statistical analysis method

This method consists of collecting actual consumption data from buildings and comparing with similar types of other buildings. This allows benchmarking using real data and compare the building performances with respect to the developed benchmark. However, these benchmarks tend to change over time, if the research teams keep collecting real time consumption data. Since most of the new building projects tend to implement energy efficiency measures and renewable energy systems, statistically developed benchmarks appear to become stringent with the time [4].

2.2.2 Points-based rating systems

Points-based rating systems use already well-established standards to set up benchmarks to evaluate building performance, instead of comparing with the other buildings. Most widely used point-based rating systems such as "Leadership in Energy & Environmental Design" (LEED) developed by US Green Building Council, uses ASHRAE 90.1 energy standard to specify the benchmark figures and develop a baseline building against which the actual building can be compared [4]. Upon the number of points the designed building receives, it can be compared with respect to the benchmark set up by the rating system.

2.2.3 Simulation model-based benchmarking

This method uses mathematical models developed by simulation programs to set up a theoretical consumption benchmark. This allows researchers to identify the significance of various parameters combined with the building energy consumption and come up with the best solutions with the model. Then it allows to compare between the theoretical model results and real results obtained from buildings to verify the energy efficiency implementations and savings [4].

2.2.4 Hierarchical and end-use metrics

These metrics uses climate, building envelope and operational factors to determine the energy efficiency measures, and thereby develop the benchmarks. Studies on parameters related to energy efficiency such as window-to-wall ratio, shading coefficient, thermal transmittance, and overall heat transfer coefficient have been carried out by various research teams using this method [4].

2.3 Energy and Water Benchmarking of Commercial Buildings

As explained in Section 2.1.1, office buildings will be analyzed under commercial building category. In Sri Lanka, the office buildings span from single story, low rise, mid-rise to high-rise buildings. These buildings are supplied with National electricity grid as their main and only energy source, with backup power generation options. Other energy sources such as diesel or coal are not used in commercial office buildings, as steam or hot water generation for space heating is not required in Sri Lankan context due to the warm climatic conditions. In most of the cases, use of renewable sources depend upon the building owner. Solar PV is the most common renewable source used in commercial buildings in Sri Lanka.

Municipal water supply with in-house storage is used as the primary water source for the commercial buildings. Other sources such as ground water/well water is not utilized by the commercial buildings due to the space and operational restrictions. Almost all of the commercial office buildings use municipal water supply for sanitary and cleaning purposes, while drinking water is purchased from a different supplier.

2.3.1 Energy Usage Patterns of Commercial Buildings

Lighting accounts for 10-20% of the total electricity consumption of the commercial buildings [5]. Lighting level required for office workstations is 300-500 lux [6], while the common areas and car parking areas require 100-200 lux for proper functioning. In addition, lighting power density is maintained at 8.61-11.84 W/m^2 in the commercial buildings in Sri Lanka. Since the majority of the commercial buildings in Sri Lanka operate in the daytime (8 am to 5 pm operating hours), adaptation of daylight harvesting techniques have been prominent in the past decade. In addition, phasing out CFL and T8 lights and adopting to T5 and LED technologies have shown significant energy saving potential.

Due to the warm climatic conditions in Sri Lanka, majority of the commercial buildings operate air conditioning equipment to maintain thermal comfort inside the building. Therefore, air conditioning and ventilation accounts for 45-50% of the total electricity consumption of the commercial buildings [7]. Depending upon the net conditioned floor area, MVAC system types can be either centralized systems or VRF or single/multi-split AC units.

In the case of VRF, multi-split or single split systems, 45-50% of total electricity will be consumed by the air conditioning system for cooling purpose. In centralized MVAC systems, about 35% of total electricity will be consumed by central cooling equipment (chillers), while 5-10% of electricity will be consumed by pumps. In addition, cooling towers and ventilation fans will also consume around 10% of the total building electricity consumption. In combination, the system will ultimately account for 45-50% of building electricity consumption.

In addition, receptacle loads account for about 20% of the total electricity consumption of commercial buildings. This portion consists of office equipment such as computers, printers, photo copiers and other plug loads such as mobile phones and laptops.

Apart from the major energy end-uses, there are other loads such as Elevators, plumbing system pumps, Fire protection system pumps and other extra low voltage (ELV) systems such as CCTV and Fire detection systems These will account for 10-15% of the total building electrical consumption.

Aforementioned breakdown is illustrated in Figure 1. It is important to note that the percentages will change within the above discussed ranges depending upon the building total floor area and installed system types.

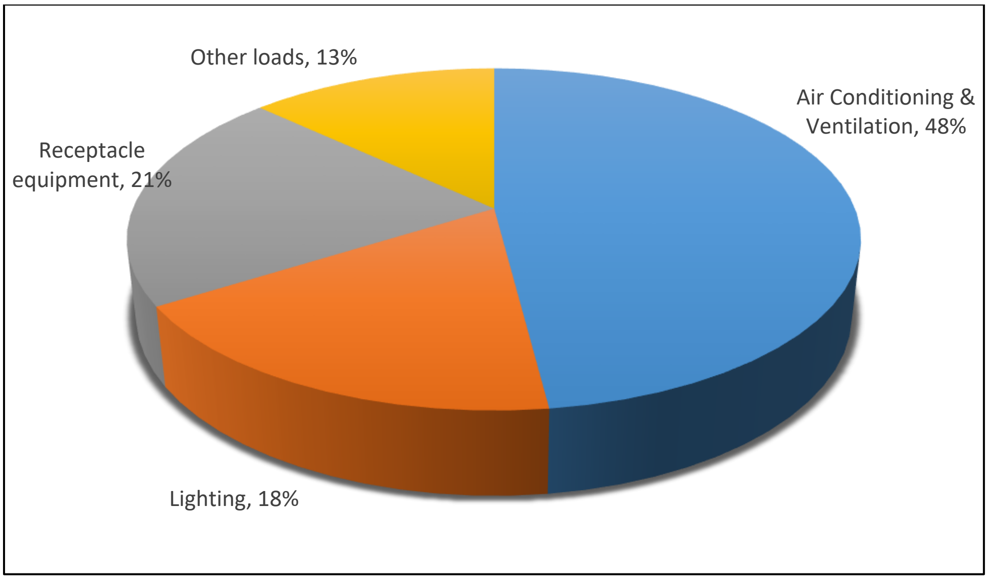

Figure 1: Electricity usage breakdown of commercial buildings *[7]*

2.3.2 Energy Usage Benchmarking of Commercial Buildings

In order to analyze and benchmark the energy consumption of commercial buildings, it is important to study the energy usage indicators and already developed benchmarking figures by various authorities. One of the most commonly used indicators that can appropriately illustrate the energy usage of commercial buildings is Energy Use Intensity (EUI) [8]. This is expressed as the annual energy consumption per unit area of the building. Countries that use imperial units tend to use "kWh/year/ft^2" to indicate EUI, while metric system use "kWh/year/m^2". Certain British standards sometimes use BTU (British thermal units) instead of kWh to express the EUI. This indicator gives a specific energy consumption value for a given building, and it allows to compare with other buildings and rate buildings in terms of energy consumption. In addition, per person consumption is also used as an energy usage indicator. This is expressed as either "kWh/year/person" or "BTU/year/person". Per person energy consumption indicates the impact of people towards the building energy consumption. However, this figure depends on the number of occupants in the building. A lesser number of occupants can imply a larger "per person" energy consumption compared to the other buildings. According to the "Energy Consumption Benchmark Analysis" published by Sri Lanka Sustainable Energy Authority, commercial buildings consume about 8% of the total building electricity consumption [9]. The study has analyzed electricity consumption data gathered from 2012 to 2016 at 27 commercial buildings, and came up with a benchmark of 136.55 kWh/m2/year. Apart from this, there are many energy audits that have been conducted in various office buildings by different institutions.

Table *1* illustrates the different electricity consumption figures obtained in these audits and performance compared with the SLSEA benchmark.

Table 1: Specific consumptions obtained by energy audits *[9]*

Primary Building function	**Tariff Category**	**Specific consumptions obtained through energy audits (kWh/year/m^2)**	**SLSEA benchmark**
Commercial office	GP1	150.69	136.55
Commercial office	GP2	132.15	
Commercial office	GP3	226.50	

2.3.3 Water Usage Patterns of Commercial Buildings

Water usage patterns and usage breakdowns depend on the water consuming systems installed in different office buildings. In water cooled air conditioning systems, significant portion of the building water consumption will be dedicated for cooling towers. Since cooling towers work on the evaporative cooling principle, 30-35% of the building water consumption is required to make-up for that evaporated water volume [10]. Although there are ample research going on to explore the usability of reclaimed water for cooling tower make-up, water quality is a big concern for building operators. Therefore, most of the buildings use potable water for this purpose.

Toilets accounts for a significant portion of office building water consumption. If the building has water cooled HVAC systems, toilet flushing accounts for 35-40% of the total water consumption, which is a similar percentage to the air conditioning. But, when the building is not equipped with the water-cooled HVAC systems, toilet flushing becomes the major water end-use. In this scenario, flushing will account for 65-70% of the total building water consumption [11]. However, there is a huge potential to achieve significant water savings in this category. Different technologies have been developed in recent years, such as low flow dual flush closets and using reclaimed water for flushing. Majority of the building operators are keen on these measures as it can cut down a considerable percentage of water cost.

Lavatory and Kitchen faucets account for about 15% of the total water consumption in office buildings. This 15% permits for ample opportunities for water savings, as most of the building operators tend to install low flow faucets and devices such as aerators and sensor operated taps in order to achieve those savings.

Urinals and Bidets account for 2-4% of the total building water consumption. Although the percentage is quite lower, bidet water consumption is one of the major differences in terms of water usage in Sri Lankan context, compared to the other regions and standards. Water saving technologies have been developed in recent years to save water in urinals, such as low flow urinals and water-less urinals. Apart from above discussed end-uses, cleaning of toilets, pantries and office floors consume about 5-10% of total water consumption of office buildings. This percentage is reflected in all kinds of office buildings in Sri Lanka, since hygiene is an important factor in Sri Lankan context. Other uses such as irrigation for landscape, fire protection, vehicle washing and water features account up to 5% of the total building water consumption.

All the above discussed end-uses are illustrated in Figure 2. It is important to note that, drinking water consumption has not been included in this breakdown, as majority of the office buildings purchases bottled drinking water from external suppliers.

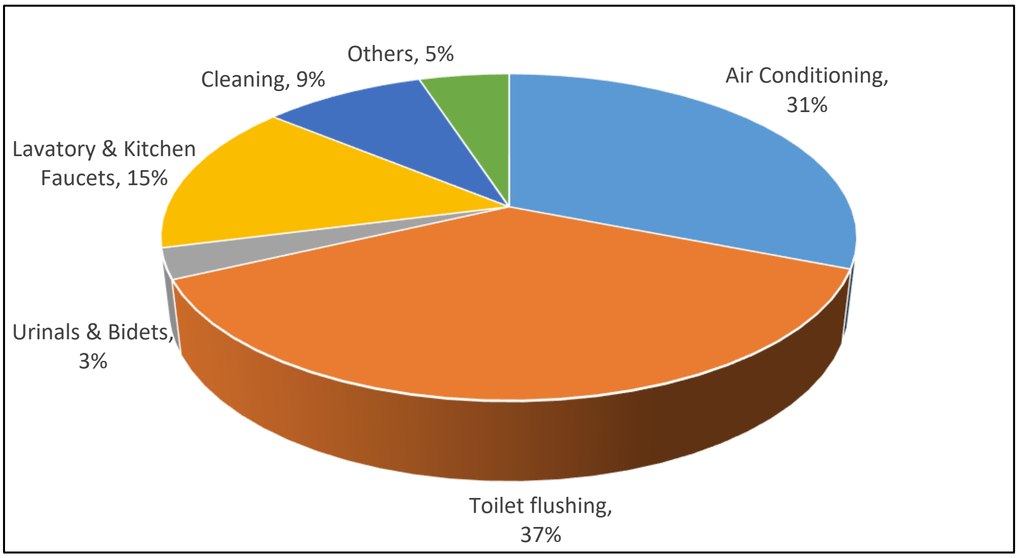

Figure 2: Water use breakdown of commercial buildings *[10]*

2.3.4 Water Usage Benchmarking of Commercial Buildings

Unlike energy, water usage benchmarking is not an area that has been studied widely in Sri Lanka. It can be due to the adequate availability of natural water resources in the country. However, it is important to study and develop the benchmarking factors for water consumption, in order to preserve the resources. Most frequently used water usage indicators are "Liters/year" or "m^3/year". US standards often use "Gallons/year" as the water usage indicator [12]. However, these indicators do not clearly indicate a specific water consumption, so that it is difficult to compare buildings with each other.

In certain countries, the water usage is defined in terms of "Water Efficiency Index (WEI)" which is measured in "m^3/m^2 of floor area/year". This unit allows comparison of water usage between similar types of buildings and understand the building performance clearly with respect to established benchmarks.

Most of the established sustainable certification systems tend to specify the benchmark water consumptions in terms of the fixture flow rates, instead of providing a single figure for the total building. For example, GreenSL certification system developed by Green Building Council of Sri Lanka (GBCSL) specifies the baseline flowrates for the different plumbing fixtures that are being installed in commercial buildings. Similar baseline is widely used in the LEED rating system as well. Table 2 illustrates the comparison of these two benchmarks.

Table 2: GreenSL and LEED water usage benchmarks for commercial buildings

Fixture or Fitting	**GreenSL Baseline** [13]	**LEED Baseline** [12]
Commercial Toilet (WC)	6 lpf[1]	6 lpf[1]
Commercial Urinal	4 lpf[1]	3.8 lpf[1]
Public Lavatory faucet	2 lpm[2] @ 4 bar 1 liter per cycle for metering faucets	1.9 lpm[2] @ 4.15 bar

[1]Liters per flush
[2]Liters per minute

Although there is very limited information available for water usage benchmarking in Sri Lankan context, many studies have been conducted regarding this topic in global scale. Table 3 shows the office building benchmarks for water consumption in different countries.

Table 3: Water usage benchmarks for office buildings, developed for other countries

Country	Benchmark (m^3/m^2/year)
Singapore [14]	1.00
UK [15]	0.60
New Zealand [15]	1.03
USA [15]	1.59
Australia [15]	1.21

2.4 Energy and Water Benchmarking of Retail Buildings

Retail buildings can be categorized into two major groups, which are food retail buildings and non-food retail buildings. Electricity from national grid is the main energy source of the majority of the retail buildings in Sri Lanka. In addition, food retail buildings use LPG for cooking purposes. Similarly, municipal supplied water is the main water source for the majority of the retail buildings in the country, often with a storage maintained at the premises. Pipe borne water is used for sanitary, cooking and cleaning purposes of the retail buildings. Drinking water is either taken from the same source and further treated, or purchased through a drinking water supplier. In certain areas, filling fuel/gas stations may use ground water for washing and cleaning purposes, in addition to the pipe borne water.

2.4.1 Energy Usage Patterns of Retail Buildings

As mentioned above, non-food retail buildings such as filling fuel/gas stations use electricity to fulfil their energy requirements. However, food retail buildings consume 80-85% electricity and 15-20% LPG to cater the energy requirements. Figure 3 illustrates the energy usage breakdown for food retail buildings.

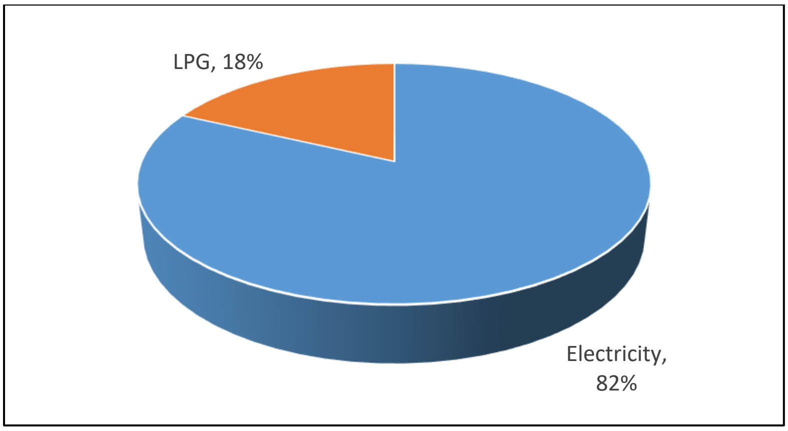

Figure 3: Energy usage breakdown for food retail buildings *[16]*

LPG requirement will be entirely used for the cooking purpose in food retailers. However, electricity consumption can be broken down into multiple end-uses.

Refrigeration accounts for 40-45% of the total building electricity consumption of food retailers [16]. This is due to the high energy demand required for chilling and freezing food items. Different equipment such as meat freezers, fruit & vegetable chillers, beverage chillers and general refrigerators will contribute to this percentage.

Lighting is another major electricity end-use in retail buildings. In non-food retail buildings, lighting accounts for about 50% of the total electricity consumption of the building [16]. This is a significantly higher percentage compared to the office buildings, as most of the retail buildings are open until 10 pm. Another reason for this is, retail stores require a higher lighting level, which are in between 500-1,000 lux depending upon the retail items and scale of the building [6].

In food retail buildings, lighting accounts for 15-20% of the total electricity consumption [16]. Although food retail building operating times are similar to non-food retail buildings, percentage for lighting is lower due to other significant end-uses such as refrigeration. Air conditioning & ventilation systems are present in retail buildings such as shopping malls and restaurants. Most of the small-scale restaurants have single-split or VRF systems installed, while large shopping malls may have large VRF systems or centralized chilled water systems depending upon the building size. Irrespective of the system type, MVAC systems will account for 35-45% in non-food retail buildings, and 20-30% in food retail buildings.

Receptacle and other loads consist of computers, cash registers, water supply pumps, fire protection system pumps and extra low voltage (ELV) systems such as CCTV and Fire detection systems. These loads will account for 10-15% in both food retailers and non-food retailers. However, in places like filling fuel/gas stations, pumping energy can go up to 40-45%, as there is no significant consumption for MVAC or refrigeration.

Figure 4 and Figure 5 illustrate the above discussed percentage electricity end-uses in food retail and non-food retail buildings respectively.

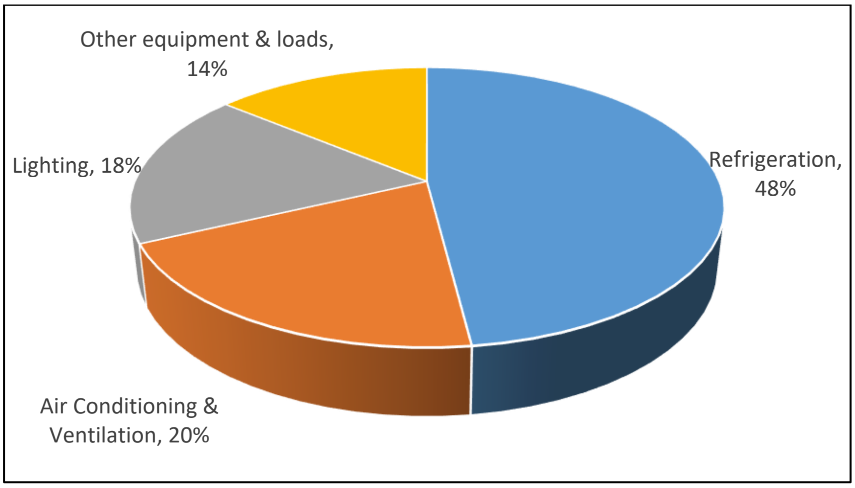

Figure 4: Electricity usage breakdown of food retail buildings *[16]*

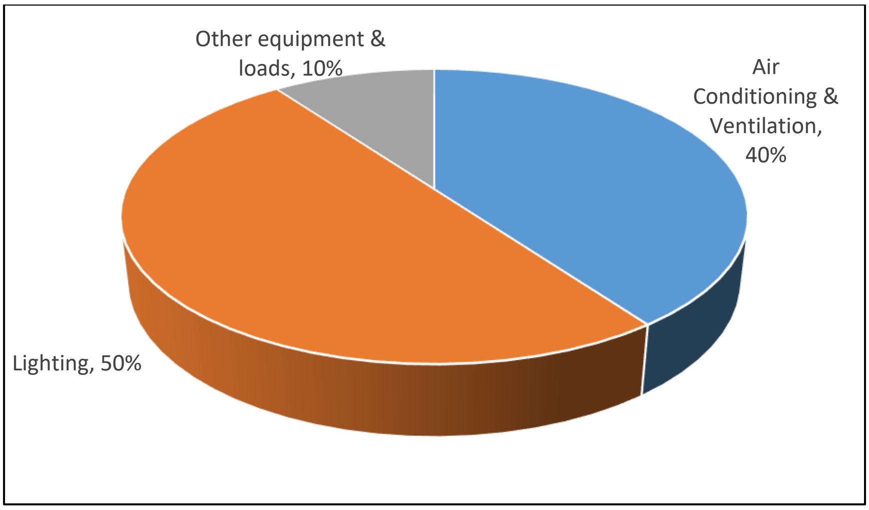

Figure 5: Electricity usage breakdown of non-food retail buildings *[16]*

2.4.2 Energy Usage Benchmarking of Retail Buildings

This Section will discuss the applicable energy usage indicators and already developed benchmarks for retail buildings by various authorities. For retail establishments, EUI is often expressed either with respect to Total Floor Area (TFA) or Sales Floor Area (SFA). In addition, LPG usage can be indicated in terms of kWh/year/m^2 or BTU/year/m^2. "Per person" energy consumption may not be suitable for retail buildings, as the number of occupants change rapidly during the operation time of retail buildings. Therefore, "kWh/year/person" indicator will lead to less accurate results in retail buildings.

There are different benchmark values for Energy Use Intensity in Retail buildings, that have been developed by various authorities. Charted Institution of Building Services Engineers (CIBSE) specifies the electricity usage benchmarks and fossil fuel usage benchmarks (such as LPG or Natural gas) as per Table 4.

Table 4: CIBSE benchmarks for retail buildings *[17]*

Retail Building Type	**Electricity usage benchmark (kWh/year/m^2)**	**Fossil fuel usage benchmark (kWh/year/m^2)**
Fast food restaurants	820	480
Clothes shops (all electric)	270	-
Department store (all electric)	209	-
Small food shops	400	80
Supermarkets	915	200

Another study has obtained specific electricity consumption benchmark of supermarkets in United Kingdom as 450 kWh/year/m^2 (per total floor area) and 566 kWh/year/m^2 (per sales floor area) [18]. However, there are very limited details are available when it comes to the retail buildings in Sri Lanka.

2.4.3 Water Usage Patterns of Retail Buildings

Water consumption and water end-uses in retail buildings depend on the type of retail buildings such as food retail, non-food retail and etc. Major water end-uses for two different types of retail buildings, have been discussed below.

Food Retail

Major portion of the water consumption of food retail buildings is accounted by cooking process. About 45% of total water consumption will be dedicated to cater for this end use. Toilets will account for about 35% of the total water usage. Compared to other building types, air conditioning takes up a less percentage of the total water consumption, which is around 1%-5%. This is not due to the less water usage of air conditioning systems, but because of the relatively higher water consumption of other components such as cooking and sanitary usage. Other uses such as landscaping and cleaning consume about 18% of the total water consumption [19]. Figure 6 illustrates the water consumption breakdown of food retail buildings.

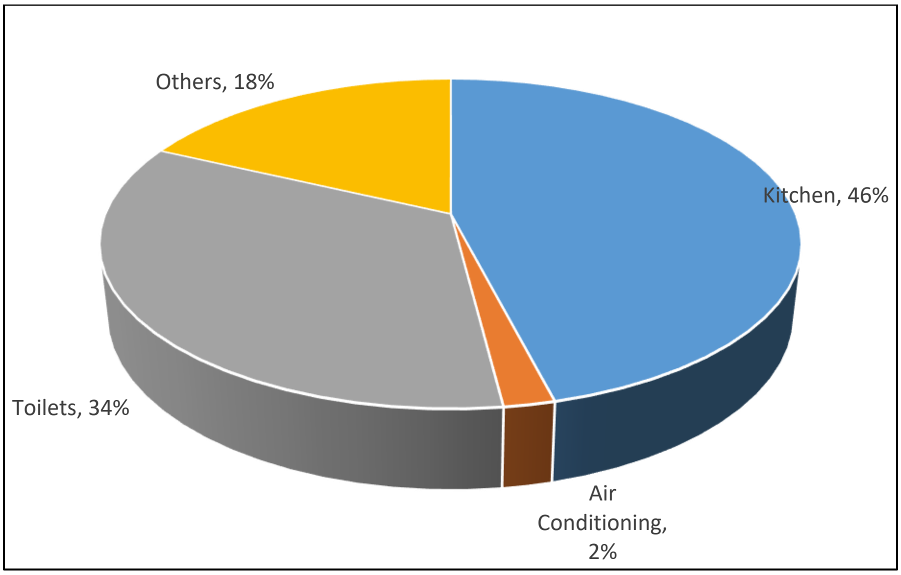

Figure 6: Water usage breakdown of food retail buildings *[19]*

Non-food Retail

In non-food retail buildings, largest water consuming end-uses are toilets and pantries. About 50% of the total water consumption is catered for this end-use. Moreover, 35-45% of total consumption is accountable for air conditioning systems. Other miscellaneous uses such as washing and irrigation will account to about 15% of the total consumption. Figure 7 illustrates the water consumption breakdown of non-food retail buildings.

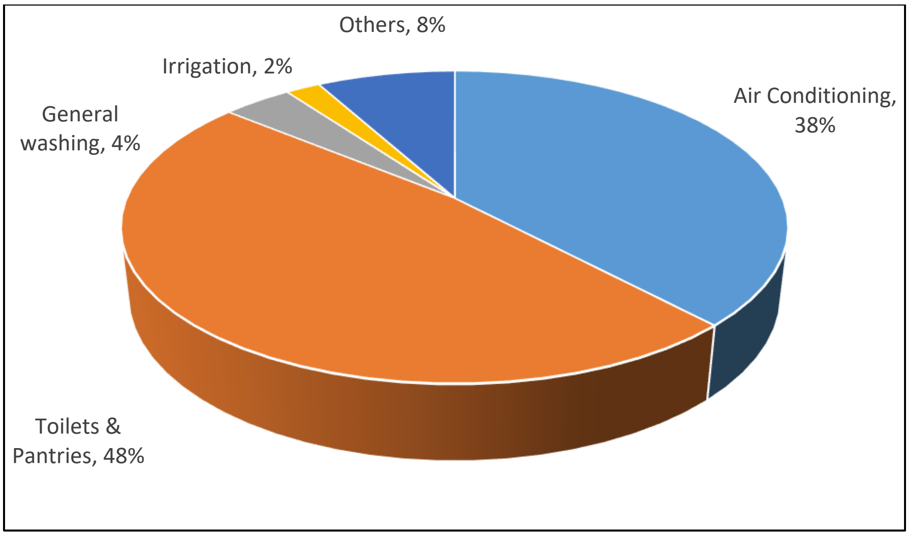

Figure 7: Water usage breakdown of non-food retail buildings *[20]*

2.4.4 Water Usage Benchmarking of Retail Buildings

Although water usage benchmarks for retail buildings have not been developed for Sri Lanka, they have been developed in some other countries. Table 5 shows some of the water benchmarks developed for retail sector.

Table 5: Water usage benchmarks for retail buildings developed in other countries

Country	Retail Type	Benchmarks
USA [19]	Food Retail	48.8 L/meal
Singapore [20]	Shopping malls (excluding toilet usage)	1,300 L/m^2/year
	Shopping malls (only toilet usage)	2.6 L/person/day
Australia [21]	Retail centers	560 L/m^2/year

In addition, benchmark flow rates of water fixtures have been developed by US Green Building Council, which is widely used in the LEED Certification System. These standards specify individual fixture flow rates for toilet fixtures and kitchen equipment, in order to establish a benchmark. Then, the retail buildings can compare the actual consumption with LEED benchmark.

2.5 Energy and Water Benchmarking of Hospitality Buildings

In Sri Lanka, all the types of hospitality buildings are available from lodging facilities and motels to large 5-star hotels. Smaller buildings such as lodging facilities and motels usually use electricity as their main and only energy source. However, larger facilities such as hotels from 3-star and upwards, use multiple energy sources for effective operation of the facility. While using national grid electricity as the main energy source, these facilities use LPG for cooking purposes and diesel/furnace oil to generate steam for laundry operations. In addition, most of the large hotels tend to utilize renewable energy, mostly in the form of solar PV systems.

Common water practice in Sri Lankan hospitality industry is to utilize the municipal supplied water with reusing reclaimed water. This reclaimed water comes in terms of harvested rainwater or treated waste water, that is being used for purposes such as landscaping and flushing. This section will discuss the energy and water usage patterns and benchmarking of hospitality buildings in Sri Lanka.

2.5.1 Energy Usage Patterns of Hotels

According to various studies that have been done to analyze the energy consumption in hotel sector, 45-55% of the total energy requirement is catered by the National Electricity grid [22]. LPG accounts for 10-20% of the total energy consumption, which will be utilized in the cooking processes [22]. In addition, diesel and furnace oil/HFO (heavy fuel oil) is used to cater for 30-35% of the energy consumption, which are used for steam generation purposes [22]. Most of the newly built hotels and ongoing hotels projects tend to use electric heat pumps for hot water generation. Therefore, the furnace oil/HFO usage is expected to reduce in future. These end-uses are illustrated by Figure 8.

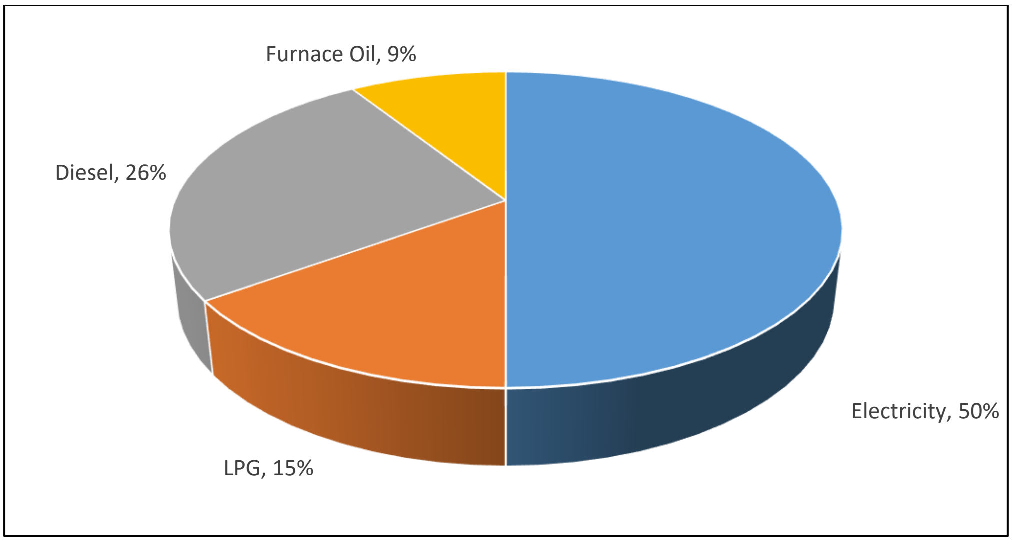

Figure 8: Energy usage breakdown of hotels *[22]*

Although LPG, Diesel and other energy sources often used for a single purpose, electricity is used for many end-uses in hotel industry. Since occupant comfort is the biggest objective in the hospitality industry for building owners, operators make sure that the MVAC systems are running the entire time without failures. Therefore, MVAC systems accounts for 50-55% of the total electricity consumption irrespective of the hotel class [23]. Within this percentage, 30-35% will be consumed by the central cooling equipment. Water side equipment such as pumps and cooling towers will consume about 10% and AHUs' (air handling unit) and FCUs' (fan coil unit) will consume another 10-15% electricity.

In addition, lighting systems play a major role in hospitality sector, since architectural lighting is an important aspect in hotel designing. Usually, lighting accounts for 10-20% of the total electrical usage. Illuminance level requirements for hospitality buildings are complex, since different types of spaces require different levels of illuminance. In addition, star class hotels use lighting control systems to efficiently control the visual comfort and architectural lighting features of the common areas.

Another major electricity end-use for hotel sector is kitchen operations. It is monitored separately in all the large hotels as a separate entity. Since the energy for the cooking process is entirely catered by LPG, electrical consumption of the kitchen equipment is monitored separately by the operators, to analyze how much electricity is consumed by the kitchens. Electricity is consumed by equipment such as ovens, refrigerators, food chillers and blenders. Altogether, kitchens consume 15-20% of the total electricity consumption of the hotel buildings.

Laundry operation is another sector-specific feature which is monitored separately by the hotel operators. Apart from the steam consumption which is intended for drying and ironing purposes, other laundry equipment such as washing machines, extractors, dry cleaning machines & presses consume electricity for their operations. These equipment consume about 5-10% of the total electricity consumption of the hotel. Apart from these major components, there are certain other loads that include elevators, pumps in the plumbing and fire protection systems, ELV systems and receptacle loads in guest rooms and offices. These will account for 5-10% of the total electricity consumption of the facility.

All the above discussed electricity end-uses are shown in Figure 9.

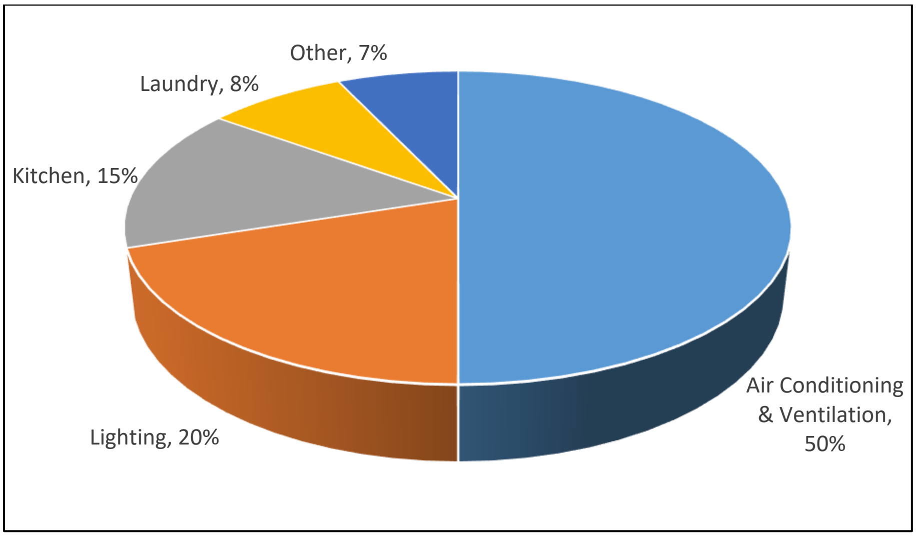

Figure 9: Electricity usage breakdown of hotels *[23]*

2.5.2 Energy Usage Benchmarking of Hotels

Energy consumption monitoring and usage benchmarking are widely practiced by the hotel owners and operators, in order to minimize the operational energy usage of their facilities. It is noteworthy, that the energy usage indicators used in hospitality buildings are specific to the sector, which are not used in any other sector.

Most common EUI in hospitality sector is to indicate the energy consumption in terms of the number of room nights. The unit is expressed as “kWh/room night”. This allows to analyze the energy consumption of the hotel per one night of one room.

However, it is important to note that, comparison between hotels should be done considering the occupancy levels of the hotels. According to Sri Lanka Tourism Development Authority (SLTDA), the country-wide annual average occupancy is 77% for Sri Lankan hotels [24]. Therefore, in order to compare the specific energy consumptions among hotels, the figures either should be normalized into 77% occupancy, or the specific consumptions at difference occupancy levels shall be compared separately.

Another complicated scenario is various functions such as weddings and conferences that are taking place at certain hotels. Since these functions are not held at all the hotels, the consumption of these functions needs to be correctly included into specific consumption figures. In a study done by Sri Lanka Sustainable Energy Authority, 20 function guests have been considered as equivalent to one room night [9]. This means energy and water consumption of 20 guests who are attending a function, is equivalent to energy and water consumption of a one occupied room in one night. Sri Lanka Sustainable Energy Authority published specific “primary” energy consumption levels in hotel industry, which include all the energy sources consumed in the analyzed hotels. These benchmarks have been published considering 77% of occupancy levels in all hotels. In addition, there are more studies have been conducted and benchmark figures have been published. Table 6 illustrates the energy benchmarks developed by SLSEA and SLTDA.

Table 6: Energy consumption benchmarks for Sri Lankan hotels

Category	**Occupancy**	**SLSEA Benchmarks kWh/Room night** [9]	**SLTDA Benchmarks kWh/Room night** [24]
Five Star	77%	137.4	96.5
Four Star	77%	90.7	47.8
Three Star	77%	79.3	33.2
Two Star	77%	54.5	21.9
One Star	77%	58.4	12.7
Boutique	77%	137.6	69.4

It is important to note here that, SLSEA benchmarks represent the primary energy which includes electricity, LPG and other sources consumed in hotels, while SLTDA study represents the electricity consumption benchmarks only.

Another study which has been conducted in China has estimated the EUI in terms of the floor areas. The study has obtained following EUI benchmarks 3-star, 4-star and 5-star hotels.

Table 7: Energy consumption benchmarks for hotels in Shanghai [25]

Category	**Energy consumption benchmark (kWh/m^2/year)**
Five Star	279.8
Four Star	234.8
Three Star	215.7

In addition, energy benchmarks for hospitality sector specified by CIBSE Guide F, are shown in Table 8.

Table 8: CIBSE benchmarks for hotels [17]

Hotel type	**Electricity usage benchmark (kWh/year/m^2)**	**Fossil fuel usage benchmark (kWh/year/m^2)**
Holiday	80	260
Luxury	90	300
Small	80	240

2.5.3 Water Usage Patterns of Hotels

Water consumption of hotels depend upon different factors such as the climatic conditions of the region, category of the hotel and air conditioning system types used in the hotel. One of the major water end-use of hotels is guest room usage. It is monitored as a separate entity in hotels, which accounts for 35-40% of the total water consumption. This includes the toilet flushing, wash basin usage, shower and bath tub usage of guest rooms.

Water usage for air conditioning depends upon the air conditioning system type used in the hotel building. No water usage is reflected for air cooled systems. However, large hotels use water cooled systems fully or partially for air conditioning purposes. Depending upon the percentage of floor area conditioned by water cooled systems, up to 20% of the total water consumption is catered for this end-use. In addition, hot water and steam production are very important aspects of hospitality sector as they directly affect the guest comfort and satisfaction. Hot water is consumed at showers, kitchens and spa, while steam is consumed at spa and laundry. These end-uses will account for about 15-20% of the total water consumption.

Food and beverage is another important and specific water end-use for hospitality sector. This entity will consume 10-15% of the total water usage of the building, which is used for washing of vegetables, fruits, meat dishwashing, cooking and preparing beverages in restaurants and bars. Hotels with laundries will dedicate about 3% of the total water usage for washing purposes. However, laundry operations are not present in all the hotels. Some hotels have outsourced the laundry operations to external parties under a contract, so that they do not have to design electricity and water supply services for laundry operations. In addition, common toilets that are located in public areas such as multi-functional lobbies, restaurants and changing rooms will consume about 3% of the total water usage of the hotel. Apart from those major water end-uses, there are some other uses that include irrigation water for landscaping, swimming pool make-up, housekeeping and cleaning. These will account for about 7% of the total water consumption. Figure 10 illustrates the above discussed major water end-uses in hotel sector.

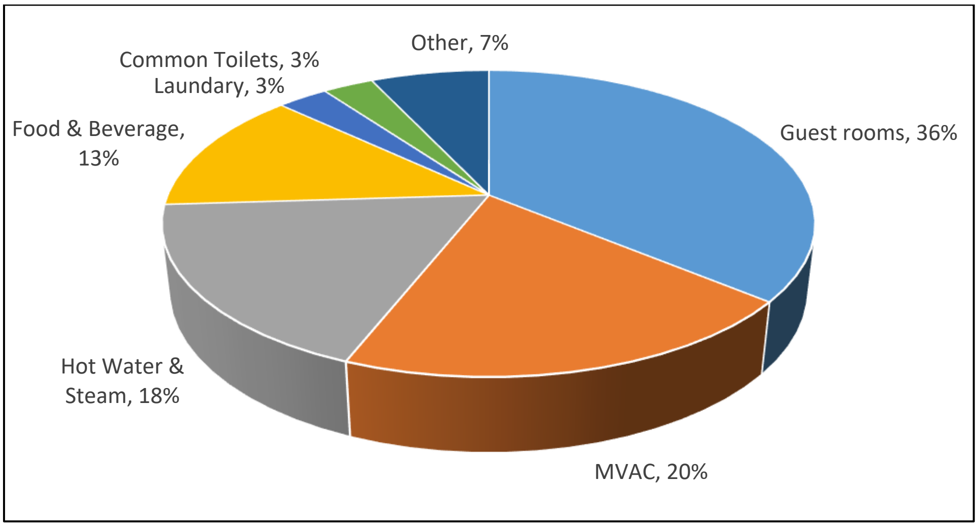

Figure 10: Water usage breakdown of hotels *[26]*

2.5.4 Water Usage Benchmarking of Hotels

Similar to energy usage, water usage also indicated per room nights in the hotel sector. This is a reasonable water usage indicator for hotels, since more than 80% of their water consumption is directly related to occupancy level of the hotel. Therefore, rather than presenting the water usage in terms of floor area or number of people, it is accurate to represent the water usage in "m^3/room night". Various researchers around the world have conducted many studies to benchmark the water usage in hospitality sector. Water consumption benchmarks have been developed for Sri Lankan hospitality sector by a study carried out by SLTDA. Those benchmarks are given in Table 9.

Table 9: Water usage benchmarks developed by SLTDA *[24]*

Hotel Type	Occupancy	Water Usage Benchmark (m3/room night)
Five-star	77%	1.26
Four-star	77%	0.85
Three-star	77%	0.86
Two-star	77%	0.71
One-star	77%	0.18
Boutique	77%	1.05

Water efficiency benchmarks for hotels published by "International Hotels Environmental Initiative (IHEI)" are given in Table 10.

Table 10: IHEI water efficiency benchmarks for hotels *[27]*

Hotel Size	Water usage performance (m^3/guest night)			
	Good	Fair	Poor	Very poor
<50 rooms	<0.44	0.44-0.51	0.51-0.58	>0.58
50-150 rooms	<0.58	0.58-0.67	0.67-0.81	>0.81
>150 rooms	<0.67	0.67-0.86	0.86-0.98	>0.98

Water usage benchmarks developed for other countries are shown in Table 11. However, none of these studies specified an occupancy level for the results.

Table 11: Water usage benchmarks developed for hospitality sector in other countries

Country	Water Usage Benchmark (m^3/guest night)
Singapore 4-Star Hotels (Exclude Resort Style) with Water Cooled Cooling Towers [26]	0.36
Singapore 5-Star Hotels (Exclude Resort Style) with Water Cooled Cooling Towers [26]	0.57
India 5-star hotels [28]	0.4
European hospitality sector Fully serviced hotels [29]	0.14

2.6 Energy and Water Benchmarking of Educational Buildings

Educational sector can be categorized into three major categories as primary, secondary and tertiary education. In Sri Lanka, the usual practice is to combine primary and secondary education as a single unit. Therefore, the students learn from Grade 1 to Grade 13 in a single school. Majority of the schools in Sri Lanka are state-operated, while there are private schools also established in the country. In either case, the main energy source for schools is electricity supplied by the national grid. In addition, LPG is used for cooking purposes in school canteens and dormitories/hostels. Water requirement for these schools is supplied by the NWSDB.

However, tertiary educational facilities such as universities have different working patterns from schools, due to the differences of their occupancy patterns and functional performances. These tertiary educational facilities consume various energy sources such as electricity, LPG and diesel, due to their operational requirements in Laboratories and large workshops. Water is supplied for these institutions by NWSDB. Certain government universities have their water own water intake and purification processes to cater the water requirement.

2.6.1 Energy Usage Patterns of Educational Buildings

Since the operational schedules and occupancy patterns of schools and higher education institutes show major differences, their energy usage patterns should be discussed separately. Usually, schools are functional for 6 to 8 hours per day for five week-days, while higher education institutes such as state universities are functional for more than 10 hours per day through the entire week.

Schools use electricity as their main energy source, while LPG is used in smaller quantities for cooking. Electricity consumption in Sri Lankan schools is mainly divided between lighting and equipment usage. Apart from the computer rooms and very few areas, vast majority of the schools are naturally ventilated. Moreover, space heating is not required in Sri Lanka due to the warm climatic conditions in the country. Figure 11 shows the major electricity end-uses in a typical Sri Lankan school building.

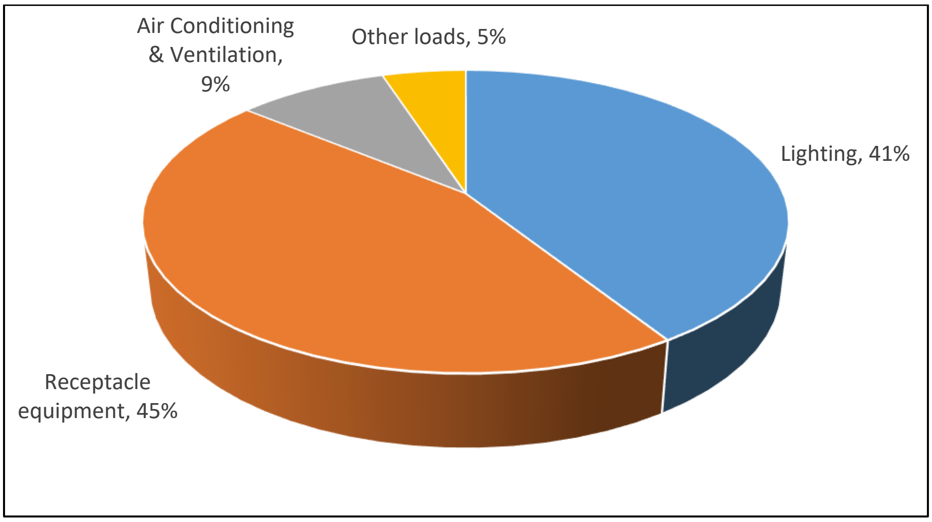

Figure 11: Electricity usage breakdown for a typical school building

Higher educational buildings such as universities consume much more energy compared to the schools. These institutions consist of large air-conditioned seminar rooms, laboratories and workshops that consume electricity and other sources such as diesel, furnace oil, etc. Receptacles and other equipment consume about 50% of the total electricity. Air conditioning and Ventilation also consume about 20% of the total electricity consumption due to the laboratories, seminar rooms and computer centers. Lighting accounts for 20-25% of electricity. Figure 12 illustrates the major electricity end-uses for a typical higher education institution.

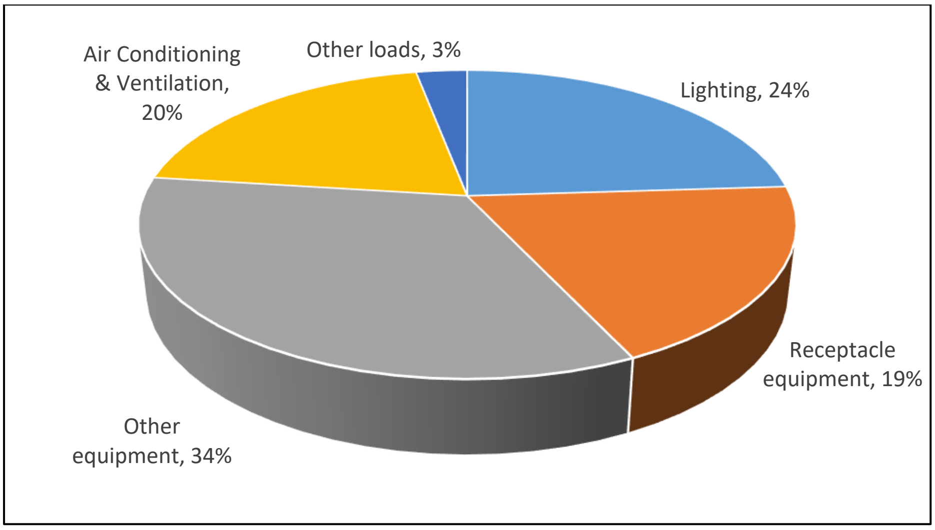

Figure 12: Electricity usage breakdown for a higher education institution

2.6.2 Energy Usage Benchmarking of Educational Buildings

Energy benchmarking for Sri Lankan educational buildings has not caught attention of any individual or institution yet. However, multiple studies have been carried out to benchmark the energy consumption of educational institutions in other countries and regions.

Table 12 shows the energy benchmarks of educational buildings in USA, estimated by Energy Star portfolio manager.

Table 12: Energy Star benchmarks for educational buildings in USA *[30]*

Building Type	**Source EUI (kWh/year/m²)**	**Site EUI (kWh/year/m²)**
College/ University	569.7	265.9
K-12 School	329.3	153.0
Pre-school/Daycare	414.8	204.4
Vocational school/ Adult education	348.3	165.3

In addition, Table 13 illustrates the CIBSE Guide F energy benchmarks for schools and educational buildings.

Table 13: CIBSE Guide F energy benchmarks for educational buildings *[17]*

Building Type	**Electricity usage benchmark (kWh/year/m^2)**	**Fossil fuel usage benchmark (kWh/year/m^2)**
Primary	22	113
Secondary	25	108
Secondary (with swimming pool)	29	142
Lecture room, arts	67	100
Lecture room, science	113	110
Library, air conditioned	292	173
Library, naturally ventilated	46	115

2.6.3 Water Usage Patterns of Educational Buildings

Similar to energy usage, water usage in higher educational institutions is much higher than that of schools. Sanitary usage accounts for the maximum water usage percentage of educational establishments, which is over 60% for schools. In addition, cooking consumes about 9% and cleaning purposes account for about 11% of total water consumption. Moreover, landscaping consumes about 12% of the total water consumption at schools. There are additional end uses such as sports areas and water features, which are categorized as other uses. [31]

In higher educational establishments, more water consumption is reflected for research work at laboratories and workshops, which is about 45% of the total consumption. Since most of the higher education institutions have student housing or dormitories, they consume about 35% of the water consumption, in terms of sanitary usage and drinking.

Figure 13 and Figure 14 show water usage breakdowns for schools and higher educational facilities respectively.

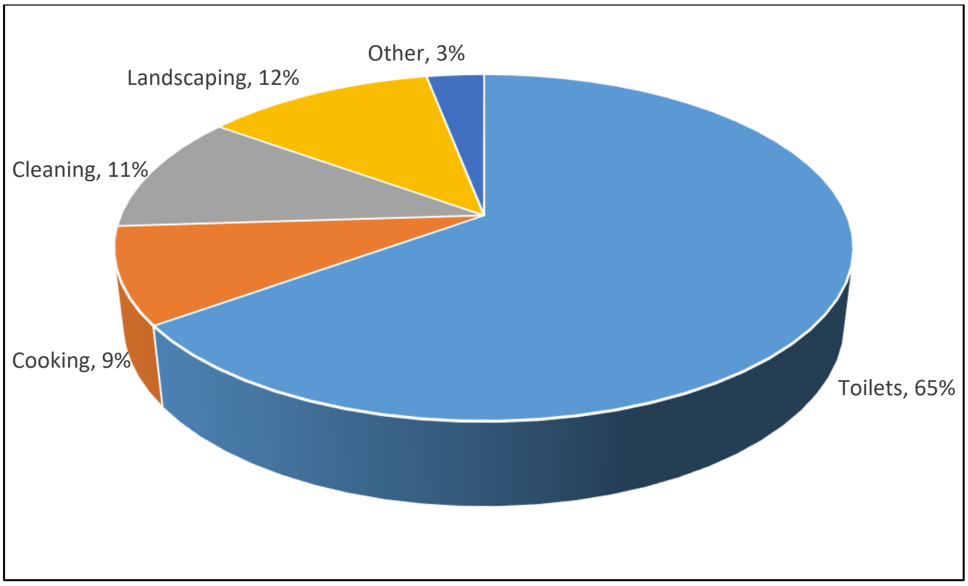

Figure 13: Water usage breakdown for schools *[31]*

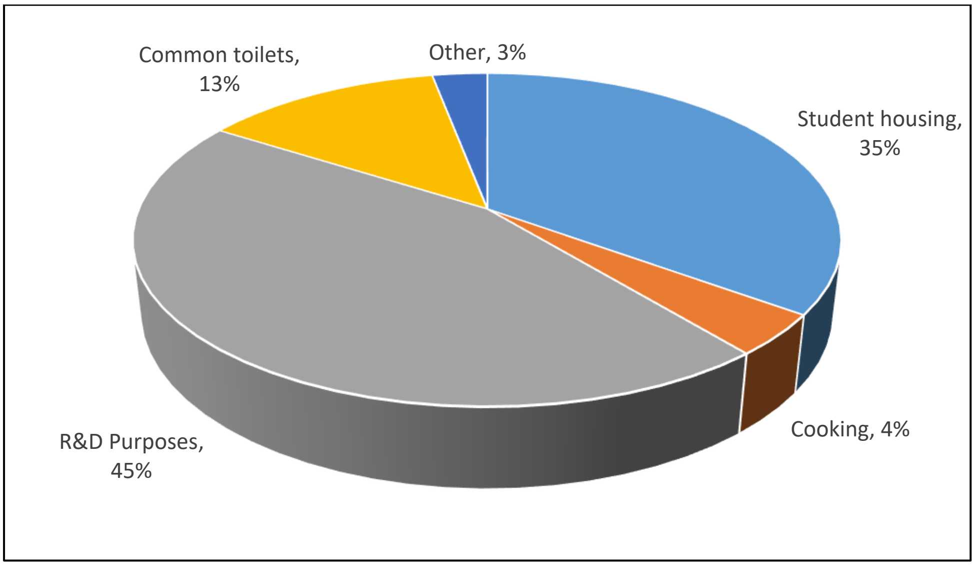

Figure 14: Water usage breakdown for higher education institutions *[32]*

2.6.4 Water Usage Benchmarking of Educational Buildings

Studies on water usage benchmarking for educational institutions have been conducted in various countries by researchers. However, it has not been conducted yet in Sri Lankan context.

Table 14 illustrates the benchmarks developed for educational building in various countries.

Table 14: Water usage benchmarks for educational buildings in various countries

Country	Type of institution	Benchmark
Singapore [33]	Primary school	11.9 L/person/day
	Secondary school	14.8 L/person/day
	Junior college	17.3 L/person/day
Italy [34]	Primary school	16.4 L/person/day
Brazil [35]	Regular school	11 ± 2 L/student/day
	Extended period school	13.5 ± 3.5 L/student/day
	Full day period school	22 ± 6 L/student/day
	Technical school	18.5 ± 6.5 L/student/day

2.7 Energy and Water Benchmarking of Manufacturing Buildings – Tea Industry

Tea industry accounts for about 5% of the total energy consumption of the industrial sector of Sri Lanka [9]. Tea processing requires thermal energy for withering and drying processes, and electrical energy for operating the machineries, blowers, lighting and other utilities. Overall, 80-90% of the energy is accounted by thermal energy, while 10-15% is provided by electricity [36]. In Sri Lanka, firewood (bio mass) is used as the major thermal energy source, while diesel/furnace oil also partially used. Figure 15 illustrate the major energy sources used for tea industry.

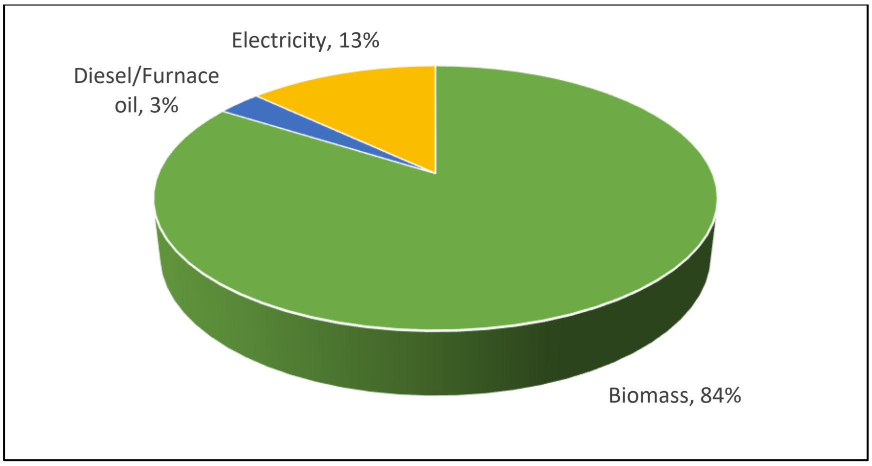

Figure 15: Energy usage breakdown for tea industry *[36]*

2.7.1 Major energy end-uses of Tea Industry

Withering and drying processes are the major end-uses of the thermal energy, in a tea processing facility. Withering consumes about 45% of the thermal energy, while drying consume about 55% of the thermal energy [36]. In addition, withering consumes 50-55% of the total electrical consumption of orthodox tea processing facilities. In addition, drying, grading and rolling consume about 5%, 14% and 25% of the total electrical consumption of orthodox tea processing facilities respectively [36].

In CTC (Crush, Tear, Curl) tea processing facilities, CTC operation accounts for about 45% of the total electricity consumption of the facility, while withering, grading and drying accounts for 14%, 23% and 15% of the total electricity consumption respectively [36]. In both cases, other utilities such as lighting and water pumps consume about 3% of electricity.

Above discussed end-use breakdowns are illustrated by Figure 16, Figure 17 and Figure 18.

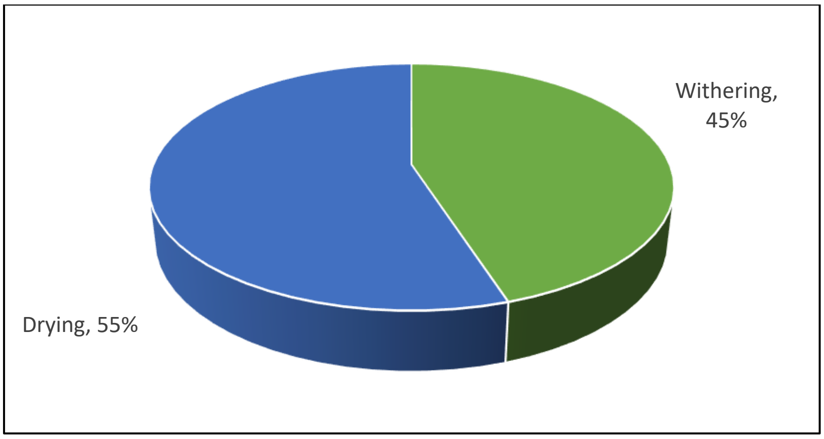

Figure 16: Thermal energy end-uses in tea industry *[36]*

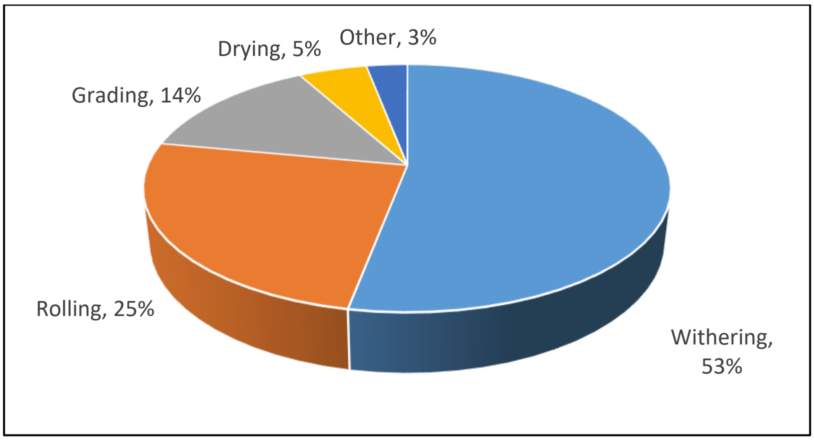

Figure 17: Electrical energy end-uses in orthodox tea processing *[36]*

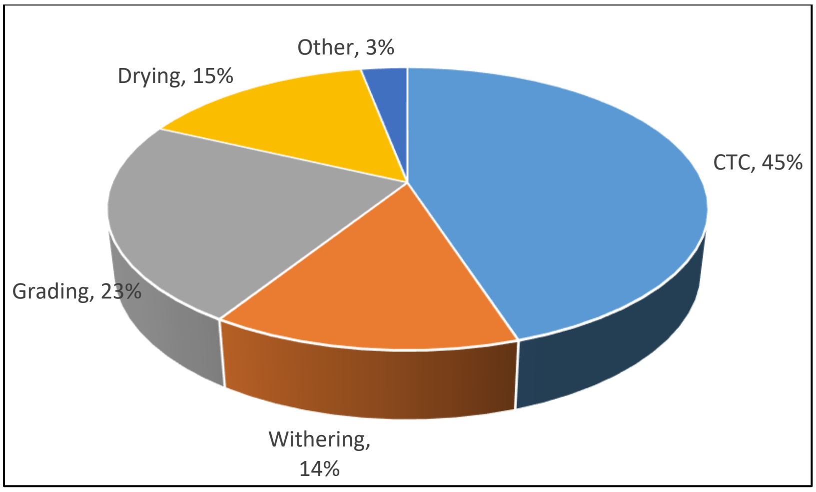

Figure 18: Electrical energy end-uses in CTC tea processing *[36]*

2.7.2 Energy benchmarks of Tea industry

There are several studies that have been carried out to estimate the energy benchmarks incorporated with the tea industry in Sri Lanka. Sri Lanka Sustainable Energy Authority has published energy benchmarks for Up/Mid country and Low country tea production, in terms of kg of made tea, which are shown in Table 15.

Table 15: SEA benchmarks for tea industry *[9]*

Energy Source	Benchmark (Up/Mid country)	Benchmark (Low country)
Electricity	0.78 kWh/kg of made tea	0.82 kWh/kg of made tea
Diesel	0.007 L/ kg of made tea	0.006 L/ kg of made tea
Biomass	2.02 kg/ kg of made tea	2.01 kg/ kg of made tea
Total Energy	35.2 MJ/kg of made tea	34.9 MJ/kg of made tea

Another study has estimated overall energy benchmarks and specific energy benchmarks for different steps of the process in Asian countries. Estimated results are given in Table 16.

Table 16: Benchmarks for tea industry in Asian countries *[36]*

Process	Benchmarks			
	Sri Lanka Up/Mid Country	Sri Lanka Low Country	India	Vietnam
Total Energy (kWh/kg made tea)	6.96	6.88	4.53	12.7
Withering (kWh/kg made tea)	3.29	3.04	0.63	Not reported
Drying (kWh/kg made tea)	4.40	3.65	4.49	Not reported

2.7.3 Water end-uses of Tea Industry

Water is required in tea industry at different stages from crop water requirement to the process water requirement such as withering. There are three components of water usage can be identified.

Green water refers to the water contained in plants and soil in the form of moisture. Mostly, green water relates to the rainfall, and it is relevant to the agricultural aspects of the tea industry [37]. Blue water refers to the consumption of surface or ground water throughout the manufacturing process of a product (tea). This blue portion is not returned to the reservoir or ground source [37]. Grey water refers to the amount of fresh water required to dilute the pollutants generated by the process, before it is released to the original source [37].

Factory functions such as sanitary needs, cleaning and irrigation consume less than 1% of water compared with the water footprint of tea production. Global average water footprint breakdown for Green and Black tea is given in Figure 19.

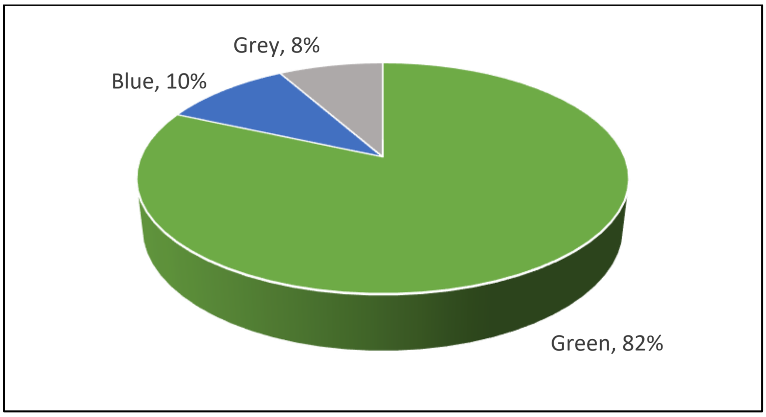

Figure 19: Water footprint breakdown of tea industry - global average *[37]*

2.7.4 Water benchmarks of Tea industry

There are multiple studies that have been carried out to estimate the water footprint of tea production, in Sri Lanka and globally. One study that has been carried out in Nuwara Eliya, Sri Lanka, estimated the blue water footprint of black tea as 65.79 m^3/ton of made tea and grey water footprint as 73 m^3/ton of made tea [38].

Another study which has been carried out in Sri Lanka, has estimated that virtual water footprint from cultivation stage to packaging stage of a 1.5 g tea bag as 19.8 liters for black tea, 18.46 liters for green tea and 20.22 $\pm$ 7.04 liters for flavored tea [39].

In addition, the virtual water footprint of tea industry in global scenario has been estimated for green and black tea as 7,232 m^3/ton of green water, 898 m^3/ton of blue water and 726 m^3/ton of grey water [40].

2.8 Energy and Water Benchmarking of Manufacturing Buildings – Apparel Industry

Textile and apparel sector consume about 14% of the total energy consumed by all the industrial sectors of Sri Lanka [9]. Apparel industry consume variety of energy sources such as electricity, diesel and furnace oil to cater for the various end-use requirements of the facility.

Electricity is used to operate the machinery within the facility such as sewing machines, cutters and fusing machines. In addition, electricity is required to provide the utility requirements of the facility, such as air conditioning, pumping and compressed air. In addition, most of the apparel factories require steam for production process and ironing purposes. While smaller steam requirements are fulfilled by small electric boilers, medium to large steam requirements are fulfilled by operating steam boilers within the facility, that run on diesel or furnace oil. In addition, majority of apparel manufacturing groups invest in Solar PV systems, as sustainability is one of the main objectives in apparel sector.

Water requirements for apparel sector is catered mainly by national water supply and drainage board, while some facilities use deep tube wells located within their own premises. Re-using of treated water/harvested rainwater for flushing and irrigation purposes is quite common in the sector, since apparel sector is widely engaged with the sustainability initiatives.

2.8.1 Major energy end-uses of Apparel Industry

Energy end-uses of an apparel factory depend upon the manufacturing process of the particular facility. For example, a knit composite factory or a wet process factory will consume much more electrical energy than a cutting and sewing factory. Therefore, the energy end-uses of a knit composite factory has been discussed below, to cover the total range of apparel manufacturing processes.

In Sri Lanka, the thermal energy requirement is catered by diesel and furnace oil. However, in most of other South Asian countries like Bangladesh and Pakistan, the thermal energy requirement is fulfilled by Natural gas, since there is an abundance supply of natural gas. Generally, 30-40% of thermal energy is consumed by bleaching process. Also, about 15% of thermal energy is accounted by dyeing and printing processes. Other purposes such as ironing and sizing consume about 15% of thermal energy. However, boiler plant losses and steam distribution losses account for almost 35% of the total thermal energy produced within the facility [41].

Electrical energy is utilized for manufacturing processes and utility requirements of the plant. Spinning and weaving operations consume about 40-45% of the total electricity consumption of the facility. Wet processes such as washing plants consume another 10-15% of the total consumption. Other manufacturing processes such as sewing and cutting operations consume about 12% of the total electricity consumption. Utilities such as air conditioning, lighting, pumps and compressors will consume 20-30% of the electricity consumption of the facility [41].

Above discussed energy end-uses are illustrated in Figure 20, Figure 21 and Figure 22.

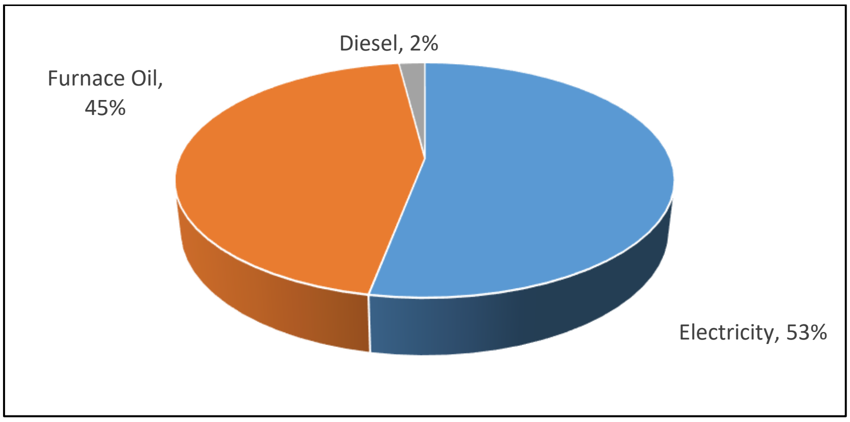

Figure 20: Energy usage breakdown for apparel industry *[41]*

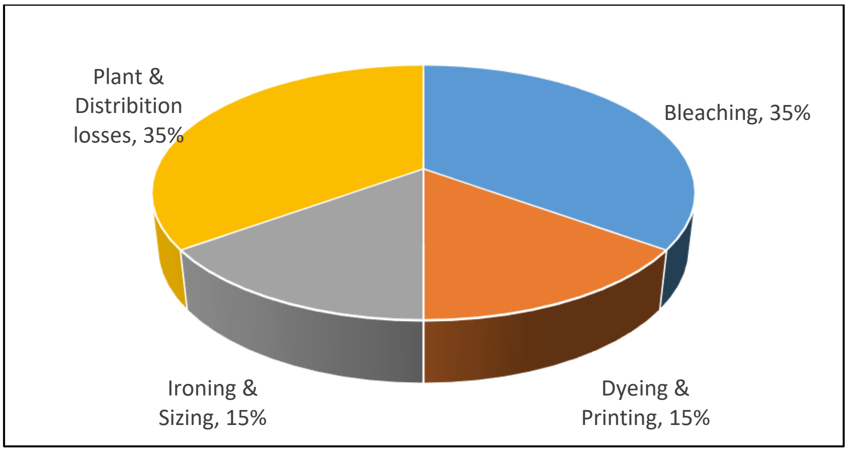

Figure 21: Thermal energy end-uses in apparel industry *[41]*

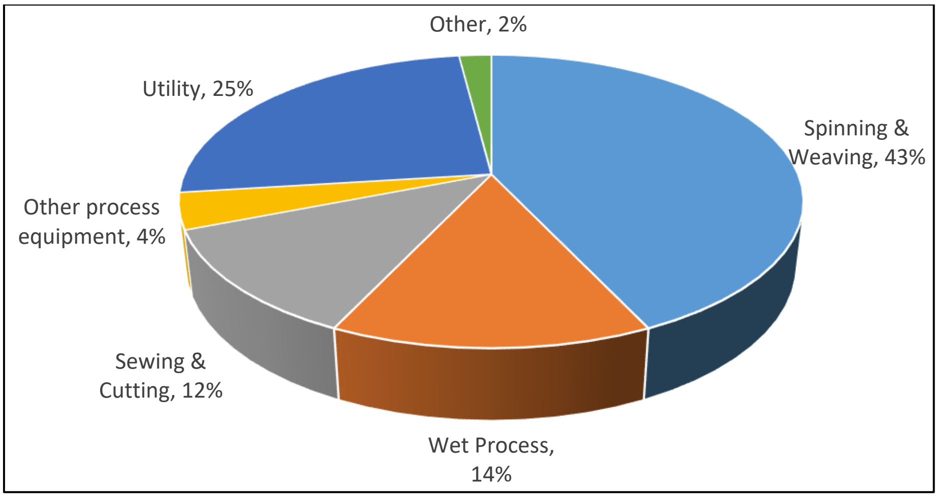

Figure 22: Electrical energy end-uses in apparel industry

2.8.2 Energy Benchmarks of Apparel Industry

Energy usage intensity in apparel industry is expressed in different terms than the other building types. While most of the buildings express EUI in terms of "kWh/m^2/year" or "BTU/ft^2/year", apparel factories calculate EUI as energy consumption per standard minute value, or standard clock hour. Standard Minute Value (SMV) is defined as the time required for a qualified worker to produce output at an average rate, adhering to the specified method of work [42]. Standard Clock Hour is obtained by dividing SMV by 60. Energy consumption benchmarks that have been developed for apparel sector by Sri Lanka Sustainable Energy Authority are illustrated in Table 17.

Table 17: SLSEA benchmarks for apparel industry *[9]*

Energy Source	Benchmark	
Electricity	1.31	kWh/ Clock Hour
Diesel (Electrical)	0.008	L / Clock Hour
Diesel (Thermal)	0.031	L/Clock Hour
Biomass	0.17	kg /Clock Hour
Furnace Oil	0.096	L/Clock Hour
LPG	0.01	kg/Clock Hour
Kerosene	0.018	L/Clock Hour
Total Energy	6.46	MJ/Clock hour

2.8.3 Water end-uses of Apparel Industry

Similar to energy consumption, water consumption of apparel manufacturing sector is heavily dependent on the manufacturing process of particular manufacturing plants that are chosen for analysis. Therefore, water usage of textile sector from cotton cultivation to end product has been discussed in this section, to cover the entire range of processes.

More than 90% of the water footprint of the textile manufacturing process is accounted by the cotton cultivation. Another 3-4% of water is consumed in fabric washing, dyeing & finishing processes. Spinning, yarn dyeing, sewing and cutting operations will consume about another 4% of the total water footprint [43].

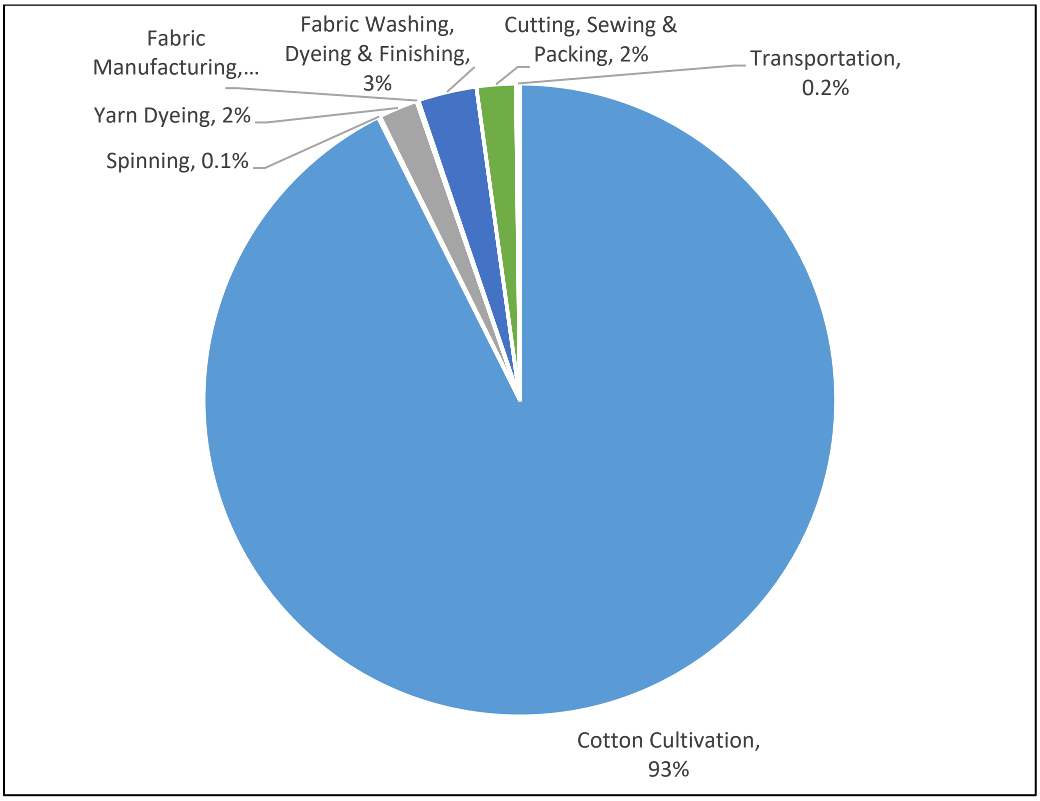

Figure 23: Percentage of water consumption in different stages of apparel manufacturing process *[43]*

However, the water consumption breakdown of the different stages in manufacturing process (excluding cotton cultivation), is dominated by fabric manufacturing process, which include washing & dyeing. 50-55% of water will be consumed by these processes. In addition, 25-30% of water will be consumed in yarn dyeing. Sewing, Cutting & Finishing processes will account for 15-20% of the total water consumption.

Although sewing, cutting and finishing process do not directly consume water, steam requirement for these processes will utilize the above-mentioned percentage of water. In addition, spinning will also consume about 1% of the water footprint [43]. It is important to note that, the human water requirements such as sanitary purposes are included in the relevant end-use components.

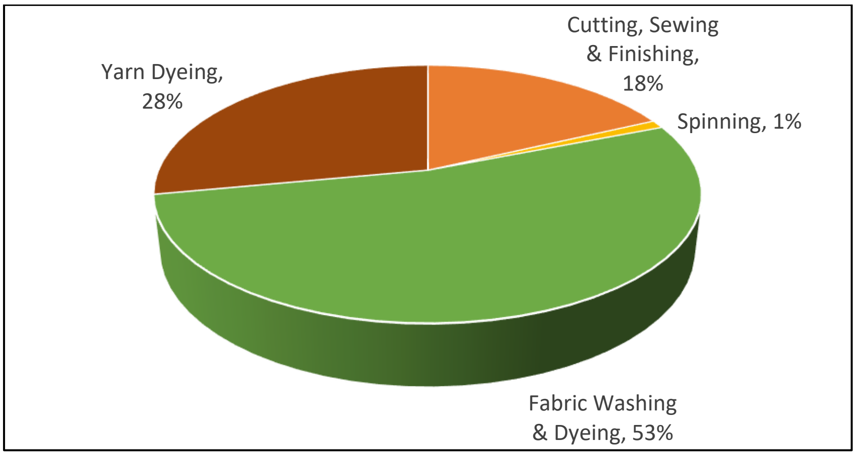

Figure 24: Water Usage breakdown within Manufacturing Facility *[43]*

2.8.4 Water Benchmarks of Apparel Industry

Water usage benchmarking in apparel industry has been done in leading textile manufacturing countries, including Sri Lanka. A study that has been carried out in Bangladesh, has estimated the total water footprint for different types of textile products. The results of this study are illustrated in Table 18.

Table 18: Water footprint of different textile products *[43]*

Product	Green Water Footprint (L)	Blue Water Footprint (L)	Grey Water Footprint (L) (without waste water treatment)	Grey Water Footprint (L) (with waste water treatment)
T-Shirt	1,598	1,639	1,273	1,026
Shirt	743	696	642	482
Bedsheet	2,475	2,292	2,139	1,609
Pair of Jeans	3,218	2,979	2,781	2,443

In addition, multiple number of audits conducted in Sri Lanka have estimated the water consumption benchmarks for apparel facilities. However, it is noteworthy that, these facilities only represent the cutting, sewing, finishing and washing processes, as knit composite facilities are not very popular in Sri Lankan context. Here, the benchmarks have been developed in terms of the output of the facility, which is Standard Minute Value (SMV).

Table 19: Water usage benchmarks established by various audits

Facility Type	Water Usage Benchmark
Apparel Facilities without washing section	0.38 L/SMV
Apparel Facilities with washing section	1.63 L/SMV

2.9 Energy and Water Benchmarking of Healthcare Buildings

Healthcare sector is another complex area to study in terms of energy and water consumption, due to the diversity of functions and complex occupancy patterns. Due to these reasons, healthcare buildings consume energy from multiple sources.

Main energy source for Sri Lankan healthcare buildings is Electricity, which is supplied by the national grid. In addition to that, majority of the government hospitals and large private hospitals have in-house cooking facilities for the hospitalized patients. For this purpose, LPG is used as the energy source. Moreover, old hospitals used to operate boilers to generate steam for sterilization purposes, and hot water for cooking purposes. However, in present, sterilization is done using autoclaves and hot water is produced using electric heat pumps. Therefore, boilers are gradually phasing out from the hospitals.

Water requirements of the healthcare sector is almost completely supplied by the national water supply and drainage board.

2.9.1 Energy Usage Patterns of Hospitals

According to the studies that are conducted regarding the energy consumption in healthcare sector, about 90% of the energy is supplied by electricity, which is supplied by the national grid. In addition, 5-10% of energy is supplied by LP Gas, which caters for the cooking purposes. In addition, diesel or fuel oil is used for incineration purposes, which accounts for less than 5% of total energy consumption [44].

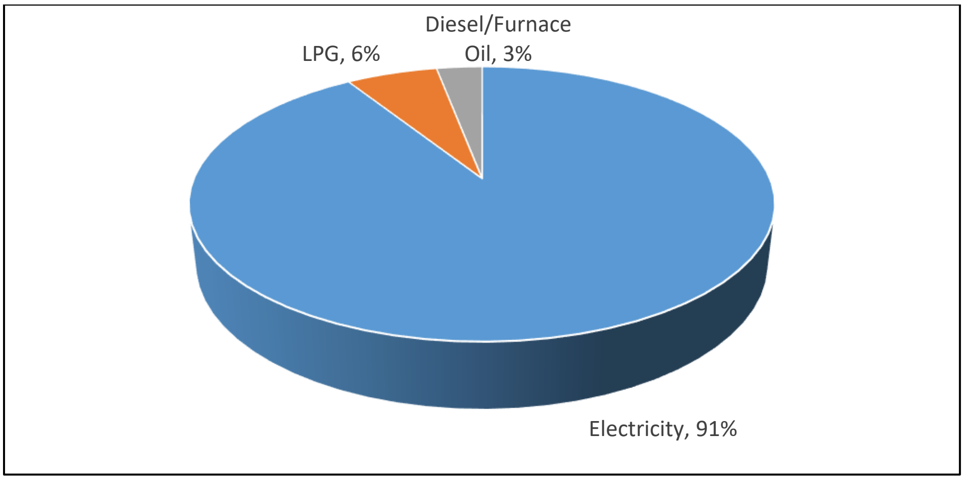

Figure 25: Energy usage breakdown in a typical hospital building *[44]*

While LPG and diesel may entirely be used for single purpose, electricity is used for multiple end-uses, as mentioned earlier. Out of the total electricity usage, 45-50% is consumed by the Air Conditioning and Ventilation system. This high percentage results from the air-conditioned operation theaters and intensive care units. Also, certain operation theaters require 100% treated fresh air, instead of recirculation. This causes a significant increment of energy consumption compared to the recirculating MVAC systems. Lighting system consume about 30% of the total electricity consumption of the hospital. Lighting is another major aspect of the hospital design, since it is extremely important to maintain the correct illuminance levels in the operation theaters. In general, 300 lux is recommended for wards and 1,000 lux is recommended for operation theaters [6].

Medical equipment accounts for 10-15% of the total electricity consumption of a typical hospital building. This includes oxygen supply units, ventilators, patient monitors and scanners. This percentage may increase depending upon the scale of treatments and services provided by the hospital. Utility and other equipment account for about 10% of the total electricity consumption. This portion include utility equipment such as heat pumps, air compressors, water pumps, firefighting systems and ELV systems such as CCTV, MATV and Data. In addition, this includes kitchen equipment and office equipment such as computers, photo copiers and printers.

All the above discussed end-usage percentages are illustrated in Figure 26.

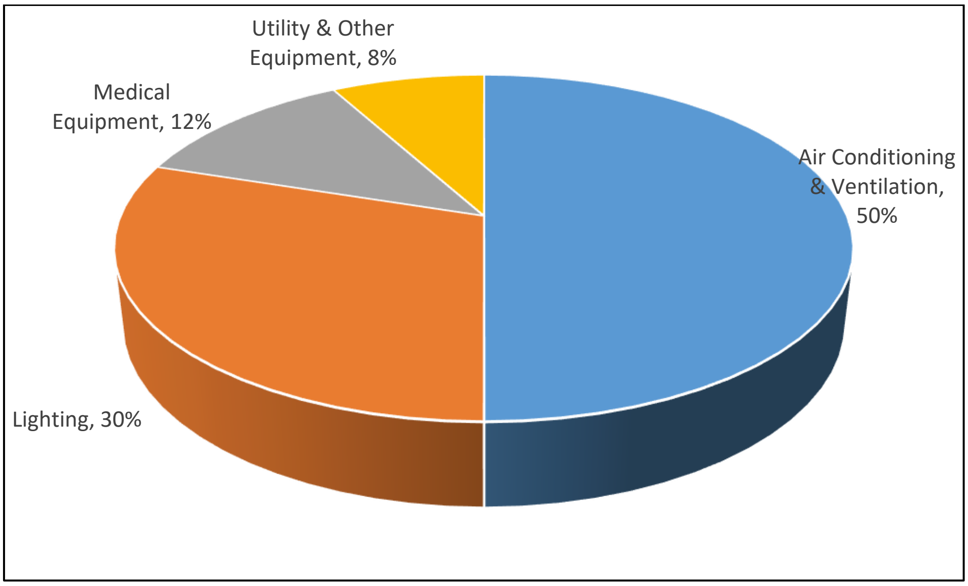

Figure 26: Electricity end-uses in a typical hospital building *[45]*

2.9.2 Energy Usage Benchmarking of Hospitals

Energy benchmarking in Sri Lankan healthcare sector has not been a subject of study for any institution yet. Some of the private hospitals conduct their own energy audits and saving initiatives, but a national benchmark has not been developed. However, various institutions and researchers have conducted a number of studies globally, to benchmark the energy usage of healthcare sector.

Studies carried out in other countries have estimated the targeted energy consumption for acute hospitals for heating (air conditioning) and other electricity uses separately. The outcomes are given in Table 20, Table 21 and Table 22.

Table 20: Energy usage benchmarks for healthcare buildings in Europe *[46]*

Country	Hospital type	Targeted kWh/m^2/year (Benchmark)	
		Heating	Other electricity
UK	General acute hospital	317	122
Germany	< 250 beds	170	32
	>251 and <450 beds	172	45
	>451 and <650 beds	204	48
	>651 and <1000 beds	230	36
	>1000 beds	270	47

Table 21: Energy usage benchmarks for healthcare buildings in India *[47]*

Hospital type	Energy Usage Benchmark	
	kWh/bed/year	kWh/m^2/year
Government hospitals	2,612	90
Private hospitals	15,432	746

Table 22: Energy star benchmarks for healthcare buildings in USA *[30]*

Hospital type	Energy Usage Benchmark (kWh/m^2/year)	
	Source EUI	Site EUI
Ambulatory Surgical Center	436	196
Hospital (General Medical & Surgical)	1,347	739
Other/Specialty Hospital	1,369	652
Medical Office	384	162
Outpatient Rehabilitation/Physical Therapy	436	196
Urgent Care/Clinic/Other Outpatient	460	203

2.9.3 Water Usage Patterns of Hospitals

Healthcare sector consumes water for a diverse range of end-uses. Main water consuming end-use will be the sanitary usage by patients. About 30% of the total water consumption is accounted for this purpose. About 25% of water is consumed by air conditioning systems. Medical equipment and medical processes consume about 15-20% of total water consumption of the facility. In addition, kitchen operations consume about 17% of the total water consumption, which will be used for cooking process for in-house patients.

Laundry process will consume about 1% of the water consumption of the building. However, most private hospitals tend to outsource the laundry services due to the space restrictions on site. In addition, other uses will account for 10-15% of the total water consumption.

These end-use percentages are illustrated below in Figure 27.

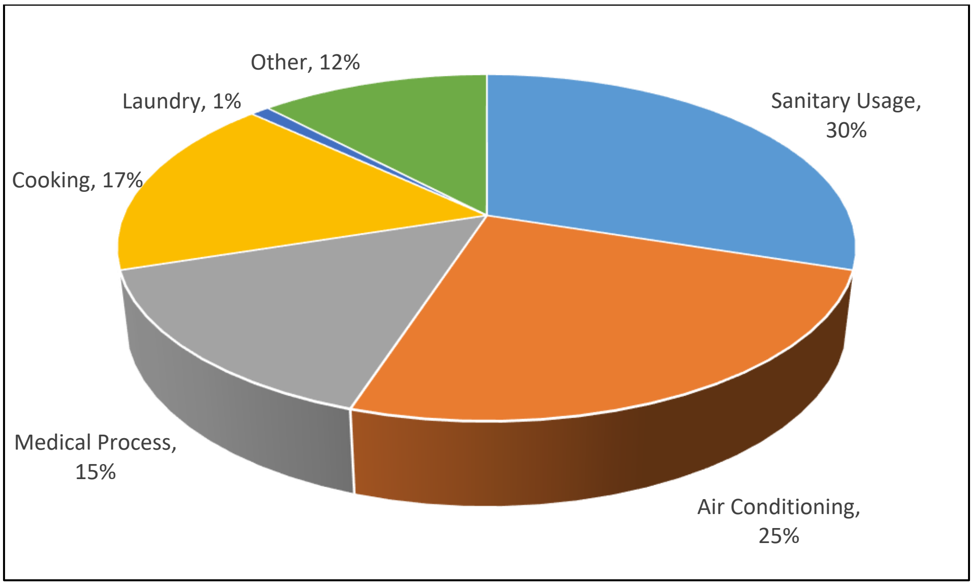

Figure 27: Major water end-uses in a typical hospital building *[48]*

2.9.4 Water Usage Benchmarking of Hospitals

Similar to energy consumption, water consumption benchmarking for Sri Lankan hospitals has not been studied by any institution yet. However, there are studies carried out in global scenario, by various researchers and parties. Table 23 illustrates the different benchmarks that are being developed for different countries.

Table 23: Water usage benchmarks established for healthcare buildings in different countries

Country	Benchmark
USA [48]	2.06 m^3/m^2/year
Spain [49]	1.59 m^3/m^2/year
	53.69 m^3/worker/year
	195.85 m^3/bed/year
UK Small acute/long-stay hospitals without laundry [50]	0.9 m^3/m^2/year
UK Small acute/long-stay hospitals without laundry [50]	1.24 m^3/m^2/year
UK Large acute/teaching hospital [50]	1.38 m^3/m^2/year
Ireland Acute hospitals [51]	0.75 m^3/bed-day
Ireland Community Health hospitals [51]	0.38 m^3/bed-day

2.10 Energy and Water Benchmarking of Residential Buildings

Individual houses and apartments are the most common types of residential buildings in Sri Lanka. Since mid-rise and high-rise apartment projects are becoming popular in the country, it is important to benchmark the energy and water usage of these buildings. Both apartments and individual dwellings use grid supplied electricity and LPG as energy sources. For individual houses, use of Solar power for electricity and hot water is an available option, which depends upon the owner. In apartment sector, renewable energy investment lies with the developer. In addition, households in rural areas of Sri Lanka use biomass (wood) for cooking purposes instead of LPG [52]. Water is supplied for all types of residential establishments by municipal supply of NWSDB.

2.10.1 Energy Usage Patterns of Residential Buildings

Energy usage patterns of regular Sri Lankan households are fairly simpler than the other types of buildings. Majority of the individual houses are naturally ventilated instead of using mechanical ventilation and air conditioning. Space heating is not required for Sri Lanka due to the hot and humid climatic conditions of the country. Therefore, the electricity usage is accounted by lighting and household appliances. Hot water for sanitary purposes is produced mostly by electric heaters and geysers, and rarely by gas geysers.

In a regular household, about 20% of the total electricity is consumed by lighting. Refrigeration consumes about 32% of the electricity, and more than 40% is consumed by the other appliances. These appliances include regular household equipment such as TVs', rice cookers, ovens and washing machines.

However, mid and high-rise apartment buildings are equipped with mechanical ventilation and air conditioning, and all the apartments have hot water systems installed. Therefore, energy consumption of apartments is much higher than that of the individual houses. In apartment complexes, dwelling units consume about 80% of total electricity, while common services such as public area lighting, elevators and pumping systems consume about 20% of electricity.

In a single dwelling unit of an apartment building, about 45% of electricity is used for MVAC equipment. Lighting will consume about 28% and refrigeration will consume about 13% of electricity. Other appliances such as TVs', ovens and washing machines consume about 10-15% of the total electricity within that dwelling unit [53].

Figure 28 shows the electricity usage breakdown of a typical household.

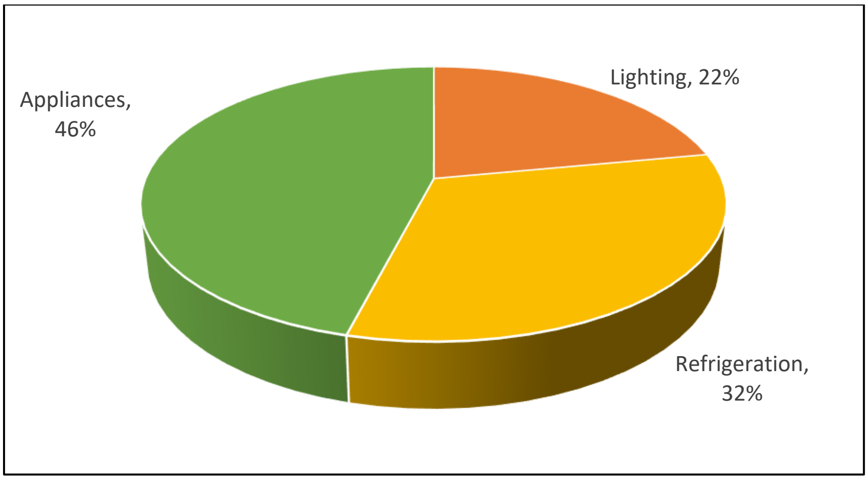

Figure 28: Electricity usage breakdown of a naturally ventilated household

Above discussed electricity usage breakdown of apartment buildings is shown in Figure 29 and Figure 30.

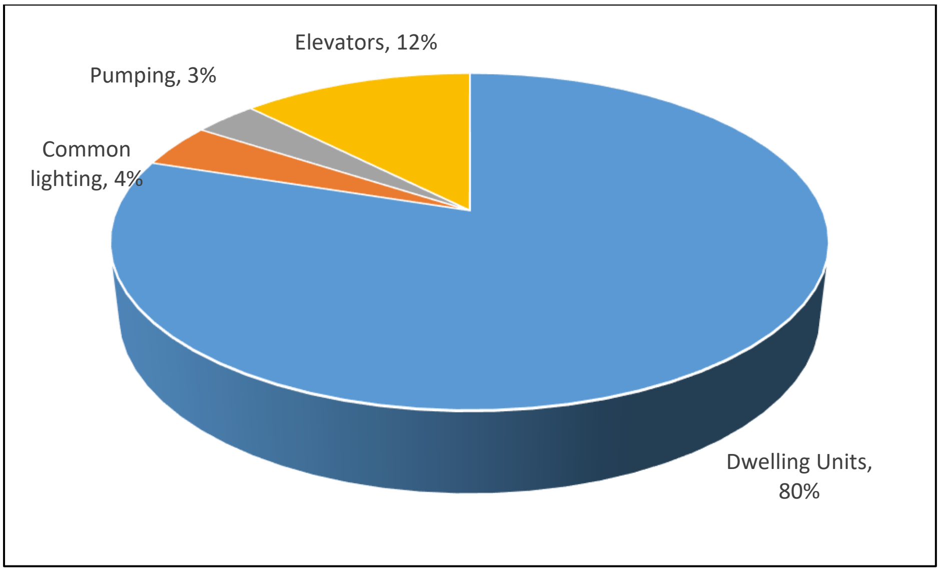

Figure 29: Electricity usage breakdown for a typical apartment complex *[53]*

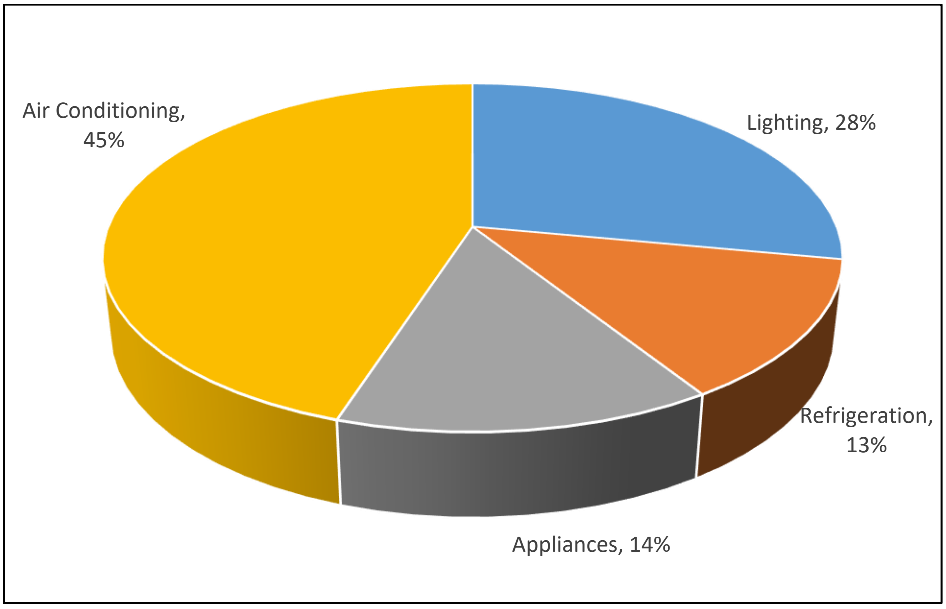

Figure 30: Electricity usage breakdown of a single apartment *[53]*

2.10.2 Energy Usage Benchmarking of Residential Buildings

Although there are many studies conducted on household energy consumption patterns in Sri Lanka, a benchmark has not been developed. However, there are similar studies have been carried out and energy benchmarks have been developed for residential building in other countries.

Energy Star portfolio manager which is managed by US Environmental Protection Agency (EPA) and US Department of Energy (DOE) specifies energy benchmarks for multi-family residential buildings in terms of site energy and source energy.

Table 24 shows the energy usage benchmarks for residential buildings developed for various countries.

Table 24: Energy usage benchmarks for residential buildings developed in various countries

Country	Building Type	Benchmark ($kWh/m^2/year$)
USA [30]	Multi-Family housing	188.0
Jordan [54]	Apartment dwelling unit	91.4
Norway [55]	Apartment dwelling unit	166.0
Tajikistan [55]	Apartment dwelling unit	131.0

2.10.3 Water Usage Patterns of Residential Buildings

Water consumption volumes depend upon certain factors of residential buildings. Sometimes, luxury apartments may show a higher water consumption than that of ordinary households, as the occupants expect certain level of luxury living standard. However, with current sustainability initiatives, many developers tend to install low flow water saving fixtures in apartment buildings. On the other hand, most of the time individual house owners do not necessarily install the low flow fixtures. However, water usage in apartment buildings and individual houses tend to show a similar breakdown.

Residential water usage breakdown is different from region to region, and it depends on factors i.e., people's hygiene practices and climatic conditions. According to the household water consumption study conducted during 2018-2019 by Singapore National Water Agency, showers accounts for maximum end-use percentage in residential buildings, which will be about 30%. WC/toilet flushing will consume about 17% and lavatory and kitchen faucets also consume about 35% of total water consumption. In addition, washing machines use about 15% of water consumption

[56]. Figure 31 shows the aforementioned water end-use breakdown with other minor uses.

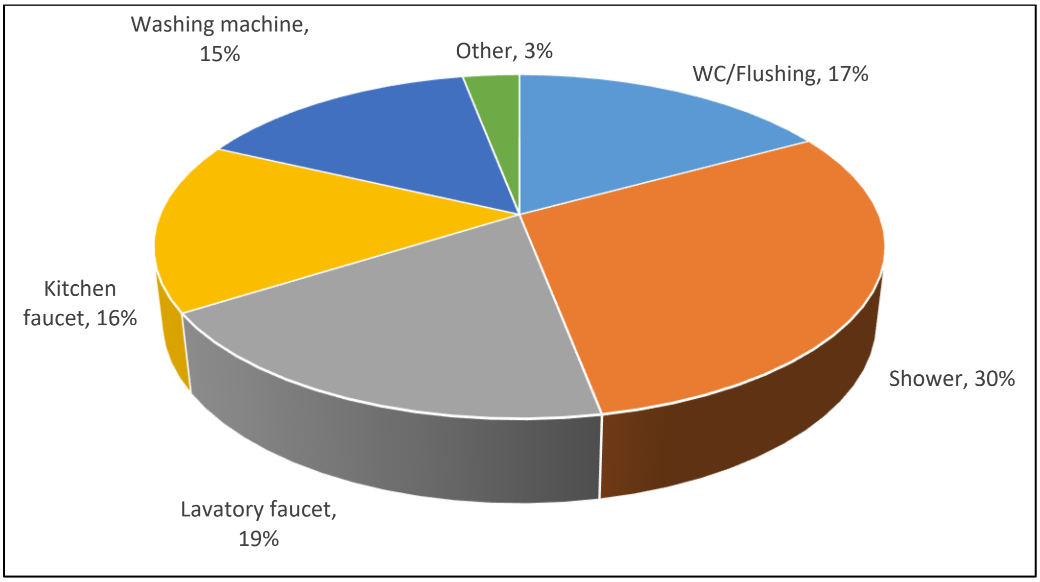

Figure 31: Water usage breakdown in residential buildings *[56]*

2.10.4 Water Usage Benchmarking of Residential Buildings

Water usage benchmarking studies for residential buildings have been carried out in several countries. However, there is no country-wide benchmark developed for Sri Lanka yet. In USA, studies have been carried out to estimate water benchmarks for multi-family and single-family residences in several cities. Similar studies have been carried out in European countries to benchmark domestic water consumption as shown in Table 25, Table 26 and Table 27.

Table 25: Residential water usage benchmarks for USA *[57]*

City/Region	**Benchmark**	
	Multi-Family Residential (L/ Dwelling unit /day)	**Single Family Residential (L/ Dwelling unit /day)**
Denver	503	1,026
New York	644	765
Phoenix	689	1,253
San Diego County	621	1,166
Tampa Way	443	723

Table 26: Residential water usage benchmarks for UK *[58]*

No. of people living	Benchmark (L/Dwelling unit/day)
1	149
2	276
3	367
4	450
5	523
6	592
7	655

Table 27: Residential water usage benchmarks for other countries

Country	Benchmark (L/person/day)
Hongkong [59]	167.7
Denmark [60]	131.0
Finland [60]	150 .0
Netherlands [60]	127.5
Germany [60]	115 .0
Belgium [60]	107.0
Austria [60]	135.0

2.11 Conclusion of the Literature Review

It can be concluded that, energy and water usage benchmarks for retail, educational, healthcare and residential sectors have not been developed in Sri Lankan context. SLSEA has developed national energy benchmarks for Commercial, Hospitality, Tea Industry, Apparel Industry and other industries, using the data recorded during 2012-2013 period. Therefore, these available benchmarks should also be updated.

Furthermore, water consumption benchmarks for Sri Lanka have only been developed for Hospitality sector by SLTDA, in 2014 and is outdated. Therefore, a nation-wide program to update & develop energy and water benchmarks for different types of buildings is clearly required.

Table 28 provides a summary of all the major building types and availability of local benchmarks for each type.

Table 28: Summary of benchmark availability in local context

Building Type	Energy benchmark availability	Water benchmark availability	Developed institution
Commercial	Available	Not available	SLSEA
Retail	Not available	Not available	-
Hospitality	Available	Available	SLSEA & SLTDA
Educational	Not available	Not available	-
Industrial – Tea	Available	Available	SLSEA & Research studies
Industrial - Apparel	Available	Available	SLSEA & Research studies
Healthcare	Not available	Not available	-
Residential	Not available	Not available	-

Further steps for the continuation of this study, are proposed in below sections.

2.11.1 Research Gaps

Four major research gaps have been identified in retail sector, educational sector, healthcare sector and residential sector. As indicated in Table 28, both energy and water benchmarks have not been developed for these four sectors in Sri Lanka. Main reason for these gaps is the difficulties faced in data collection, as there is no proper program for collection of energy and water consumption data from the respective sectors. Moreover, certain building operators are reluctant to share data due to confidentiality. Among these four sectors, Retail sector has been identified as the least studied area, as there is extremely limited amount of literature available. During this study, energy and water benchmarking of Retail supermarket sector of Sri Lanka will be analyzed and proposed.

CHAPTER 3

3 METHODOLOGY

3.1 Data Collection

There are several private and government retail supermarket chains operated in Sri Lanka. Most of the private sector retail operators have initiated sustainable implementations in their supermarkets, in order to gain the savings in energy and water consumption. Most of these supermarket chains record their electricity and water usage manually or through building management systems on monthly basis.

Three major retail supermarket operators were contacted in order to collect the data for this study. Eventually, one of these companies agreed to participate in the study after providing an introduction to the research including the aim, objectives, importance of data recording, benchmarking and sub-metering. Recorded monthly electricity and water data were requested from the company after assuring that these data will not be published without their prior approval, and will be used solely for the research purposes. Following data were obtained from the branches of the said retail company, for the analysis.

- Outlet location
- Electricity supplying authority
- Water supplying authority
- LPG supplying company
- Monthly and Annual electricity consumption
- Monthly and Annual LPG consumption
- Monthly and Annual water consumption
- Renewable energy usage and capacity (if available)
- Total floor area (TFA)
- Sales floor area (SFA)
- Average number of occupants within operating time

Electricity and water consumption data of 101 branches of the above supermarket chain was collected for the study. These 101 outlets are located island wide. Electricity consumption data recorded for past 12 years from 2008 to 2020 and water consumption data recorded for past 3 years from 2018 to 2020 were obtained from each outlet.

LPG is used only in a limited number of outlets of the supermarket chain, those serve cooked food in the in-built kitchen facilities in the premises. Others do not have kitchens due to space restrictions, lower demand for cooked food and various other reasons. During the data collection, it was found out that LPG data was not recorded consistently and hence, LPG consumption was excluded from the study.

Range of the total floor areas of 101 supermarkets is 771 m^2, and the range of the sales floor areas of 101 supermarkets is 512 m^2.

3.2 Electricity Consumption Analysis

Collected data from 101 supermarkets was analyzed using Microsoft Excel and JASP Statistical Analysis software. The outlets of the supermarket chain had recorded the electricity consumption data in the following format, as shown in Table 29.

Table 29: Format of the recorded electricity consumption data

Outlet	**Month**	**Jan 2008**	**………**	**Dec 2020**
Location name	Period			
	Number of Days			
	Unit Start			
	Unit End			
	kWh Units			
	Peak			
	Day			
	Off Peak			
	kVA Units			
	kWh Amount			
	Fixed Charge			
	kVA Amount			
	Fuel Surcharge			
	Generator Charge			
	Total Amount			

Firstly, the monthly data was added up to obtain the figures for annual electricity consumption (kWh/year) and annual electricity cost (Rs/year) from 2008 to 2020.

Electricity cost was calculated for these supermarkets by GP2 (General Purpose – 2) tariff rating by Ceylon Electricity Board. Then these annual data for the 101 locations were divided by sales floor area and total floor area, to create four data sets. Sales floor area (SFA) is defined as the area that is accessible to the customers. This excludes spaces such as offices, storage areas, kitchen areas (if available) and toilets.

Total floor area (TFA) is defined as the area enclosed by building envelope, which include the sales area, offices, storage areas, kitchen areas (if available) and toilets.

Format of the created data sets is shown in Table 30.

Table 30: Format used for data analysis

Outlet	**Floor areas (sqm)**		**2008**		**……….**		**2020**	
	Sales floor area	**Total floor area**	**Avg. kWh/sqm/yr**	**Avg. Rs/sqm/yr**			**Avg. kWh/sqm/yr**	**Avg. Rs/sqm/yr**
Location 1								
Location 2								
Location 3								
Location 4								
Location 5								
Location 6								
Location 7								
Location 8								
Location 9								
…………								
Location 101								

The annual average electricity consumption and electricity cost across all 101 locations were calculated from 2008 to 2020 for the two scenarios in terms of SFA and TFA.

Analyzed four types of electricity related parameters are as follows.

$$\left.\begin{matrix} Specific\ Electricity \\ Consumption\ TFA \\ (kWh/sqm/year) \end{matrix}\right\} = \frac{Annual\ Electricity\ Consumption}{Total\ Floor\ Area\ (TFA)} \qquad \text{Eq. 1}$$

$$\left.\begin{matrix} Specific\ Electricity \\ Consumption\ SFA \\ (kWh/sqm/year) \end{matrix}\right\} = \frac{Annual\ Electricity\ Consumption}{Sales\ Floor\ Area\ (SFA)} \qquad \text{Eq. 2}$$

$$\left.\begin{matrix} Specific\ Electricity \\ Cost\ TFA \\ (Rs/sqm/year) \end{matrix}\right\} = \frac{Annual\ Electricity\ Cost}{Total\ Floor\ Area\ (TFA)} \qquad \text{Eq. 3}$$

$$\left.\begin{matrix} Specific\ Electricity \\ Cost\ SFA \\ (Rs/sqm/year) \end{matrix}\right\} = \frac{Annual\ Electricity\ Cost}{Sales\ Floor\ Area\ (SFA)} \qquad \text{Eq. 4}$$

Annual variations of these four parameters were analyzed from year 2008 to 2020. Moreover, the relationship between the annual electricity consumption and annual electricity cost with the floor areas were developed using linear regression.

In order to develop the benchmarks for electricity consumption and cost, most recent data from 2016 to 2020 were selected and analyzed, and the results are presented in CHAPTER 4.

3.3 Building Energy Simulation

Analyzing the electricity consumption patterns of a building is important in benchmarking, as it helps the building owners to identify the main electricity end-uses within the facility. It allows them to attend to the systems which require improvements to reduce the consumption.

However, sub-metering of different systems is not commonly practiced in most of these supermarkets, as they are more concerned about the total electricity cost. Therefore, a building energy simulation has been carried out for one of these supermarkets to assess the energy consumption by the different systems of the facility. Energy simulation was performed using “eQUEST” simulation software with the weather file for Colombo.

3.3.1 Validating the Simulation Model

Before carrying out the energy simulation for supermarket building, simulation software and inputs were validated. In order to validate the results of the energy simulation, 3 similar case studies were selected. These 3 case studies include a commercial building, a retail building and a 5-star hotel located in Sri Lanka. Energy simulations were performed using eQUEST simulation software for the mentioned three buildings, and the results were validated against the available electricity consumption patterns and available benchmarks for the relevant building types. Building material schedules are attached in Annexure 1. Figure 32, Figure 33 and Figure 34 represent the 3D models of simulated commercial building, retail building and hotel respectively.

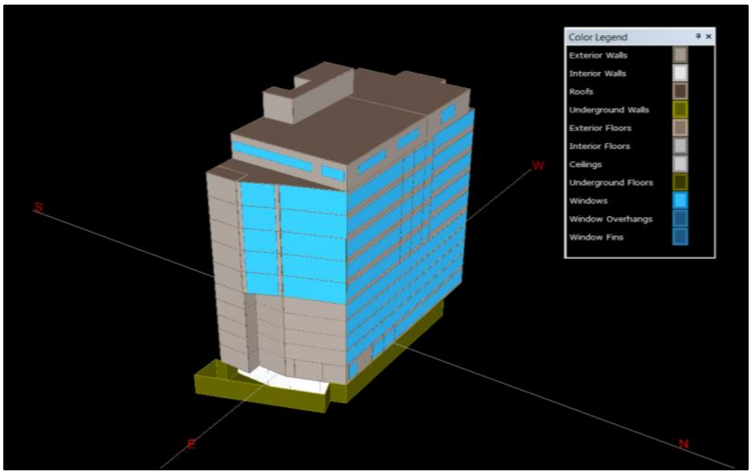

Figure 32: 3D model of simulated commercial building

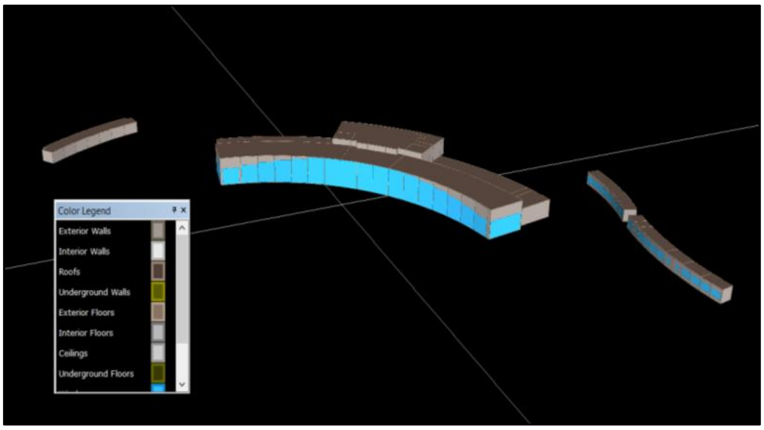

Figure 33: 3D model of simulated retail building

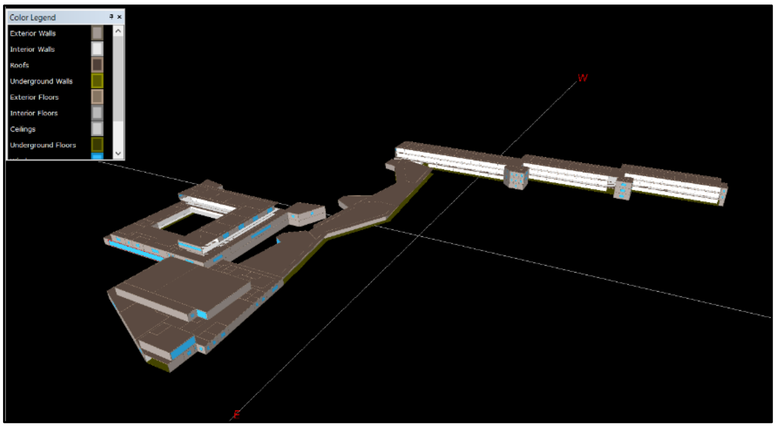

Figure 34: 3D model of simulated hotel

3.3.2 Energy Simulation of Supermarket Building

Once the simulation results were validated using the three case studies, an energy simulation was performed for the selected supermarket.

Building was modeled for the actual building envelope, fenestration and internal loads. Utility systems such as lighting, air conditioning and ventilation fans were modeled as built. Operating hours of the outlet are from 7 am to 10 pm, which is reflected in the simulated model. In addition, the actual electricity tariff (GP 2) was modeled in the simulation program.

One of the major issues in the modelling process was to accurately define the number of occupants within the building over the operating hours. As explained earlier, keeping track of the number of people entering the building appeared to be a difficult task. Therefore, it was decided to define the number of occupants according to the expected average daily inflow to the supermarket. This was based on the floor area requirement per one person within a supermarket, and the busiest times of the day.

3D model of the simulated building is shown by Figure 35. Building material schedule is attached in ANNEXURE 1.

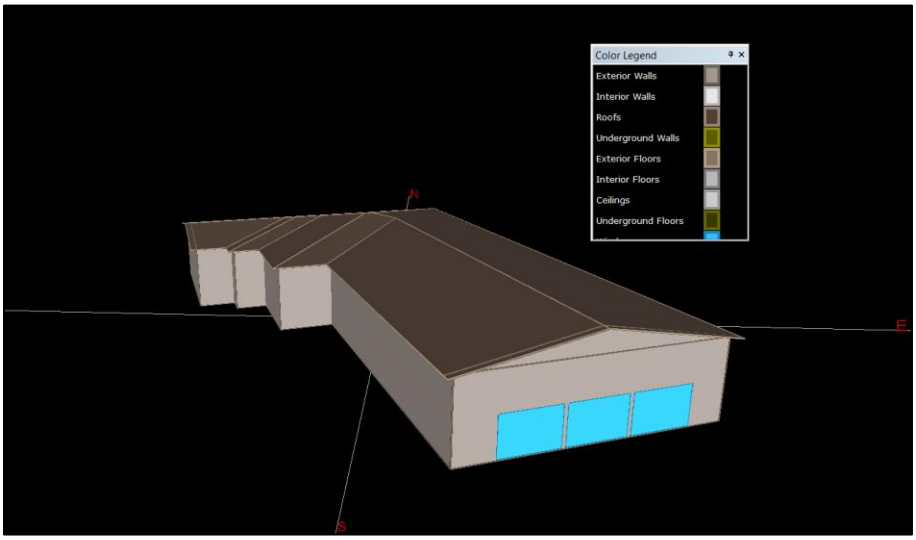

Figure 35: 3D model of the simulated supermarket building

Simulation results were obtained for annual electricity consumption, annual electricity cost and electricity end use percentages. Results are discussed in Chapter 4.

3.4 Water Consumption Analysis

Similar to the electricity consumption analysis, water consumption of these 101 supermarkets from 2018 to 2020 was analyzed. Unlike other types of buildings, specific water usage for supermarkets had to be obtained in terms of L/m^2/year. This was mainly due to the difficulties in tracking the number of occupants within the premises at a given time.

Following two parameters were analyzed.

$$\left.\begin{matrix} Specific\ Water \\ Consumption\ TFA \\ (L/sqm/year) \end{matrix}\right\} = \frac{Annual\ Water\ Consumption}{Total\ Floor\ Area\ (TFA)} \quad \text{Eq. 5}$$

$$\left.\begin{matrix} Specific\ Water \\ Consumption\ SFA \\ (L/sqm/year) \end{matrix}\right\} = \frac{Annual\ Water\ Consumption}{Sales\ Floor\ Area\ (SFA)} \quad \text{Eq. 6}$$

Annual water consumption of the supermarkets was plotted against total floor area and sales floor area, in order to identify the relationship between water consumption and floor area. Benchmarks were developed for above two parameters given by Equation 5 and Equation 6, and will be discussed in the next chapter.

CHAPTER 4

4 RESULTS

4.1 Electricity Benchmarking

As explained in Section 3.2, annual electricity consumptions of all 101 supermarkets were calculated over the operating years. Sample values obtained for two supermarkets in Colombo and Kandy are shown in Table 31.

Table 31: Sample values obtained for two supermarkets in Colombo and Kandy

Year	**Colombo (SFA-300 m^2 and TFA-548 m^2)**		**Kandy (SFA-461 m^2 and TFA-670 m^2)**	
	kWh/year/SFA	**kWh/year/TFA**	**kWh/year/SFA**	**kWh/year/TFA**
2008	1,098.9	601.5	752.2	517.4
2009	1,127.3	617.1	716.4	492.7
2010	1,068.6	584.9	710.3	488.5
2011	1,127.4	617.2	722.3	496.8
2012	966.7	529.1	690.4	474.9
2013	906.1	496.0	711.2	489.2
2014	954.0	522.2	677.0	465.6
2015	1,010.7	553.2	676.3	465.2
2016	983.1	538.1	701.6	482.5
2017	986.4	539.9	757.4	520.9
2018	994.4	544.3	796.3	547.7
2019	1,090.3	596.8	746.3	513.3
2020	1,081.5	592.0	750.8	516.4

It can be observed that in most years, the specific electricity consumption of Colombo outlet is higher than the specific electricity consumption of Kandy outlet. To further analyse the regional differences in electricity consumption, these 101 supermarkets are analysed by dividing them to relevant provinces of the country. Figure 36 shows the differences in annual average electricity consumption in supermarkets located in different provinces.

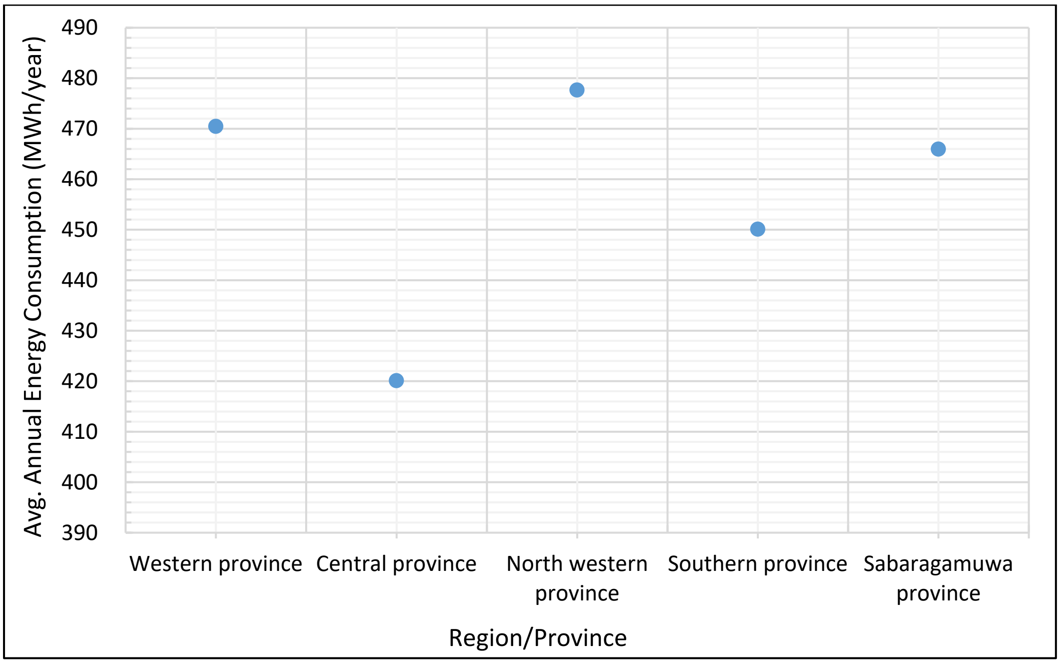

Figure 36: Average annual electricity consumptions of supermarkets located in different provinces

It can be observed that the average annual electricity consumption of central province supermarkets (420 MWh/year) is much lower than that of the other regions. Also, supermarkets in North-Western province and Western province demonstrate highest average electricity consumption figures of 478 MWh/year and 470 MWh/year respectively. This can be related to the climatic conditions at the location, as central province demonstrates much lower average annual temperature (24 – 25 ^{0}C) than the other regions. North western and western provinces have highest average annual temperatures among the above mentioned regions (27 – 28 ^{0}C). Therefore, it can be observed that electricity consumption of supermarkets are related to climatic conditions of the locations, due to the high percentage of refrigeration loads present.

Once the above analysis is completed, the average annual electricity consumption was plotted against the sales floor area (SFA) and total floor area (TFA) as shown in Figure 37 and Figure 38 respectively.

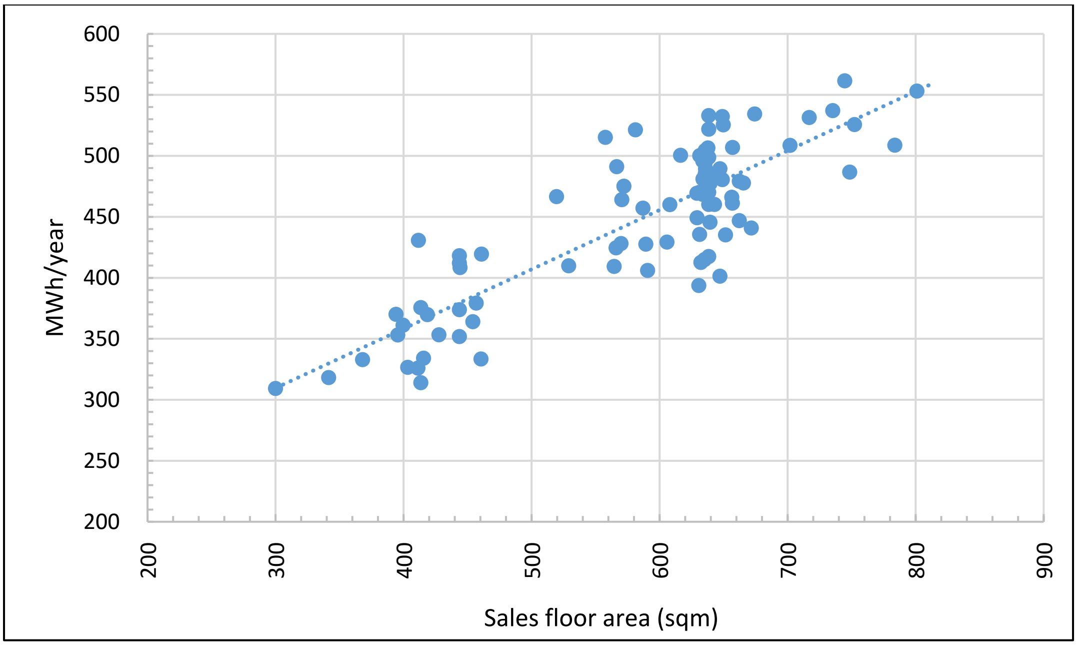

Figure 37: Variation of annual electricity consumption with SFA

As shown in Figure 37, annual electricity consumption increases with the SFA. Relationship between annual consumption and SFA is obtained through linear regression, as shown in the Equation 7.

$$\left.\begin{matrix} Annual\ Electricity \\ Consumption \end{matrix}\right\} = 0.4866 * SFA + 163.66 \qquad ; (R^2 = 0.7143) \qquad \text{Eq. 7}$$

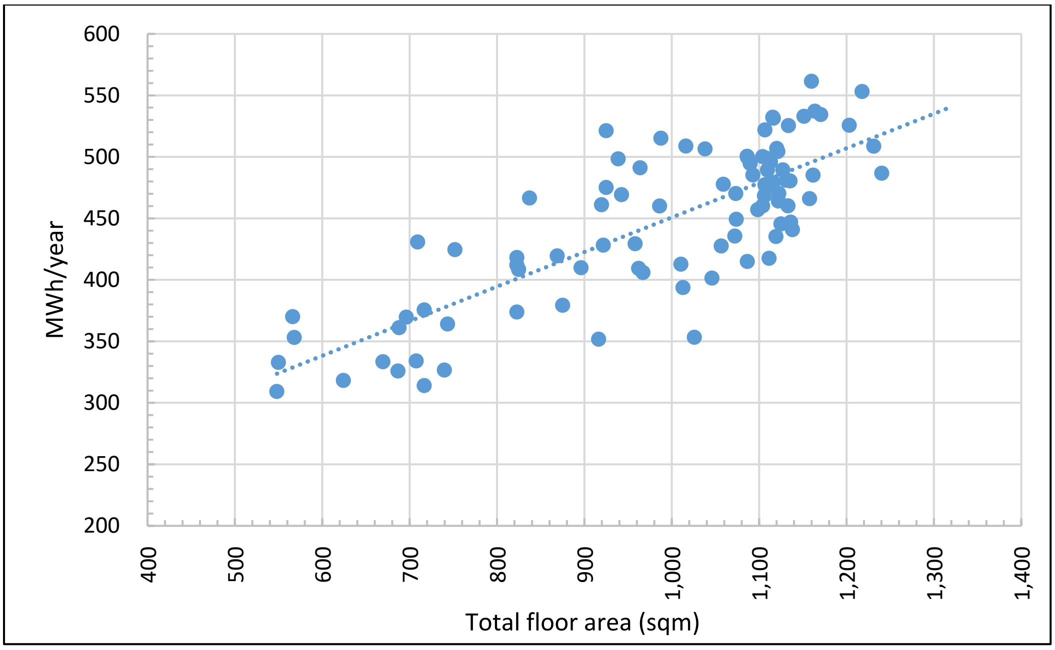

Figure 38: Variation of annual electricity consumption with TFA

Similar to above, relationship between annual electricity consumption and TFA was also obtained through linear regression.

$$\left.\begin{matrix} \mathit{Annual\ Electricity} \\ \mathit{Consumption} \end{matrix}\right\} = 0.2811 * TFA + 169.6 \qquad ; (R^2 = 0.6389) \qquad \text{Eq. 8}$$

In the linear regression model given by equation 7, R^2 was obtained as 0.7143, which means over 70% of the data can be correctly interpreted using this regression model. Also, model represented by equation 8 gives R^2 value of 0.6389, which means over 60% of data can be correctly interpreted using equation 8.

Once the linear regression models for electricity consumption was obtained, annual electricity cost was plotted against SFA and TFA. Similar to annual electricity consumption, electricity cost also appears to be increasing with the floor areas. However, the cost variation was found to be far more scattered than the electricity consumption variation. This was confirmed by the low R^2 values given by two graphs. Therefore, although the trendline was generated on the plots, linear regression equations were not taken into the consideration for electricity cost variation.

Figure 39 and Figure 40 illustrate the variation of annual electricity cost in million Sri Lankan Rupees against SFA and TFA respectively.

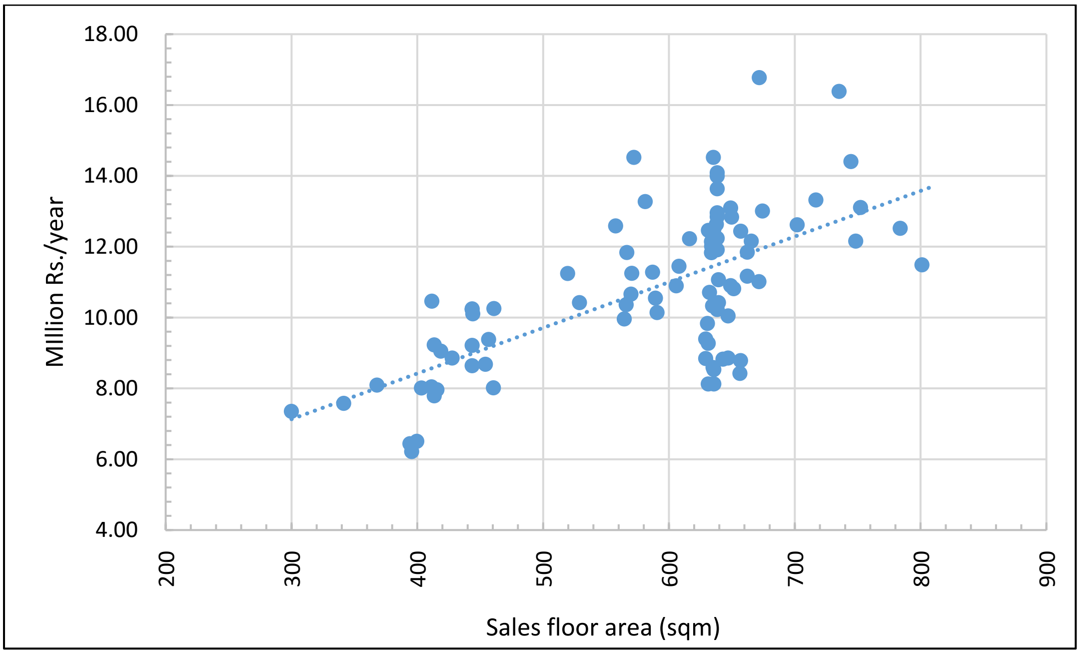

Figure 39: Variation of annual electricity cost with SFA

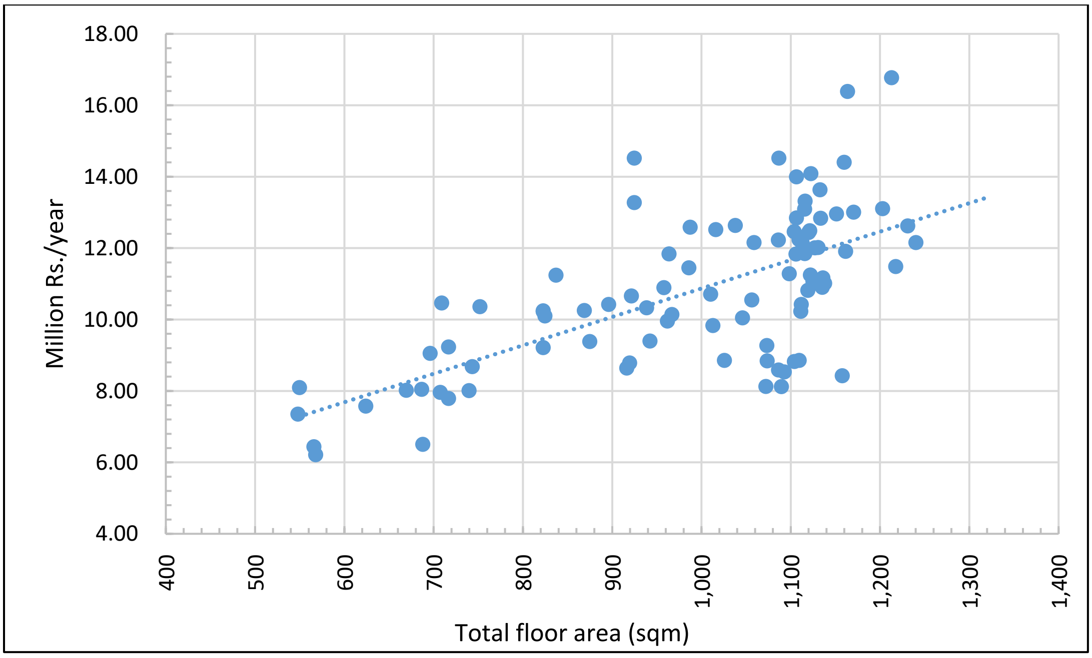

Figure 40: Variation of annual electricity cost with TFA

As explained in Section 3.2, benchmarks were developed for four parameters related to electricity. Specific electricity consumption and specific electricity cost data from 2016 to 2020 were analyzed against respective sales floor areas and total floor areas.

Figure 41 shows the histogram for “kWh/year/m^2” per sales floor area for analyzed 101 supermarkets within the mentioned time frame. Figure 42 shows the histogram for “kWh/year/m^2” per total floor for the same sample within the same timeframe.

Similarly, Figure 43 shows the histogram for specific electricity cost in terms of sales floor area (Rs/year/m^2) for the analyzed 101 supermarkets. Figure 44 shows the histogram for specific electricity cost in terms of total floor area (Rs/year/ m^2) from 2016 to 2020. In these Figures, Y axis which is labeled as “Frequency” represents the number of supermarket outlets that fall into the relevant consumption/cost range during the considered time frame. Summary of the obtained results are given in Table 32.

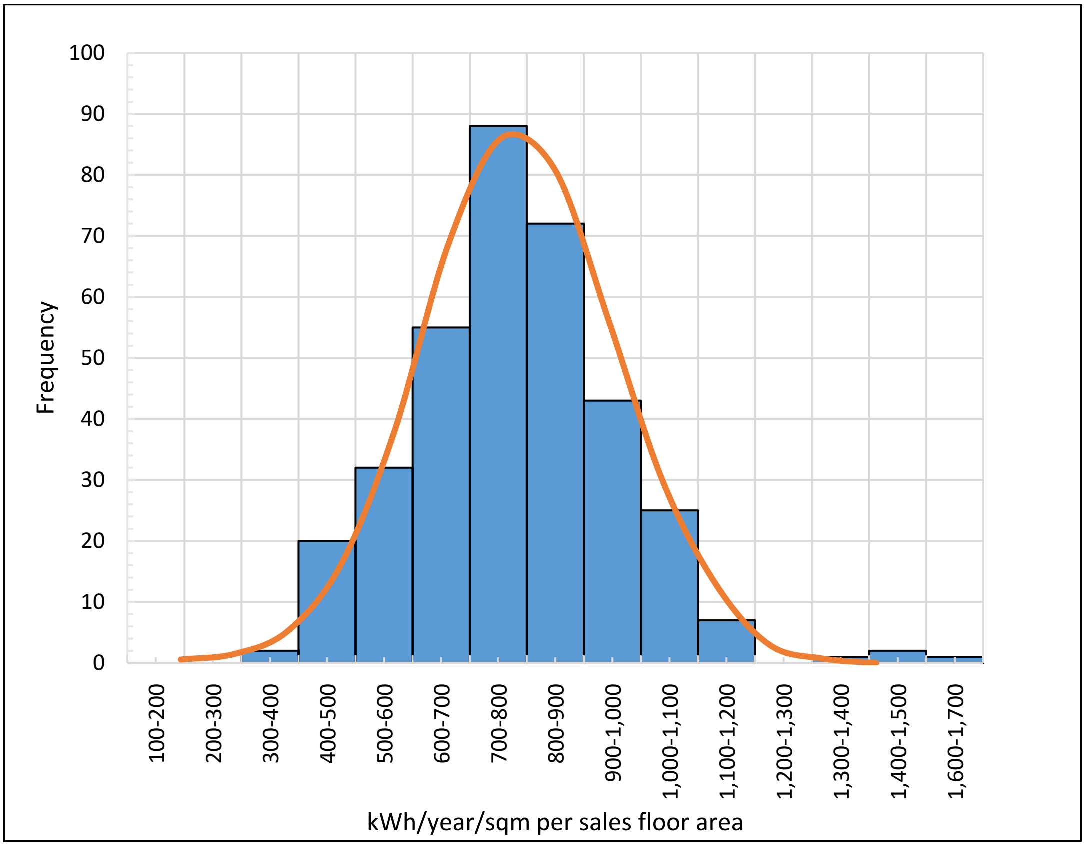

Figure 41: Specific electricity consumption (per SFA) from 2016 to 2020

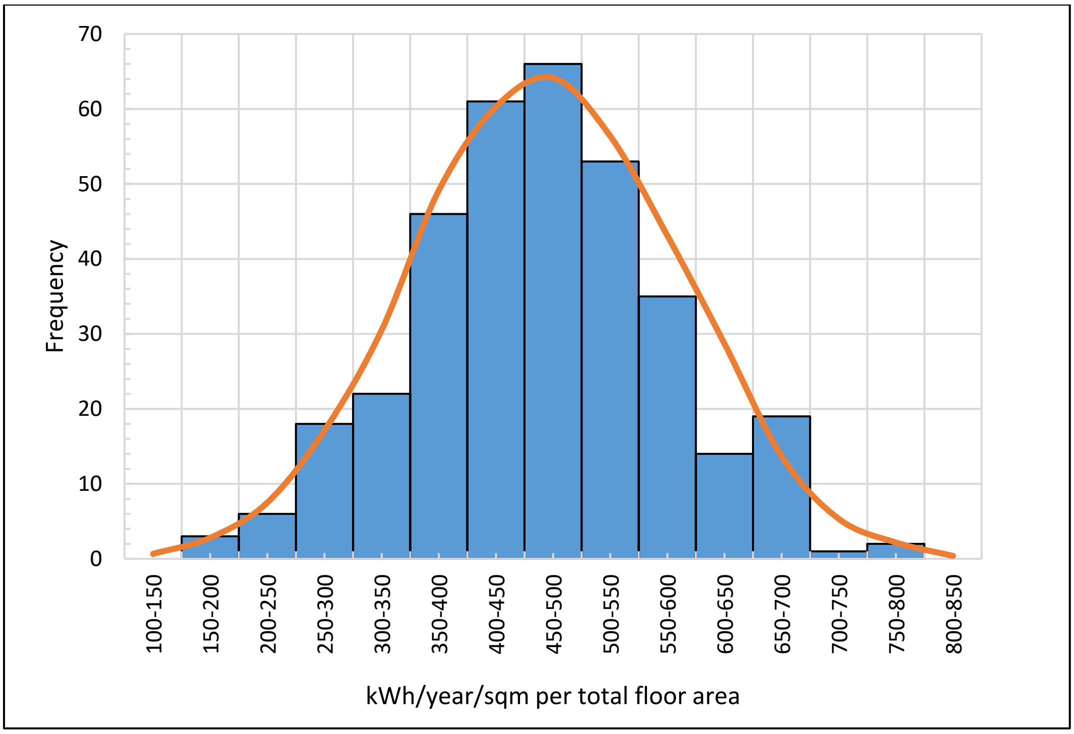

Figure 42: Specific electricity consumption (per TFA) from 2016 to 2020

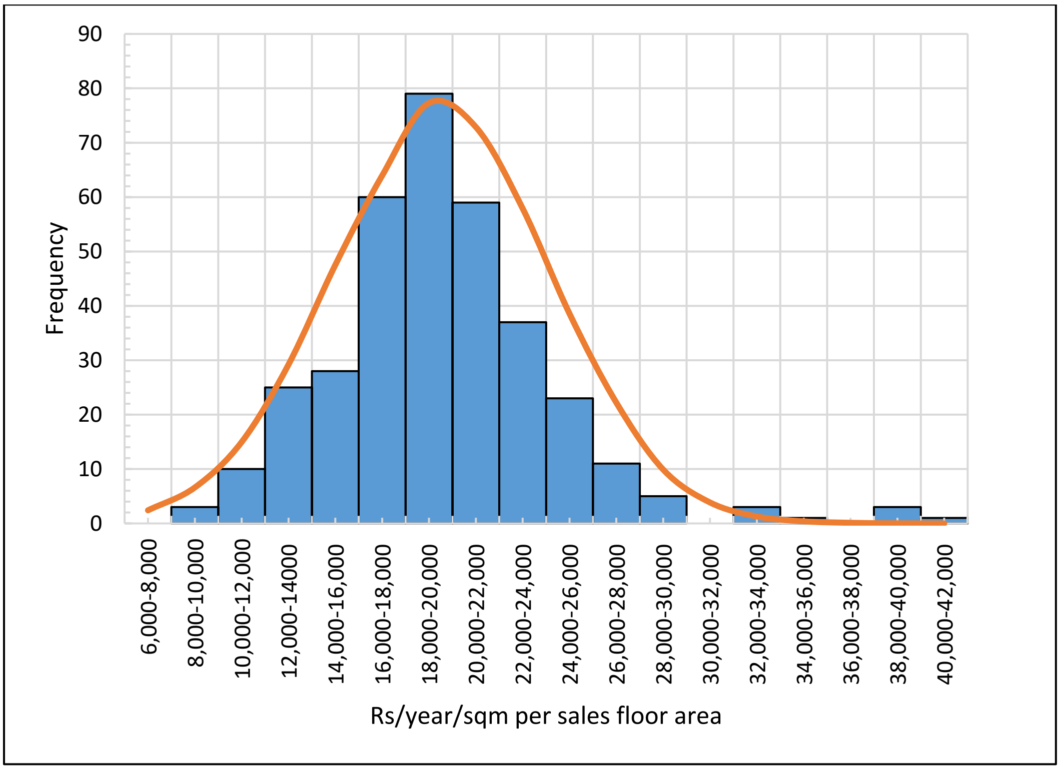

Figure 43: Specific electricity cost (per SFA) from 2016 to 2020

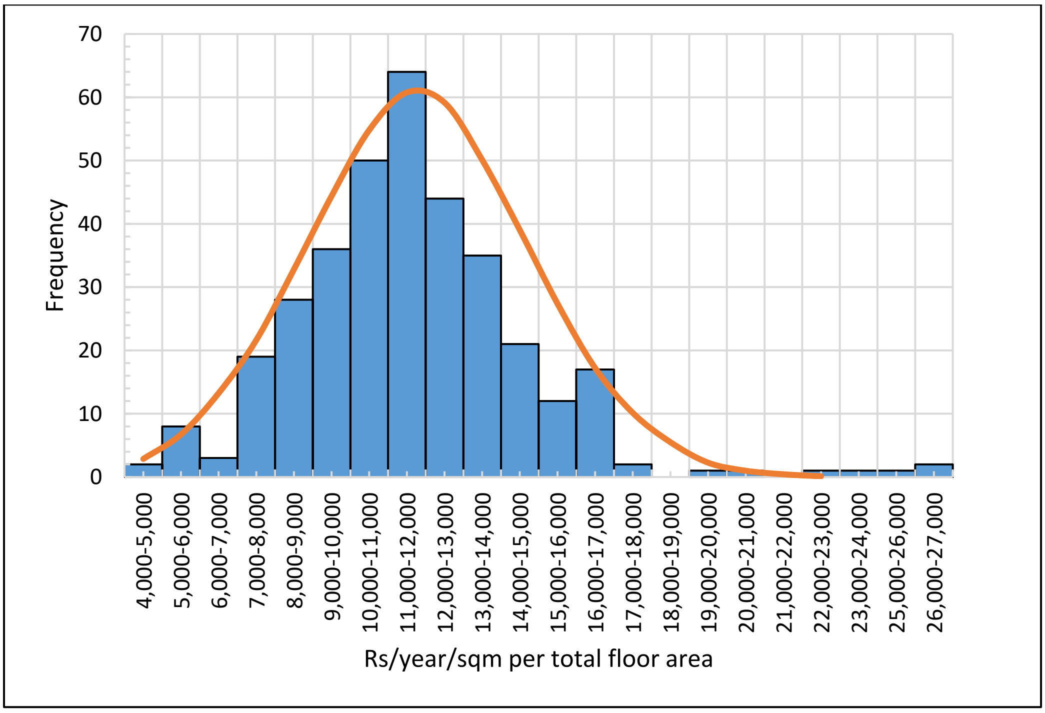

Figure 44: Specific electricity cost (per TFA) from 2016 to 2020

Table 32: Summary of electricity benchmarking analysis

Parameter	Minimum	Maximum	Mean	Standard Deviation
kWh/year/m^2 (SFA)	350	1,632	780	180
kWh/year/ m^2 (TFA)	164	953	465	114
Rs/year/ m^2 (SFA)	8,554	40,656	19,466	4,707
Rs/year/ m^2 (TFA)	4,126	26,180	11,621	3,079

4.2 Building Energy Simulation

4.2.1 Results of the Simulated Case Studies

As explained in Section 3.3, three case studies were conducted in order to validate the simulation program results, before simulating the supermarket.

<u>Validation of the model – Case study 1 – A Commercial Building</u>

First, an energy simulation has been performed for a commercial building, which is located in Colombo 02. The building was modeled using the actual building envelope and actual internal loads. Electricity end-use breakdown obtained from the simulation is shown in Figure 45.

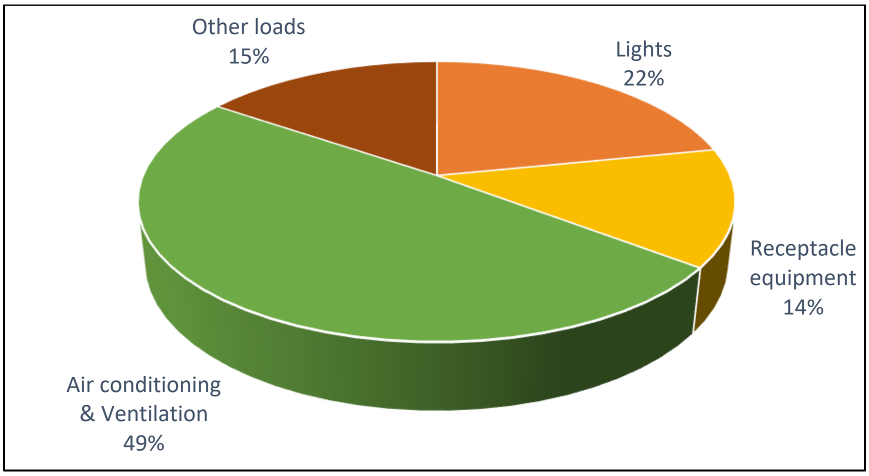

Figure 45: Electricity end-use breakdown for simulated commercial building model

It can be observed that, end-use breakdown obtained through simulation model is almost identical to the established electricity end-use breakdowns of commercial buildings given in Section 2.3.1.

In addition, specific electricity consumption for the simulated model was obtained as 92.9 kWh/year/m^2. This lower figure obtained as a result of the four car parking floors of the building. As these parking floor does not consume electricity for receptacle equipment and space air conditioning, the overall energy consumption per unit floor area tend to take a lower value than expected. Once the area of the parking floors is removed from the calculation, a specific energy consumption of 163.8 kWh/year/m^2 was obtained, which is a more accurate figure for this type of commercial building. In addition, 163.8 kWh/year/m^2 figure is closely relatable to the benchmark developed by Sri Lanka Sustainable Energy Authority, which is 136.55 kWh/year/m^2 [9].

Table 33 represents the comparison between simulation model outputs and already established energy and electricity consumption breakdowns.

Table 33: Electricity breakdown comparison between simulated commercial building model and actual scenario

	Electricity breakdown			
	MVAC	**Lighting**	**Receptacles**	**Other**
Simulated model	49%	22%	14%	15%
Established breakdown [7]	48%	18%	21%	13%

Validation of the model – Case study 2 – A Retail Building

As the second case study, an energy simulation has been performed for one of the well-known retail buildings in the country. This is a primarily a food-retail building as majority of the building area is dedicated for the food outlets and food court. However, there are certain non-food retail stores located within the facility, which makes the building a combination of food and non-food retail components. Similar to the above case study, the building was modelled using actual building envelope and actual internal loads. Figure 46 shows the total energy breakdown of the simulated model.

Moreover, Figure 47 illustrate the total electricity consumption breakdown, as obtained from the simulation model.

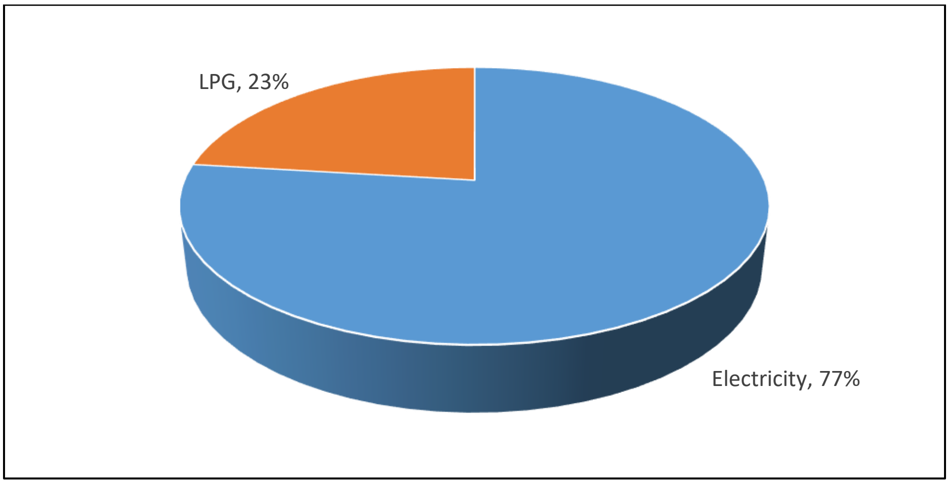

Figure 46: Energy consumption breakdown for simulated retail building model

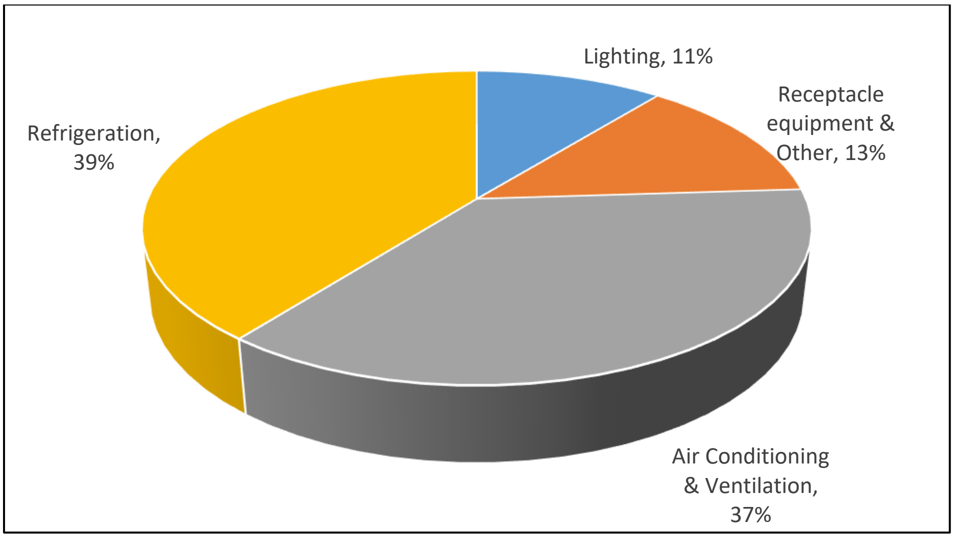

Figure 47: Electricity consumption breakdown for simulated retail building model

It was observed that these two breakdowns also relatable for the already established consumption patterns for retail buildings, which were discussed in Section 2.4.1.

Table 34 represents the comparison between simulation model outputs and already established energy and electricity consumption breakdowns.

Table 34: Energy and electricity breakdown comparison between simulated retail building model and actual scenario

	Energy breakdown		Electricity breakdown			
	Electricity	**LPG**	**Refrigeration**	**MVAC**	**Lighting**	**Other**
Simulated model	77%	23%	39%	37%	11%	13%
Established breakdown [16]	82%	18%	48%	20%	18%	14%

In addition to the energy and electricity consumption breakdowns, specific electricity usage and specific LPG usage have been obtained from the simulation model. Specific electricity usage was obtained as 488.2 kWh/year/m^2 and specific LPG usage was obtained as 146.5 kWh/year/m^2 (both per sales floor area). These two specific consumption values are somewhat less than the established benchmarks. The considered building has been designed to achieve a green certification; therefore, its internal systems were designed to operate efficiently than similar buildings. Consequently, lower specific consumption values can be predicted.

Validation of the model – Case study 3 – A 5-Star Hotel

Finally, as the third case study, a 5-star hotel located at Galle district was simulated. The hotel consists of 105 bedrooms, 3 main kitchens, 3 restaurants and 2 bars. Entire hotel is air conditioned using a centralized chilled water system. Also, the hotel has a hot water system with electric heat pumps. Similar to the previous two cases, the simulation was performed using the actual building envelope and actual internal loads.

Figure 48 shows the electricity consumption breakdown of the simulation model.

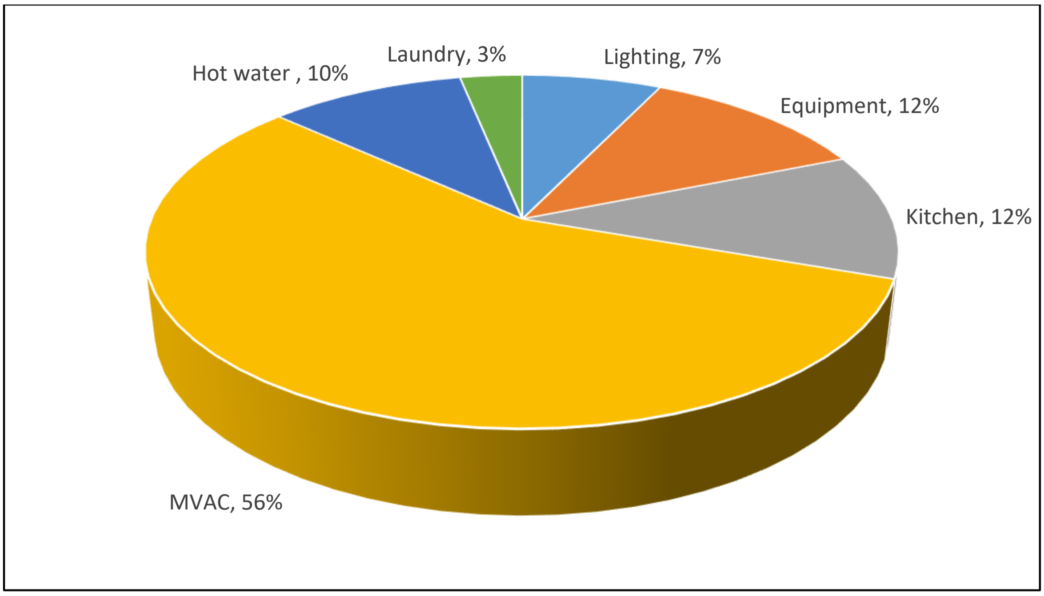

Figure 48: Electricity consumption breakdown for simulated hotel model

It is observed that, electricity consumption breakdown obtained through the simulation is relatable to the electricity consumption patterns discussed in Section 2.5.1.

Specific electricity consumption (or electricity usage intensity – EUI) was obtained as 197.25 kWh/m^2/year and 126.0 kWh/room night. These two values also closely related to the relevant benchmarks established for hospitality sector. Benchmark developed for 5-star hotels by Sri Lanka Sustainable Energy Authority is 137.4 kWh/room night, and the benchmark developed by Sri Lanka Tourism Development Board for 5-star hotels is 96.5 kWh/room night.

Table 35 represents the comparison between simulation model outputs and already established energy and electricity consumption breakdowns.

Table 35: Electricity breakdown comparison between simulated hotel building model and actual scenario

	Electricity breakdown					
	MVAC	**Hot water**	**Lighting**	**Other equipment**	**Kitchen**	**Laundry**
Simulated model	56%	10%	7%	12%	12%	3%
Established breakdown [23]	50%	Not specified	20%	7%	15%	8%

It was observed that, energy and electricity consumption patterns and specific energy consumptions of above discussed three models are closely related to the established benchmarks and consumption patterns of respective building sectors and proved that the modelling approach is accurate.

4.2.2 Results of the Simulated Supermarket Model in this study

Annual electricity consumption patterns obtained from the eQUEST Building Simulation Model is shown in Figure 49. In addition, Monthly electricity percentage breakdown and Annual average electricity percentage breakdown are shown in Figure 50 and Figure 51 respectively.

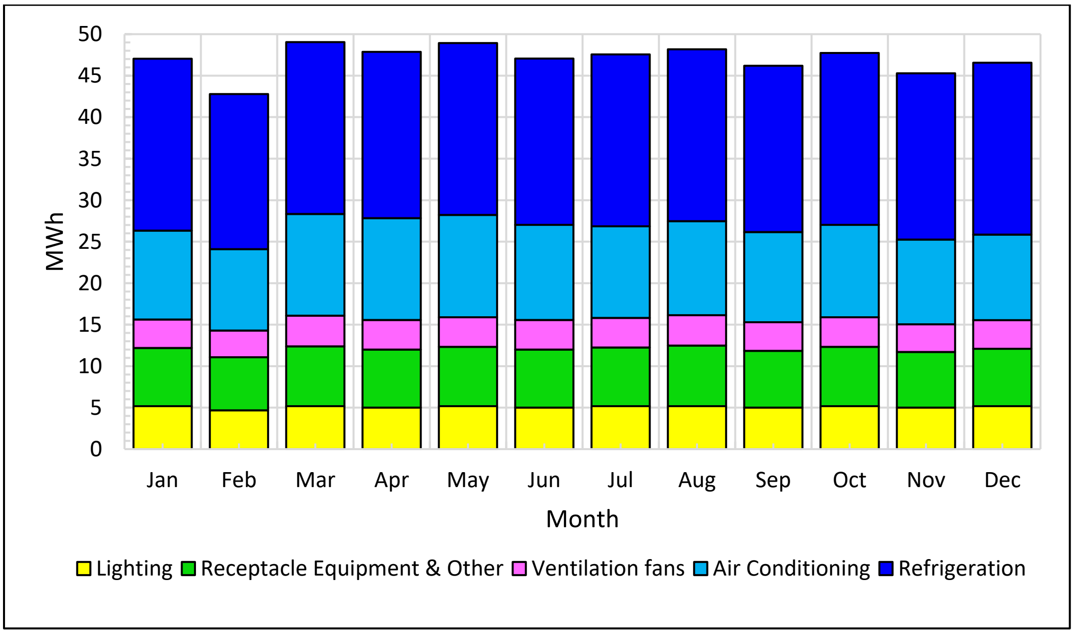

Figure 49: Simulation output - monthly electricity consumptions

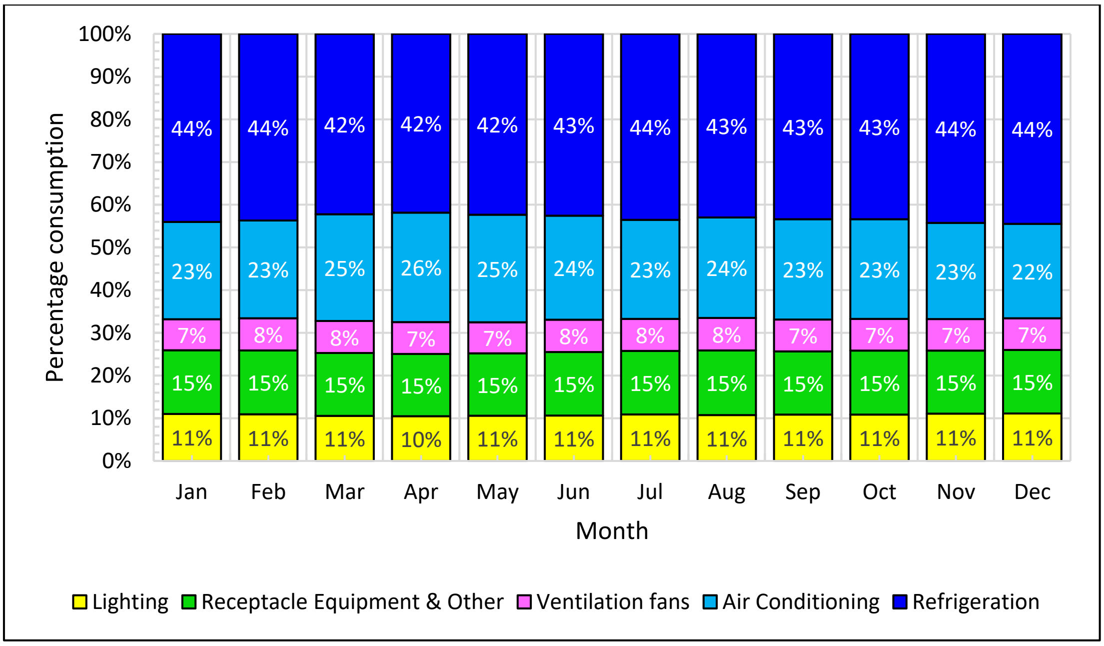

Figure 50: Simulation output – monthly electricity breakdown

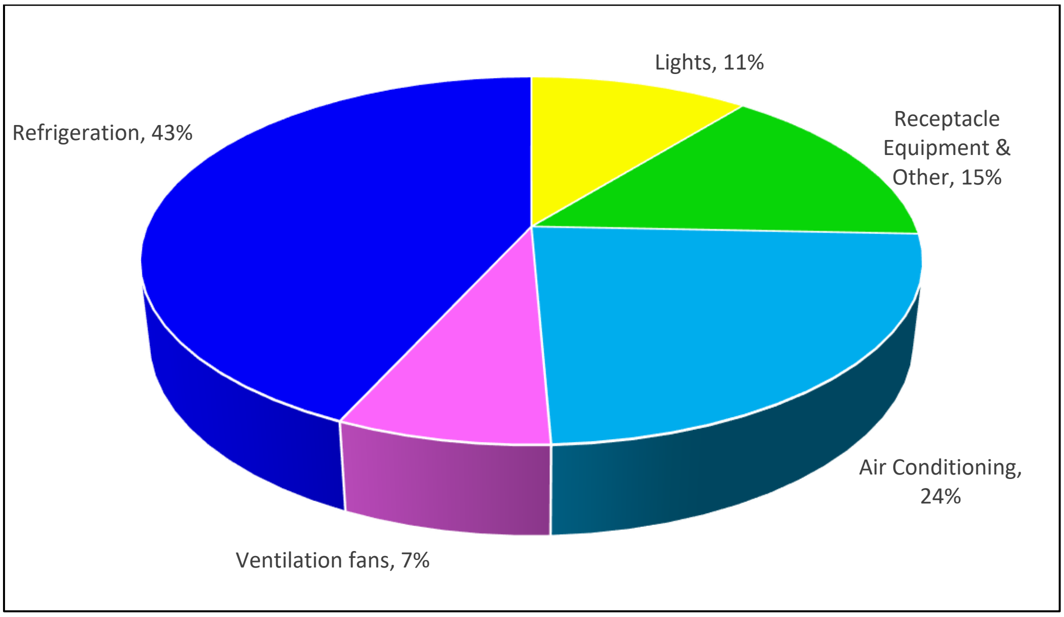

Figure 51: Simulation output – average annual electricity breakdown

According to the energy simulation, 43% of electricity is consumed by refrigeration systems, 31% of electricity is consumed by Air conditioning and Ventilation systems, 11% of electricity is consumed by the lighting systems and receptacles and other equipment consume about 15% of electricity. Therefore, it can be observed that, this end-use breakdown is closely related to the electricity consumption breakdown for food retail buildings, which was given in Figure 4.

Table 36 represents the comparison between simulation model outputs and already established energy and electricity consumption breakdowns.

Table 36: Electricity breakdown comparison between simulated supermarket model and already established data

	Electricity breakdown			
	Refrigeration	**MVAC**	**Lighting**	**Other**
Simulated model	43%	31%	11%	15%
Established breakdown [16]	48%	20%	18%	14%

Furthermore, the specific electricity consumption and specific electricity cost obtained from the simulation were compared with the benchmarks developed in this study (“Mean” column of Table 32). Table 37 illustrate the comparison of benchmarks obtained from energy simulation model with the benchmark obtained from numerical model in Section 4.1, and the actual consumption and cost figures for the simulated building. Electricity cost was calculated using the actual tariff rate for the building, which is GP 2 tariff structure from CEB. The conversion rate was assumed as 1 USD = SLR 198.00 on the date of the simulation.

Table 37: Results comparison - simulation model vs numerical model vs actual

	Benchmarks obtained from the Simulation model		**Benchmarks obtained from the Numerical model**		**Actual Consumption & Cost of the Simulated Building**	
	kWh/year/sqm	Rs/year/sqm	kWh/year/sqm	Rs/year/sqm	kWh/year/sqm	Rs/year/sqm
Per SFA	750.0	18,255.0	780.4	19,465.9	698.6	17,415.5
Per TFA	468.9	11,414.7	465.4	11,621.2	436.8	10,889.7

It can be observed that, energy simulation results are much closer to the developed benchmarks through numerical model, and higher than the actual consumption of the particular building. Actual consumption and simulated consumption can vary depending upon the variations of occupant loading inside the building. As explained in Section 3.3, occupancy was modeled using the assumptions considering the time of the day and the architectural standards for floor area per person. However, actual scenario cannot be predicted 100% accurately, where occupant loading can differ from the assumed conditions. In addition, actual operational diversities of internal loads such as MVAC systems also can cause differences between the actual results and simulated results.

However, it is observed that energy simulation results and actual results are closer to the developed benchmarks in Section 4.1. In fact, both simulation results and actual data of the considered building are within one standard deviation of the relevant benchmark figure.

4.3 Water Benchmarking Results

Similar to the electricity consumption analysis in Section 4.1, average annual water consumption was also plotted against TFA and SFA for analyzed 101 supermarkets. Unlike electricity, water consumption does not show a clear relationship with floor areas. The reason for this can be, water consumption depends upon the factors such as number of occupants, number of toilets and availability of cooking facilities, rather than the floor area. However, as explained earlier water consumption has been analyzed in “L/year/m^2”, due to the difficulties in tracking the number of occupants within the premises at a given time.

Figure 52 and Figure 53 show the variation of annual water consumption (in m^3) with sales floor area and total floor area respectively.

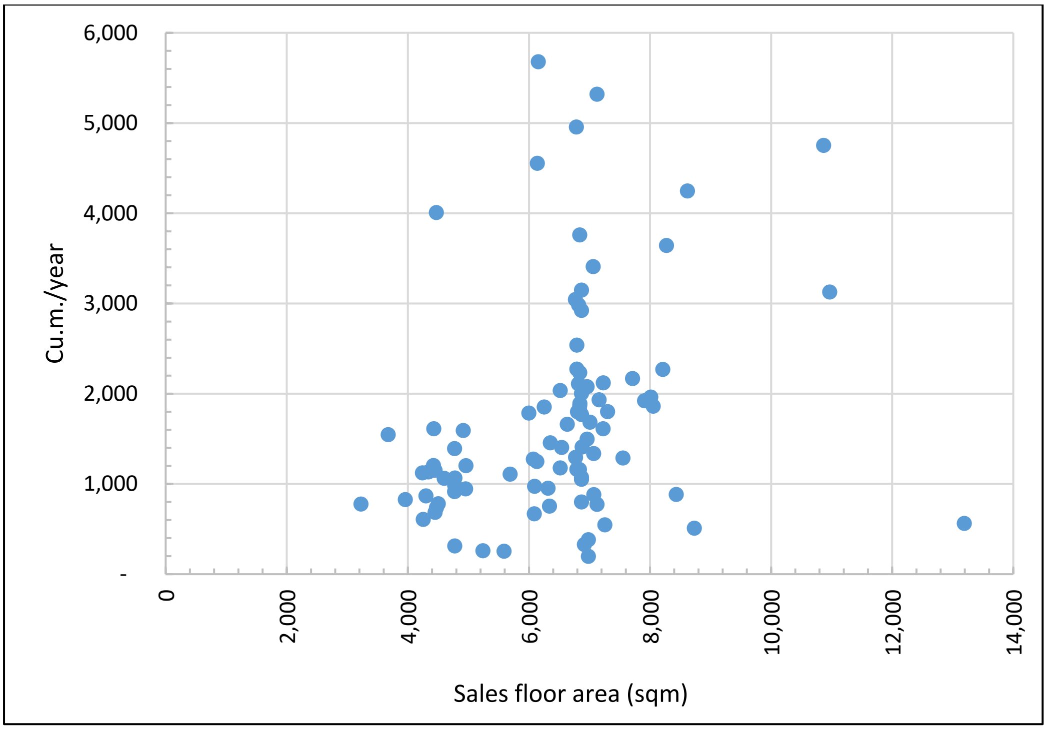

Figure 52: Variation of annual water consumption with SFA

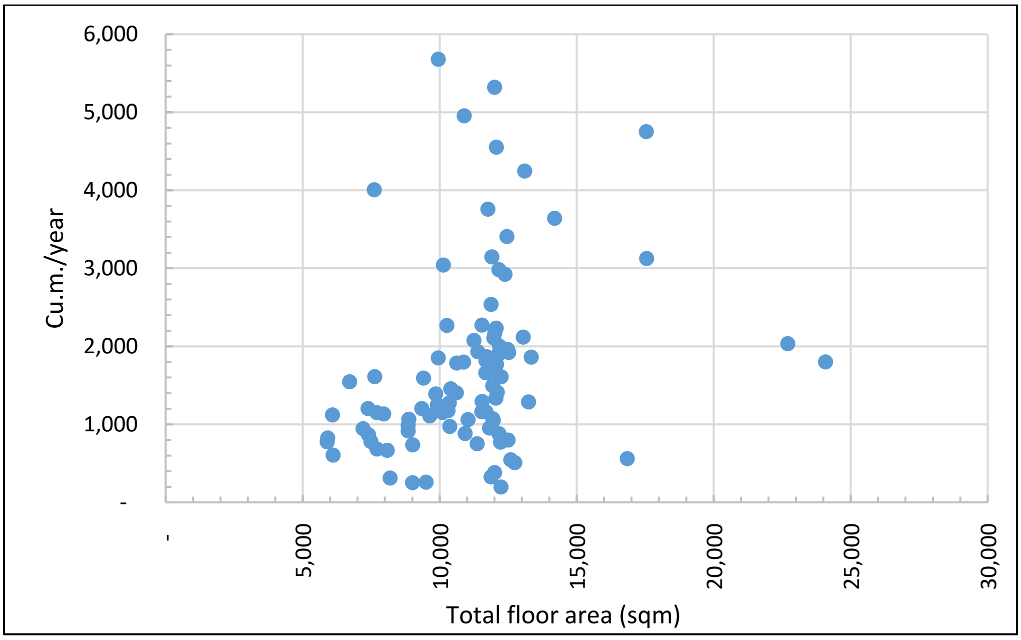

Figure 53: Variation of annual water consumption with TFA

Figure 54 shows the histogram for annual water consumption per sales floor area ("L/year/m^2 per SFA") for the analyzed supermarkets within the considered time frame. Similarly, Figure 55 shows histogram for annual water consumption per total floor area ("L/year/m^2 per TFA") for the analyzed supermarkets, within the same timeline.

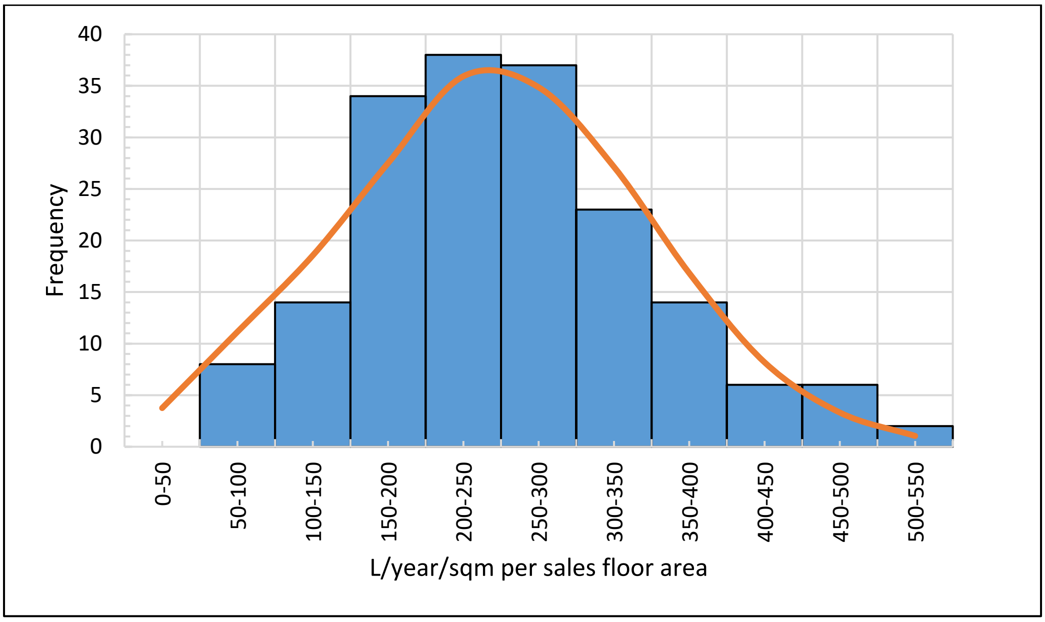

Figure 54: Specific water consumption (SFA) from 2018 to 2020

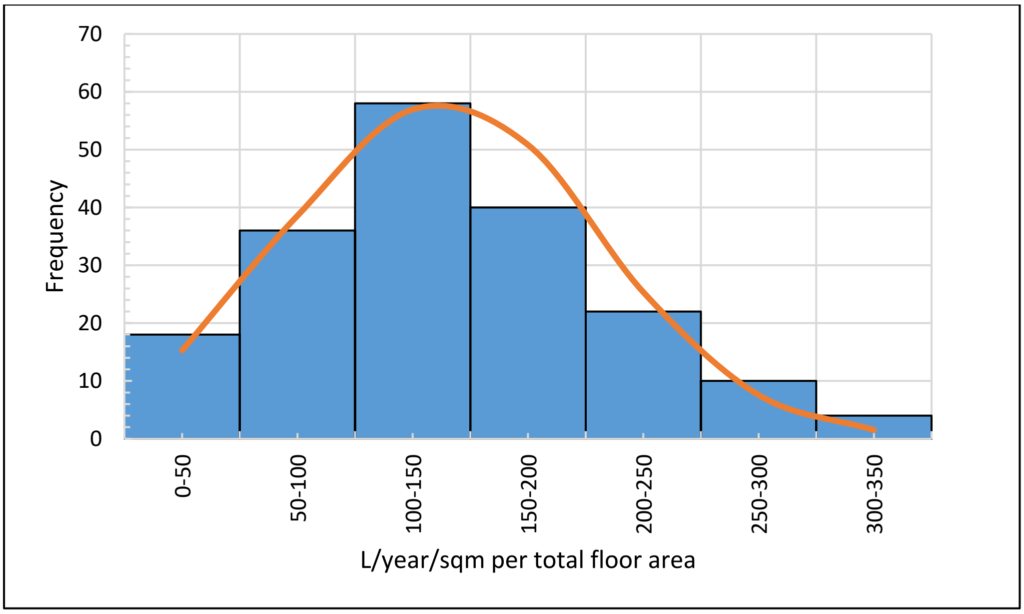

Figure 55: Specific water consumption (TFA) from 2018 to 2020

Summary of the obtained results are given in Table 38.

Table 38: Summary of Water benchmarking analysis

Parameter	Minimum	Maximum	Mean	Standard Deviation
L/year/m^2 per SFA	54	549	247	105
L/year/m^2 per TFA	16	324	137	67

CHAPTER 5

5 DISCUSSION

5.1 Electricity Consumption Analysis

Obtained benchmarks for electricity consumption in Section 4.1 can be compared with the established international benchmarks for the same building sector. There are two major institutions that have developed energy benchmarks for retail buildings in global scenario. US Environmental Protection Agency (US EPA) has developed benchmarks for the retail sector in USA and Canada, which are available at EnergyStar Portfolio Manager [30] and, benchmarks for UK retail sector have been defined by CIBSE Guide F [17].

Table 39 shows the above mentioned two major international benchmarks. Generally, USA benchmarks are presented in "BTU/ft^2/year" and here they have been converted into "kWh/m^2/year" for convenient comparison.

Table 39: International benchmarks for energy consumption of retail supermarkets

Benchmarking system	Building Type	Energy Consumption Benchmark per SFA (kWh/m^2/year)	Energy Consumption Benchmark per TFA (kWh/m^2/year)
EPA Energy Star (USA)	Supermarket	-	618.3
EPA Energy Star (Canada)	Supermarket	-	530.6
CIBSE Guide F	Supermarket	915.0	-

It is important to note that, the Energy Star benchmarks for USA and Canada have been developed considering the total floor areas. Moreover, Energy Star benchmarks usually represent the primary energy consumption including electricity, and natural gas.

Therefore, in order to compare Energy Star and Sri Lankan benchmarks, Energy Star benchmarks should be converted into electricity. According to the energy studies and audits conducted in USA, generally food-retail buildings use 82% electricity from the total energy consumption [16]. Therefore, USA benchmarks for electricity consumption can be simplified into 507 kWh/m^2/year, and Canada benchmark can be simplified into 435.1 kWh/m^2/year (per total floor area). Table 40 illustrate the comparison of the developed electricity benchmarks for Sri Lankan Supermarkets in Section 4.1, against the two major international benchmarking systems.

Table 40: Comparison of developed Sri Lankan electricity consumption benchmarks with Energy Star and CIBSE benchmarks

Benchmarking system	Electricity Consumption Benchmark per SFA (kWh/m^2/year)	Electricity Consumption Benchmark per TFA (kWh/m^2/year)
EPA Energy Star (USA)	-	507.0
EPA Energy Star (Canada)	-	435.1
CIBSE Guide F	915.0	-
Sri Lankan Benchmark (Developed in Section 4.1)	780.4	465.4

It can be observed that, the Electricity consumption benchmark per total floor area developed in Section 4.1, is closely related with the Energy Star benchmarks in both USA and Canada.

In addition, it can be observed that the benchmark per sales floor area developed in Section 4.1 is lower than the CIBSE benchmark, which is developed for UK supermarkets.

Figure 56 shows the comparison of the Sri Lankan benchmark developed in Section 4.1, and benchmark obtained from the simulation model with USA and Canada benchmarks (per total floor area). Similarly, Figure 57 shows the comparison of Sri Lankan benchmark developed in Section 4.1, and benchmark obtained from the simulation model with CIBSE benchmark (per sales floor area).

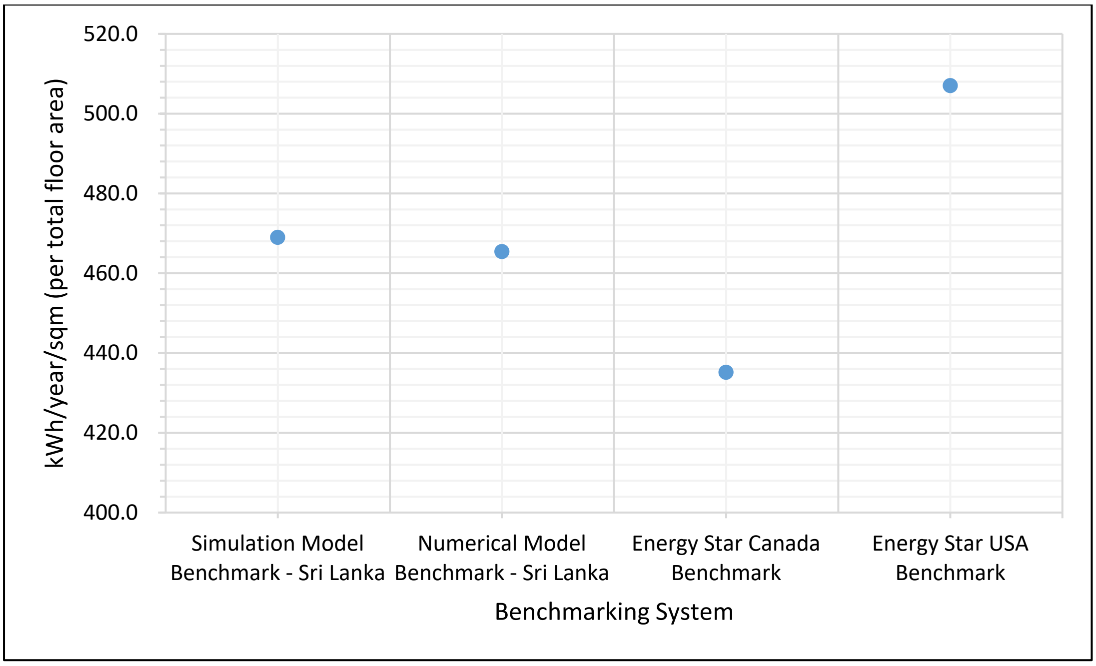

Figure 56: Comparison of simulation benchmark, numerical benchmark and Energy Star benchmarks for USA & Canada (kWh/year/m^2 per total floor area)

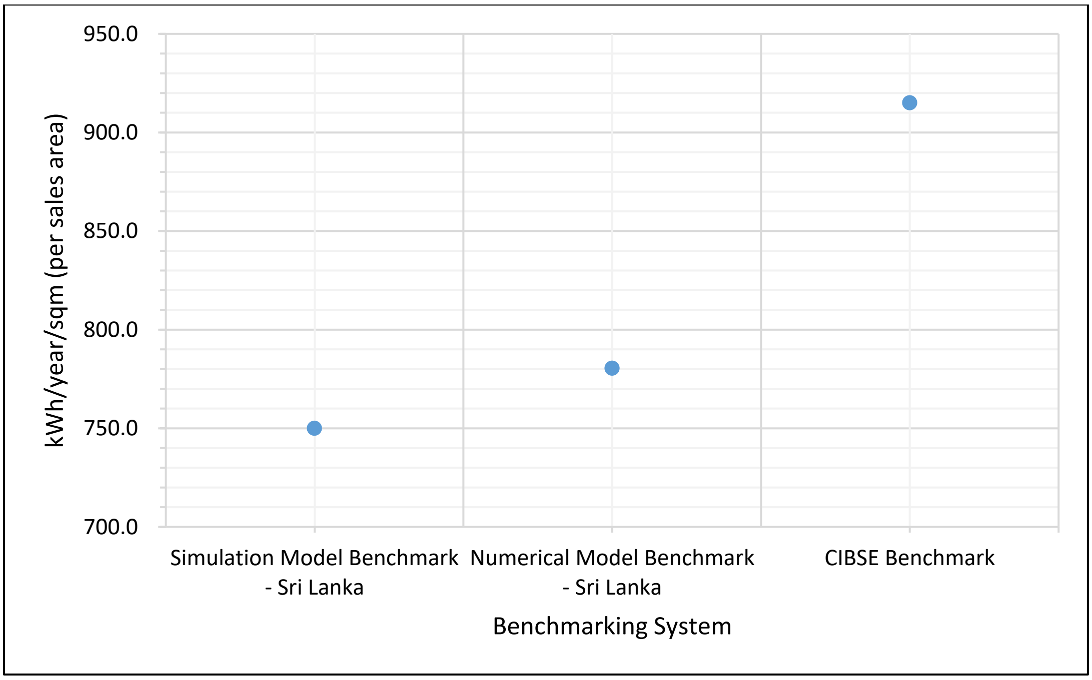

Figure 57: Comparison of simulation benchmark, numerical benchmark and CIBSE benchmark (kWh/year/m^2 per sales floor area)

There are certain similarities and differences can be observed in electricity usage patterns in retail supermarkets in Sri Lanka and other countries mentioned above, which are reflected through the developed benchmarks.

As shown in Figure 51, refrigeration systems consume 43% of total electricity in the simulated model of the local supermarket. Similarly, researchers and established benchmarking systems have shown that refrigeration takes up between 35-45% of electricity in supermarkets. Therefore, it can be observed that the refrigeration systems consume similar percentage of electricity at supermarkets located in any region. Moreover, in the simulated model lighting consumes 11% of the total electricity requirement. This is also related to the established electricity consumption patterns in other regions. The studies have shown that lighting consumption can take between 10-20% in food retail buildings.

However, air conditioning and ventilation systems show noticeable difference in electricity consumption. Space cooling of Sri Lankan buildings are normally supplied with active air conditioning systems powered by electricity, and space heating is not required in due to the hot and humid climatic conditions in the country. However, countries that encounter winter season have to use space heating in buildings in order to maintain interior thermal comfort. These countries use both space cooling and space heating throughout the year, whenever required. Very often, space cooling is provided by the active AC systems which consume electricity, and space heating is provided by burning natural gas or LP gas. In addition, most of these countries implement setback cooling during unoccupied hours. Consequently, it is extremely difficult to predict the electricity percentage consumed for cooling, without sub-metering or energy modelling. Therefore, electricity consumption of air conditioning systems of supermarkets in Sri Lanka and other regions do not necessarily relate to each other.

5.2 Water Consumption Analysis

Water consumption benchmarks have been developed for the retail sector mainly in USA, Singapore and Australia. Table 41 shows the aforementioned water consumption benchmarks for retail sector, developed in other countries.

Table 41: International benchmarks for water consumption in retail sector

Country	Retail Type	Benchmarks
USA [19]	Food Retail	48.8 L/meal
Singapore [20]	Shopping malls (excluding sanitary usage in toilets)	1300 L/year/m^2 $_{TFA}$
	Shopping malls (only sanitary usage in toilets)	2.6 L/person/day
Australia [21]	Retail centers	560 L/year/m^2 $_{TFA}$

It can be observed that, none of these benchmarks cannot be directly compared with the Sri Lankan benchmarks developed in Section 4.3. USA benchmark has been developed for food retail outlets, where the benchmarks has been defined in terms of number of meals served. However, in Sri Lankan supermarkets, not all the outlets serve cooked meals. Therefore, Sri Lankan benchmarks are not defined in terms of number of meals.

Moreover, Singapore benchmarks are developed for shopping malls. These malls include large restaurants, supermarkets and other non-food retail outlets such as clothing stores, cinemas, etc. Water consumption of these malls are expected to be much higher than the supermarkets alone. Benchmarks for Singapore shopping malls are presented in two ways. First benchmark is given in terms of total floor area. However, this benchmark does not include the sanitary water usage in toilets. Other end-uses such as cooking purposes, air conditioning and cleaning are included in the first benchmark, which is 1,300 L/year/m^2 per total floor area. Second benchmark is given for sanitary usage only. This is given as 2.6 L/person/day, as sanitary usage depends on number of people rather than the floor area of the building. However, water usage for supermarkets alone cannot be extracted from either of these figures. Therefore, Singapore benchmarks also cannot be directly compared with the benchmarks developed in Section 4.3.

Similar to the Singapore scenario, Australian benchmarks are also developed for Retail Centers, that include both food and non-food retail outlets. However, Australian benchmarks is given as 560 L/year/m^2 per total floor area, which is considerably less than the Singapore benchmark. However, this also cannot directly be compared with the Sri Lankan benchmarks.

CHAPTER 6

6 CONCLUSION

During the literature review, it was found out that benchmarking of energy and water consumption of Sri Lankan retail supermarkets is a least studied area. Therefore, it was decided to develop electricity and water consumption benchmarks for the sector. Data was collected from 101 supermarkets which has been analyzed during this research study.

Developed electricity benchmarks are 780 kWh/year/m^2 per sales floor area and 465 kWh/year/m^2 per total floor area. It can be concluded that both these figures for electricity benchmarks can be related to the international benchmarks of the sector. Similarities and differences of these local and international benchmarks were discussed in Section 5.1. It was found that refrigeration systems consume about 40-50% and lighting systems consume about 10-20% of electricity in supermarkets in Sri Lanka and other countries. However, air conditioning systems in supermarkets have major differences between Sri Lanka and other countries.

Water consumption benchmarks have been developed in terms of sales and total floor areas, similar to electricity benchmarks. Developed benchmarks are 247 L/m^2/year in terms of sales floor area and 137 L/m^2/year in terms of total floor area. It was found that, water consumption benchmarks developed for Sri Lankan supermarkets cannot be compared directly with the international benchmarks available for the sector. The reason for this is, most of the international benchmarks for water consumption in retail sector have been developed for Retail malls or shopping malls, that include both food retail and non-food retail components. Hence, water consumption benchmarks for supermarket alone cannot be extracted from these benchmarks. Therefore, they cannot be compared with the aforementioned Sri Lankan benchmarks developed for supermarkets.

It is recommended to review and update the developed benchmarks at least every five years.

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ANNEXURE 1

Building material schedules for energy simulation models

Simulation Model	Building Envelope Component				
	External wall envelope	**Roof envelope**	**Floor envelope**	**Internal wall envelope**	**Fenestration**
Commercial building model	Cement mortar Brick layer Cement mortar	RCC roof	Concrete slab Ceramic tile adhesive Flooring tiles	Cement mortar Brick layer Cement mortar	Efficient double glazed windows
Retail building model	External cladding Thermal insulation Steel structure Internal finishing board	Roofing sheet Supporting bars Thermal insulation Linear sheet (Inner) Steel structure	Concrete slab Ceramic tile adhesive Flooring tiles	Cement mortar Brick layer Cement mortar	Laminated glazing
Hotel model	Cement mortar Brick layer Cement mortar	Clay roofing tiles Supportive roofing structure	Concrete slab Ceramic tile adhesive Flooring tiles	Cement mortar Brick layer Cement mortar	Single glazed windows
Supermarket model	External cladding Thermal insulation Steel structure Internal finishing board	Roofing sheet Supporting bars Thermal insulation Linear sheet (Inner) Steel structure	Concrete slab Ceramic tile adhesive Flooring tiles	Internal partition boards Partition supportive structure	Laminated glazing