POTENTIAL FOR PROMOTION OF DEMAND SIDE MANAGEMENT THROUGH A MARKET BASED APPROACH

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Degree of Master of Science

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University of Moratuwa
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May 2016

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering

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DECLARATION OF THE CANDIDATE & SUPERVISORS

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ACKNOWLEDGEMENTS

First of all my gratitude is towards my two supervisors, Professor J. P. Karunadasa and Dr. Tilak Siyamabalapitiya, who guided me throughout my thesis work, in spite of their busy schedules.

Also I would like to extend my gratitude to all the lecturers of Electrical Engineering Department, University of Moratuwa for the guidance provided by them to improve my thesis, with their valuable comments.

My gratitude also given towards Deputy General Manager Eng. K.M.K. Perera, Deputy General Manager Eng. R.A.A.S. Seneviratne, Deputy General Manager N.W. Kumarasinghe and Chief Engineer R.M.S.K. Gunatilake from Ceylon Electricity Board for all the support given to me to complete my research successfully.

I would also like to appreciate my colleagues K.H.G.S. Jayaneth, D.M.D.K. Dissanayake, A.M.G.H.S.B. Abeysinghe for the motivation given to me complete my research work.

Finally, I owe my gratitude to my parents, my husband and my little son for their endless support and encouragement and without them I would not have come this far.

ABSTRACT

Today with the developments of technology, expansion and developments in industries and increase in the standard of living of the society, the demand for electricity keeps rising every day. It is the responsibility of the utility to increase its supply to meet this demand in order maintain the demand supply balance. It is not always economical to meet this increasing demand by building new power plants. Hence today, more interest is shown towards controlling the demand, through Demand Side Management (DSM).

In this thesis, several customer categories were first studied in order to identify the potential DSM options that can be implemented. The selected option was Thermal Energy Storage in buildings, by constructing storage tanks to store chilled water during the off-peak tariff period, and using the stored chilled water to meet the peak-time cooling demand. The technical potential for savings that can be obtained through applying this technology in Sri Lankan context is analyzed, and the potential saving that can be achieved in the General Purpose and Hotel category customer group is calculated.

DSM projects should ideally be a win-win option to the economy, the utility and the customer. The potential benefits of thermal energy storage, to the three parties expected to benefit are separately analyzed in this study.

The results of the thesis is that Chilled Water Storage technology is a viable DSM project in Sri Lanka. It is the responsibility of the Utility to actively market it to its customer base and motivate them to participate in the project. This also requires the utility intervention to make this project more attractive to its customers through providing part of the investment cost. The effect of the customer payback period is also studied.

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LIST OF ABBREVIATIONS

Abbreviation	Description
BST	Bulk Supply Tariff
CEB	Ceylon Electricity Board
CWS	Chilled Water Storage
DL	Distribution Licensee
DSM	Demand Side Management
FOM	Figure of Merit
GP	General Purpose
GV	Government
H	Hotel
I	Industrial
IPP	Independent Power Producer
IRR	Internal Rate of Return
kVA	kilovolt Ampere
kW	kilowatt
kWh	kilowatt hour
LECO	Lanka Electricity Company
PUCSL	Public Utilities Company Sri Lanka
RT	Ton of Refrigeration
SPP	Small Power Producer
TES	Thermal Energy Storage
TL	Transmission Licensee
TOU	Time of Use
UNT	Uniform National Tariff

Chapter 1

1 INTRODUCTION

1.1 Background

The demand for electricity originates at the customer end, and Ceylon Electricity Board (CEB), the utility, needs to match this demand with its supply. As demand increases, it requires the utility to dispatch its high cost plants to match the demand increase. Since the power plants are dispatched in order of ascending marginal cost, energy from the plants that come online to meet the system peak is the most expensive. In addition, the utility has to possess adequate capacity to meet the varying peak demand, which requires the utility to pay for ongoing availability of peaking plants that may only be dispatched for a few hours per day or month [1]. The sharp evening peak in the Sri Lanka load profile justifies the analysis and implementation of DSM in the country.

1.2 Sri Lankan Power Sector

Public Utilities Commission Sri Lanka (PUCSL) is the regulator in the electricity sector. It has issued licenses for generation, transmission and distribution. Generation licenses are held by CEB, Independent Power Producers (IPPs) and Small Power Producers (SPPs). CEB is the transmission licensee (TL).

The transmission licensee dispatches power plants, buys from power plants and sells electricity to the distribution sector. Five licenses have been issued for the distribution sector and four of them are owned by CEB and the other license is owned by Lanka Electricity Company (LECO). The five Distribution Licensees (DLs) maintain the respective distribution networks and supply services to customers.

The five DLs are significantly different to each other in terms of their customer mix and sales volumes. However, electricity is sold to all the customers in the country at a Uniform National Tariff (UNT) by all the five DLs. If the Bulk Supply Tariffs (BST) for the sale of electricity by the TL to DLs is fixed, then DLs would be required to sell electricity to their customers at non-uniform rates. To enable DLs to sell at the same UNT, the national average BST is adjusted ex-ante as well as ex-post, to reflect the forecast and actual sales of each DL. Results of these adjustments are given in Table 1.1. The adjustments allow each DL to recover their allowed revenue for the distribution (wires) and supply business. The business of purchase of energy from the TL and sales to customers is thus a revenue-neutral activity to each DL.

Presently, the DLs do not carry any market risk. This policy also means that DLs do not need to “market” electricity, including the promotion of nationally important requirements such as DSM.

Table 1.1: BST from TL to each DL effective from 1st July 2015 [10]

Licensee	Day (LKR/kWh)	Peak (LKR/kWh)	Off Peak (LKR/kWh)	Capacity Tariff (LKR / MW. month)
DL 1	8.71	10.98	6.48	2,713,469
DL 2	6.40	8.07	4.76	2,713,469
DL 3	5.82	7.34	4.33	2,713,469
DL 4	6.40	8.07	4.76	2,713,469
DL 5	10.73	13.52	7.97	2,713,469

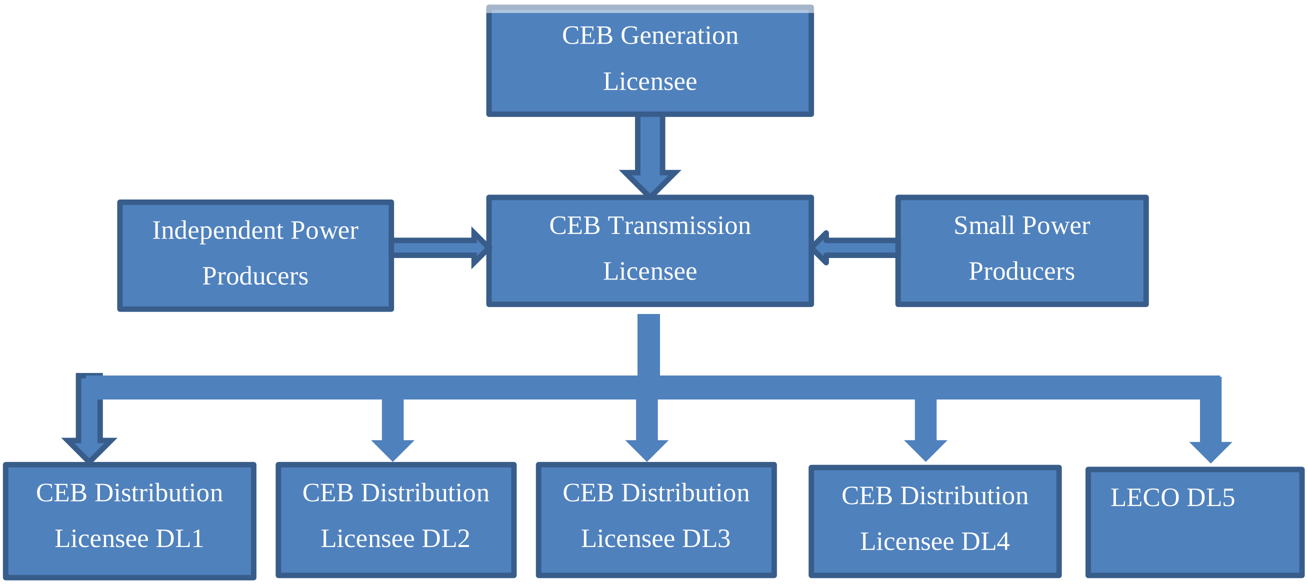


Figure 1.1 : Sri Lankan Power Sector

1.3 Demand Side Management (DSM)

DSM is the range of activities that a utility does in order to create desired changes in the utility's load curve, by influencing the manner in which its customers use electricity [2]. DSM can be achieved through energy efficiency by reducing energy consumption or by managing the demand itself. Through DSM measures, customers are encouraged to restrict their consumption during the peak time, when the grid is stressed. This allows the utility to dispatch a lower generation capacity and use peaking plants less often. [1]. DSM does not necessarily reduce the total energy used by the customers, but through effective DSM, it can be expected that it will reduce the need to invest in power plants and network expansions to meet the peak demand [2].

1.4 DSM Planning Procedure

The process of planning and implementation of DSM programmes generally consists of the steps shown in figure 1.2. This planning procedure will change depending on the requirements of the utility. [4]

1.4.1 Develop end-use demand forecast

The utility should have a clear picture on how its demand will grow through the years, in order to identify its requirement to increase the supply to be matched with the growing demand. This will help the utility to identify whether it is required to build more power plants to meet the demand or whether the investment can be delayed for a few years through effective implementation of DSM. [4]

1.4.2 Identify end-use patterns and market barriers

The next step in the DSM planning process is to identify the electricity consumption pattern of the customer, how the customers are responding to DSM measures already implemented by the utility, and what kind of barriers exist that prevents the customers from adopting DSM measures. Load research can be conducted through analyzing customer billing data, load profile information available in their smart meters and through customer surveys. [4]

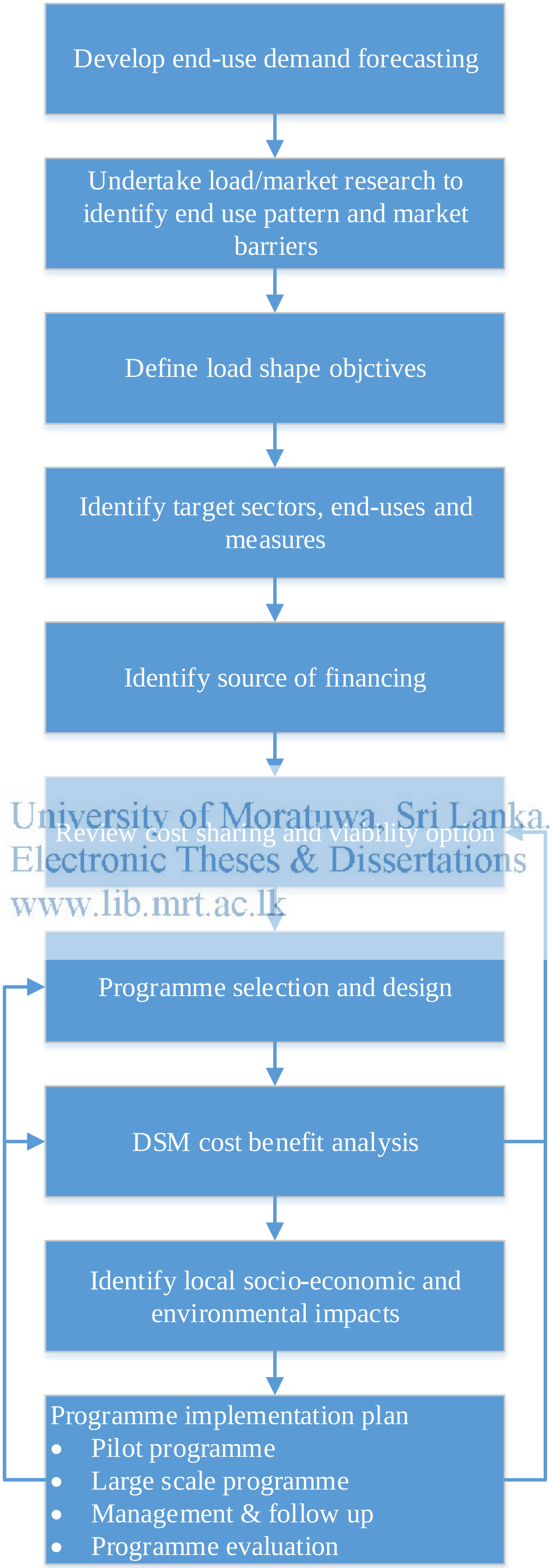


Figure 1.2: DSM planning procedure [4]

1.4.3 Effect on the load shape through DSM

Through DSM measures the following changes are typically expected to be made to a utility's load curve.

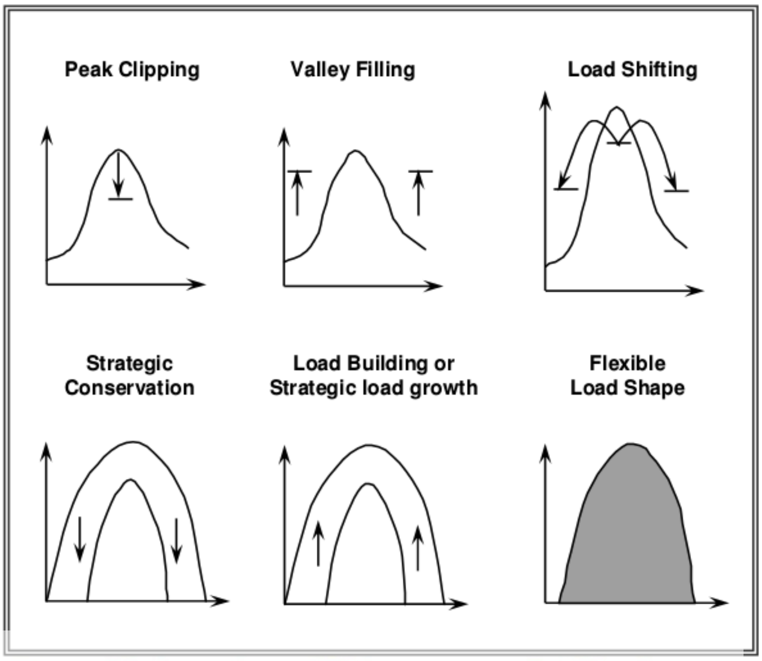


Figure 1.3: Load shape objectives of DSM [3]

- Peak Clipping – Peak clipping is the reduction of peak load. This is generally done by the utilities through directly controlling its customer-load. This is done with the purpose of reducing peak demand in order to reduce capacity cost of the peak, reduce the operating cost of power stations and dependence on critical fuels by economic dispatch [2]. As a result of peak clipping, peak demand as well the total energy consumption will reduce.

- Valley Filling – The purpose is to increase the off peak loads. This is useful in the Sri Lankan context since a larger portion of the off peak load is served by the coal power plants operating at a reduced load, and by increasing the off peak load, the plants can be operated at a higher load and at a higher efficiency at a lower costs. This will increase the system load factor. Valley filling can be achieved by adopting many methods out of which thermal energy storage is one of the most popular methods [2]. Another method of valley filling is through charging of electric vehicles during the off peak period when the utility is not required to generate as much power as during the day time.

- Load Shifting – Through this strategy it is intended to shift the load from the on-peak to the off-peak periods. This does not significantly change the total sales of the utility. Thermal energy storage is a strategy that can be used for valley filling as well as load shifting. This allows the customers to store chilled water or ice during the off peak period and this stored thermal energy is utilized in the peak period. [2]
- Strategic Conservation – Through strategic conservation, the utility's entire load shape is targeted to be reduced. In adopting energy conservation, the utility has to consider what activities of conservation will occur naturally and evaluate the cost-effectiveness of these activities and encourage these activities [2]. Examples of strategic conservation are appliance efficiency improvement, time of use rates, etc.
- Strategic Load Growth – The purpose of this DSM method is to increase the utility overall sales, by motivating its customers. This may mean increase in the electricity usage due to introduction of new appliance to the market (electric cars, industrial process heating, microwave technologies, automation)
- Flexible Load Shape – This concept may be conveniently perceived as a load-shape change [4]. This method is used to address problems with demand forecasts. Since it is difficult to guarantee a balance between the generation capacity and the customer demand, utilities ensure that they can curtail the customer demand, if the need arises, in exchange for various incentives. During the period of curtailment, the customer has to produce their own electricity requirements [3].

1.4.4 Identify target sectors, end-uses, and measures

The utility can target on DSM programmes that will bring the largest benefit to the utility and target on a group of customers that have large electricity consumption and that can achieve higher savings in the peak time [4]. In Sri Lankan context, the hotel sector will cause higher benefit over the general purpose sector customers, because they will be able to make a peak time energy saving, while the GP customers can only make a day time energy saving since they do not generally operate in the off peak period.

1.4.5 Identify sources of financing

In any DSM project, financing is required for implementation of the project. Sometimes it may not be feasible only for the customers to bear the investment. In this case, the utility may have to intervene and provide the required financing to cover administrative costs and even share the investment.

1.4.6 Review cost sharing and viability options

The sharing of costs in DSM should be in a way that it is viable to all the parties that are involved (customer, utility and society). If the current tariffs are below the marginal cost of new power supply options, it is financially viable for the utility to share the cost of DSM technology in order to maximize the number of customers participating in the project. If the environment cost of power supply is higher than the average cost, then the government (society) can contribute by providing tax incentives and financial support. [4]

1.4.7 Programme selection and design

In this process, the identified group selected in step 4 is analyzed to identify the DSM programmes that can be adopted to the target group. Once the DSM measures are identified, an in-depth evaluation should be conducted to identify their cost benefit ratios.

1.4.8 Cost /benefit analysis of DSM

DSM is the activity that should be beneficial to three parties. That is the customer, the utility and the economy.

Benefit of DSM to the customer

- Mainly the customer will benefit through reduction in their electricity bill.

Benefit of DSM to the utility

- DSM may allow the utility to avoid investment in generation, as well as transmission and distribution upgrades.

- Reduction in cost of meeting total energy demand by reducing peak time energy demand through reducing the need to dispatch high cost plants.
- Ability to deliver electricity to its customers more economically.
- Reduction in the need to invest on new power plants.
- Improving reliability and quality of power supply.
- Reduction in the risk of power shortages.
- Allow increased generation efficiency and reduction in fuel bills.

Benefit of DSM to the economy (society)

- Avoided capital cost on construction of new power plants or development of the network, can be utilized for another cause.
- Reduction in greenhouse gas emissions.
- Reduce the dependency of the economy on foreign energy sources.

The following are the basic cost components of the DSM measure.

- Technology Costs - The incremental cost of the DSM technology
- Transaction Costs - The administrative and other costs of running the programme
- Financing Costs - The cost of financing the DSM technology [4]

1.4.9 Identify local socio-economic and environmental impacts

Most of the DSM technologies indirectly derive economic and environmental benefits on top of its direct benefit of shifting of peak-time energy use. Indirect benefits such as reduction in emissions, and other impacts of power supply facilities, customer savings reinvested in other goods and services, creation of jobs in other service industries can be derived. The investment costs that the utility will be saving or being delayed through delaying the establishment of a new power plant, can be used to make improvements in the existing network [4].

1.4.10 Programme implementation plan

The programme implementation plan requires the utility to develop a suitable DSM programme through identifying its customers' demand pattern and processes, and properly market the DSM strategy to its relevant customer group to maximize the participation and manage its implementation.[4]

1.5 DSM Initiatives Taken by the Sri Lankan Utility

In Sri Lankan context, DSM is not actively marketed by the utilities among its customers. Some DSM measures are embedded in the current tariff structure. This is a passive approach taken by the utility, and the features of the tariff structure are not marketed to the customers by the utility in order to maximize customer participation. The following DSM features are embedded to the Sri Lankan tariff system,

- Time of Use (TOU) tariff implemented for the bulk supply customers.
- Maximum demand charge imposed on bulk supply customers.

Table 1.2: Distribution tariff for non-domestic customers (effective from 15 November 2014)

Tariff Category	Unit	Unit Charge (LKR/kWh)			Fixed Charge (LKR/Month)	Demand Charge (LKR/kVA)
		Peak (1830hr - 2230hr)	Off-Peak (2230hr-0530hr)	Day (0530hr-1830hr)		
General Purpose						
GP-1 <42 kVA	< 211 units	18.30			240.00	-
	> 210 units	22.85			240.00	
GP-2	-	26.60	15.40	21.80	3,000.00	1,100.00
GP-3	-	25.50	14.35	20.70	3,000.00	1,000.00
Industrial Purpose						
I-1 <42 kVA	< 301 units	10.80			600.00	-
	> 300 units	12.20				
I-2	-	20.50	6.85	11.00	3,000.00	1,100.00

I-3	-	23.50	5.90	10.25	3,000.00	1,000.00
Hotel Purpose						
H-1 <42 kVA	-	21.50			600.00	-
H-2	-	23.50	9.80	14.65	3,000.00	1,100.00
H-3	-	22.50	8.80	13.70	3,000.00	1,100.00

1.6 Identification of the Problem

Under the current tariff methodology, distribution utilities have no motivation to promote DSM among its customer base to reduce the peak demand and to shift demand to off-peak periods. Objectives of DSM and features of the tariffs that promote DSM are not "marketed" by the utility except providing some general advice to customers who contact the utility for support. This affects the economy because larger investments and operating costs are incurred to generate electricity during peak hours, while DSM measures embedded in tariffs are not marketed by the utility.

1.7 Research Objectives

The objective of this research is to identify the potential demand savings that can be achieved through active marketing of DSM to the Bulk Supply customers of CEB.

Following are the actions to be carried out in the study,

- Identify the customer groups that have the potential for adopting DSM saving options.
- Identifying what DSM options can be adopted to this group.
- Generate a model to calculate the potential savings that exists in these groups.
- Calculate the financial savings to the customer, utility and the society (economy).
- Conduct a financial feasibility study for the DSM project identified.

1.8 Organization of the Thesis

After this introductory chapter, chapter 2 provides an analysis of the consumption patterns of different customer categories. This analysis is conducted to identify and filter out the group where the potential for DSM exists. Four main sectors tea industry, ceramic industry, office buildings and hotels were selected for the analysis. Chapter 3 covers the TES technologies available and is analyzed to identify the best TES technology for the study. In chapter 4 a technical evaluation is conducted on Chilled Water Storage (CWS) DSM option and the potential savings that can be obtained from this method are calculated. Chapter 5 presents of the financial viability and the feasibility of the results obtained in chapter 4. The final chapter provides conclusions and recommendations based on the results.

2 CUSTOMER BEHAVIOUR ANALYSIS

In order to identify the customer behavior and their potential for DSM, four case studies were conducted selecting four customer categories. Their response to the already implemented TOU tariffs is also to be studied. A site visit was done selecting one customer from category 1 and 2, in order to identify their specific consumption patterns.

2.1 Case Study 1: Tea Industry

Six factories operating in the tea industry were selected for the case study and their consumption pattern on a typical day over the 24 hour period, and their power factor were considered for the study.

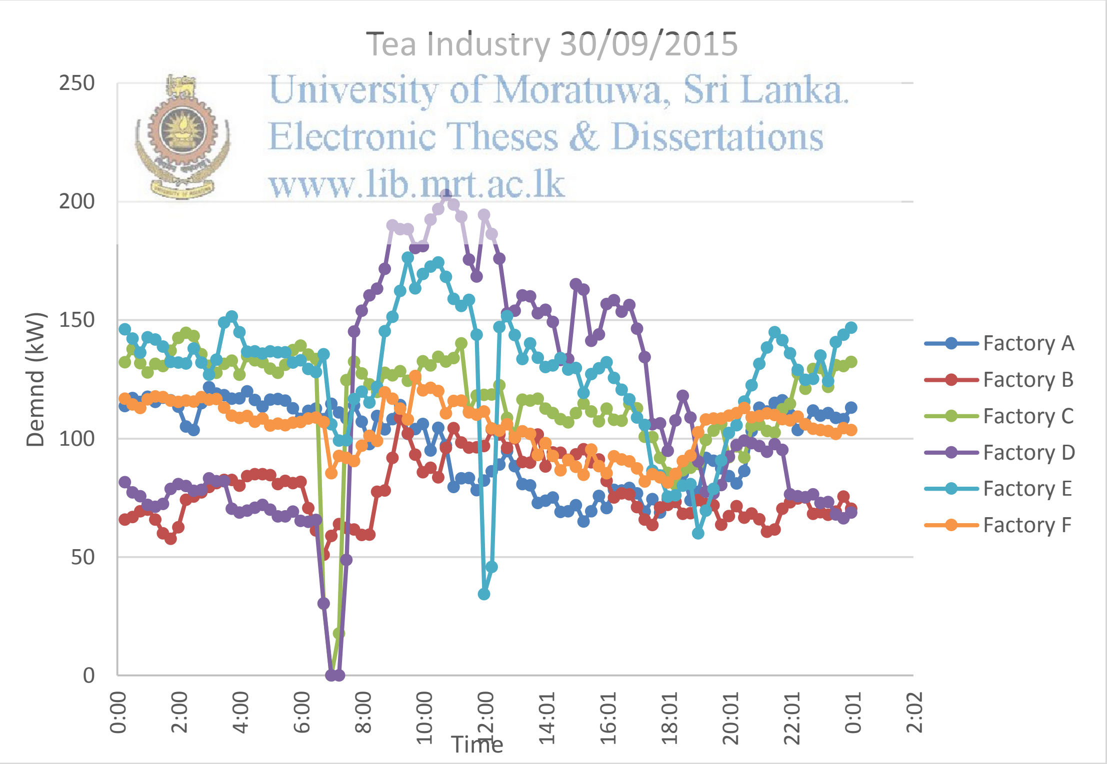


Figure 2.1: Load Profiles of Tea Industries

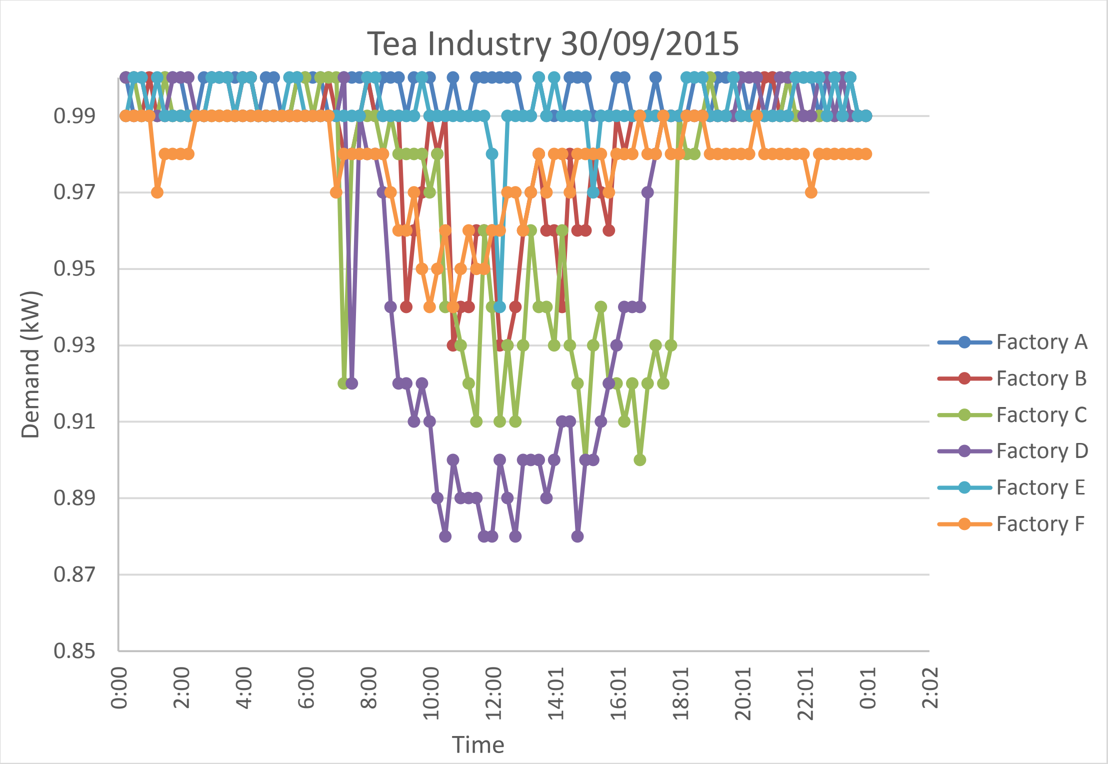


Figure 2.2: Power Factor of Tea Industries

2.1.1 Factory visit to Factory F

A factory visit was made to Factory F, to identify the normal operations of the factory and identify the potential saving options that exist in the tea industry. The manufacturing process in the tea industry is as follows.

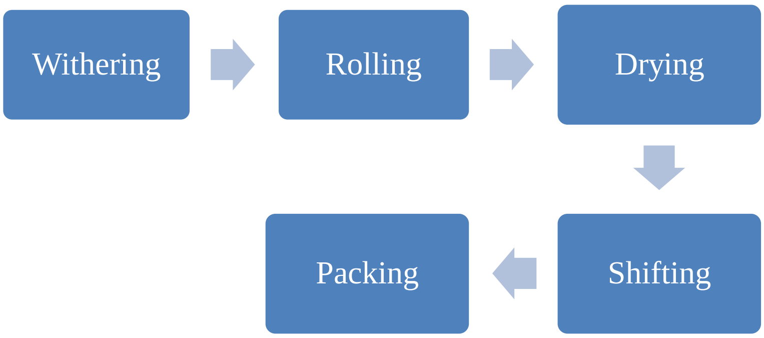


Figure 2.3: Manufacturing Process in the Tea Industry

Table 2.1: Equipment used – Tea Industry

Equipment type	No being used	Capacity (kW)	Capacity (HP)	Operating Hours
Trough	9	3.73	HP 5	24 hrs
	13	2.24	HP 3	24 hrs
Roller	7	14.91	HP 20	8 am – 5 pm
Conveyor	7	11.19	HP 15	8 am – 5 pm
Dryer	1 (2 available)	18.64	HP 25	9 am – 6 pm
Shifting machines				
Milton	3	0.74	HP 1	24 hrs
Michi shifter	8	1.5	HP 2	24 hrs
Winover	3	4	HP 5.5	24 hrs
Colour separator	3	1.11	HP 1.5	24 hrs

Figure 2.4: Withering process done through troughs

Figure 2.5: Rolling process done through rollers and conveyers

Figure 2.6: Drying process done through dryers

Figure 2.7: Separation done through shifting machines

2.1.2 Observations

The following observations were made from the studying their consumption pattern, manufacturing process;

- Almost all the customers are responding to the TOU tariff and have reduced their consumption during the peak time interval (6.30 pm – 10.30 pm)
- The main reason may be because the tea industry is running at a low profit margin and the energy cost savings at the peak time will reduce their production cost.
- This will be a motivating factor for the tea industry to reduce their peak demand.
- Some customers are maintaining a good power factor, but some customers still need to improve their power factor.
- Since the customers have already responded to the TOU tariff, there is not much potential to implement DSM further.
- Hence the tea industry is not considered further in this thesis.

2.2 Case Study 2: Ceramic Industry

Four ceramic factories were selected for the case study and their consumption pattern on a typical day over the 24 hour period and their power factor were considered for the study.

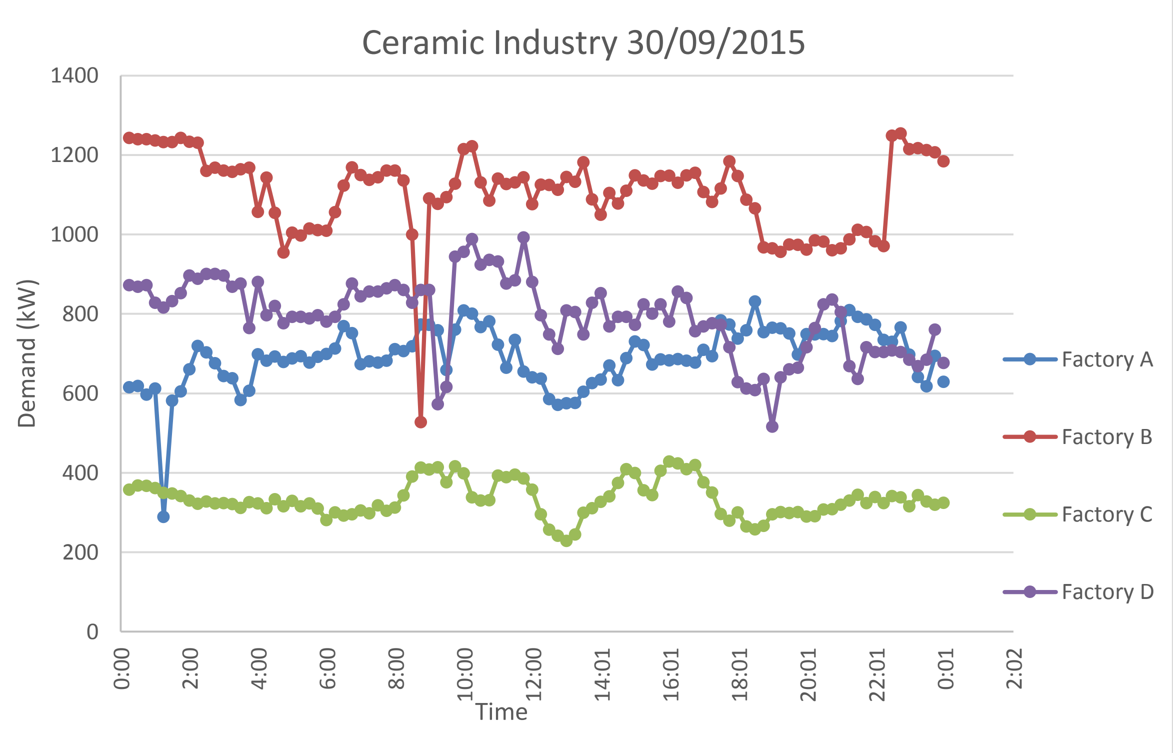


Figure 2.8: Load Profiles of Ceramic Industries

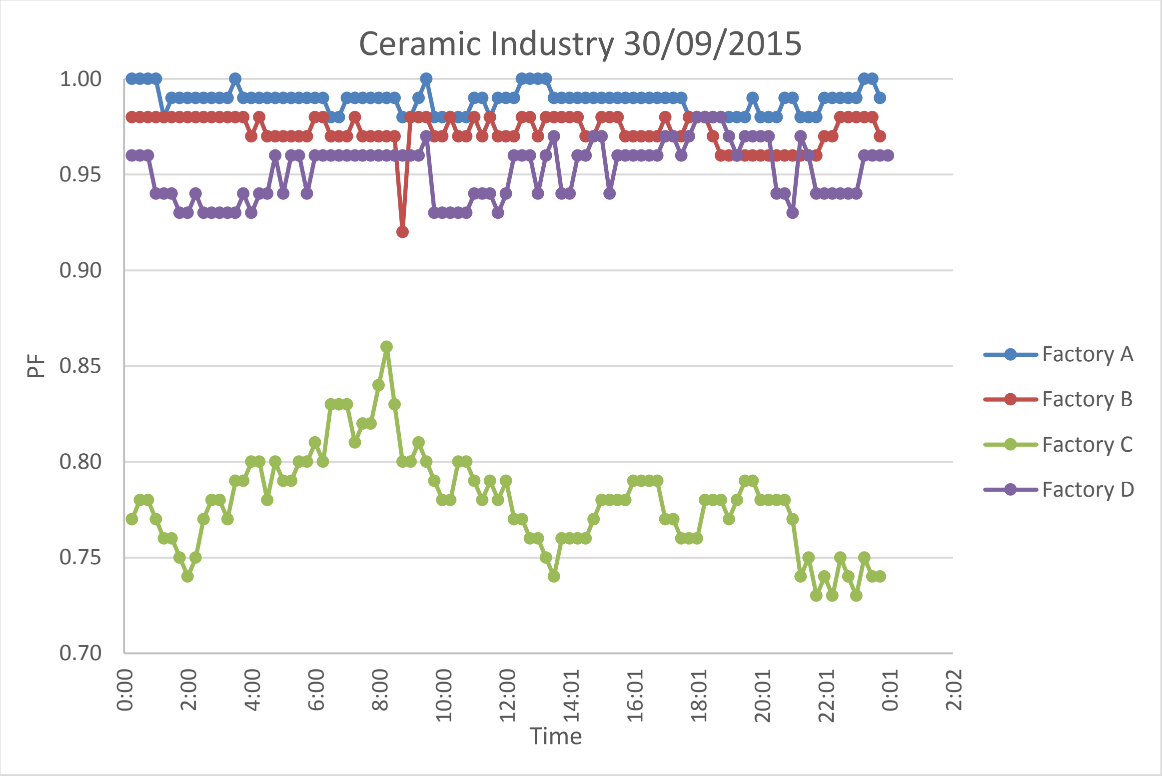


Figure 2.9: Power Factor of Ceramic Industries

2.2.1 Factory visit to Factory A

A factory visit was made to Factory A, to identify the normal operations of the factory and identify the potential saving options that exists in the ceramic industry. The manufacturing process in the ceramic industry is as follows.

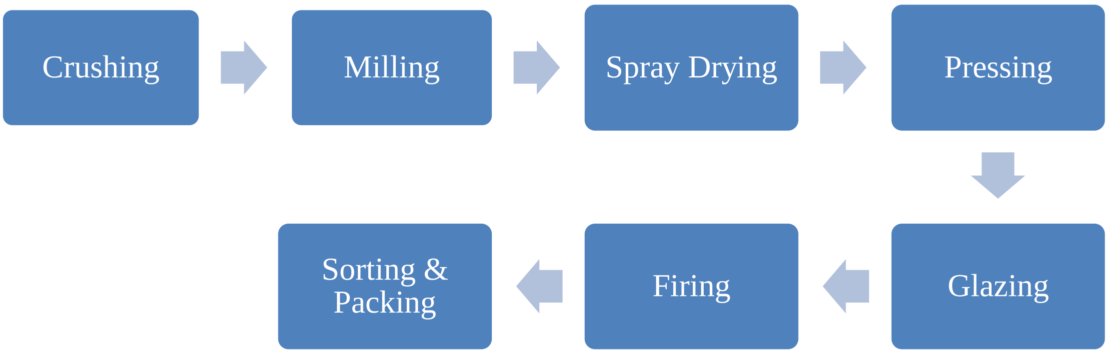

Crushing
Milling
Spray Drying
Pressing
Glazing
Firing
Sorting & Packing

Figure 2.10: Manufacturing Process in the Ceramic Industry

Table 2.2: Major Equipment used in Ceramic Industry

Equipment type	No being used	Capacity per unit	Budgeted consumption per month (kWh)
Crusher	1	Not available	2,608
Ball mills	9	5 kW x 10 motors	267,790
Spray Dryers	3	Not available	95,457
Pressing machine	5	75 kW motor	295,418
Glazing machine	4	0.75 kW x 30 motors	84,095
Firing – A	1	37 kW x 2 motors	75,399
Firing - B	2	22 kW x 2 motors	135,771
Sorting	5		106,000
Glaze making -A	5	37 kW	97,994
Glaze making -B	5	22 kW	
Agitators	5	16 kW	
Compressors -A	4	45 kW	110,797
Compressors -B	1	75 kW	

Figure 2.11: Raw material storage

Figure 2.12: Milling process done through ball mills

Figure 2.13: Spray drying is done for 40 hours

Figure 2.14: The powder is stored for one day

Figure 2.15: Material compressed by the pressing operation

Figure 2.16 : Glazing

Figure 2.17: Firing process is done in the kiln

2.2.2 Observations

The following observations were made by studying their consumption pattern and the manufacturing process;

- All the customers have a fairly distributed load curve over the 24 hour period.
- Except for factory B, no other customer has reduced their consumption during the peak period.
- This may be because in the ceramic industry, it is difficult to stop their machinery during the peak period because some machinery has to be operated continuously to prepare the raw material required.
- Almost all the customers are maintaining a good power factor.
- From monitoring their manufacturing process and their consumption pattern, it is identified that there is significant potential for implementing DSM measures.
- Hence the ceramic industry is not considered further in the thesis.

2.3 Case Study 3: Commercial Buildings

Five commercial buildings were considered for the case study on a typical day over the 24 hour period and their power factors were also considered for the study. These customers belong to the General Purpose (GP) tariff category.

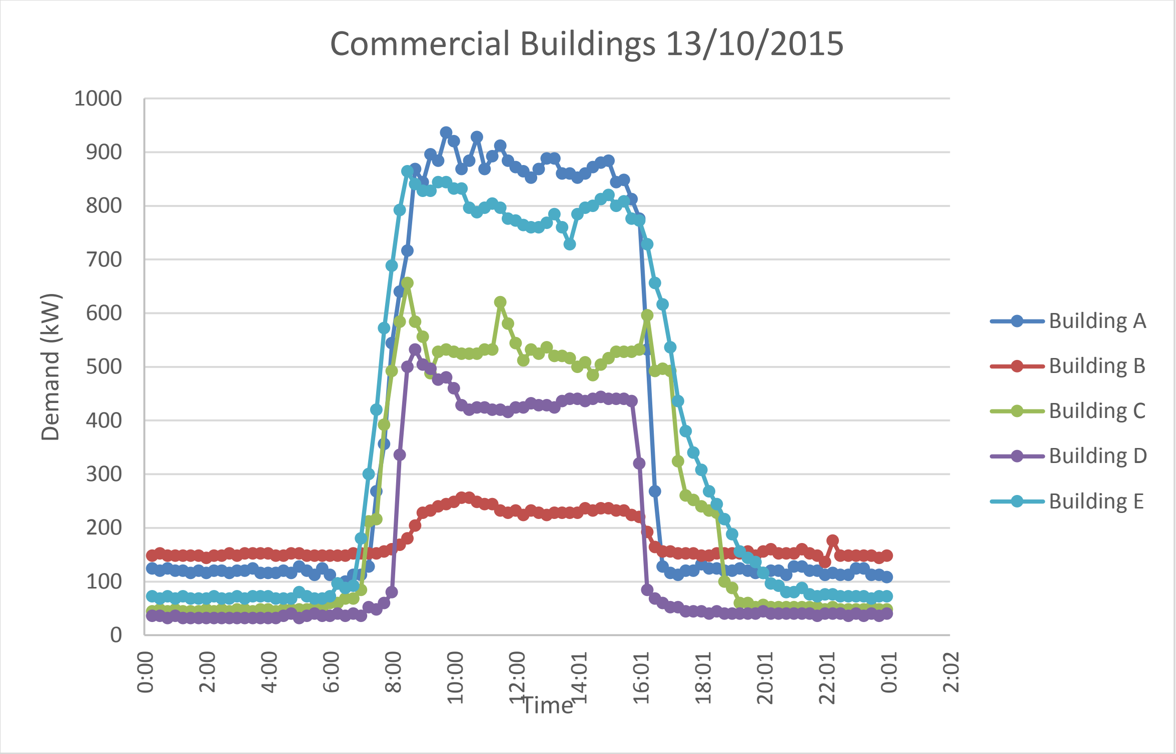


Figure 2.18: Load Profiles of Commercial Buildings

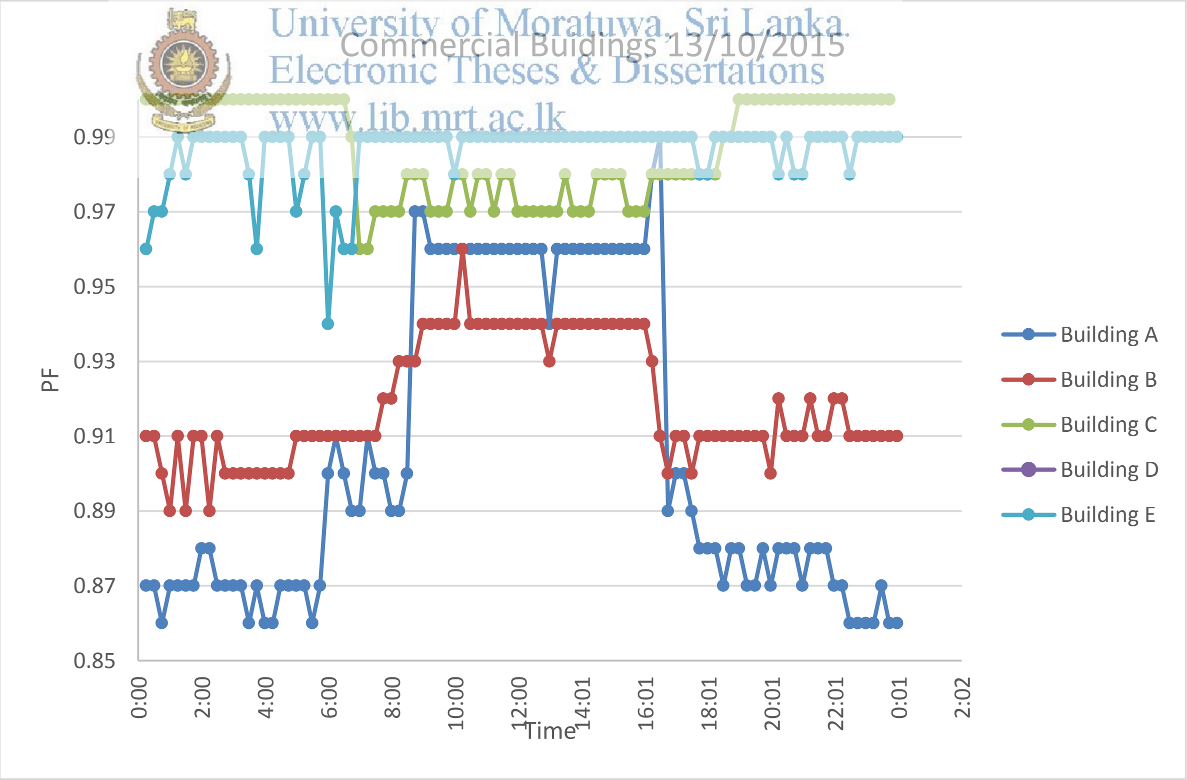


Figure 2.19 Power Factor of Commercial Buildings

2.3.1 Observations

The following observations were made from the studying the consumption pattern of the commercial buildings;

- Only day time load exists for this customer category.
- Major portion of their consumption is due to air conditioning requirement.
- Buildings with higher contract demand have central air conditioning systems (Chillers) installed.
- Some buildings have maintained a good power factor, whereas some buildings still have the potential to improve the power factor.
- Since their off peak consumption is low, there is potential in shifting the day time consumption to the off peak period through implementing DSM measure of Thermal Energy Storage (TES).
- Hence this customer category is considered for this study.

2.4 Case Study 4: Hotel Industry

Seven major hotels operating in the country were included in the case study on a typical day over the 24 hour period, and their power factor profiles were also recorded. These customers belong to the Hotel (H) tariff category.

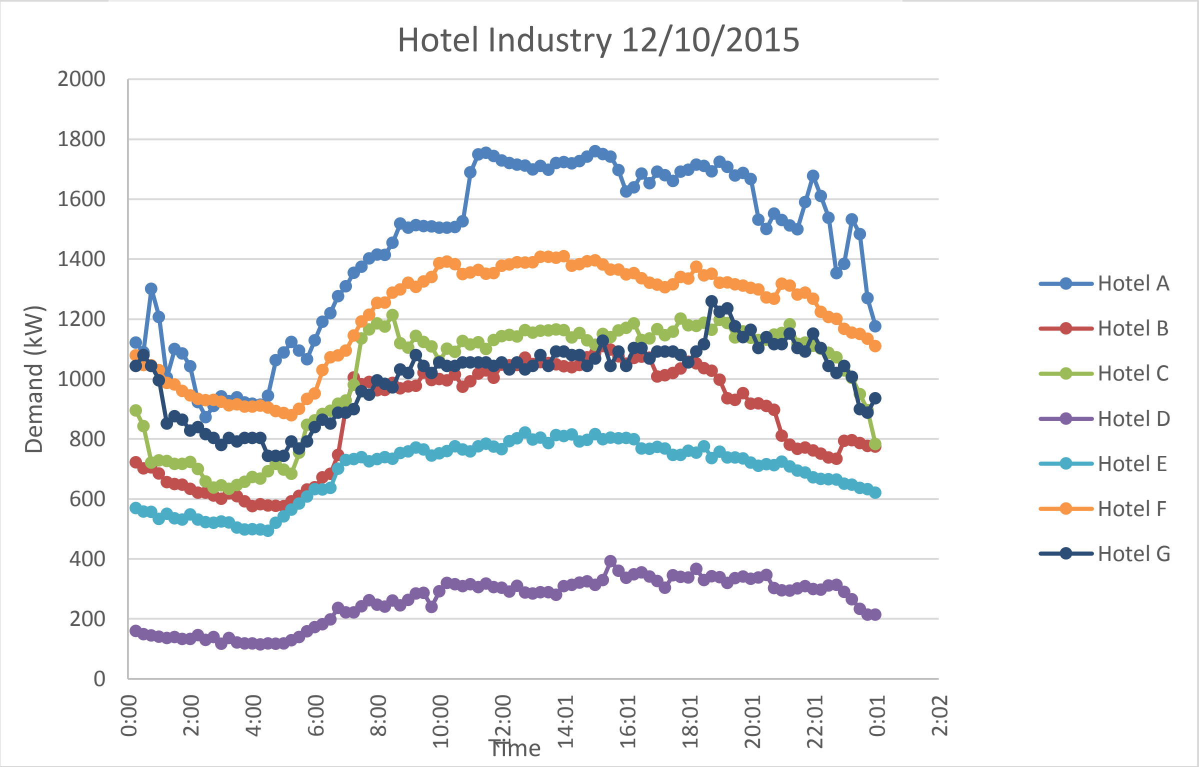


Figure 2.20: Load Profiles of Hotel Industries

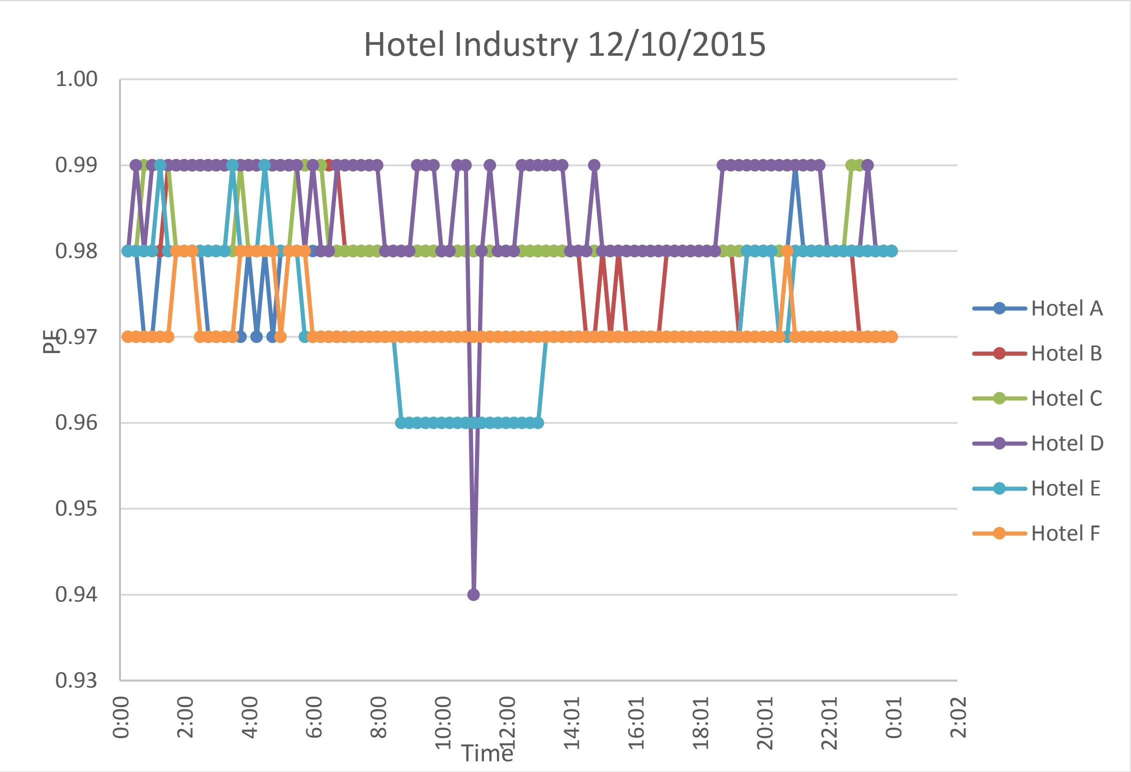


Figure 2.21: Power Factor of Hotel Industries

2.4.1 Observations

The following observations were made by studying the consumption pattern of the hotels;

- Major portion of their consumption is for air conditioning requirement.
- Hotels with higher contract demand have central air conditioning systems (Chillers) installed.
- All the major hotels are maintaining a good power factor.
- Since their off peak consumption is lower than their day time or peak time consumption, there is potential in shifting their peak time consumption to the off peak period through implementing the DSM measure of TES.
- Hence this customer category is considered for this study.

2.5 Conclusion

The four case studies conducted in the four different sectors, derived the result that one potential DSM option that the utility can adopt is TES through storing the cooling requirement at a time when the tariff rates are favorable. The potential for adopting this technology exists in the hotel sector and commercial sector, where most of their electricity consumption is for air conditioning.

In the industry sector, even though most of their machinery are energy intensive, it is difficult to stop them during the peak time. In some industries, the required input material is manufactured by their machinery and in order to maintain the flow of their work process, production of the required input material has to be done continuously. Therefore, adopting DSM into the industry sector is not examined in this research study.

The potential saving that can be achieved through adopting TES to hotels and commercial buildings is looked into through this research, and a financial analysis is also conducted to identify the feasibility of this technology.

3 SELECTION OF TECHNOLOGY

The customer consumption analysis conducted in chapter 2 derived the results that the DSM measure to be adopted to the hotels and commercial buildings is Thermal Energy Storage (TES) for the air conditioning systems. Depending on the storage medium used TES can be mainly divided into chilled water storage and ice storage. Through this chapter it is expected to identify the best TES technology to be adopted by analyzing both technologies in detail.

3.1 Thermal Energy Storage (TES)

The concept of TES in air conditioning systems, is that it separates the time of generating the cooling requirement from the time of use. This allows the user to generate their cooling needs at a time where tariff conditions are favorable, and use the stored energy for a period where the tariff are high [5].

TES system requires a storage medium that can hold the cooling energy for later use. Energy can either be stored as sensible (chilled water) or as latent heat (ice). The storage media that is selected should have high thermal capacity in order to reduce the storage volume. Water meets this requirement since it has the highest specific heat (4.19 kJ/kg.K) of all common material and it is inexpensive [7].

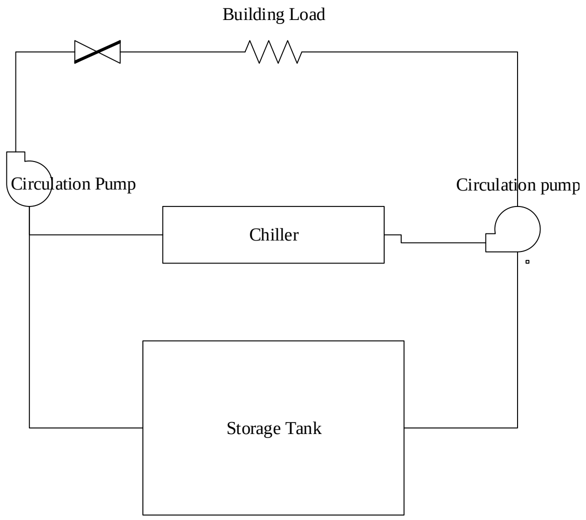


Figure 3.1: Schematic of building circuit for TES [7]

3.1.1 Advantages of TES

- Saving on energy cost – Through adopting a TES system the user will be able to generate their thermal energy requirement at a less expensive off peak tariff period and stop or reduce the use of their chillers at the expensive peak tariff period. [5]
- Reduction in the size of the equipment – TES system will allow its users to design their machines to meet the average load instead of the peak demand of the air conditioning system. [5]
- Capital cost saving – For a system which is newly designed or needs to be expanded, the capital cost saving will more than offset the cost of construction of the storage tank. The requirement of smaller cooling equipment will allow the designers to reduce the size of the transformers and electrical distribution systems that provide the required power to the chiller systems. [5]
- Energy saving – The main purpose of TES is shifting of energy instead of conserving energy, but indirectly it may be able to reduce consumption. This is because the chillers are mostly operated during the night, when lower condensing temperatures improve equipment efficiency. Also this allows the chillers to operate at full load, increasing performance efficiency. [5]
- Back up capacity –The capacity of the existing system can be increased by installing a TES system rather than adding conventional non storage equipment. Any backup cooling required can be taken from the storage.
- Extending existing system capacity – Increasing the existing system capacity, can be achieved at a lesser cost by installing a TES system, instead of investing on new non-storage equipment. Existing chillers can be operated in the normally non-operating or in the period where the chillers run at a reduced load to generate the additional cooling requirement. [5]

3.2 Chilled Water Storage (CWS)

In a CWS system, the sensible heat capacity of water is taken to use and temperature difference that exists between the supply water and the return water going into and returning from the cooling load of the particular premises. In this method, the volume of the storage tank is higher than any other TES technology. The chilled water and the returned warm water is stored using a single tank without an intervening physical barrier. A stable density gradient prevents mixing of the two volumes. The separation of water at two temperature levels is achieved by placing the cooler, denser water at the bottom of the tank and the warmer water at the top of the tank [6]. The chilled water that is stored in the tank is taken at a low velocity and in horizontal flow so that the buoyancy forces dominate the inertial effects [5]. A special piping network known as diffusers, are used to allow the water to enter and leave without causing significant mixing inside the tank. This help form a layer of chilled water that is separated from a layer of warm water by a thermocline as shown in figure 1.5 [6]

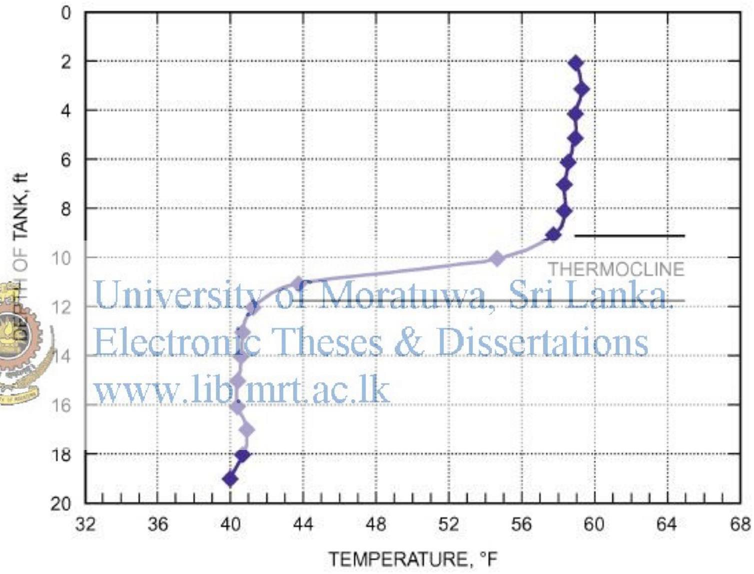


Figure 3.2 : Typical temperature stratification profile of the storage tank [6]

3.2.1 Advantages of CWS system

CWS systems have several advantages over the ice storage and phase change systems.

- It is possible to use conventional chillers, pipes and air handling units; this allows a broad selection and can select equipment at competitive prices.
- This can be used when modifying the existing non storage system into a storage system because CWS system does not require any modification to the existing chillers.

- Using water as the storage medium eliminates the need for secondary coolants and heat exchangers, and therefore, the conventional chillers can be used without degrading the performance of the chiller or its capacity.
- System will operate at higher efficiency because the storage will be done in the off-peak time, that is during late night and early morning when the ambient temperature is low. This improves the performance of heat rejection equipment.
- This reduces the complexities in training the staff for operations and maintenance, since the conventional equipment and controls are used.
- System designing will be familiar since the system is designed on the supply water temperature that is used in conventional chiller systems. [7]

3.2.2 Disadvantages of CWS system

- The volume of the storage tank required is large, therefore finding the required space may be difficult.
- The thermal losses occurring in the system with the surrounding environment will be higher due to the large surface area of the tank.
- Higher cost of maintenance and water treatment.
- Technical difficulties faced to avoid mixing of chilled water with the warm returned water.
- Skilled construction is required when building the tank in order to avoid any leaks or cracks in the tank. [7]

3.3 Ice Storage

Water is used as a phase change storage medium in order to take advantage of its higher storage capacity [7]. There are mainly four types of ice storage systems.

3.3.1 Static ice systems (ice building)

The static system is more compact and less costly than dynamic systems. In this system, ice produces around multiple coils or tubes that are submerged in a storage tank filled with water. Through the coils a fluid that has a lower freezing temperature than water is circulated. The fluid that is mostly used is water/ethylene glycol solution. Since the temperature of the fluid has a lower freezing point temperature than water, ice is formed at coil surface. The formed ice is then melted from inside out during the discharge cycle. [5]

3.3.2 Dynamic ice systems (ice harvesting)

In dynamic ice storage systems, the ice is formed in the evaporator surface and once a certain ice thickness is achieved, it is removed and stored in a storage container. The removal of ice can be achieved through mechanical means or through injection of hot gas into the evaporator plates. The ice producing unit has to be placed on top of the storage container [7].Chilled water from the storage tank is pumped from the storage tank and the returned warm water is sent to the ice generator [5].

3.3.3 Ice slurry system

In this system, small ice particles are formed within a solution of glycol and water. The ice particles are formed by passing a weak glycol water solution (~ 5-10% glycol) through tubing that is surrounded by an evaporating refrigerant contained within a shell. The solution is cooled by the evaporating refrigerant and ice particles are formed. The formed particles can either be dropped directly or pumped into the storage tank. Discharge is achieved by pumping the cool solution from tank either directly through the cooling load or through an intermediate heat exchanger that isolates the cooling load from the ice slurry system. The warm solution is returned to the top of the tank distributed over the ice slurry through multiple spray nozzles [6].

3.3.4 Encapsulated ice system

This system consists of water contained in plastic containers surrounded by a coolant inside a storage tank. In the charging cycle the subfreezing coolant from a chiller is circulated through the storage tank, and past the containers forming the ice. In the discharging cycle, the warm coolant is circulated through the tank and the containers melting the ice. The containers are factory filled and spherical in shape [6].

3.3.5 Advantages of ice storage systems

Ice storage system has several advantages,

- The storage volume required is lower than CWS, therefore a larger cooling capacity can be achieved by a given storage volume.
- The space requirement is low due to compactness of the storage tank.
- Less thermal losses occurring with the system due to lower surface area.
- Lower cost of maintenance and water treatment since lesser amount of water is circulated.
- Factory built tanks can be used for this purpose. [7]

3.3.6 Disadvantages of ice storage systems

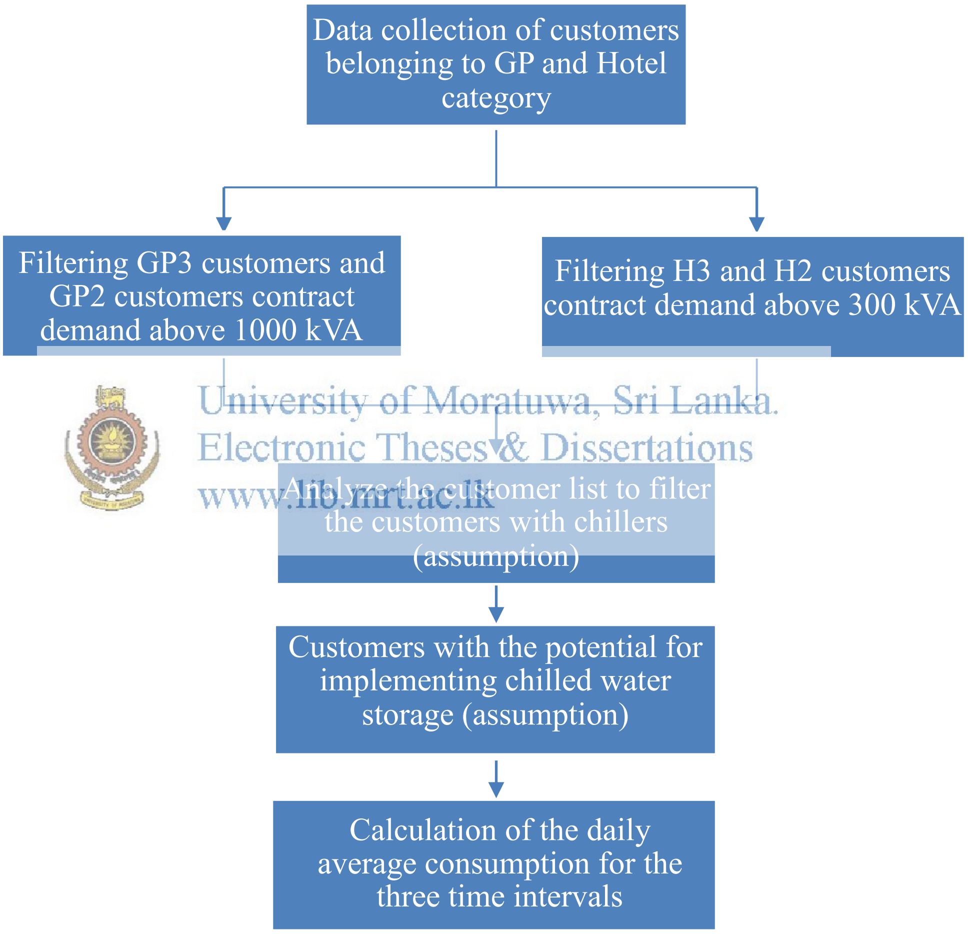
- Since the chiller suction temperature is low, there is a limited selection for machinery and less competitive pricing available.
- The efficiency of the refrigeration cycle will reduce due to the lower suction temperature.
- Increased expenses on training the operational and maintenance personnel, since unconventional equipment are used.
- Some control problems exists in the static systems in measuring the ice level [7]

Through the above analysis, it is identified that CWS technology is the most suitable technology because in this study it is expected to adopt the storage technology to existing non storage systems. In adopting CWS to the non-storage system, it does not require any modifications to the existing chillers, thereby making it easier to adopt.

Chapter 4

4 TECHNICAL EVALUATION

The main objective of the thesis is to identify the potential saving that can be achieved from implementing the DSM option of CWS in the selected category of general purpose and hotel customer. The following methodology was adopted to calculate the potential savings.



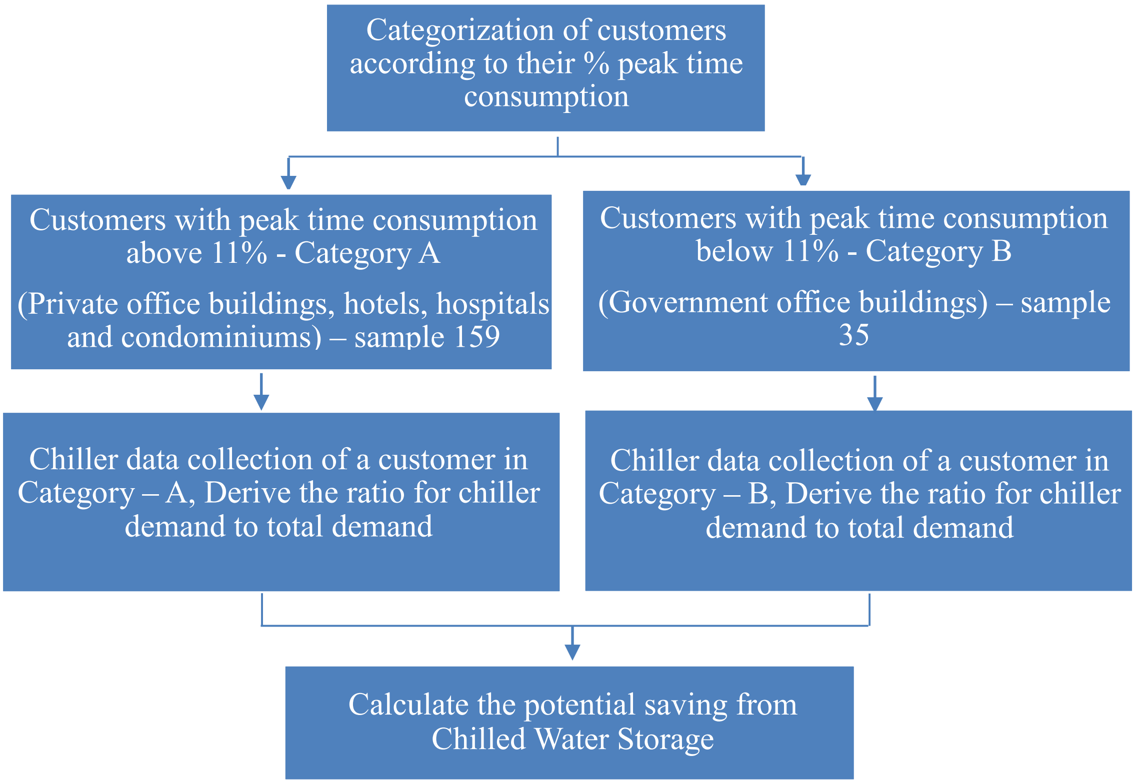


Figure 4.1: Methodology for calculating DSM potential

4.1 Data Collected for the Study

The potential energy saving that can be achieved through CWS was derived by selecting a sample from the above mentioned group of General Purpose and Hotel category customers. In order to filter the sample, TOU energy consumption, contract demand and maximum demand of all bulk customers belonging to General Purpose (GP2 and GP3) and Hotel (H2 and H3) category was selected. This data group consists of 3256 GP customers and 270 hotel category customers.

4.2 Filtering and Grouping the Selected Data

In filtering the collected data the following assumption was made. Customers with higher contract demand will have central air conditioning systems installed in their premises. Hence first the sample was filtered as follows,

- Sample 1: GP3 customers and GP2 customers with contract demand above 1000 kVA (107 customers)

- Sample 2: H3 customers and H2 customers with contract demand above 300 kVA (87 customers)

The selected two sample groups were then analyzed to filter the customers that may have central air conditioning systems installed in their premises (assumption). This gives the sample of customers who have the potential to implement CWS systems. Daily TOU average consumption of each customer was then calculated. Based on their daily average consumption, their percentage consumption for each time period was calculated.

Table 4.1: Sample calculation on percentage energy use in TOU intervals

Customer	Off peak energy consumption (kWh)	Day time energy consumption (kWh)	Peak time energy consumption (kWh)	Total consumption (kWh)	% off peak	% day	% peak
Customer 1 - H3	8,259	20,723	6,752	35,734	23	58	19
Customer 2 – H2	2,581	6,413	2,174	11,168	23	57	20
Customer 3 – GP3	7,089	18,528	5,337	30,954	23	60	17
Customer 4 – GP2	323	3,718	209	4,250	8	87	5

Based on the peak time consumption of each customer, selected customers in the sample were grouped into two categories.

- Category A: This category consists of customers with their peak time consumption 11% or above. The sample consists of 159 customers.
- Category B: This category consists of customers with their peak time consumption below 11%. The sample consists of 35 customers.

The basis of 11% was taken to divide the two categories. This was chosen because customers with considerable peak time consumption will fall above this ceiling.

4.3 Category A Customers

Category A customers mainly consists of private office buildings, hotels, hospitals and condominiums. For this category customers, the potential exists for stopping their chillers in the peak period and storing the energy required in the off peak period. The average daily demand for each TOU period was calculated for each customer. In order to identify the potential savings, it is required to derive a ratio between the total demand and chiller demand for this sample. For this purpose, a chiller profile of a customer belonging to this category was obtained by installing a data logger in the premises and the customer total demand profile was obtained from the customer meter.

4.3.1 Deriving the ratio between total demand and chiller demand

The chiller profile of a customer in the hotel industry belonging to this category was selected.

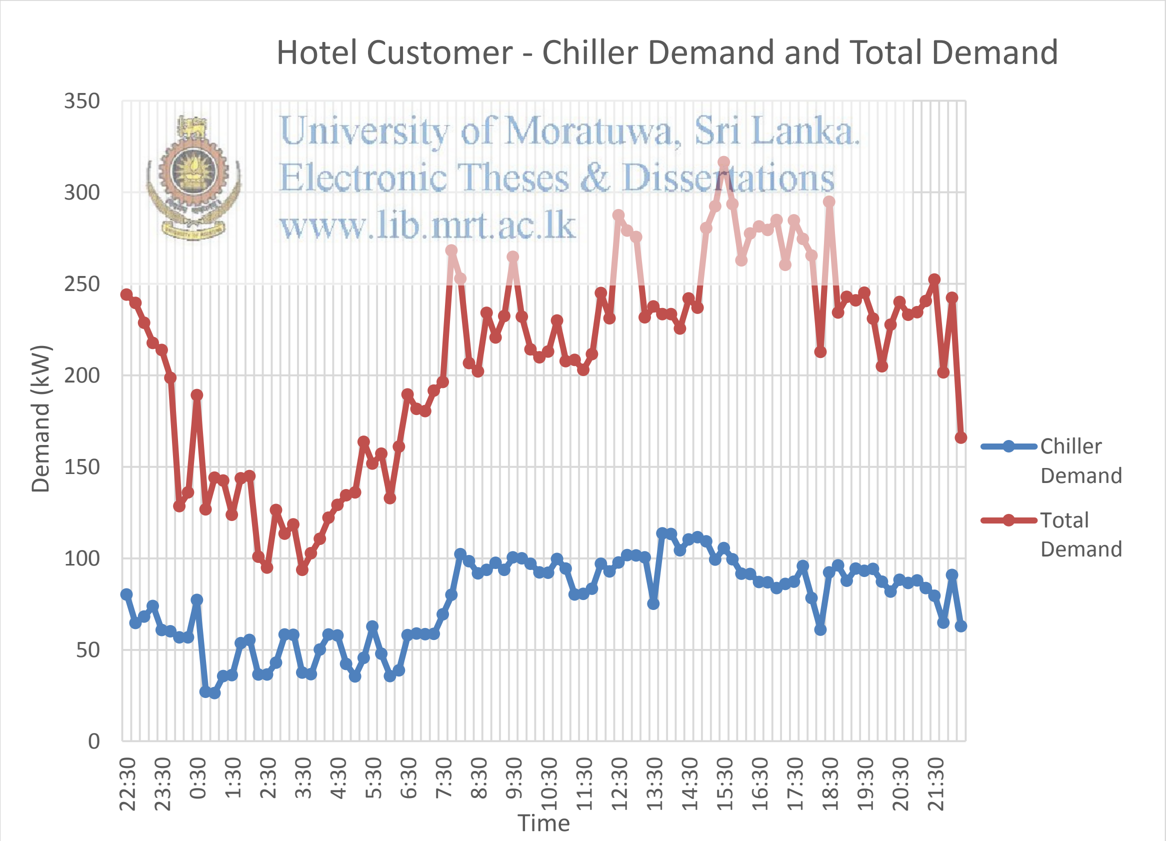


Figure 4.2: Chiller demand and total demand curve of hotel customer

From studying the two curves, it can be observed that there is a direct relationship between the chiller curve and the total demand curve, but it is difficult to obtain the relationship between the two curves because the demand fluctuates frequently. Therefore in order to derive the relationship between the two curves the curves were drawn taking the average demand for three time intervals.

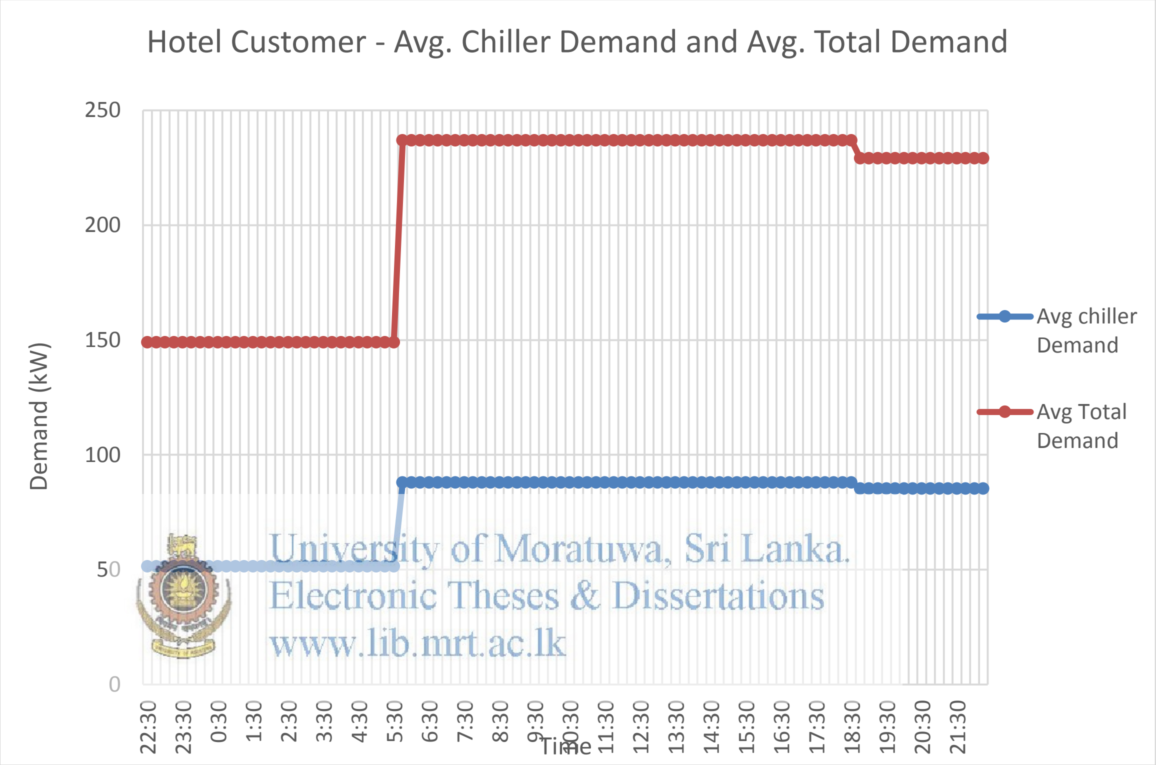


Figure 4.3: Average chiller demand and average total demand curve for Hotel customer

From the above analysis, the following ratios were derived.

Table 4.2: Chiller demand ratio to total demand

Time interval	Chiller demand ratio to total demand
Off peak (2230 - 0530)	0.35
Day (0530- 1830)	0.37
Peak (1830 – 2230)	0.37

The following outcome is expected from implementing CWS for Category- A customers.

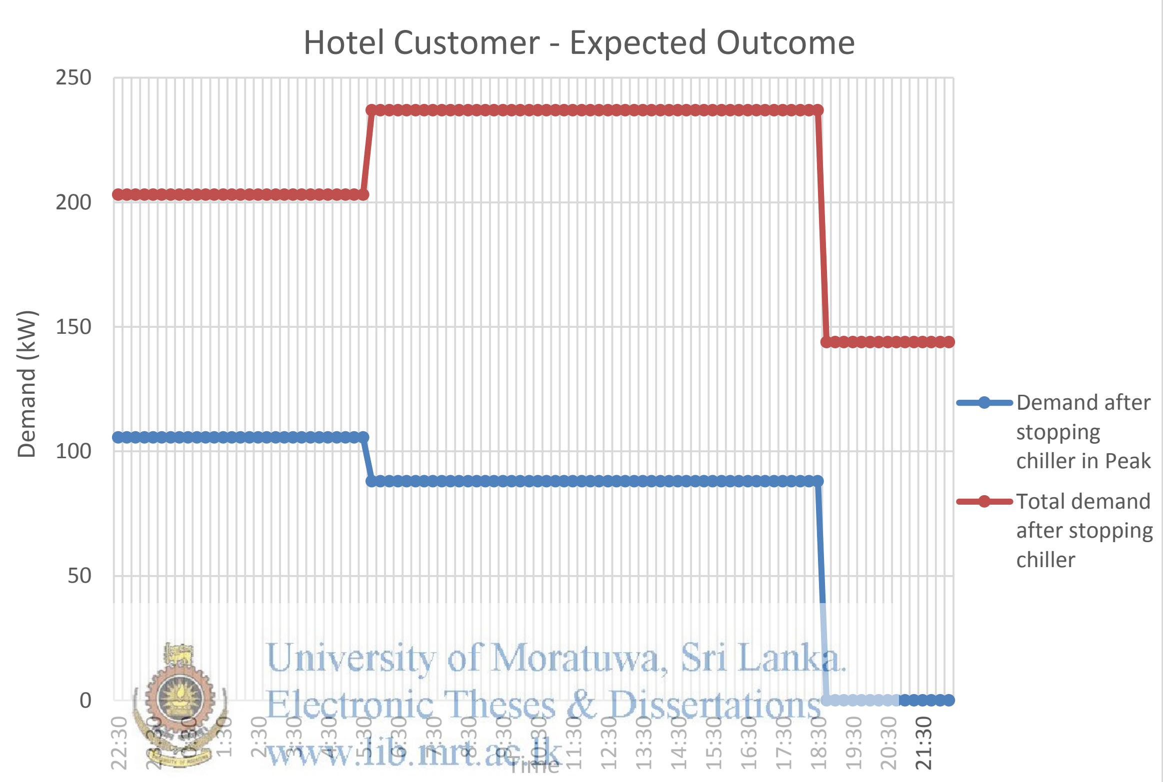


Figure 4.4: Expected outcome CWS for Hotel customer

4.3.2 Assumptions

The following assumptions were made for Category - A customers,

- All the customers with the peak consumption above 11% behave in the same pattern.
- It is assumed that the chiller profile of customers in this category follows the same pattern.
- The derived ratio between total demand and chiller demand is the same for the entire customer list in this category.

4.4 Category B Customers

Category B customers mainly consist of government office buildings and some private office buildings. For this category, only day time demand exists, and therefore, a potential exists for stopping their chillers for part of the day time period and storing the energy required in the off peak period. The same steps were followed as with Category - A customers to derive the ratio between the total demand and chiller demand for the sample. For this purpose, a chiller profile of a customer belonging to this category was obtained by installing a data logger in the premises and the customer total demand profile was obtained from the customer meter.

4.4.1 Deriving the ratio between total demand and chiller demand

The chiller profile of a government office building belonging to this category was selected.

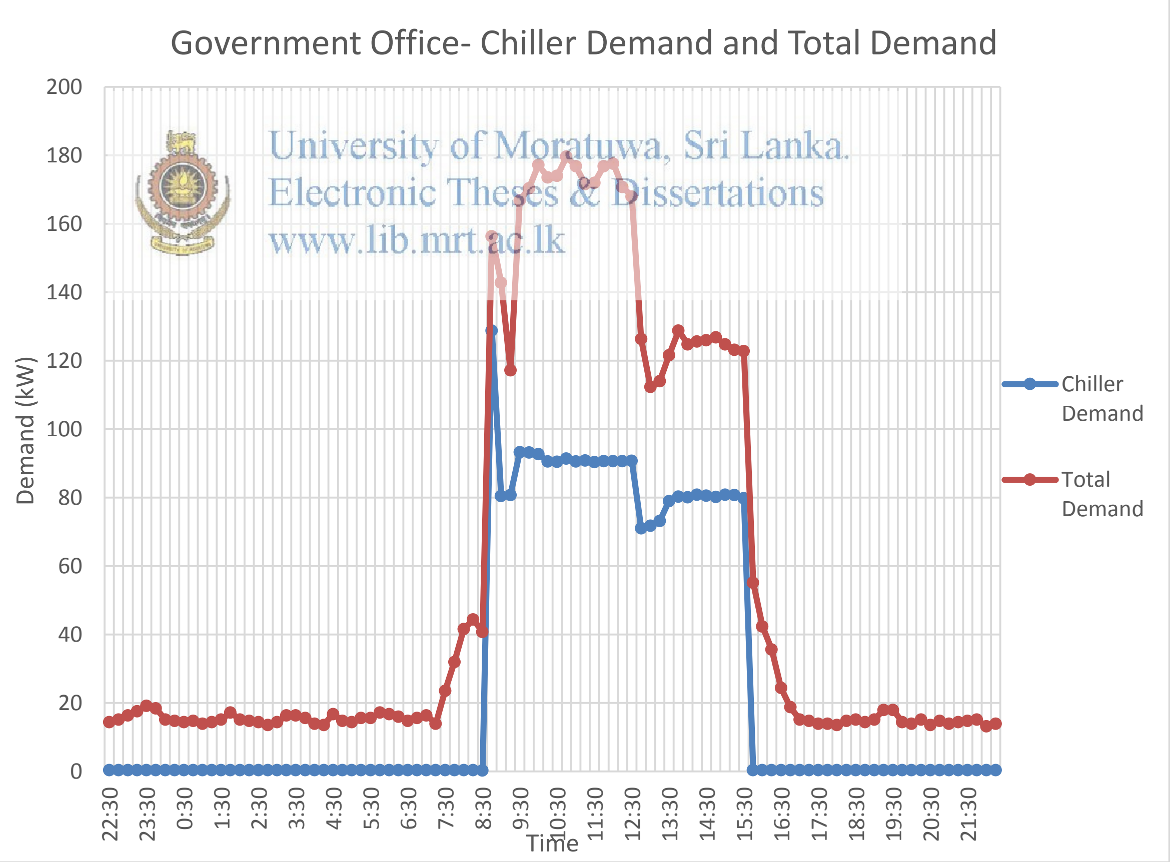


Figure 4.5: Chiller demand and total demand curve of government office

From studying the two curves, it can observed that there is a direct relationship between the chiller curve and the total demand curve, but it is difficult to obtain the relationship between the two curves because the curves fluctuate frequently with time. Therefore, in order to derive the relationship between the two curves the curves were drawn taking the average for three time intervals.

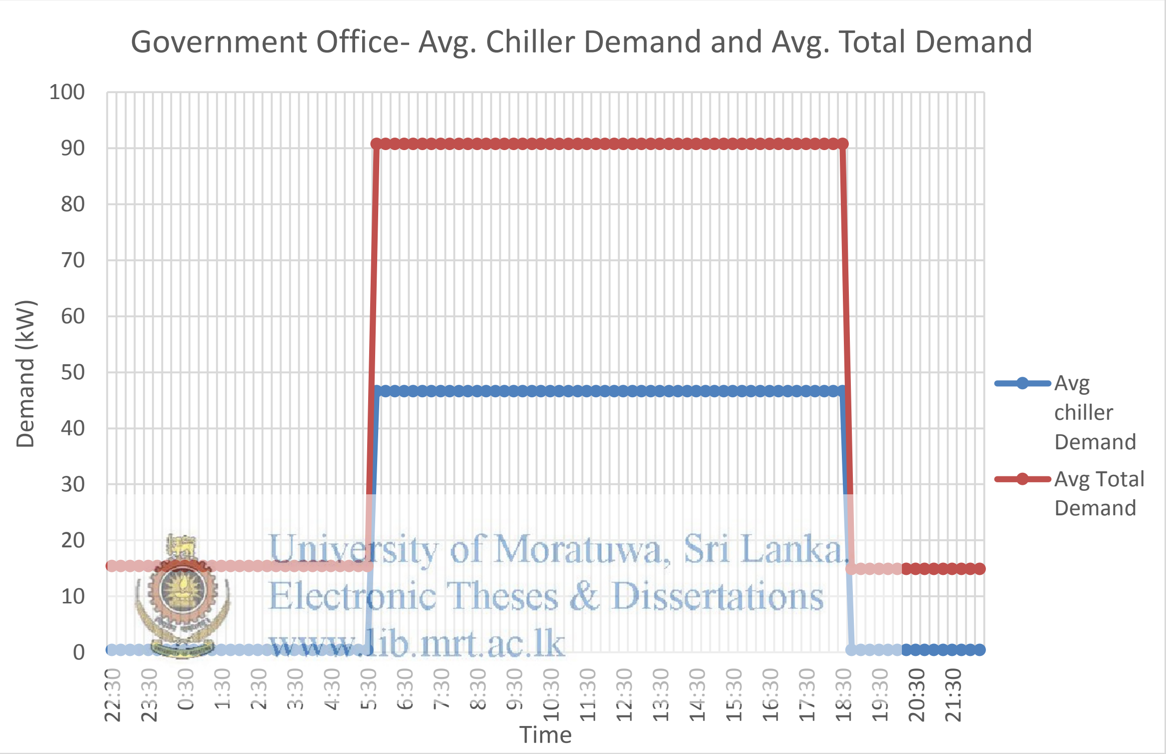


Figure 4.6: Average chiller demand and average total demand curve for Government office

From the above analysis the following ratios were derived.

Table 4.3: Chiller demand ratio to total demand

Time interval	Chiller demand ratio to total demand
Off peak (2230 - 0530)	0.03
Day (0530- 1830)	0.51
Peak (1830 – 2230)	0.03

The following outcome is expected from implementing CWS for Category- B customers.

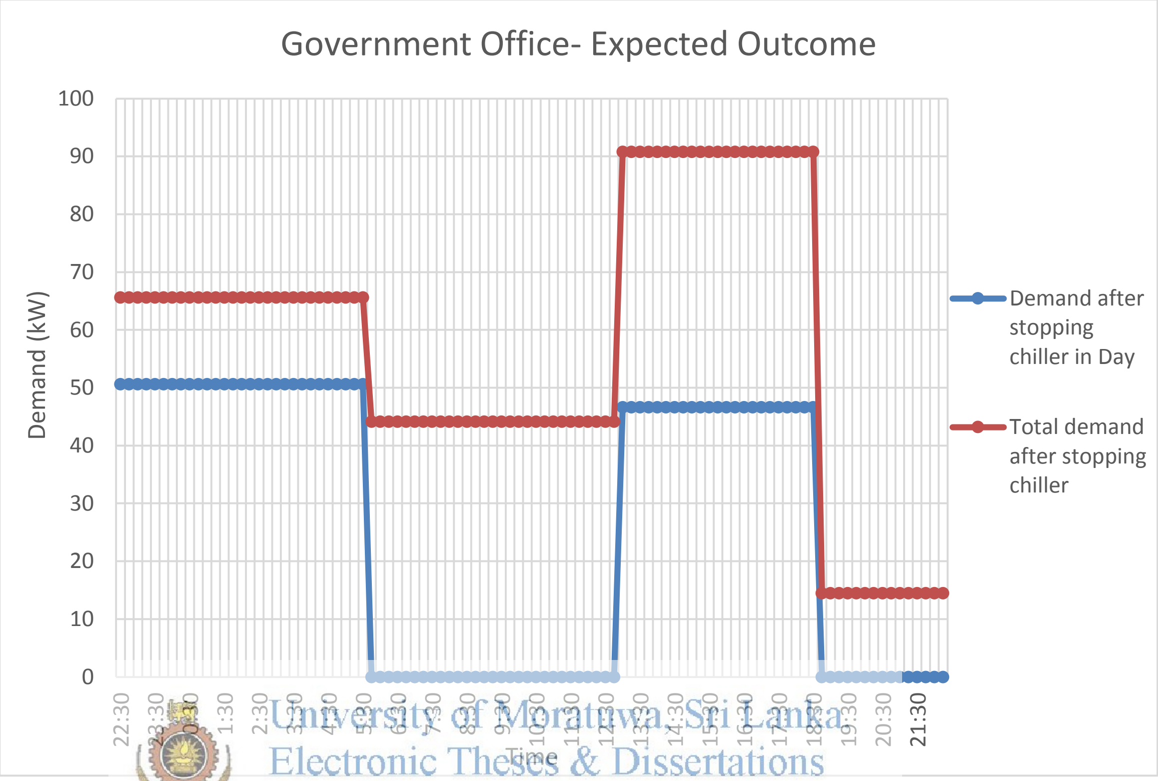


Figure 4.7: Expected outcome CWS for office building

4.4.2 Assumptions

The following assumptions were made for Category B customers,

- All the customers with the peak consumption below 11% behave in the same pattern.
- It is assumed that the chiller profile of customers in this category follows the same pattern.
- The derived ratio between total demand and chiller demand is the same for the entire customer list in this category.

4.5 Performance of CWS System

In a theoretical CWS tank, it will be able to maintain water at the same temperature at which it was stored. But in the stratified storage tank the useful energy is lost in three main ways. That is through conduction across the thermocline, mixing near the inlet diffuser and heat exchange with the surrounding of the tank [5] [9]. In order to measure the performance of the CWS tank a performance matric that reflects the loss of usable capacity in addition to ambient heat gains called the Figure of Merit (FOM) was proposed by Tran et al (1989). FOM is the ratio of integrated discharge capacity for a given volume to the ideal capacity that could have been withdrawn in absence of mixing and losses to the environment [9].

$$FOM = \frac{[\sum mc(T_{in} - T_{out})\Delta t]_{Discharge}}{Mc(T_h - T_c)} \text{[9]}$$

Where,

m = mass flow rate over a time increment

c = specific heat

M = the total mass cycled through the tank (equal for charge and discharge)

T_{in} = inlet temperature

T_{out} = outlet temperature

Δt = time increment

T_h = mass averaged discharge inlet temperature

T_c = mass average inlet temperature during previous charge cycle

FOM includes the capacity losses to the environment and losses due to conduction and mixing within the tank. According to the work done by William P. Bahnfleth and Amy Musser [9] the FOM for a stratified CWS tank is in the range of 92%. In the research it was taken as 90% for the calculations, which is the typical value that is been adopted for CWS calculations.

4.6 Chiller Demand Before and After CWS

The daily TOU energy consumption for each customer, belonging to the two categories, was derived from their total monthly TOU energy consumption data. The daily energy consumption data was used to calculate their demand for each time period in the TOU tariff, for all the customers in the sample.

Table 4.4: Sample TOU demand Category - A

Customer	Energy Consumption (kWh)			Demand (kW)		
	Off peak	Day	Peak	Off peak	Day	Peak
Customer 1 -GP3	9,843	23,283	5,949	1,406	1,791	1,487
Customer 2 -H3	8,259	20,723	6,752	1,180	1,594	1,688
Customer 3 - GP2	5,836	10,928	3,408	834	841	852
Customer 4 –H2	2,817	7,172	2,137	402	552	534

Table 4.5: Sample TOU demand Category - B

Customer	Energy Consumption (kWh)			Demand (kW)		
	Off peak	Day	Peak	Off peak	Day	Peak
Customer 1 -GP3	3,116	15,684	2,055	445	1,206	514
Customer 2 -GP3	1,009	6,544	800	144	503	200
Customer 3 - GP2	5,367	596	6,617	93	413	149
Customer 4 –GP2	283	2,942	251	40	226	63

The ratio between chiller demand to total demand, derived for Category A and Category B above, was used to calculate the chiller demand of each customer. For Category A customers, the chillers will be turned off during the peak period for four hours, and the cooling requirement for the peak period will be generated in the off peak period over seven hours. For Category B customers, the chillers will be turned off in the first seven hours in the day time and the cooling requirement of that time period will be generated in the off peak period when the chillers were usually switched off. Considering the above assumption, the new chiller demand of each customer was calculated after implementing CWS. Table 3.6 and 3.7 shows an extract of the effect on the chiller demand after implementation of CWS for Category A and B. The new chiller demand data was used to calculate effect on the total demand after CWS. This calculation was done for all the customers in the sample to identify the total savings that can be achieved from CWS.

Table 4.6: Sample chiller demand after CWS Category - A

Customer	Chiller Demand (kW)			Chiller Demand after CWS (kW)		
	Off peak	Day	Peak	Off peak	Day	Peak
Customer 1 -GP3	492	663	550	842	663	0
Customer 2 -H3	413	590	625	810	590	0
Customer 3 - GP2	292	311	315	492	311	0
Customer 4 –H2	141	204	198	266	204	0

Table 4.7: Sample chiller demand after CWS Category – B

Customer	Chiller Demand (kW)			Chiller Demand after CWS (kW)			
	Off peak	Day	Peak	Off peak	Day (0530-1230)	Day (1230-1830)	Peak
Customer 1 -GP3	13	615	15	707	0	615	0
Customer 2 -GP3	4	257	6	293	0	257	0
Customer 3 - GP2	3	211	4	240	0	211	0
Customer 4 –GP2	1	115	2	131	0	115	0

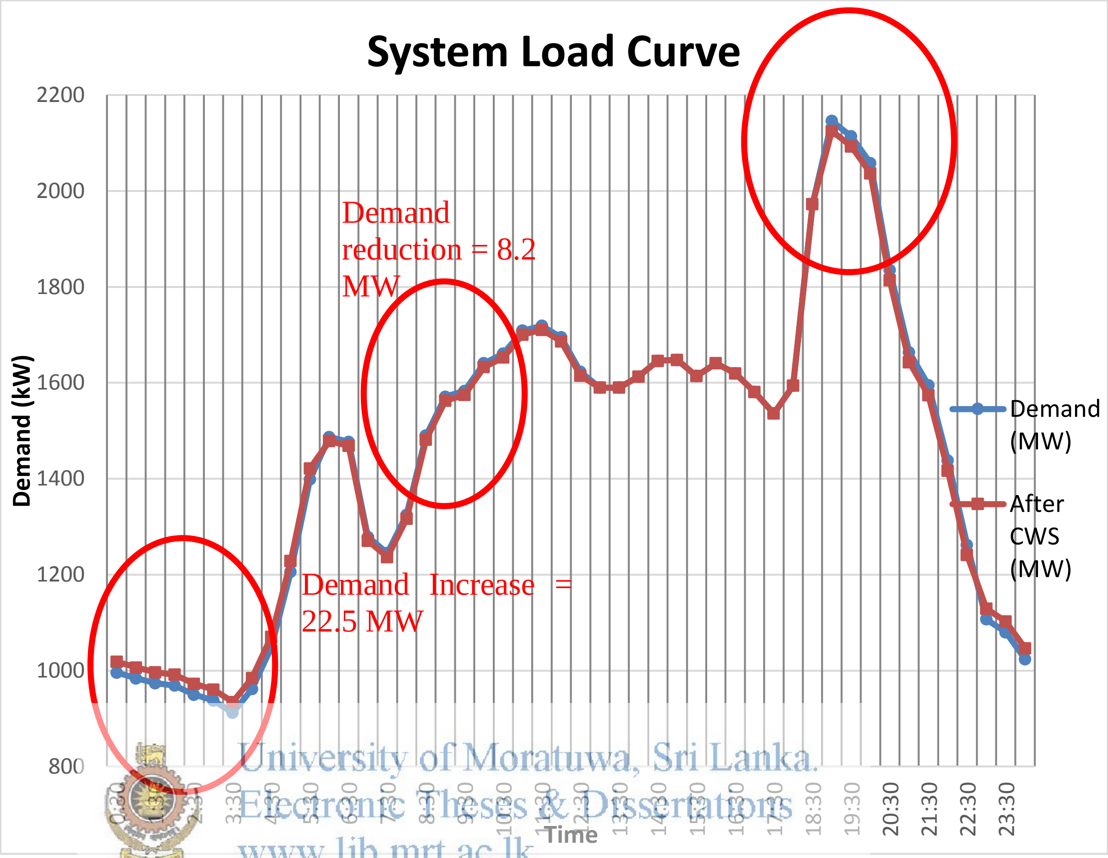
4.7 Potential Savings Achievable from CWS

The sample for the study was selected, so that it represents the entire customer group of CEB with the potential of implementing CWS. Hence it can be concluded that this sample represents the potential savings that exists in the country for implementing CWS. The total savings that can be achieved in the peak and day time period and the off peak demand increase is shown in table 3.8.

Table 4.8: Potential demand saving results

Category	Peak demand saving (kW)	Day demand saving (kW)	Off peak demand increase (kW)
A	20,790	-	13,200
B	154	8,291 (from 0530-1230)	9,311
Total	20,944	8,291	22,511

Demand reduction = 20.9 MW



Demand reduction = 8.2 MW

Demand Increase = 22.5 MW

Figure 4.8: Effect on the system load curve

Table 4.9 : Potential effect on energy consumption per month

Category	Peak energy saving (MWh)	Day energy saving (MWh)	Off peak energy increase (MWh)	Net energy increase/ (decrease) (MWh)
A	2,494.8	-	2,772	277.2
B	18.5	1,741.3	1,955.4	195.6
Total	2,513.3	1,741.3	4,727.4	472.8

The analysis on energy consumption per month shows the result that the energy consumption has increased when the demand is shifted from the peak and day time to the off peak period. The primary objective of this DSM strategy is not to reduce the consumption but to reduce the demand during the peak period and to shift that demand to the off peak period. The overall consumption during the off peak period increases because of the thermal energy losses that occur through the storage tank. In order to ensure that enough cooling capacity is stored, the FOM of the CWS tank is considered and higher amount of chilled water is stored during the off peak period.

4.8 CWS Tank Capacity and Volume Calculation

The above derived ratios for each customer category were used to calculate the average chiller demand for each time interval of each and every customer in the two categories. In order to calculate the CWS tank capacity and the volume requirement for each customer, a spread sheet model was developed for Category A and Category B. The required input to the model is the chiller average cooling requirement for the three TOU intervals.

The following formula was used for calculating the CWS tank volume.

$$V = \frac{X * 12{,}000\ Btu/Tonhours}{Cp\ *\ \Delta T\ * SG\ \left(62.4\frac{lb}{ft3}\right) * eff} \qquad [5]$$

Where,

V = TES tank volume, ft^3

X = amount of thermal capacity required, ton-h

C_P = specific heat of water (1 Btu/lbm·°F)

ΔT = temperature difference, °F

SG = specific gravity

eff = storage efficiency, typically 0.9

Table 4.10: CWS tank capacity and volume calculation sheet – Category A

Time	Chiller Demand (kW)	Chiller Demand (RT)	New Chiller Demand (RT)	CWS Charge (Ton hours)
23:00	51.40	14.62	30.01	15.39
0:00	51.40	14.62	30.01	30.78
1:00	51.40	14.62	30.01	46.17
2:00	51.40	14.62	30.01	61.56
3:00	51.40	14.62	30.01	76.95
4:00	51.40	14.62	30.01	92.35
5:00	51.40	14.62	30.01	107.74
6:00	87.98	25.02	25.02	107.74
7:00	87.98	25.02	25.02	107.74
8:00	87.98	25.02	25.02	107.74
9:00	87.98	25.02	25.02	107.74
10:00	87.98	25.02	25.02	107.74
11:00	87.98	25.02	25.02	107.74
12:00	87.98	25.02	25.02	107.74
13:00	87.98	25.02	25.02	107.74
14:00	87.98	25.02	25.02	107.74
15:00	87.98	25.02	25.02	107.74
16:00	87.98	25.02	25.02	107.74
17:00	87.98	25.02	25.02	107.74
18:00	87.98	25.02	25.02	107.74
19:00	85.25	24.24	0.00	83.50
20:00	85.25	24.24	0.00	59.25
21:00	85.25	24.24	0.00	35.01
22:00	85.25	24.24	0.00	0.00
Total Ton Hours		524.51	535.29	
CWS tank size (Ton Hours)		107.74		
Extra Capacity (Ton Hours)		10.77		
Chilled Water tank Volume (m^3)		144.86		

Conversion Units

1 Ton of Refrigeration (RT) =	3.51685	kW
1 kilo Watt =	0.284345	RT
1 cubic feet (ft^3) =	0.0283168	m^3

Table 4.11: CWS tank capacity and volume calculation sheet – Category B

Time	Chiller Demand (kW)	Chiller Demand (RT)	New Chiller Demand (RT)	CWS Charge (Ton hours)
23:00	0.40	0.11	14.92	14.80
0:00	0.40	0.11	14.92	29.61
1:00	0.40	0.11	14.92	44.41
2:00	0.40	0.11	14.92	59.22
3:00	0.40	0.11	14.92	74.02
4:00	0.40	0.11	14.92	88.83
5:00	0.40	0.11	14.92	103.63
6:00	46.63	13.26	0.00	90.37
7:00	46.63	13.26	0.00	77.11
8:00	46.63	13.26	0.00	63.85
9:00	46.63	13.26	0.00	50.60
10:00	46.63	13.26	0.00	37.34
11:00	46.63	13.26	0.00	24.08
12:00	46.63	13.26	0.00	10.82
13:00	46.63	13.26	13.26	10.82
14:00	46.63	13.26	13.26	10.82
15:00	46.63	13.26	13.26	10.82
16:00	46.63	13.26	13.26	10.82
17:00	46.63	13.26	13.26	10.82
18:00	46.63	13.26	13.26	10.82
19:00	0.40	0.11	0.00	10.70
20:00	0.40	0.11	0.00	10.59
21:00	0.40	0.11	0.00	10.48
22:00	0.40	0.11	0.00	0.00
Total Ton Hours		173.62	183.98	
CWS tank size (Ton Hours)		103.63		
Extra Capacity (Ton Hours)		10.36		
Chilled Water tank Volume (m^3)		139.34		

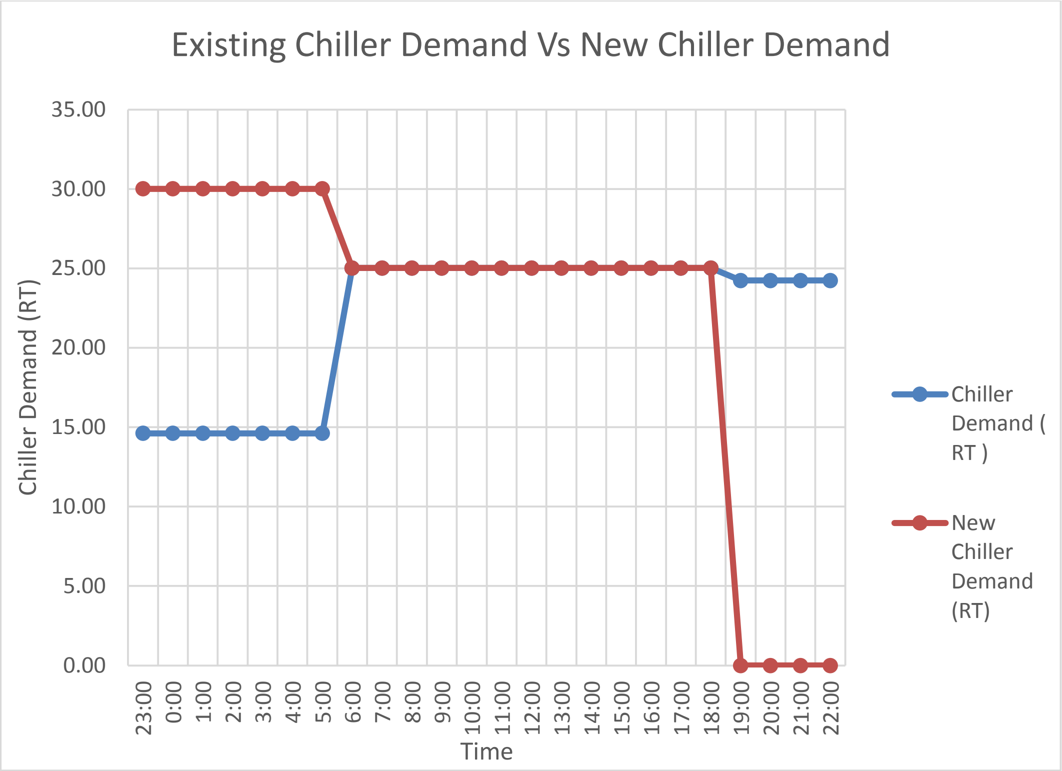


Figure 4.9: Existing chiller demand Vs. New chiller demand – Category -A

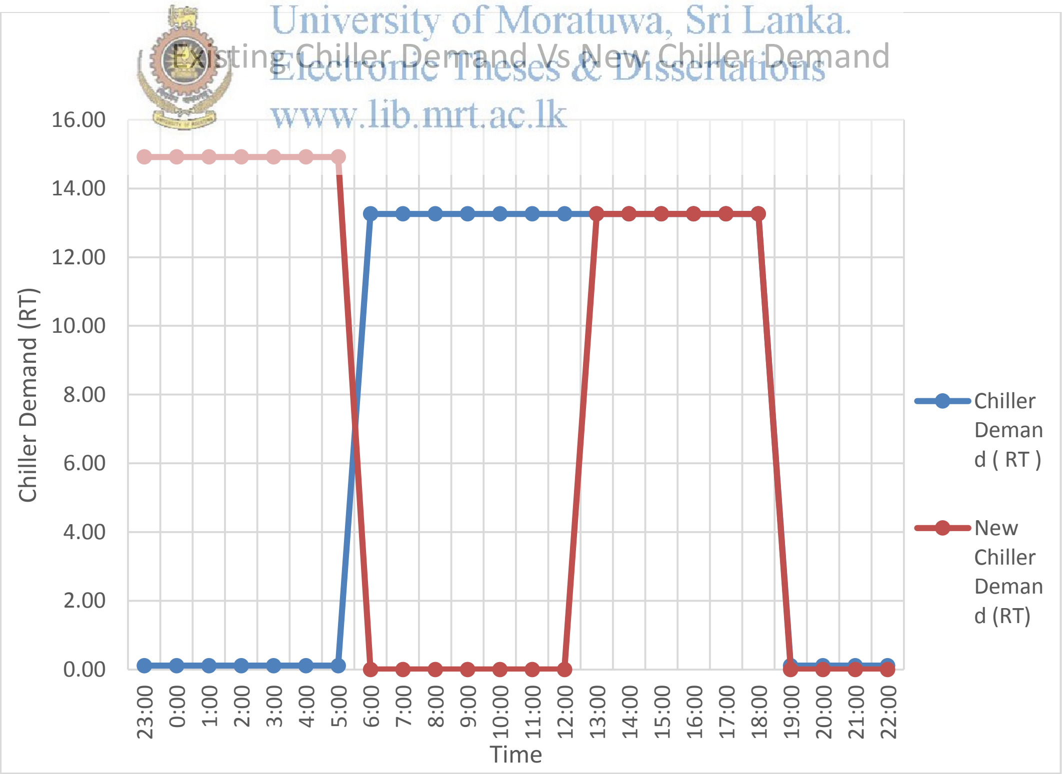


Figure 4.10: Existing chiller demand vs. new chiller demand – Category –B

5 FINANCIAL EVALUATION

In this chapter a financial evaluation is presented to establish the viability of the CWS system. It is intended to identify the benefit to the customer, the utility and the society. For the financial evaluation, it is required to identify the investment cost for the CWS system and the potential benefits it will derive.

5.1 Investment Cost Calculation

It is intended to identify the cost per cubic meter for construction and other necessary changes to the system, so that it can be applied to the entire population in the sample.

Cost of construction of a 400m^3 concrete tank and modifying the existing system

1. Fabrication of the tank is to be done using concrete.
    - Construction of the concrete tank including reinforcement and beams = LKR 13,500,000

2. Heat insulation is done by using a brick wall having an air gap of 150mm in between the brick wall and concrete tank and filling Glass wool/Rock wool in the air gap. Inner surface should be painted by heat insulating paint 'Nansulate LDS'. If necessary, Insulating material such as Nitryl Rubber can be used.
    - Estimated cost = LKR 2,500,000
3. Additional piping, motors, insulating materials for piping, Electrical wirings, gauges and accessories.
    - Estimated cost = LKR 4,000,000
4. Cost of modifying the existing control systems connected to the chillers.
    - Estimated cost = LKR 2,000,000
5. Total cost investment for modifying the chiller system with a 400m^3 storage tank = LKR 22,000,000

Estimated cost of 1 m^3 = LKR 55,000

5.2 Benefit to the Customer

The customers will be making a benefit through shifting their peak time energy use to the off peak period through the difference in tariff between the two time periods.

$$Benifit\ to\ the\ customer(Category\ A) = (peak\ energy\ reduction) * peak\ tariff\ - (off\ peak\ energy\ increase) * off\ peak\ tariff$$

$$Benifit\ to\ the\ customer(Category\ B) = (day\ time\ energy\ reduction) * day\ tariff + (peak\ energy\ reduction) * peak\ tariff\ - (off\ peak\ energy\ increase) * off\ peak\ tariff$$

In order to evaluate the viability of the investment, the payback period for the investment was calculated.

$$Payback\ period = \frac{Invesment\ Cost}{Energy\ saving\ per\ year}$$

Table 4.1 and 4.2 shows an extract of the calculations done for customers in Category A and Category B. Tank volume was calculated from the method described in Section 3.7 and the investment cost for each customer was calculated from the following equation.

$$Invesment\ Cost = Estimated\ cost\ per\ m^3 * tank\ volume\ (m^3)$$

The benefits and the payback period for each customer was also calculated by using the above equations. Table 4.3 shows the overall results for Category A and Category B customers.

Table 5.1: Sample payback period calculation Category –A

Customer	Tank volume (m^3)	Investment cost (m LKR)	Benefit to the customer (LKR)	Payback period (years)
Customer 1 -GP3	935	51.43	7,572,451	6.79
Customer 2 -H3	1,061	58.37	11,442,264	5.10
Customer 3 - GP2	536	29.46	4,306,951	6.84
Customer 4 –H2	336	18.47	3,589,173	5.15

Table 5.2: Sample payback period calculation Category –B

Customer	Tank volume (m^3)	Investment cost (m LKR)	Benefit to the customer (LKR)	Payback period (years)
Customer 1 -GP3	1,788	98.33	7,585,542	12.96
Customer 2 -GP3	745	40.99	3,159,316	12.98
Customer 3 - GP2	611	33.58	2,584,647	12.99
Customer 4 – GP2	334	18.36	1,409,020	13.03

Table 5.3: Results -total savings and payback period

Category	Total Tank Volume (m^3)	Cost of CWS tank (mLKR)	Total saving on energy per year (mLKR)	Pay Back period (Years)
A	35,327	1,942.98	322.56	6.02
B	24,013	1,320.73	101.50	13.01
Total	59,340	3,263.72	424.06	7.70

5.3 Benefit to the Utility

DSM is an option that is not only beneficial to its implementer. DSM should be beneficial to the utility as well, for a DSM project to be successful, or “win-win”. Here it is intended to find the benefit gained by the utility. Typically, the utility benefits in two ways; through the energy reduction in the peak and day time period, also it will gain from the reduction in peak time capacity required. However, in Sri Lanka’s present tariff methodology, the capacity costs and energy costs are pass-through items. DLs are not allowed to make a profit (or loss) in the business of buying energy and capacity (from TL) and selling (to customers). ie Total sales income from demand charges + energy charges - capacity charges paid to transmission - energy charges paid to transmission = Allowed revenue. The allowed revenue is determined on the basis approved assets, investments. If there is a difference, it is adjusted ex-post. [18]

Reforms to the tariff methodology are expected in the near future, where the market risk will be passed on to DLs. Then, DLs energy and capacity sales off-peak will usually carry a higher profit, while peak-time sales will carry a lower profit. That is one way DLs can be encouraged to sell more at off-peak, and sell less at peak time and during the day.

Although the tariff methodology does not provide incentives to DLs to promote DSM, for the purpose of this study, the BST was considered to be the indicative price at which each DL would save capacity and energy costs through implementation of DSM.

The tariff applicable to the utility was taken from the Bulk Supply Tariff (BST) for sale of electricity from the Transmission Licensee (TL) to the Distribution Licensees (DLs). The tariffs with effect from 1st July 2015 were taken for calculations [10].

The total investment cost of implementing CWS for the customers was considered to represent the economic cost of the DSM project to the Utility, in order to calculate the payback period in the Utility perspective.

Table 5.4: Approved BST with effective from 1st July 2015 [10]

	LKR/kWh
BST day	9.50
BST peak	11.97
BST off-peak	7.06
Capacity Charge	
LKR/MW/month	2,713,469

- Investment cost = mLKR 3263.71
- Benefit from system peak capacity reduction
    - Peak Capacity reduction = 20.94 MW
    - Peak Capacity saving per year = mLKR 682.00
- Benefit from system energy saving
    - Total peak time energy saving per month = 2,513.38 MWh
    - Day time energy saving by Category - B customers per month =1,741.32 MWh
    - Total Off peak time energy increase per month= 4,727.43 MWh

- Saving on Energy Cost per year = mLKR 159.02
- Total Saving per year = mLKR 841.02

Pay Back Period = 3.9 years

The benefits gained from DSM to the Utility is not only limited to the savings on energy costs and capacity cost. There are many other benefits which were not considered in to the calculation, but will benefit the Utility. Some of the benefits are,

- Delay in the investment costs on new power plants that will be required if demand is not reduced by DSM.
- Delay the investment on transmission and distribution upgrades.
- Efficiency improvement of the coal power plants during the off peak time interval through the increased demand.
- Increase in the system stability.
- Avoided cost on purchasing high cost peak energy.

5.4 Benefit for the Society

The other party who should be benefiting from DSM is the society. When considering the benefit to the society tax portion embedded in the investment cost and the capacity saving is removed.

- National Investment Cost = 3263.71* 0.8
  = mLKR 2,610.96
  (Only 80% of the cost portion considered, to remove government taxes)
- Benefit from system peak capacity reduction
  - Peak Capacity reduction = 20.94 MW
  - Peak Capacity saving per year = mLKR 545.60
- Benefit from system energy saving
  - Total peak time energy saving per month = 2,513.38 MWh
  - Day time energy saving by Cat B customers per month =1,741.32 MWh

    - Total Off peak time energy increase per month= 4,727.43 MWh
    - Saving on Energy Cost per year mLKR = 159.02
- Total Saving per year mLKR= 704.62

Pay Back Period = 3.7 years

Chapter 6

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6 CONCLUSION AND RECOMMENDATION

The results obtained on the potential saving achievable and the cost benefit analysis on the investment was studied. The following problems were identified from the results.

6.1 Problems Identified

- The potential saving that can be achieved in the peak time interval is 20.9 MW. This is a considerable saving through CWS.
- However the customers may not be interested in investing on CWS because the payback period is relatively higher that other investment options.
- Implementing CWS technology on Category –B customers does not seem practical because the payback period is around 13 years.
- This is a considerably larger simple payback period.
- The benefit to Category-B customers are low mainly because they only make a daytime saving, and the difference between the daytime tariff and the off peak tariff for GP category is low when considering the difference between the peak and off peak tariff of GP and hotel customers.
- Hence, a strategy is needed to make the investment on CWS to be more attractive to the customers.

6.2 Barriers to Implementation of CWS by Customers

The following factors are the barriers to the customers in implementing CWS.

- CWS technology is a fairly new technology to the country, and there are lesser number of people in the country with the required knowledge and skill. Therefore, this will be a barrier and customers will be reluctant to invest on a new technology to the country.
- The project requires a large investment, and finding the required funds at once may be difficult to customers.

- As it can be seen from the results obtained, the simple payback period is about 6 years for Category –A customers and around 13 years for Category-B customers. Since this project payback period is fairly long, customers may not be interested to tie up their money for a project.
- Some of the customers may have practical problems in implementing CWS tanks in their premises. Since CWS system requires to construct large size tanks for storage, some premises in urban areas may not be able to find the required space to construct the tank.

6.3 Recommended Options

When considering the results obtained and the problems identified, it is evident that a method of motivation has to be provided in order to make the investment more attractive to customers. This is where the utility has to intervene and actively market this DSM option to its customers and promote this as an attractive DSM option. In order to make this more attractive, it is required to reduce the payback period of the DSM project from the customer point of view.

Since the benefit to the customer will depend on the energy saving and the tariff, one way to reduce the payback period is to reduce the investment cost burden on the customer. One way to achieve this is for the utility to provide a portion of the investment to its customers as a grant. The utility will be able to borrow at a lower interest rate than an individual customer, and this can be given as a grant to the customers. Considering the higher benefit the utility will gain from capacity saving and energy saving, this will be attractive to the utility.

It is intended to provide a grant to customers to make it a win-win situation to all the parties directly benefiting from the project, which is to the customer, utility and the society. The utility will only gain the benefits of the DSM project if only the customers invest on the project. Unless hurdles such as high payback period are cleared the customer may be reluctant to make the investment and all the parties will be losing. The percentage of the investment cost that will be covered by the utility can be decided after carefully studying the DSM project and the benefits gained to the utility.

A case study analysis was done for a hotel in the Category – A in order to identify how providing a grant will affect the payback period to the customer. Here it was assumed as 40% of the investment will be made by the utility as a grant.

6.3.1 Investment cost case study – hotel

This analysis was done considering two scenarios.

1. 100% of the investment cost will be borne by the customer.
2. 40% of the investment will be made by the utility.

Table 6.1: Investment cost case study results

Scenario	Investment (mLKR)	Saving (Y1-Y15)	IRR	Simple Payback period (years)
1	7.7	1.55	18%	5.15
2	4.78	1.55	32%	3.09

The case study analysis reveals that the 2nd scenario is beneficial and will make the investment much more attractive to the customer. When 40% of the investment is made by the utility the payback period of the project will reduce to 3 years and the Internal Rate of Return (IRR) will increase up to 32% from the original 18%. Both these factors are significantly more attractive to the customer, and will help to motivate them to implement this DSM option.

6.4 Conclusion

As it can be seen from the results obtained in table 3.8 it can be concluded that through this DSM measure of CWS, a saving of 20.9 MW can be achieved in the peak time interval and a saving of 8.2 MW can be achieved in the day time interval. This energy saved is transferred to the off peak period with an off peak demand increase of 22.5 MW. Hence it can be concluded that this is a **Viable DSM project**.

The financial analysis was done in chapter 4 to establish the economic viability of the project. From the results shown in table 4.3, it was observed that the payback period for Category – A customers is 6.02 years. In the same category the payback period for hotel category customers are better than the payback period of GP category customers. This is because the difference in tariff between the peak and the off peak is greater for hotel category customers. Hence the benefit is higher for them. Therefore, the payback period for hotel customers in Category A is between 5 to 6 years, and for GP customers in Category A, the payback period is around 6 to 7 years. The payback period for Category B customers is 13 years because it is only possible for them to achieve a daytime energy saving. Hence, it is not economical for Category B customers to invest on CWS.

When considering the utility point of view, it is seen that higher benefit is there for the utility because the utility gains and energy cost saving as well as a capacity cost saving by stopping the unnecessary starting of some power plants just to cater to the peak time energy requirement. The utility payback period is 3.9 years. The payback period when considering the benefit to the society is 3.7 years. Hence when considering the utility payback period, this DSM option is beneficial to the utility.

As discussed in topic 5.3, even though this DSM measure is highly beneficial to the utility, the customers will be reluctant to invest in this option because their payback period is higher, compared to other investment options they may consider. Therefore, the utility intervention is required. As shown, one measure the utility can do to support its customers is to provide part of their investment cost as a grant to the interested customers. This will reduce the payback period of the project as well as increase the IRR.

It is also required for the utility to actively market these DSM measures and make its customers aware of the potential benefits they can achieve. They can also provide the technical support that is required to their customers. They can develop a vendor list that can do the required construction work and provide their customers, so they can easily adopt this technology.

6.5 Problems and Limitations with the Study

The study was conducted on a sample of 194 customers. When selecting the sample the GP category, it was limited to customers with their contract demand above 1000 kVA, owing to the difficulty of analyzing a large sample of customers. Therefore, since the sample size was limited, some customers who have chilled water systems installed in their premises were not considered for the study. Therefore, the actual potential can be higher than the obtained results.

In the selected sample, there may be customers who have practical limitations in implementing CWS systems due to the lack of space in constructing the storage tank. Therefore, the obtained theoretical potential may reduce, when considering the practical potential.

6.6 Recommendations

From the study, it was concluded that the customers in Category –A have the potential for peak energy saving and a higher benefit. Therefore, they are the best group to implement the CWS systems. It is recommended to analyze this customer group in more detail to in order to identify the practical potential in implementing CWS.
Two or three customers in Category – A can be selected and CWS can be implemented as a pilot DSM project in order to evaluate the practical viability of the project and to find the practical problems in implementing the project.

Chapter 7

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