

# **OPTIMIZED DEMAND SIDE MANAGEMENT VERSUS NEW RENEWABLE GENERATION AS A MEANS OF REPLACING RETIRING ROTATIONAL GENERATION**

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**Bachelor of Engineering in Electrical and Electronics Engineering, Kathmandu  
University, Nepal, 2014**

A Thesis Submitted in Partial Fulfilment  
of the Requirements for the Degree of

**Master of Science in Engineering**

In the Graduate Academic Unit of Electrical and Computer Engineering

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This thesis is accepted by the

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**THE UNIVERSITY OF NEW BRUNSWICK**

**June 2022**

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## **ABSTRACT**

Power systems must work continuously to match the generation and the load every second of every hour. Utilities sometimes act in the short term to vary the load for control purposes, and this is called Demand Response. To maintain the balance between supply and demand in the longer term several energy efficient activities, called Demand Side Management (DSM) strategies, are being adopted worldwide. These programs are implemented within the service area of any utility to promote reduced energy consumption especially during peak hours or emergencies and to smoothen the load profile. It improves the performance of the grid by changing the electricity consumption pattern, time of usage, and conditions of immediate demand.

This study has analysed the possibility of Demand Side Management as an alternate replacement of retiring conventional rotational units compared with renewable generation. The study is based in the context of Barbados Light and Power Company's service area. The scenario is such that the existing Heavy Fuel Oil (HFO) type rotational generators are being retired in the near future and there is a need to compensate for this loss of generation. This thesis compares optimized Demand Side Management opportunities or measures with renewable generation, especially central PV and wind, for the replacement of retiring conventional generating units.

A linear optimization model has been developed to calculate the cheapest combination among the available DSM opportunities utilizing the software "What's Best" Version 17, a product of LINDO. Additionally, a sensitivity analysis has been performed to analyse the possibility of DSM in focused end-use intervention. The cost comparison of

DSM versus renewables shows the possibility of implementing DSM at a lower cost under many different generator replacement scenarios.

## **ACKNOWLEDGEMENT**

I would like to express my deepest appreciation to my supervisor Dr. Eugene Frederick Samuel Hill. The overall study has been an interesting journey for me with his unwavering support and patience. I will be forever grateful to him for providing me with guidance and this incredible opportunity to undertake research. It was a great experience and a great privilege to work and study under his guidance. He has always mentored me to express my ideas simply and solidly. I would also like to thank him for his simplicity and reachability. I would also like to extend my sincere thanks to Dr. Chris Diduch for his valuable support during this study.

Starting my Master's study away from home during a pandemic was not easy. There have been times of extreme hopelessness. It would have not been possible without the support of my dear husband Birat Gyawali. He believed in me, reminded me of my abilities and never let me down. I am very lucky that we have continued our journey at UNB together.

I am extremely fortunate to have a supporting family. I am forever indebted to my parents Govinda Nepal and Kamala Nepal for their relentless love and support throughout my life. I would like to thank my sister Anala Nepal and my brother-in-law Magnus Gulstad for their constant motivation and encouragement to chase my dreams. I would also like to extend my deepest thanks to my in-laws Pramod Gyawali, Maya Gyawali and Bishal Gyawali for their continuous support and care.

Finally, I would also like to thank UNB for providing me with the research and funding opportunity.

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## LIST OF ABBREVIATIONS

ADR	Automated Demand Response
BLPC	Barbados Light and Power Company
C and I	Commercial and Industrial
CFL	Compact Fluorescent Lamp
CF	Capacity Factor
CRF	Capital Recovery Factor
CRT	Cathode Ray Tube
DF	Diversity Factor
DLC	Direct Load Control
DR	Demand Response
DSM	Demand Side Management
DVD	Digital Video Disc
EER	Energy Efficiency Ratio
EF	Energy Factor
ELCC	Equivalent Load Carrying Capability
EP	Economic Potential
EUI	End-use Energy Intensity
GWh	Gigawatt-hour
HEF	High Efficiency
IRRP	Integrated Resource and Resiliency Plan
kWh	kilowatt-hour
LCD	Liquid Crystal Display

LCOE	Levelized Cost of Energy
LED	Light Emitting Diode
MISO	Midwest Independent System Operator
MW	Megawatt
MWh	Megawatt-hour
O&M	Operation and Maintenance
PC	Personal Computer
PCT	Programmable Communicating Thermostats
PV	Photo Voltaic
PV	Present Value
RE	Renewable Energy
ROI	Return on Investment
SEER	Seasonal Energy Efficiency Ratio
TRC	Total Resource Cost
TOU	Time of Use
TV	Television
UEC	Unit Energy Consumption
US	United States

# **CHAPTER 1**

## **1. INTRODUCTION**

### **1.1 General**

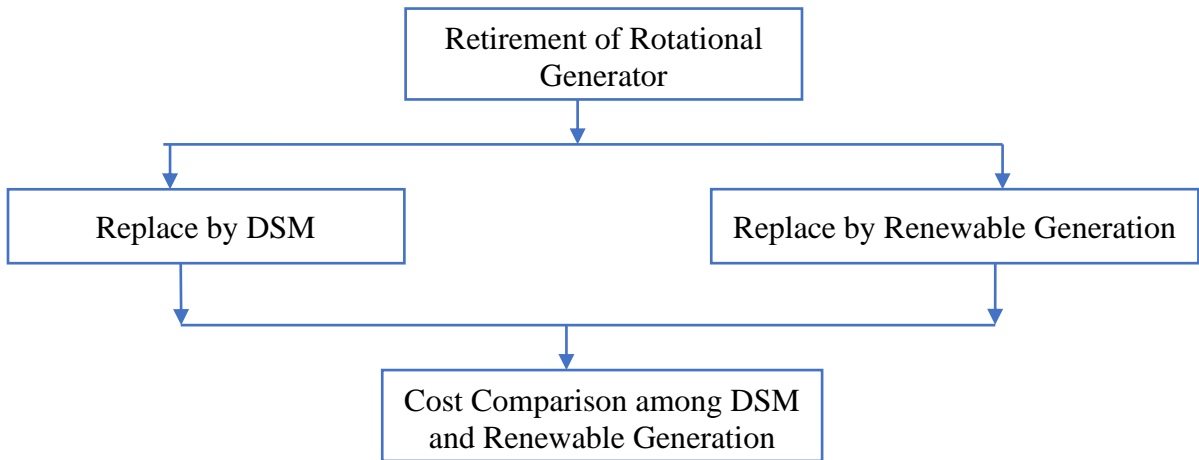
Demand Side Management (DSM) programs focus on efficient use of electricity. These programs are implemented to achieve a permanent reduction in customer consumption of capacity (MW) and energy (MWh). Demand side management and energy efficiency are one and the same thing. This is achieved by adoption of energy efficient equipment over conventional equipment and by bringing behavioural changes in energy consumption patterns at the customer level.

DSM programs create a win-win condition for both the customers and utility by benefitting both. Customers could achieve a reduction in their electricity bill and gain rewards while the utility could maintain a more reliable supply. DSM strategies are being widely implemented by the utilities to modify load, smoothen the load profile and thus to continuously meet their demand. With the improvement in load profiles, the immediate need of upgradation in the supply side could be delayed. Also, environmental benefits could be attained by the productive end use of energy.

With modernization, energy demand of every country has been increasing while the resources are limited. The strategic management of the use of energy resources ensures energy security and promotes self-sustainability. It is also an effective tool to bring about social change by empowering consumers.

## 1.2 Research Motivation

All the above benefits of DSM stand on their own. However, this thesis approaches DSM from a different perspective. Barbados Light and Power Company (BLPC) is in the position of having to retire conventional rotational generating units. This raises the question of what should replace the retiring generation sources. The Figure 1-1 suggests that DSM is one of two appropriate and competing alternatives.



*Figure 1-1: Block Diagram of general approach of study*

BLPC has a total rotational generation capacity of 239.1 MW. Also, there are a number of generation projects in the pipeline that will be added to the BLPC grid in the near future, including renewables. BLPC has developed a retirement schedule for their rotational generation sources.

The thesis is possible because of data made available from a previous study. A study called “Demand Side Management Study” was conducted by DNV-GL/KEMA in 2015 to analyse the potential of energy savings in the BLPC service area. The report which was issued is commonly known as the Kema Report. In this study, the existing loads (end uses) were identified for the two broad customer sectors of Residential, and Commercial and Industrial (C and I) to determine the energy consumption patterns in a base

configuration. For every base end use, all possible efficient replacement options were mapped. Depending on the savings factors, the technical potential savings were determined, and cost-benefit factors were considered to determine the economic potential savings. Based on the Kema study, the BLPC system has potential of achieving energy savings by implementing energy efficient Demand Side Management programs.

Therefore, in this thesis the findings of the Kema Report have been taken further to develop and compare these two alternatives by evaluating economic viability of the demand side opportunities and by estimating the technical and economic feasibility of renewable resources.

### **1.3 Research Objectives**

The main objective of this study is to evaluate the two alternatives of putting in place a major demand side program versus the installation of renewable energy sources to replace a retiring rotational unit in the BLPC system. The general objectives of this study are:

- To analyse the energy saving potential when the existing loads are replaced by energy efficient alternatives, along with consideration of the capital cost of accomplishing these savings.
- To evaluate the capacity size of renewable energy sources which in terms of capital, maintenance and operating expenses would be equivalent to the DSM activity.

### **1.4 Literature Review**

Energy efficiency is a static process where the existing loads are considered for replacement with energy efficient alternates, without compromising on customers' satisfaction. Utilities can improve their load profile by promoting energy efficient loads which often requires incentives, motivational schemes, and regulatory policies to achieve

wider acceptance by customers [1]. Many developing countries face power crises and could benefit by applying a DSM strategy, energy conservation, Time of Use (TOU) tariff structures, energy management systems and others.

The adoption of efficient loads could bring a considerable electricity savings and help the utility to manage power crises [2][3][4][5]. For example, improvement in lighting results in two benefits; direct decrease in energy consumption and indirect energy savings in cooling due to reduced heat dissipation from inefficient bulbs. The industrial sector, being the bulk consumers, can benefit by adopting energy efficient equipment and achieve a huge energy saving and reduction in production costs [6].

The latest efficient technologies are often more expensive than their preceding alternatives. This is one of the reasons why the customer ends up choosing cheaper solutions. The comparison of the savings of substitutes and the benefit in the long run is useful in promoting efficient products [7]. The holistic approach to analyse the baseline scenario, design and implement the solution, and continuously monitor the output to incorporate the correction could be very beneficial in new environments where the prediction is ambiguous. The application of energy audits through energy effective analysis methods could be adopted to improve the performance of industrial energy consumption [8][9].

Demand Response (DR) is a load management technique where a load is controlled periodically (turned on and off) to maintain a reliable supply [10]. Demand Response resource programs could be classified as modifying loads according to: Shape, Shift, Shed and Shimmy, which requires dispatchable enabling technologies like Automated Demand Response (ADR), Direct Load Control (DLC), Programmable Communicating

Thermostats (PCT), luminaire, zonal and standard control options, and base switch [11]. The DR products are also categorized to determine technical and achievable potential, to calculate levelized costs, and to develop a supply curve to reflect the cumulative achievable DR potential at the product's levelized cost [12]. A Hydro Quebec study plan [13] presents a system that allows deploying dispatchable DR and non-dispatchable DR. Demand side resources require a proper plan and programs to encourage customer participation in replacing loads with energy efficient end uses. DSM studies could be made more accurate by application of home energy management systems that generate realistic demand profiles. Also, the time of usage of each equipment could be mapped precisely [14].

The cost of energy is calculated in terms of Levelized Cost of Energy (LCOE) generation as a comparative tool for different ways of harnessing electricity [1][15][16]. It is also used in DSM to calculate the cost of electricity reduction. It gives a strong insight into making cost effective decisions in renewable integration. Together with the capital cost, the inflation rates and interest rates are incorporated in calculation of LCOE [17][18]. LCOE values can be reduced by revision of factors like operation and maintenance cost and logistics [19][20][21].

Optimization in DSM is case specific, involving single or multi-objective formulations. The objective function could be designed to minimize cost, minimize discomfort, maximize savings and maximize local generation [22]. The study [23] presents a financially attractive optimization model to implement energy efficient end uses in South Africa. A case study of a pumping station [24] shows that the optimal combination for pump operation could bring about an 8.30% energy savings. The hydraulic and electric measurements were carried out to determine the optimum flow, low power consumption

and maximum efficiency of the pumps. This kind of intervention looks attractive as it does not require any significant investment. The study [25] brings a unique optimization model to maximize the efficiency during transmission of electricity and suggests the optimal path of electricity flow.

The implementation of DSM requires the involvement of a government body to formulate a proper legislative structure. The regional and global target to green energy transition has incited energy reform campaigns and individual energy policy revision across the countries. The energy transition emphasizes de-carbonization, energy efficiency and energy security. This could be achieved through strategic promotion of energy efficiency and utilization of renewable resources. Deploying strategies like cash incentives and/or energy tax rebates for eligible customers is a sustainable way to achieve reduced consumption in the long run. It could also be developed as an advance financing mechanism for energy efficiency measures [26][27]. A novel incentive scheme for efficient utilization of power systems where utilities and market can make a choice of technology, generally referred to as output regulation, is shown in [28]. Sometimes, complexities in the programs could impact the access to incentives and alter the target [29]. It is very crucial to design strategies that simplify the procedural difficulties to achieve wider users' acceptance. Often, it is wise to intervene with small pilot projects to identify the willingness of the customers to participate and the major barriers [30][31].

An energy awareness program creates a consciousness among the customers about the appropriate utilization of energy. The increased capacity of customers in managing loads contributes to a sustainable energy saving solution. The study [32] presents the utilization of energy meters to promulgate information of production, harmonize

consumption, and achieve power quality, among the customers. Awareness programs are very effective in schools where many people could be enlightened. A study [33] shows that the students are unaware of the simple energy saving techniques which could lead to a significant reduction in energy wastage. A ripple of awareness could be created through such campaigns as the awareness developed is carried back to their individual homes.

Time of Use (TOU) tariff is often seen as a useful way of managing peak load, but at the same time it creates behavioural changes in the energy consumption pattern among customers by establishing a value of energy. Tariffs should be carefully designed to attract customers. A case [34] presents an attractive three levelled tariff structure where the rate is average during day, high during peak hours and free at night. An advanced mechanism for individualized price policy has been proposed to encourage customers to optimally manage their loads. The reference [35] demonstrates a method to see the potential effect of residential and commercial energy consumption on the total power loss and voltage deviation by considering Time-of-Using (TOU) prices and rooftop PV generation available locally.

Applying energy efficient building standards for new buildings and renovation standards for old buildings are promising approaches of achieving sustainable energy savings in residential and commercial buildings. Some encouraging programs are implemented in South Africa [36]. Tax relief programs that allow reduction in taxable income to those customers who have achieved energy savings are attractive. Energy efficiency funding programs that offer several loans, cash grants and other financial incentives have been tried.

The role of government to frame suitable laws and standards, develop incentives policy, and support in developing a financing mechanism needs to be strategic to gain wider acceptance [37]. Designing DSM approaches and evaluating their benefits is not fully adequate. The identification of gaps and barriers in implementation procedures and prevalent policies are imperative to devise alternative solutions [38].

## **1.5 Thesis Organization**

This thesis is outlined in six chapters:

- Chapter 1 introduces the Demand Side Management study, its benefits, the purpose and objectives of this research and the literature review.
- Chapter 2 is the reflection of the Kema Report. This chapter is the basis for establishing the connection of the results of the Kema Report to this thesis study. It also presents the important data taken from the Kema Report.
- Chapter 3 is the description of methodology adopted in this study. The study is carried out in different steps to obtain the results. Each step followed is thoroughly described with the data, evidence, and important mathematical formulations.
- Chapter 4 presents the results and analysis. A comparison has been made among the cost of implementing DSM, central PV and wind. Also, three sensitivity analysis cases have been presented to highlight the broader application of the model and to potentially allow BLPC to select the most attractive option.
- Chapter 5 highlights the data and modelling complexities. The explanation of important decisions and modifications taken to utilize the data have been provided.
- Chapter 6 is the Conclusion and provides an overall summary of the results, limitations, and suggestions for future works.

## CHAPTER 2

### 2. KEMA REPORT

#### 2.1 Introduction

Research theses are built on data, previous work, developed methodologies and new analytical approaches. This thesis is unique because it is based on previous work done on energy savings opportunities (DSM) at BLPC by a commercial consulting company, the work of which would be almost impossible to carry out in an academic environment.

The record of the work by the commercial consulting company is contained in a report entitled “Demand Side Management Study, Barbados Light and Power Company” by DNV-GL/ KEMA Inc, August 31, 2015, [1]. The second page of that report has a declaration on use of the report materials. It says: “Unrestricted distribution (internal and external)”. Therefore, it is public domain material just as if it had been published in an academic paper in a technical journal.

The Kema Report has two parts. The first document is the narrative, which is 137 pages in length. The second document consists of 14 Appendices of tables and matrices of numbers, which is 376 pages in length. The purpose of this brief chapter is to put the report in context as the data source for the thesis.

**Note:** Extensive reference is made to "Appendices" in the thesis document. Appendices appearing in the thesis are given numerical designations by chapter, i.e. appendix 1 to 9. Appendices that appear in the Kema Report are given letter designations like Appendix F and G.

## 2.2 Developing the Utility Base Information

An adaptation of Table 5-2 of the Kema Report shows the BLPC residential customer information obtained from BLPC billing records as presented in Table 2-1 below.

*Table 2-1: General information of BLPC residential customer as in table 5-2 of Kema Report*

Customer category	Number of customers (Number of accounts)	Total MWh sold in 2013
Residential	106,154	299,891

It is necessary to establish the details of energy consumption in each residence.

- a. What devices or appliances exist in each of these residences? This is very particular to the local situation and can only be determined by preparing and administering a statistically suitable number of paper or telephone surveys. This is a major task!
- b. What energy is used by each of these devices and appliances in a residence during the year? This variable is called end-use. Some of this information can be gained by surveys, but much of it must also be based on the experience of the consultants in order to establish a numerical value for the device or appliance in an average residence. This is also a major task!

The adaptation of Table 5-5 of the Kema Report yields the following table on residential energy use as presented in Table 2-2 below.

*Table 2-2: Residential Energy Use by Family Type and End Use as in table 5-5 of Kema Report*

Residential Energy Use by Family Type and End-Use				
End Use Number	Device or Appliance End Use	Single Family	Multi Family	Total MWh
		(MWh)	(MWh)	
1000	Base Ducted Split System Air Conditioner (11SEER)	1,717	-	1,717
1100	Base Room Air Conditioner – EER 9.7	806	939	1,745

1200	Base Ductless Split System Air Conditioner	7,895	259	8,154
1300	Base Incandescent Lighting < 2 hrs/day	1,402	256	1,657
1400	Base Incandescent Lighting >+ 2 hrs/day	3,171	578	3,749
1500	Base Lighting 15 Watt CFL < 2 hrs/day	334	61	395
1600	Base Lighting 15 Watt CFL >= 2 hrs/day	11,336	2,067	13,403
1700	Base Fluorescent Fixture	3,864	705	4,568
1800	Base Refrigerator	55,576	10,133	65,709
1900	Base Second Refrigerator	6,702	-	6,702
2000	Base Freezer (Stand Alone Unit)	50,007	-	50,007
2100	Base Second Freezer (Stand Alone Unit)	11,615	-	11,615
2200	Base 40 gal. Water Heating (EF = 0.8)	2,198	-	2,198
2300	Base Point of Use Water Heater	6,233	2,905	9,138
2400	Base Booster Water Heater (with solar)	833	68	902
2500	Base Clothes Washer (HEF = 1.26)	6,939	442	7,381
2600	Base Clothes Dryer (EF = 3.01)	8,085	515	8,600
2700	Base Dishwasher (EF = 0.65)	1,326	84	1,410
2800	Base Pool Pump (Retrofit)	12,082	-	12,082
2900	Base Plasma TV	11,073	2,268	13,341
3000	Base LCD TV	9,381	935	10,316
3100	Base LED TV	2,109	1,104	3,212
3200	Base CRT TV	4,501	922	5,422
3300	Base Set-Top Box	12,023	1,697	13,719
3400	Base DVD Player	1,534	294	1,828
3500	Base Desktop PC	16,556	2,124	18,681
3600	Base Laptop PC	4,063	350	4,413
3700	Base Cooking (range, oven, stove top)	7,524	1,372	8,895
3800	Base Miscellaneous	4,754	4,156	8,910
	Base House Practice (Total)	265,639	34,234	299,869

It is clear that the total value of energy consumed by all residences in the lower right cell of this table (299,869 MWh) has to match the total of the energy billing by BLPC as appearing in the previous table (299,891 MWh). This matching was not easy. The consultants indicated that they were surprised by several results.

- a. First is the low end-use of only 3.9% of total residential use for air conditioning, a fact explained by the habit of Barbadians to only use their air conditioners to cool their homes for a short time on return home from work.
- b. Second is the low average annual energy consumption of about 3000 kWh per residence since this might be the typical monthly consumption in winter months in North America.
- c. Third they implied that there was a requirement to adjust the estimation parameters in their software to those of a Hawaiian island rather than to those of North America.

For brevity the representative numbers above have been given only for the residential customers. Barbados does not have a lot of heavy industry, so the remainder of the customers are grouped under the one heading of C and I. While the surveys would have been carried out on individual entities such as restaurants, stores, schools, universities, churches, ports and the like, nevertheless it was soon observed that end uses such as lighting and cooling were common to all. Therefore, the presentation of numerical results is the same format for C and I as it was for the residential sector.

To summarize, it was necessary to find the energy consumption by end use because the Technical Potential energy savings available by taking proactive measures is always given as a percentage of the present circumstance.

### **2.3 End Use and Measure Identification**

A measure is any activity that can be used to decrease the energy consumption in an end use classification. Any end use could have a number of energy saving measures applied to it.

- a. The Kema Report identifies end uses by numbers in the hundreds grouping, such as 1000, 1100, 1200, ..., 3900 for the residential sector, and a like series of numbers for the C and I sector (as already introduced in column one of table 2-2).
- b. It identifies measures by unit numbers within the end use hundreds grouping. For example, under end use 2100 Base Second Freezer there are measures 2101, 2102, ..., 2114. This numbering system is used consistently in all the appendices.

#### **2.4 Technical Potential and Economic Potential**

Up to this stage, the end uses in the residential sector and in the C and I sector have been identified. Further, all measures to reduce energy consumption (DSM) in each end use have been identified. There are now two questions associated with each measure.

- a. How much energy can be saved by each measure?
- b. How much does it cost to put each measure in place?

The first question can be answered by application of the Fundamental Equation. With the exception of a handful of financial equations, this is the only technical equation used in the entire Kema Report. It is used repeatedly for measure after measure until the entire list is exhausted. The Fundamental Equation says that the Technical Potential for any measure in the residential sector is:

$$\begin{aligned} \text{Technical Potential of a Measure} &= \text{Number of households} * \text{Base case equipment} && 2.1 \\ & \text{UEC} * \text{Applicability Factor} * \text{Not Complete Factor} * \text{Feasibility Factor} * \\ & \text{Savings Factor} \end{aligned}$$

Where,

Number of households is the total households in Residential sector.

UEC = Unit Energy Consumption which is the energy consumed by a base equipment per household

Applicability factor is the percentage of household that has the base end use and is applicable for replacement with a measure.

Not complete factor is the percentage of the applicable household that is still not replaced by a measure.

Feasibility factor is the percentage of household that is technically feasible to be replaced by a measure.

Savings factor is the percentage of savings that could be achieved when a particular measure is applied.

The first two terms of equation (2.1) have been developed in the first two tables of this chapter. The next three terms are normally each equal to one, except for very unusual cases where, for example, it might not be feasible to implement a measure because of space limitations. The final term, Savings Factor, is of major importance.

It is obvious that universities would not normally have the means to develop numerical values for all these terms. Utilities would typically have no reason to collect this information as part of power system operation. Customers, both residential and C and I, would not have the skills to develop this data. Only consulting companies, who are actively immersed in the area on a day-to-day basis and who have through historical work developed extensive data bases, are able to develop this data for use in future research such as this thesis.

The identical equation is used for calculating Technical Energy potential savings in the C and I sector except the unit energy consumption is calculated per square foot rather

than per residence, and the number of residences is replaced by the square feet per facility (school, restaurant, port, and so on).

$$\begin{aligned} \text{Technical Potential of a Measure} = & \text{Total square feet of floor space} * \text{Base case} & 2.2 \\ & \text{equipment EUI} * \text{Applicability Factor} * \text{Not Complete Factor} * \text{Feasibility} \\ & \text{Factor} * \text{Savings Factor} \end{aligned}$$

Where,

Total square feet is the total area in all building space of C and I sector.

EUI = Energy Use Intensity which is the energy consumed per square feet of floor space in C and I sector.

Applicability factor is the percentage of the floor space that has the base end use and is applicable for replacement with a measure.

Not complete factor is the percentage of the applicable floor space that is still not replaced by a measure.

Feasibility factor is the percentage of the floor space that is technically feasible to be replaced by a measure.

Savings factor is the percentage of savings that could be achieved when a particular measure is applied.

The Technical Potential associated with each measure is one thing, but a test must be carried out to see if it is beneficial from a benefit/cost ratio perspective. Economic Potential defines any measure which has a benefit/cost ratio greater than one.

## **2.5 Cost of implementing a measure**

The method of determining the capital cost of a device, its installation cost, and maintenance cost, out over its lifetime is the Levelized Cost of Energy (saved) (LCOE).

As stated before, such information could only come from the database of a specialist consulting company which has developed this data based on work experience over a period of years. For the hundreds of measures considered for the BLPC system, Appendix F of the Kema Report show the Levelized Cost of (Conserved) Energy in \$/kWh for every measure in the residential, and the C and I sectors.

## **2.6 Extent of the Data**

The listing of end uses, and the measures associated with each end use, are given in Appendix F of the Kema Report. There are 60 end uses in the residential sector and 150 measures that yield the total Technical Potential energy savings. There are 352 end uses in the C and I sector with 848 measures yielding Technical Potential energy savings. A comment of explanation is needed here. The large number of measures in the C and I sector happens because the measures have to be costed out separately for different building types. As an example, the capital and installation cost of a motion detector used to initiate lighting would be much different in a school than it would be in a restaurant. However, when only those measures having Economic Potential are considered, the number of variables is significantly reduced.

## **2.7 Connection to the Thesis**

The determination of the best combination of DSM measures to be used, in total, as a possible replacement of a retiring rotational generating unit is later structured as a linear programming optimization problem.

- a. The measures determined to be in the Economic Potential category become the unknown, or decision, variables in the optimization formulation.

- b. The Levelized Cost of Energy saved by each measure becomes the cost parameter in the formulation of the linear cost function in the linear programming optimization structure.

## CHAPTER 3

### 3. METHODOLOGY

This chapter presents the description of the methodology followed in this thesis. BLPC has a retirement plan for its conventional rotational generating units. There is a need to compensate these capacities to meet the regular load demand, or a reduced load demand. The methodology followed is demonstrated in the Figure 3-1 below.

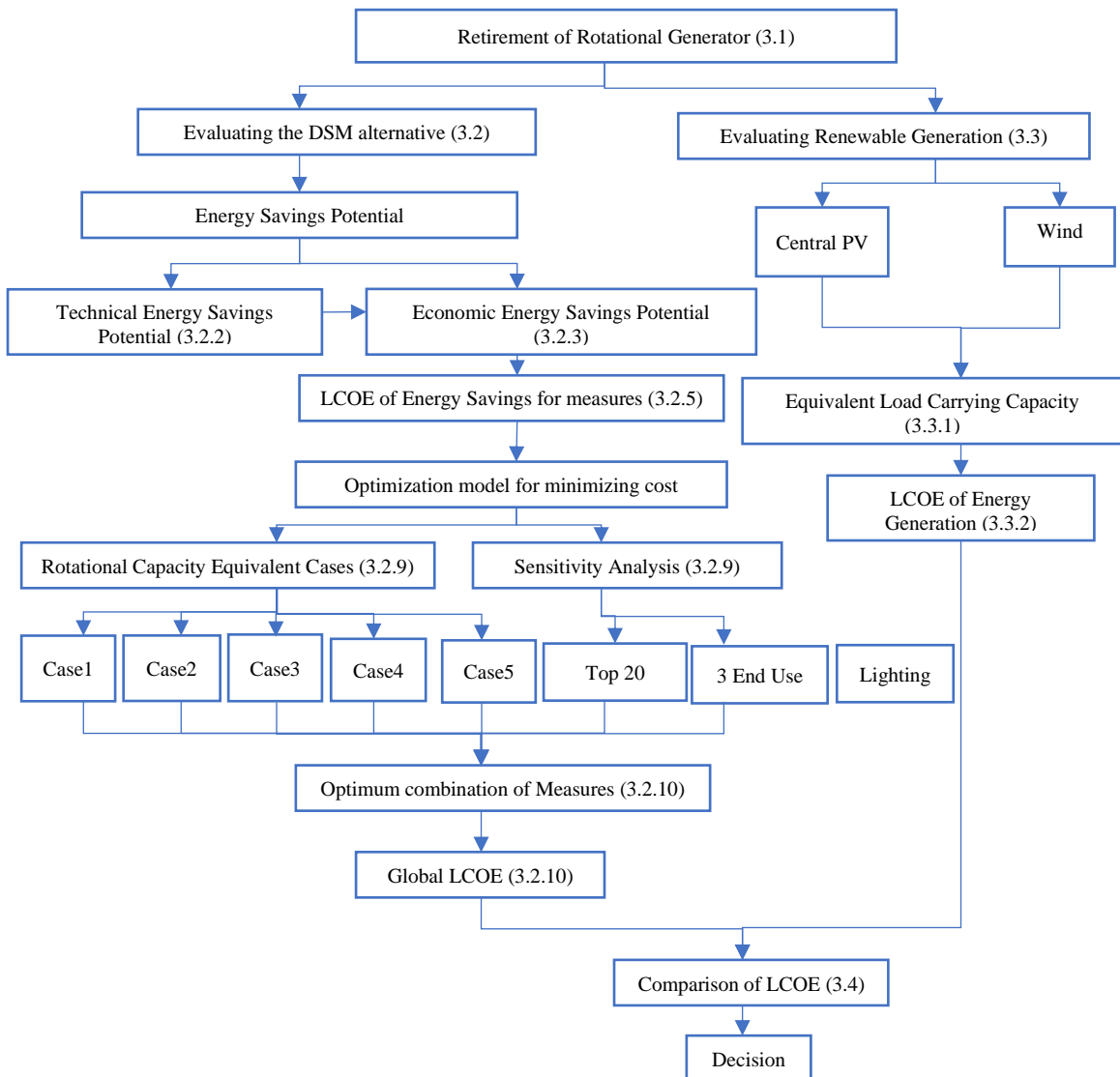


Figure 3-1: Block Diagram of methodology

### 3.1 Replacing Retiring Rotational Generation

A rotational generator has a capacity rating, and it also supplies energy. The energy which it supplies, and which therefore must be replaced upon retirement, is typically calculated as follows.

$$\text{Energy} = \text{Rated MW Capacity} \times \text{Hours in a Year} \times \text{Annual Capacity Factor} \quad 3.1$$

An example might be an 11 MW unit with an 85% capacity factor

$$\text{Energy} = 11 \times 8760 \times 0.85 = 81,906 \text{ MWh} = 81.91 \text{ GWh}$$

The total rotational capacity of the BLPC system is 239.1 MW. BLPC has a variety of rotational units with capacities ranging from 1.5 MW to 29.7 MW. The retirement plan for the 15 rotational units is shown in Table 3-1.

*Table 3-1: Retirement schedule of rotational generators of BLPC*

Retirement year	Capacity						Total
	MW						
2023	13	20					33
2026	13	20					33
2028	1.5	12.5	12.5	12.5	12.5	20	71.5
2030	20	20					40
2035	2.2	29.7	29.7				61.6
Total							239.1

### 3.2 Methodology for Evaluating DSM Alternatives

#### 3.2.1 General

The cheapest combination of DSM measures must be determined, that is the optimum combination must be found. A linear optimization, often called linear programming, is a mathematical model that minimizes or maximizes a linear objective

function subject to linear constraints, and its output provides the best outcome of all the alternatives. Typically, the objective function to be minimized involves cost, and the constraints may be equality constraints or inequality constraints. The variables in the objective function are called the decision variables and are often designated by  $x_1, x_2, \dots, x_n$ . Associated with each decision variable is a cost value  $c_1, c_2, \dots, c_n$ . The general linear optimization problem can be succinctly summarized.

$$\text{Minimize } [f(x_1, x_2, \dots, x_n) = C_T(x_1, x_2, \dots, x_n) = c_1x_1 + c_2x_2 + \dots + c_nx_n] \quad 3.2$$

Subject to one or more equality constraints among the decision variables of the form:

$$a_1x_1 + a_2x_2 + \dots + a_nx_n = 0 \quad 3.3$$

Subject to limits, or inequality constraints, on the individual decision variables:

$$x_{nMin} \leq x_n \leq x_{nMax} \quad 3.4$$

Subject to one or more inequality constraints among the decision variables:

$$b_1x_1 + b_2x_2 + \dots + b_nx_n \leq 0 \quad 3.5$$

### 3.2.2 Technical Potential in Energy Savings

Following from the discussion of data formation in Chapter 2, the variables which we have for energy saving are the “measures” available for energy savings in each end use in both the residential, and the C and I sectors. The Kema Report presents one kind of equation whose form has broad application in calculating Technical Potential energy savings for residential measures, and for C and I measures as shown in equation 2.1 and 2.2 in chapter 2.

As an example, a calculation is carried out for the Technical Potential energy savings of Energy Star Refrigerator (Measure 1801) as a replacement for Base Refrigerator (End Use 1800) using equation 2.1.

Number of single-family households = 88,960

EUI or UEC basic consumption = 619 kWh

Applicability factor = 100%

Not complete factor= 91.2%

Feasibility Factor= 100%

Savings Factors = 20%

Multiplying all these values, the Technical Potential for Measure 1801 is calculated as 10.04 GWh.

The total Technical Potential energy savings is the sum of the individual savings associated with all the measures which could possibly be adopted. The total Technical Potential shown in the Kema Report (Appendix F) is 564.61 GWh; 145 GWh in Residential and 419.61 GWh in C and I.

### **3.2.3 Economic Potential in Energy Savings**

However, not all Technical Potential energy savings opportunities would be adopted. An energy saving measure is said to have Economic Potential if the benefit or value of the potential energy reduction is greater than the cost of attaining that reduction. The Kema Report has determined the Economic Potential (EP) by measure on the basis of the Total Resource Cost (TRC) test [1][39][40].

$$TRC = \frac{Benefit}{Cost} \quad 3.6$$

$$Benefit = \sum_{t=1}^n \frac{Avoided\ cost\ of\ supply_t}{(1 + d)^{t-1}} \quad 3.7$$

$$Costs = \sum_{t=1}^n \frac{Participant\ Cost_t}{(1 + d)^{t-1}} \quad 3.8$$

Where:

d = discount rate and t = time in years

While calculating the benefits and cost, the program costs are not included as these vary according to the program chosen and the program penetration mechanisms [1].

Out of 150 replacement options/measures in the residential sector only 34 of these measures have a TRC greater than one and therefore qualify for yielding Economic Potential, as shown in Table 3-2.

*Table 3-2: Details of end-uses and measures in Residential Sector*

<b>Residential</b>	<b>Base End Uses</b>	<b>Economic Potential Measures</b>	<b>Energy Savings Potential GWh</b>
Single Family	30	30	113
Multi Family	30	4	8
Total	60	34	121

Out of 848 replacement options/measures in the C and I sector, only 317 of these measures have a TRC greater than one and therefore qualify for yielding Economic Potential which is equal to 293.05 GWh, as shown in Table 3-3.

*Table 3-3: Details of end-uses and measures in C&I sector*

<b>C&amp;I</b>	<b>Base End Uses</b>	<b>Economic Potential Measures</b>	<b>Energy Savings Potential GWh</b>
Office	30	27	103.29
Restaurant	29	22	4.7
Retail	30	31	47.02
Grocery	30	56	29.05
School	29	22	11
Health	29	30	12.49
Lodging	29	26	38.47

Industrial	29	17	6.23
WWT	28	8	7.49
Ports	29	23	8.62
Landlord	30	32	8.71
Others	30	23	15.98
<b>Total</b>	<b>352</b>	<b>317</b>	<b>293.05</b>

There are a total of 351 measures which have Economic Potential (34 in Residential and 317 in C and D). Each measure is a decision variable in the linear programming formulation.

### 3.2.4 Magnitude of Economic Potential Measures

Appendix F of the Kema Report is the table that has the magnitude values of energy savings of all measures associated with each end use. The data is broken down to two family levels (single-family and multifamily) for the Residential customer sector and twelve building types (Office, Restaurant, ..., Others) as shown in Table 3-3 for C and I customer sector.

The magnitude of energy savings associated with the 351 energy saving measures are shown in appendix 1 of this thesis. These numbers become the inequality constraints on each of the decision variables in the optimization formulation.

### 3.2.5 Cost of the Economic Potential Measures

The usual way to arrive at a representative cost is to determine the Levelized Cost of Energy reduction (LCOE) over the lifetime of the various devices as an annualized cost based on a Capital Recovery Factor (CRF) applied to capital cost, installation cost, implementation cost, and maintenance cost. In a simple way the LCOE can be stated as:

$$\begin{aligned}
 \text{Levelized Cost of Energy (reduction)LCOE} & \qquad \qquad \qquad 3.9 \\
 & = \frac{\text{Annualized cost in dollars of reduction}}{\text{kWh energy reduction/savings}}
 \end{aligned}$$

$$LCOE = \frac{\text{full unit cost} * CRF}{\text{Energy reduction/savings}} \quad 3.10$$

$$CRF = \frac{i * (1 + i)^n}{(1 + i)^n - 1} \quad 3.11$$

Full unit cost= equipment cost+ labour cost + O&M cost

CRF= Capital Recovery Factor

i = discount rate

The LCOE values have been taken directly from Appendix F of the Kema Report as input to the model developed in this study.

The LCOE of energy savings associated with the 351 energy saving measures are shown in appendix 1 of this thesis. These are the costs associated with each of the decision variables in the optimization formulation.

### 3.2.6 Objective Function to be Minimized

The generic form of an objective function is:

$$\text{Minimize } [f(x_1, x_2, \dots, x_n) = C_T(x_1, x_2, \dots, x_n) = c_1x_1 + c_2x_2 + \dots + c_nx_n] \quad 3.12$$

In this thesis, the Economic Potential measures have been given the symbol E. Since there are 351 measures having Economic Potential, the objective function can be written as:

$$\text{Minimize } [C_T(E_1, E_2, \dots, E_{351}) = C_1E_1 + CE_2 + \dots + C_{351}E_{351}] \quad 3.13$$

Where, E<sub>1</sub> to E<sub>351</sub> are the decision variables and C<sub>1</sub> to C<sub>351</sub> are the corresponding LCOE for each measure.

### 3.2.7 First Layer of Constraint

The first layer or level of constraint is the constraint on each measure, that is the constraint on each decision variable. As described above, appendix 1 of this thesis lists the

magnitude of the DSM energy savings possible for each of the measures, and this magnitude is designated by the capital letter M. Any or none of each measure may be used depending on the measure cost. For purposes of formulation of the optimization problem we can write for each measure E:

$$0 \leq E_n \leq E_{nM} \quad 3.14$$

For,  $n = 1, 2, \dots, 351$ .

### 3.2.8 Second Layer of Constraint

The second layer of constraint deals with the constraints on each like-group. As an example, a compact fluorescent bulb and an LED bulb both impact the end use of lighting, so these can be called a like-group. The Kema Report has calculated the energy savings for each like-group. Therefore, it becomes necessary to associate each subset of the decision variables with a like-group. The 351 measures are divided under 24 like-group categories (12 for Residential and 12 for C and I). As expected, the measures are not equally distributed in every like-group. The distribution of the measures in each like-group is shown in the Table 3-4.

*Table 3-4: Distribution of measures in like-groups Residential and C and I sectors*

Residential Sector			C and I sector		
Like-Group Name	Symbol	Subset of Decision Variables	Like-Group Name	Symbol	Subset of Decision Variables
Lighting	E <sub>R1</sub>	E <sub>1</sub> to E <sub>9</sub>	Indoor Lighting	E <sub>C1</sub>	E <sub>35</sub> to E <sub>119</sub>
Cooling	E <sub>R2</sub>	E <sub>10</sub>	Outdoor Lighting	E <sub>C2</sub>	E <sub>120</sub> to E <sub>150</sub>
Refrigeration	E <sub>R3</sub>	E <sub>11</sub> to E <sub>20</sub>	Cooling	E <sub>C3</sub>	E <sub>151</sub> to E <sub>213</sub>
Water Heating	E <sub>R4</sub>	E <sub>21</sub> to E <sub>24</sub>	Ventilation	E <sub>C4</sub>	E <sub>214</sub> to E <sub>224</sub>
Clothes Washer	E <sub>R5</sub>	-	Refrigeration	E <sub>C5</sub>	E <sub>225</sub> to E <sub>262</sub>
Clothes Dryer	E <sub>R6</sub>	E <sub>25</sub>	Office Equipment	E <sub>C6</sub>	E <sub>263</sub> to E <sub>307</sub>

Dish Washer	E <sub>R7</sub>	-	Data Centre	E <sub>C7</sub>	-
Pool Pump	E <sub>R8</sub>	E <sub>26</sub>	Water Heating	E <sub>C8</sub>	E <sub>308</sub> to E <sub>334</sub>
TV/PC	E <sub>R9</sub>	E <sub>27</sub> to E <sub>32</sub>	Vending	E <sub>C9</sub>	E <sub>335</sub> to E <sub>342</sub>
Cooking	E <sub>R10</sub>	-	Cooking	E <sub>C10</sub>	E <sub>343</sub> to E <sub>348</sub>
Miscellaneous	E <sub>R11</sub>	-	Motors	E <sub>C11</sub>	E <sub>349</sub> to E <sub>351</sub>
Whole House	E <sub>R12</sub>	E <sub>33</sub> to E <sub>34</sub>	Miscellaneous	E <sub>C12</sub>	-

Appendix 2 of this thesis lists the magnitude of the DSM energy savings capability of like-groups, which as shown in the table above have been called E<sub>R1</sub>, ... E<sub>R12</sub>, E<sub>C1</sub>, ... E<sub>C12</sub>. In order to assure that energy usage is not exceeded in a like-group, it is necessary to formulate a second layer of constraint. Stated in words, the formulation says:

Sum of energy saving of individual measures in a subset ≤ DSM energy savings capability of like-group.

The formulation of these constraints is obvious from the table above. Rather than show the formulation for all 24 like-groups, two examples are shown.

$$E_1 + E_2 + \dots + E_9 \leq E_{R1} \quad 3.15$$

$$E_{35} + E_{36} + \dots + E_{119} \leq E_{C1} \quad 3.16$$

### 3.2.9 Third Layer of Constraint

The target energy reduction is set to match the energy produced by the retiring rotational unit in BLPC. All the existing rotational generators are going to retire by 2035. Through this study the aim is to replace at least one of the retiring capacities with DSM opportunities. To establish the energy reduction requirement, some assumptions are made. Excluding the two small generator sizes (1.5 MW and 2.2 MW which are cogeneration units) there are four different capacities resulting in four cases. The method for determining

the energy reduction target at a capacity factor of 85% was shown in section 3.1, and the results for the four cases are shown in Table 3-5.

Also, the BLPC Integrated Resource and Resiliency Plan (IRRP) has a target of achieving 11% reduction in total demand in the 2030 Base Scenario [41]. The base load scenario in 2030 is 1277 GWh. Considering a capacity factor of 85%, the equivalent capacity would be 18.87 MW. This is developed as a fifth case as shown in Table 3-5.

The target reduction in the 2030 base scenario = 11%\*1277 GWh= 140.47 GWh

*Table 3-5: Details of 5 case studies*

Case	Capacity	Energy savings target
	MW	MWh = MW*8760*0.85
1	12.5	93,075
2	13	96,798
3	20	148,920
4	29.7	221,146
5	18.87	140,470

This energy reduction requirement then produces an inequality constraint, which is the third layer of constraint.

$$E_1 + E_2 + \dots + E_{351} \geq \text{Energy to be replaced} \quad 3.17$$

Additionally, there are three-sensitivity studies: analysing the top twenty contributors, applying only three end use areas (lighting, cooling, and behavioural program), and finally only applying lighting measures. These three-sensitivity analysis are also carried out for all five capacities mentioned above in Table 3-5.

### **3.2.10 Formulation of the optimization problem**

In order to develop the optimization model, the optimization problem is formulated in linear form by using the equality and inequality constraints and by defining the function to be minimized. The following process is followed to develop the model:

- First a list is prepared by sorting the measures on the basis of TRC values. All the measures with TRC value less than one are eliminated. All the measures with zero savings potential are also eliminated.
- The total cost of energy savings by each measure is calculated as the product of LCOE and the individual energy savings potential.
- The first layer constraints are assigned at each measure level.
- The second layer of constraints are applied at each like-group.
- The overall energy reduction target is set by assigning a third constraint. There are five energy savings target cases as explained earlier.
- Finally, the value to be minimized is defined. This is the total cost of achieving the energy saving target.
- The optimization model is also run for three sensitivity analysis scenarios for all the five cases.

The program is designed to choose the optimal combination of individual replacement options (or measures) from every like-group. The program is flexible to run for the variable targets of energy savings values to be achieved. For a target/input of 150 GWh of energy savings it would choose a combination of the cheapest measures amounting to that value of savings, and for a target of 170 GWh of savings it would again choose a new combination of cheapest measures meeting that target.

### 3.2.11 Optimization software

The optimization software chosen for developing this model is called “What’s Best! Version 17”, a product of LINDO. It uses the MS Excel Interface and appears as one tab.

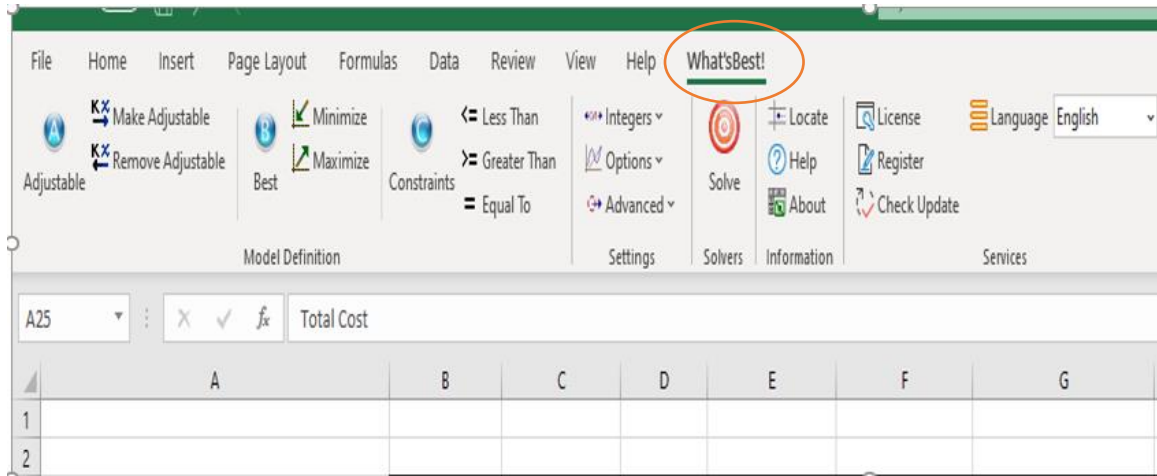


Figure 3-2: Snapshot of What’s Best tool patched in MS-Excel interface

The program demands three major steps as follows:

1. Variables need to be specified.
2. Quantity to be optimized is to be assigned.
3. Constraints needs to be defined.

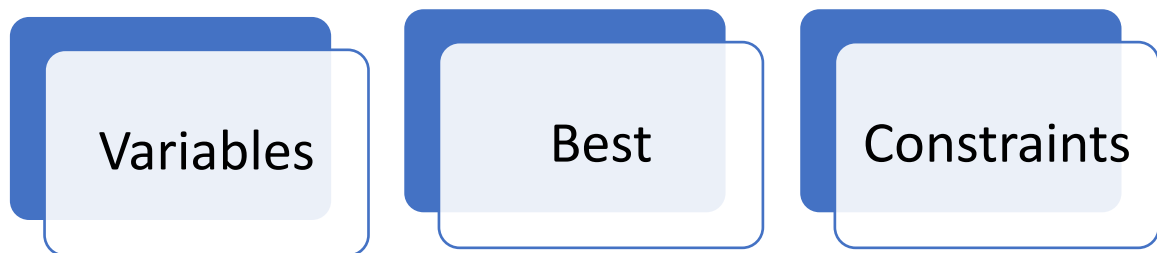


Figure 3-3: Three features in What’s Best platform

A. Variables: These are called “Adjustables” in the What’s Best platform.

Here, in this case, the energy savings measures are the variables. These values are initially input as zero and made adjustable. They change as required when the optimization is run.

B. Objective function/quantity to be optimized: It is called “Best” in the What’s Best platform. It allows options for either minimizing or maximizing the value. In this case, the total cost of replacement of the end uses is set to be minimized.

C. Constraints: Three layers of constraints are defined as described in the procedure above.

### **3.3 Methodology for Replacement of the Rotational Unit by Renewable Energy Sources**

Electric power from renewable energy sources is available only when the raw energy source is available, and the renewable source is said to be intermittent. The electrical power from such sources is not controllable, and the technical term is that such sources are non-dispatchable. While each such renewable source has a nameplate capacity rating, its impact in the power system is not nearly at that value. Its impact on the power system is said to be the effective capacity, or the Equivalent Load Carrying Capability (ELCC). A probabilistic approach to calculating power system reliability allows calculation of the Equivalent Load Carrying Capability of renewable energy sources.

#### **3.3.1 Effective Capacity of Renewable Energy Sources**

The IRRP presents the intent of the Barbados government to decarbonize generation by promoting renewable energy generation [41]. However, these renewable sources of energy may not be available in equal intensity throughout the twenty-four hours of a day.

Being variable or intermittent in nature, renewable energy sources are non-dispatchable or non-controllable. In order to ensure the reliability of supply, adequate

capacity needs to be installed. A probabilistic method called Equivalent Load Carrying Capability (ELCC) is the standard method used to determine equivalency of renewable energy sources to conventional rotational sources. ELCC is the measure of a renewable energy resource's capability to effectively meet the load demand and is expressed as a percentage of total capacity. It uses Monte Carlo simulations for power system reliability calculations [42][43][44] The steps are:

1. Establish a Base Case and calculate the appropriate reliability indices
2. Propose renewable energy sources of specified type and capacity to be added to the power system
3. Determine the now-reduced reliability indices of the power system.
4. Add increments of load to the power system until the reliability indices of the power system rise back up to the original values of Item 1

The final value of load added is called the Equivalent Load Carrying Capability, and in the market environment it has been referred to as the "capacity credit" of the renewable energy sources.

A study of capacity credit for wind in the US Midwest Independent System Operator (MISO) system shows that the ELCC for the wind is close to 10% for a capacity ranging between 25,000-30,000 MW [45]. The study calculated ELCC for seven consecutive years 2005 to 2011 for different penetration capacities expressed in percentage of maximum peak load. It was seen that for most of the cases, ELCC decreases with increase in penetration level. However, the average ELCC is obtained as 14.7% at a penetration level of 9.7%. This study is typical to the MISO system in the United States having 135,000 MW generation with 11,000 MW of wind capacity spread over 140 sites.

A similar study carried out by General Electric on the BLPC system proposed various scenarios of RE sources to be added [42] The ELCC was calculated for four different scenarios. The baseline ELCC is 48.80% for all the RE sources. Two prospective RE sources are considered in Barbados, Central PV and Wind. The average ELCC values for Central PV and Wind are 36.53% and 28.65% respectively. The values of ELCC for different scenarios is shown in the Table 3-6.

*Table 3-6: ELCC values for Central PV and Wind from GE study*

Scenario	ELCC	
	Central PV	Wind
Scenario 1	-	30.00%
Scenario 2	40.60%	28.20%
Scenario 3	34.50%	28.20%
Scenario 4	34.50%	28.20%
Average	36.53%	28.65%

### 3.3.2 Cost of Renewable Energy Sources

Renewable energy sources are costed in a manner similar to conventional sources using the LCOE. There are no fuel costs associated with renewable energy sources, and the maintenance costs may be less. BLPC has provided the levelized cost in \$/kWh for both solar renewable energy sources and wind renewable energy sources.

### 3.4 Comparison of alternatives

We start with the premise that a rotational generating unit is to be retired. A method is proposed to calculate the optimal cost of DSM energy reduction. The cost of renewable energy sources for year 2022 has been provided by BLPC. The decision then is a comparison of these two alternatives.

## CHAPTER 4

### 4. RESULTS AND ANALYSIS

#### 4.1 Assumptions and Explanations of Data

The data of the Kema Report has been used extensively in this thesis. It should be noted that all data and results are stated in Barbadian currency. Some working assumptions have been made in using the data. These assumptions are stated in the points below:

1. The Kema Report was completed in 2015, but it is based on 2013 data. The study year of this thesis is 2025. Consequently, it has been necessary to adjust the LCOE of all the measures to the year 2025 considering the cumulative inflation rate of 36% [46]. The calculation of the cumulative inflation rate from 2013 to 2025 is shown in appendix 3.
2. All the measures in the residential sector have an LCOE greater than zero \$/kWh . Nineteen measures in the C and I sector under different end uses and building types have an LCOE equal to zero. The total energy savings potential for these nineteen measures is 10.29 GWh. Whenever new equipment is installed, a cost is always associated with it. Therefore, a minimum LCOE of 0.01 \$/kWh is assumed for these nineteen measures. These measures are listed in appendix 4.
3. The value of LCOE ranges from 0.01 to 1519.94 \$/kWh. However, the measures with higher LCOE values eventually got eliminated as they did not pass the TRC test. The LCOE of 351 measures yielding economic potential ranges from 0.01 to 0.97 \$/kWh; 0.01 to 0.63 \$/kWh for Residential and 0.01 to 0.97 \$/kWh for C and I making a total of 57 different values of LCOE. The details of LCOE distribution are given in

appendix5. The table also displays the number of measures and total energy savings potential for each value of LCOE.

4. A lot of rounding has been done in the data, and as a result the peak capacity savings are zero for a large number of measures. This could not be true. Referring to the summary results in “figure 6-1” of the Kema Report, a global load factor of 90.3% can be calculated. This value has been used in calculating economic peak demand saving potential in this thesis.
5. The two renewable energy sources, central PV and wind, are considered for comparison. The values of ELCC [42] and LCOE for these two technologies have been provided by BLPC and are shown in the Table 4-1.

*Table 4-1: Details of Renewables technology used in the study*

<b>S.N.</b>	<b>Technology</b>	<b>ELCC</b>	<b>LCOE in \$/kWh</b>
1	Central PV	39.60 %	0.23
2	Wind	32.68%	0.28

6. Because of the reduced consumption of energy due to DSM activities, there will be a loss of Return on Investment (ROI) for BLPC investors. This is treated as an additional cost and added to the cost of energy savings. The average rate paid by customers for electricity sales in BLPC is 0.70 \$/kWh for the year 2022. Considering the cumulative inflation rate of 7.36% to the study year the average rate for energy sales is 0.75 \$/kWh for the year 2025. The ROI is considered to be 10%. Therefore, the loss of ROI appears as a cost of 0.075 \$/kWh for every kWh saved by DSM activities.

## 4.2 Case studies

The optimum cost of implementing DSM is studied for five different cases. The first four cases are the energy savings equivalent to retirement of different rotational generator sizes and the fifth case is the energy saving target of Barbadian government through DSM [41].

### 4.2.1 Case 1: Retirement of 12.5 MW Unit

#### 4.2.1.1. Results

The optimization model was run to achieve an energy savings equivalent to 12.5 MW capacity at a capacity factor of 85%, which is 93.075 GWh. The optimization results show that the minimum cost for all the measures selected by the software is \$ 3,247,476. Considering the cost of the loss of ROI, the global LCOE for DSM was obtained as 0.110 \$/kWh. The peak demand saving potential is 11.77 MW. The summary of the results is shown in the Table 4-2. The sample model for this case is shown in appendix 9.

*Table 4-2: Case 1 Summary of the Result*

Achieved Total Energy Savings kWh	93,075,000
Optimized Cost of energy Savings in \$	3,247,476
Cost of Loss of ROI in \$	6,999,240
Total Cost B\$	10,246,716
MW Savings	12.50
Global LCOE \$/kWh	0.110
Peak Demand Savings MW	11.77

#### 4.2.1.2. Analysis

In the residential sector, 52 GWh of energy savings was achieved at a cost of \$1,904,000. The Figure 4-1 presents the energy savings and cost for each of the family types.

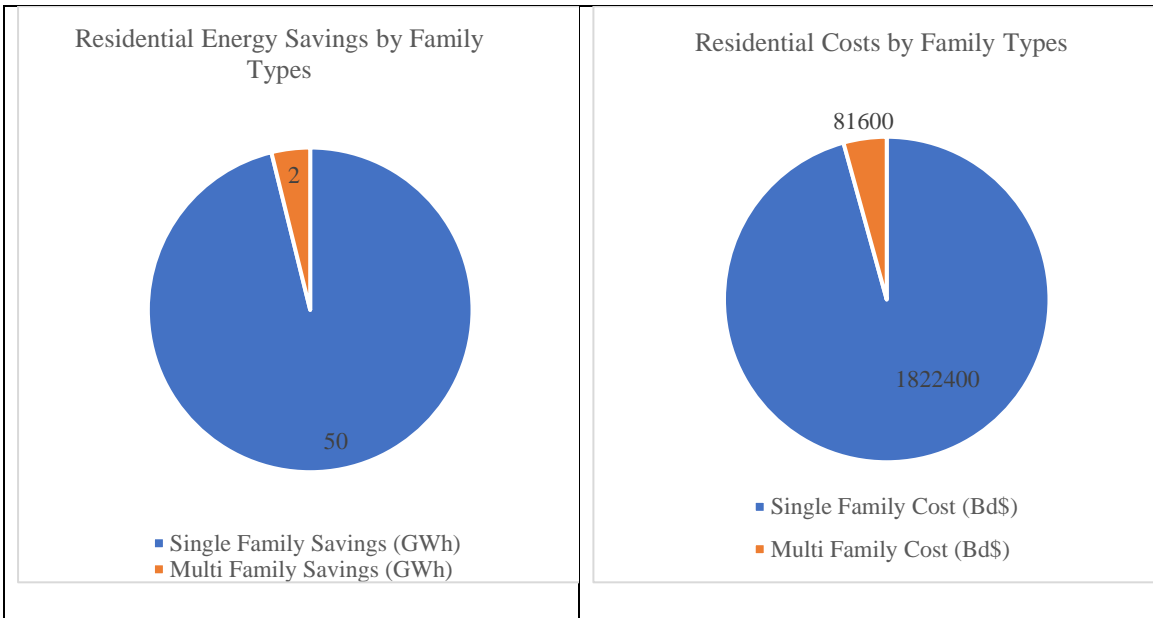


Figure 4-1: Case 1 Residential energy savings and costs by family types

The savings and the corresponding values of costs attained under each end use category for the residential sector is shown in Figure 4-2. Refrigeration, whole house, and TV/PC are the top three energy saving areas.

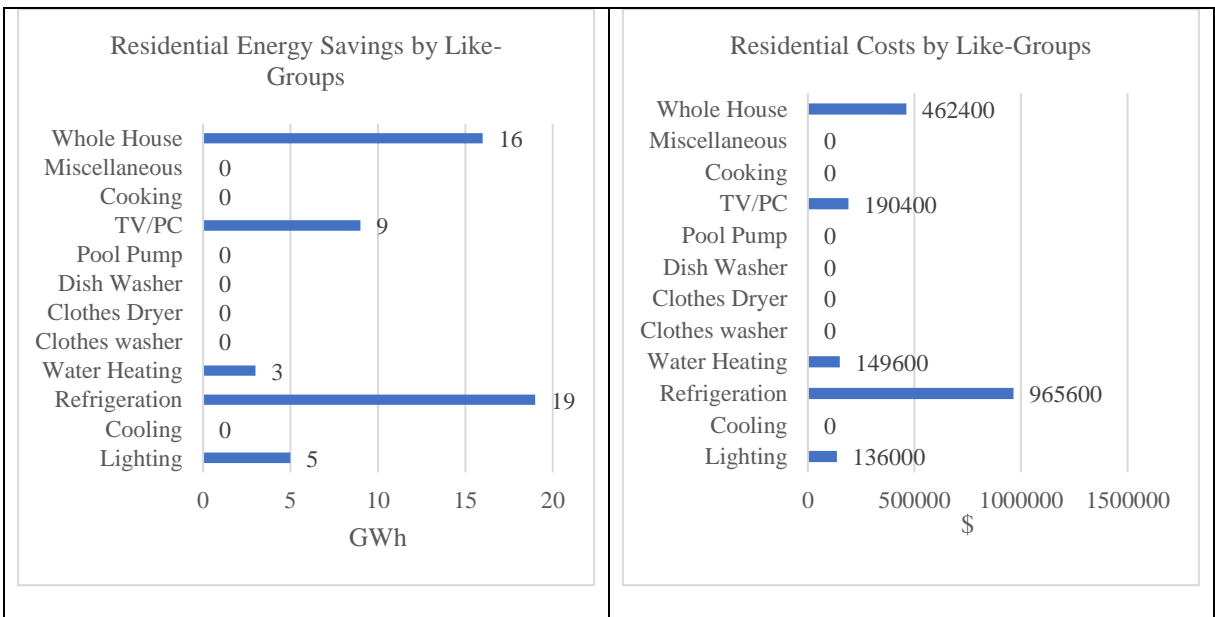


Figure 4-2: Case 1 Residential energy savings and costs by like-groups

In the C and I sector, 41.075 GWh energy savings was obtained at a cost of \$1,343,476. The Figure 4-3 presents the energy savings and cost for each of the building types.

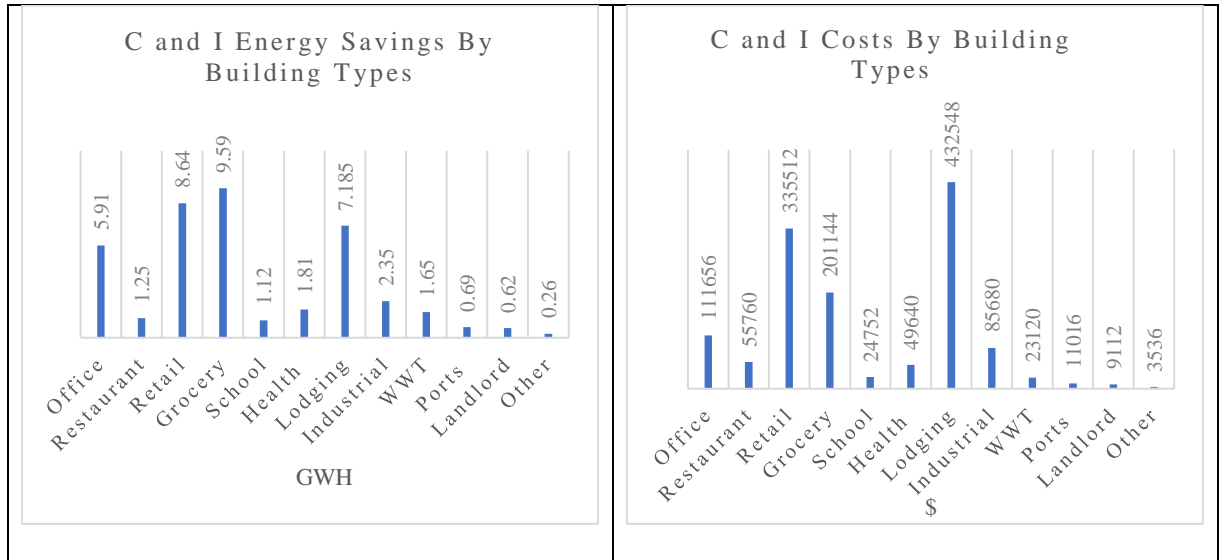


Figure 4-3: Case 1 C&I energy savings and costs by building types

The savings and the corresponding values of costs attained under each end use category for the C and I sector is shown in the Figure 4-4. Office equipment, indoor lighting and cooking are the top three energy saving areas.

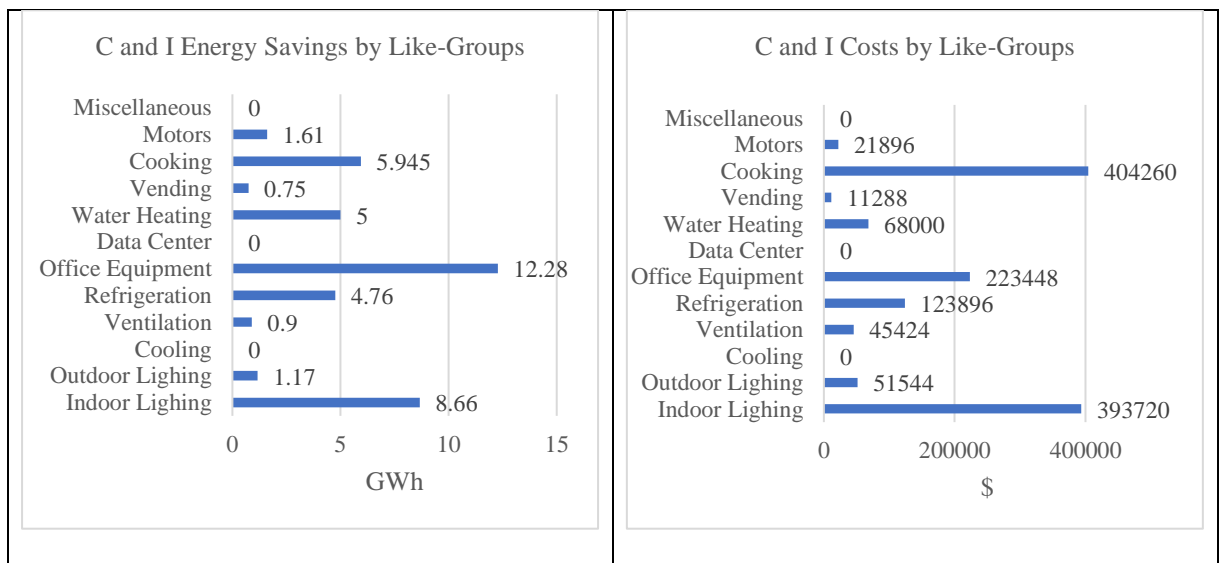


Figure 4-4: Case 1 C&I energy savings and costs by like-groups

103 measures with 5 different values of LCOE ranging from 0.01 to 0.07 \$/kWh are selected to obtain the target of 93.075 GWh. Appendix 6.1 presents the details of maximum and achieved energy savings potential for each value of LCOE. It is observed that in the two LCOE levels of 0.01 and 0.07 \$/kWh energy savings to the full potential cannot be achieved. This is because the program can choose any value of savings between zero to maximum potential (constraint 1) to best match the target.

The measures “8010 Demand controlled circulating systems” and “8070 Heat Pump Water Heater” under grocery were not selected despite having a low cost of 0.01 kWh. This is because the maximum savings potential for the water heating category is 5 GWh and it is already saturated (due to constraint 2). Also, the measure “8070 Heat Pump Water Heater” under restaurant having an LCOE of 0.03 \$/kWh is not selected. The details of these measures are shown in appendix 7.

#### **4.2.2. Case 2: Retirement of 13 MW Unit**

##### **4.2.2.1. Results**

The optimization model was run to achieve the energy savings equivalent to 13 MW capacity. This is 96.798 GWh at a capacity factor of 85%. The optimization results show that the minimum cost is \$ 3,525,772.8 for the measures selected by the software. Considering the cost of the loss of ROI, the global LCOE was obtained as 0.112 \$/kWh. The peak demand saving potential is 12.24 MW. The summary of the results is shown in the

Table 4-3.

Table 4-3: Case 2 Summary of the Result

Achieved Total Energy Savings kWh	96,798,000
Optimized Cost of energy Savings \$	3,525,772.8
Cost of Loss of ROI in \$	7,279,209.6
Total Cost \$	10,804,982.40
MW Savings	13
Global LCOE \$/kWh	0.112
Peak Demand Savings MW	12.24

#### 4.2.2.2. Analysis

In the residential sector 53.8 GWh of energy savings was achieved at the cost of \$2,054,796.8. The Figure 4-5 presents the energy savings and cost for each of the family types.

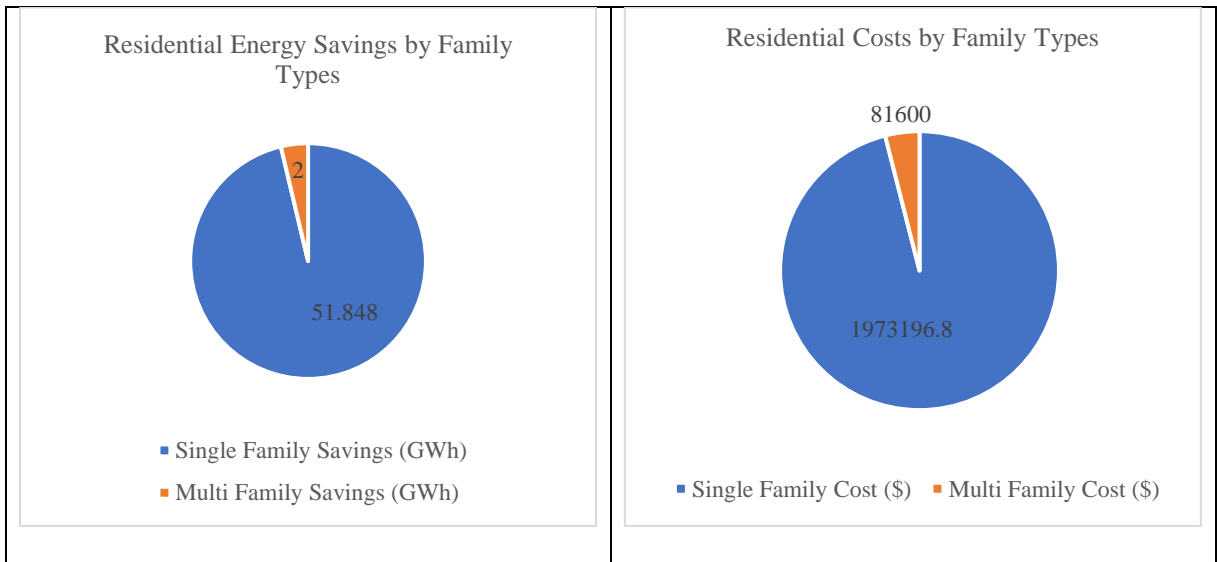


Figure 4-5: Case 2 Residential energy savings and cost by family types

The savings and the corresponding values of costs attained under each end use category for the residential sector is shown in the Figure 4-6. Refrigeration, whole house and TV/PC are the top three energy saving areas.

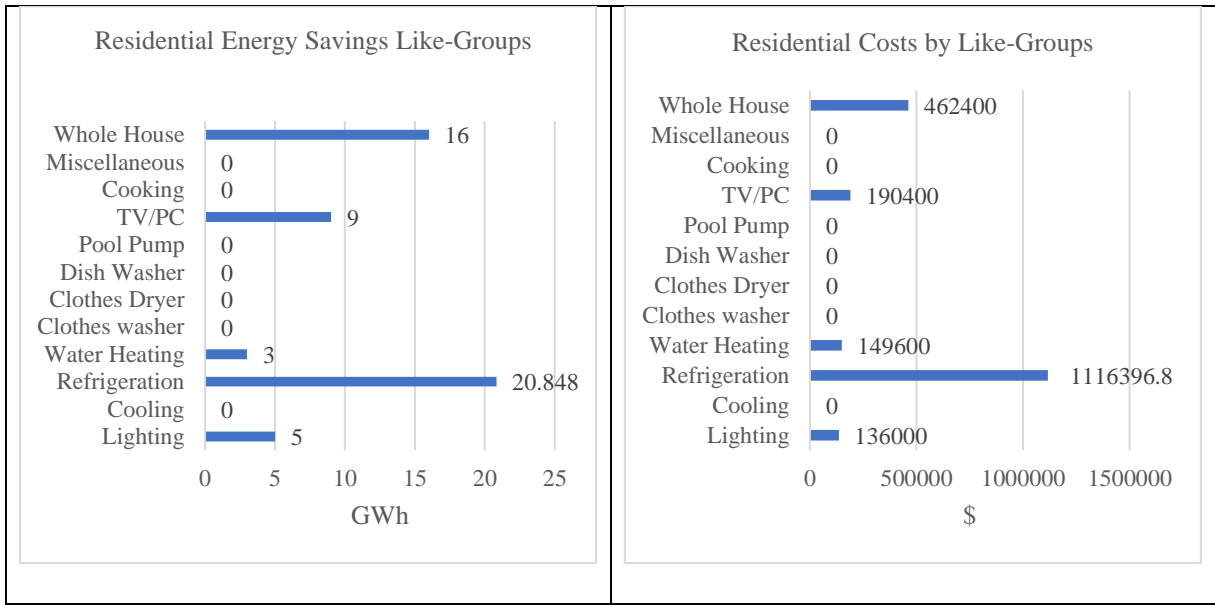


Figure 4-6: Case 2 Residential energy savings and costs by like-groups

In the C and I sector, 42.95 GWh of energy savings was obtained at a cost of \$1,470,976. The Figure 4-7 presents the energy savings and cost for each of the building types.

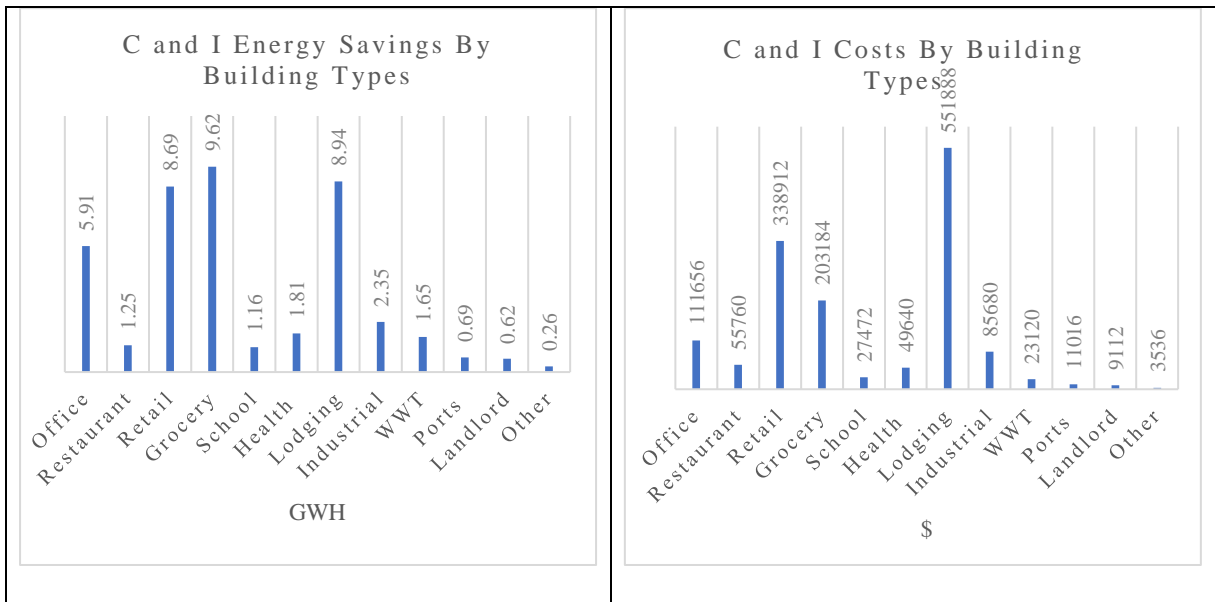


Figure 4-7: Case 2 C&I energy savings and costs by building types

The savings and the corresponding values of cost attained under each end use category for the C and I sector are shown in Figure 4-8. Office equipment, indoor lighting and cooking are the top three energy saving areas.

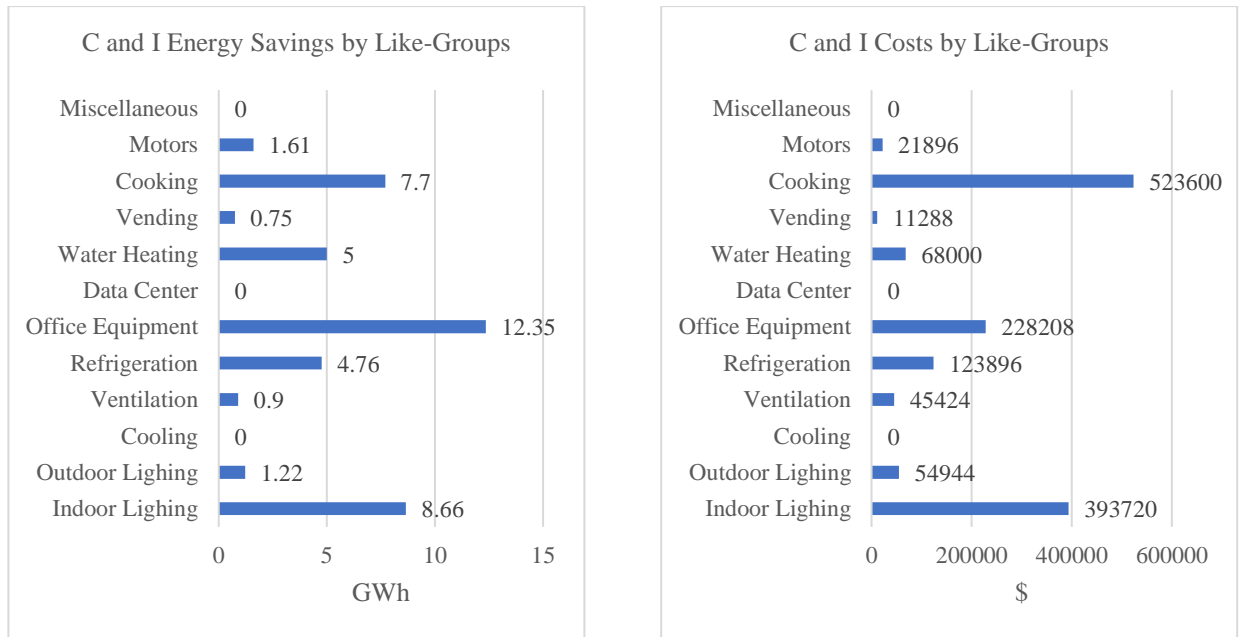


Figure 4-8: Case 2 C&I energy savings and costs by like-groups

107 measures with 6 different values of LCOE ranging from 0.01 to 0.08 \$/kWh are selected to obtain the target of 96.798 GWh. Appendix 6.2 presents the details of maximum and achieved energy savings potential for each value of LCOE. It should be noted that in the two LCOE levels of 0.01 and 0.08 \$/kWh energy savings to the full potential cannot be achieved. This is because the program can choose any value of savings between zero to maximum potential (constraint 1) to best match the target.

Six measures in different groups are not selected despite having a low value of LCOE because the maximum savings potential for the respective end use categories are already saturated (constraint 2) as shown in appendix 7.

### 4.2.3. Case 3: Retirement of a 20 MW Unit

#### 4.2.3.1.Result

The optimization model was run to achieve the energy savings equivalent to 20 MW capacity. This is 148.92 GWh at a capacity factor of 85%. The results show a minimum cost of \$ 8,468,992 for the measures selected by the software. Considering the cost of the loss of ROI, the global LCOE was obtained as 0.132 \$/kWh. The peak demand saving potential is 18.83 MW. The summary of the results is shown in the Table 4-4.

*Table 4-4: Case 3 Summary of the Result*

Achieved Total Energy Savings kWh	148,920,000
Optimized Cost of energy Savings \$	8,468,992
Cost of Loss of ROI \$	11,198,784
Total Cost \$	19,667,776
MW Savings	20
Global LCOE \$/kWh	0.132
Peak Demand Savings MW	18.83

#### 4.2.3.2.Analysis

In the residential sector, 71.7 GWh energy savings was achieved at a cost of \$ 3,538,720. The Figure 4-9 presents the energy savings and cost for each of the family types.

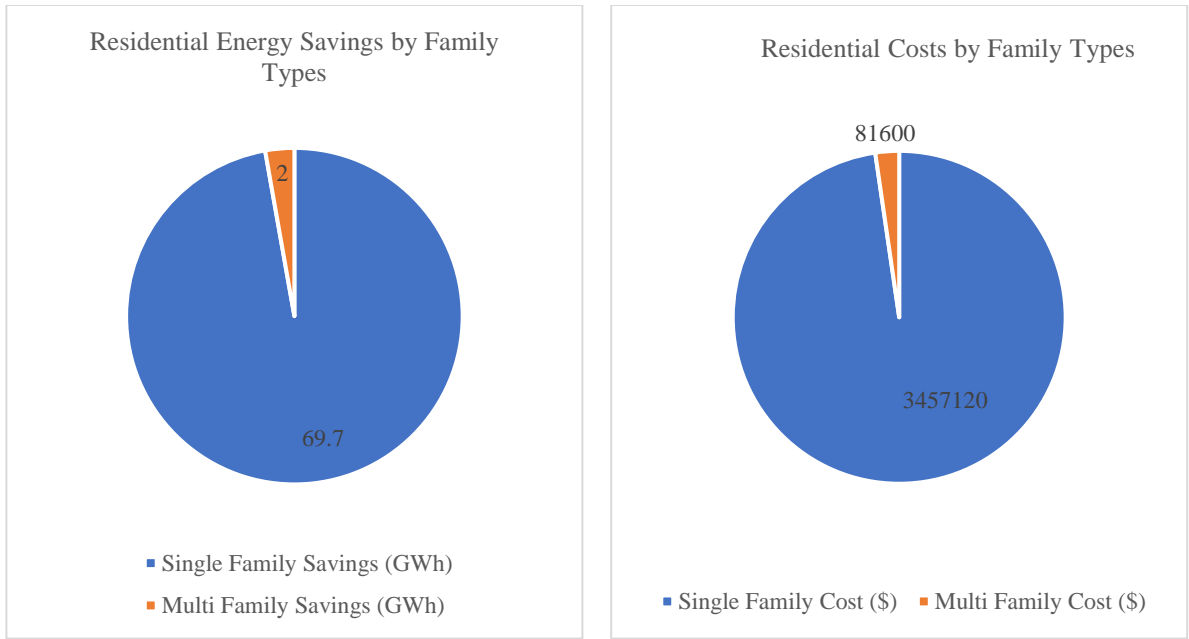


Figure 4-9: Case 3 Residential energy savings and costs by family types

The savings and the corresponding values of costs attained under each end use category for the residential sector are shown in Figure 4-10 refrigeration, whole house, and pool pump are the top three energy saving areas.

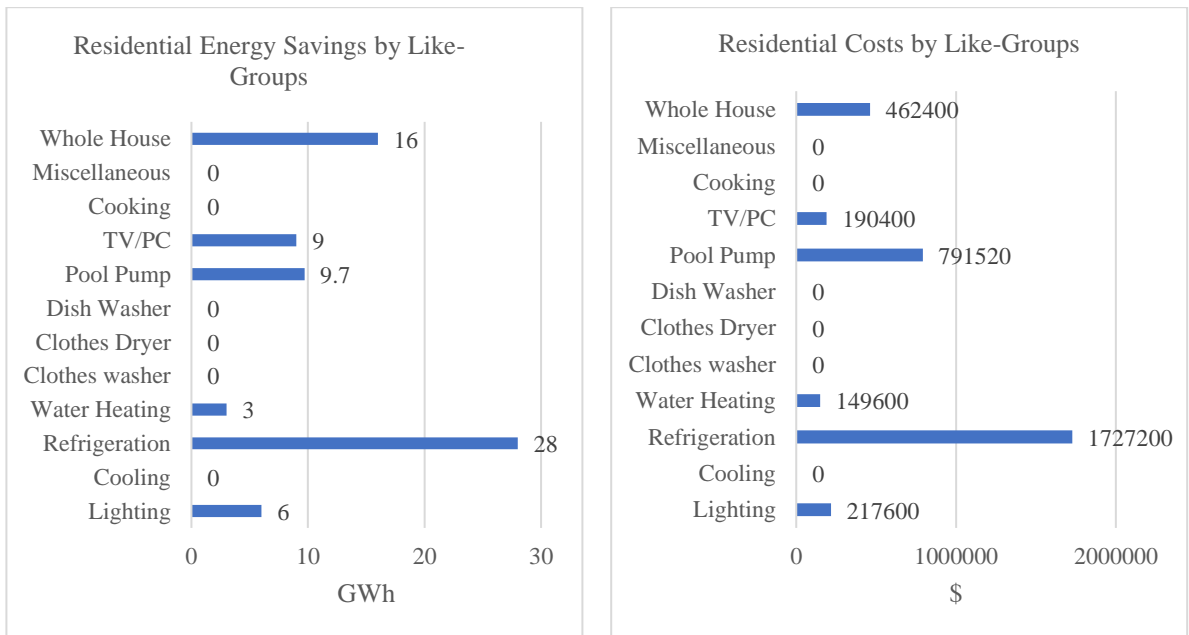


Figure 4-10: Case 3 Residential energy savings and costs by like-groups

In the C and I sector, 77.22 GWh energy savings was obtained at a cost of \$ 4,930,272. Figure 4-11 presents the energy savings and cost for each of the building types.



Figure 4-11: Case 3 C&I energy savings and costs by building types

The savings and the corresponding values of costs attained under each end use category for the C and I sector are shown in Figure 4-12. Indoor lighting, office equipment, and cooking are the top three energy saving areas.

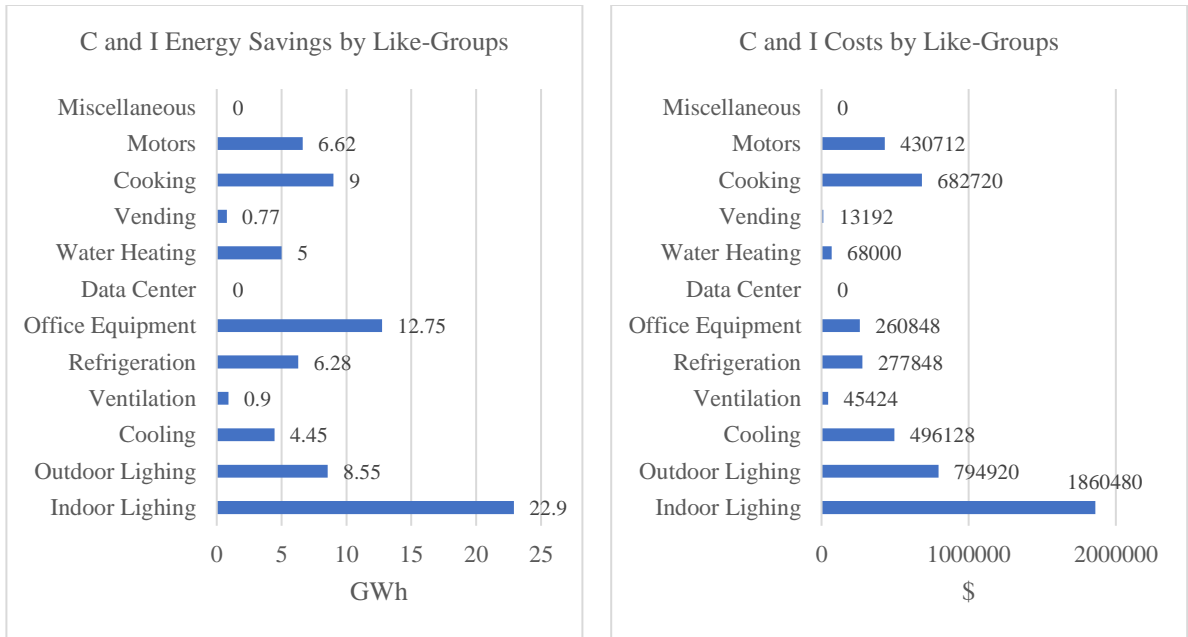


Figure 4-12: Case 3 C&I energy and costs savings by like-groups

150 measures with 9 different values of LCOE ranging from 0.01 to 0.12 \$/kWh are selected to obtain the target of 148.92 GWh. Appendix 6.3 presents the details of maximum and achieved energy savings potential for each value of LCOE. It can be observed that in three LCOE levels of 0.01, 0.08 and 0.12 \$/kWh energy savings to the full potential cannot be achieved. This is because the program can choose any value of savings between zero to maximum potential (constraint 1) to best match the target.

Nine measures in different groups are not selected despite having a low value of LCOE because the maximum savings potential for the respective end use categories is already saturated (constraint 2) as shown in appendix 7.

#### 4.2.4. Case 4: Retirement of a 29.7 MW Unit

##### 4.2.4.1.Result

The optimization model was run to achieve the energy savings equivalent to 29.7 MW capacity, which is 221.146 GWh at capacity factor of 85%. The optimization results show a minimum cost of \$ 22,853,766.4 for the measures selected. Considering the cost of the loss of ROI, the global LCOE was obtained as 0.179 \$/kWh. The peak demand saving potential is 27.96 MW. The summary of the results is shown in the Table 4-5.

*Table 4-5: Case 4 Summary of the Result*

Achieved Total Energy Savings kWh	221,146,200
Optimized Cost of energy Savings B\$	22,853,766.4
Cost of Loss of ROI \$	16,630,194.2
Total Cost \$	39,483,960.64
MW Savings	29.7
Global LCOE \$/kWh	0.179
Peak Demand Savings MW	27.96

##### 4.2.4.2.Analysis

In the residential sector 84.216 GWh energy savings was achieved at the cost of \$ 6,807,126.4. The Figure 4-13 presents the energy savings and cost for each of the family types.

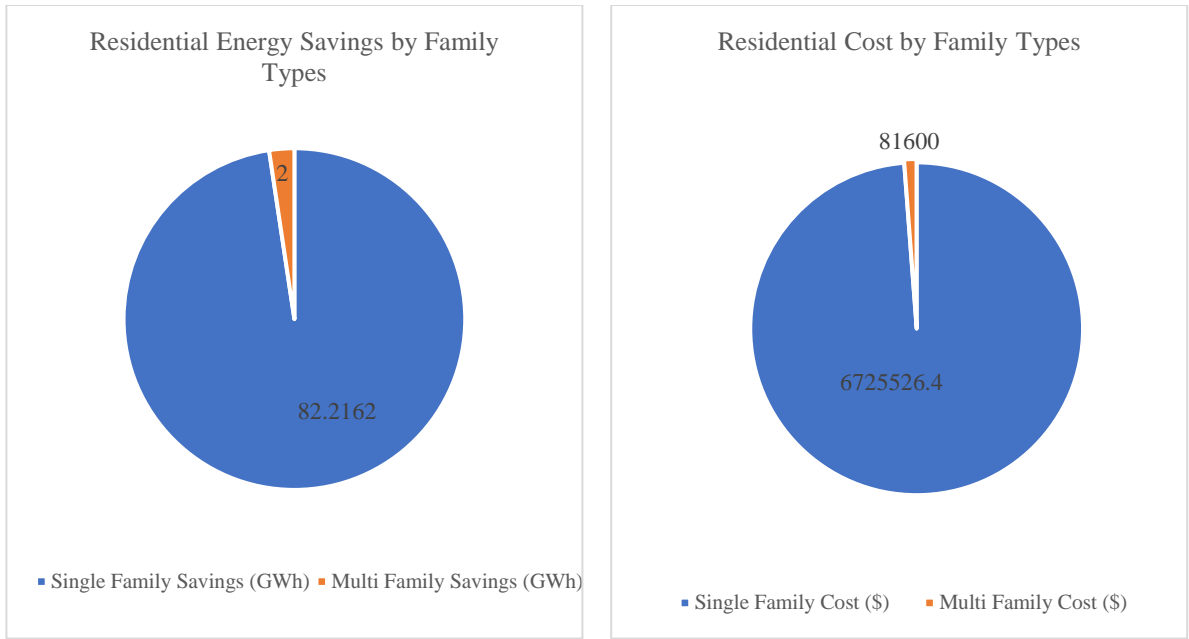


Figure 4-13: Case 4 Residential energy savings and costs by family types

The savings and the corresponding values of costs attained under each end use category for residential sector are shown in Figure 4-14. Refrigeration, whole house, and tv/pc are the top three energy saving areas.

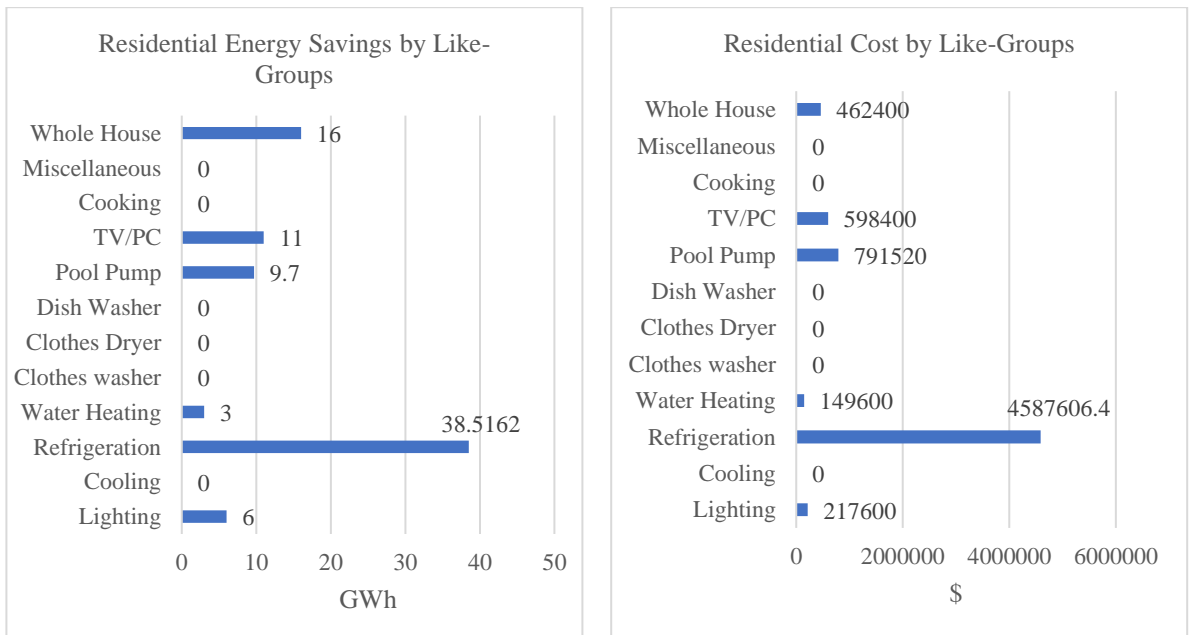


Figure 4-14: Case 4 Residential energy savings and costs by like-groups

In the C and I sector, 136.93 GWh energy savings was obtained at the costs of \$ 16,046,640. The Figure 4-15 presents the energy savings and cost for each of the building types.

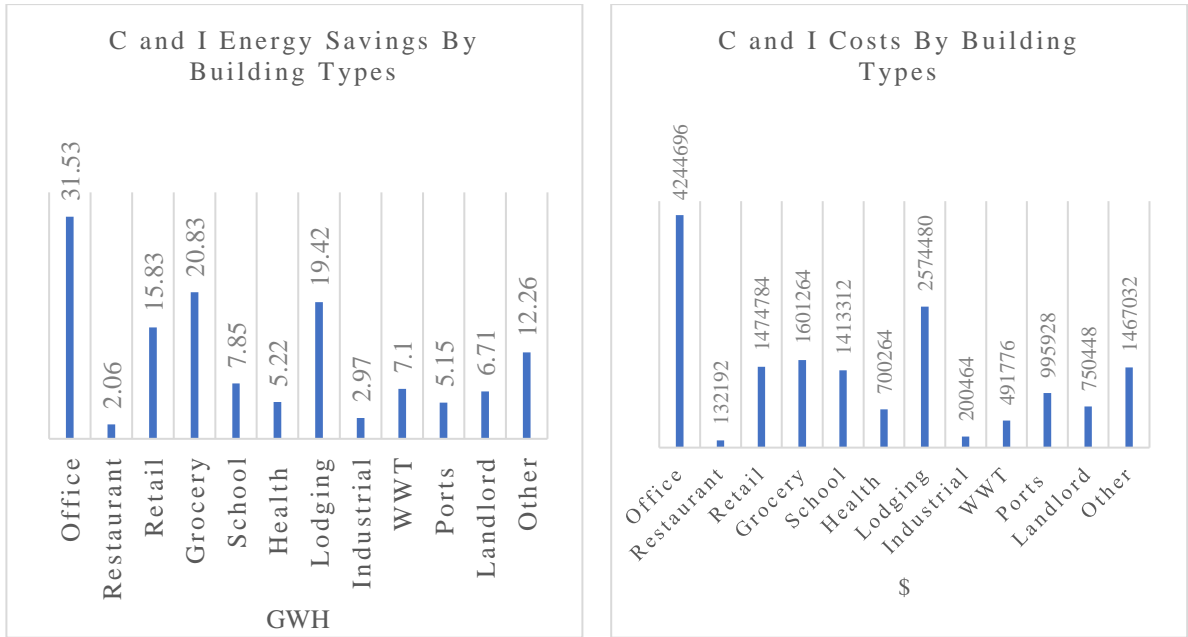


Figure 4-15: Case 5 C&I energy savings and costs by building types

The savings and the corresponding values of costs attained under each end use category for the C and I sector are shown in the Figure 4-16. Indoor lighting, outdoor lighting and office equipment are the top three energy savings areas.

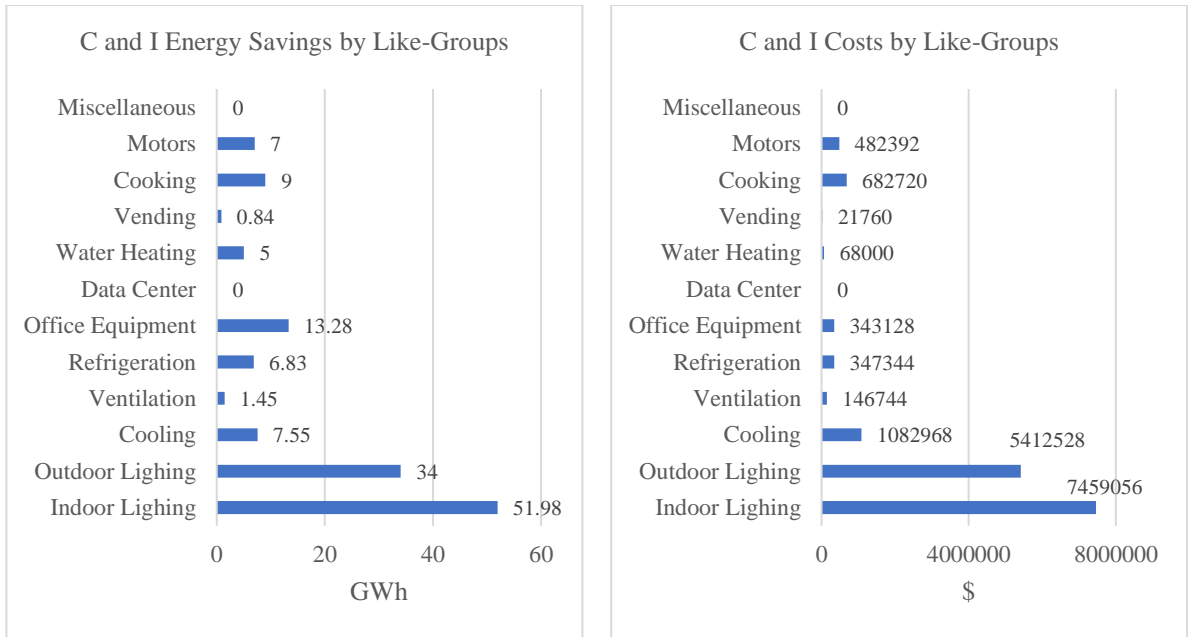


Figure 4-16: Case 4 C&I energy savings and costs by like-groups

208 measures with 20 different values of LCOE ranging from 0.01 to 0.27 \$/kWh are selected to obtain the target of 221.146 GWh. Appendix 6.4 presents the details of maximum and achieved energy savings potential for each value of LCOE. It can be observed that in five LCOE levels of 0.01, 0.08, 0.12, 0.14 and 0.27 \$/kWh, energy savings to the full potential cannot be achieved. This is because the program can choose any value of savings between zero to maximum potential (constraint 1) to best match the target.

Thirteen measures in different groups are not selected despite having a low value of LCOE because the maximum savings potential for the respective end use categories is already saturated (constraint 2) as shown in appendix 7.

## 4.2.2 Case 5: Government of Barbados Target of 18.87 MW

### 4.2.4.3.Result

The optimization model was run to achieve the energy savings equivalent to 18.87 MW capacity, which is 140.47 GWh at a capacity factor of 85%. The measures selected by the optimization software results in a minimum cost of \$ 7,434,712. Considering the cost of the loss of ROI, the global LCOE was obtained as 0.128 \$/kWh. The peak demand saving potential is 17.76 MW. The summary of the results is shown in the Table 4-6.

*Table 4-6: Case 5 Summary of the Result*

Achieved Total Energy Savings kWh	140,470,000
Optimized Cost of energy Savings \$	7,434,712
Cost of Loss of ROI \$	10,563,334
Total Cost \$	17,998,056
MW Savings	18.87
Global LCOE \$/kWh	0.128
Peak Demand Savings MW	17.76

### 4.2.4.4.Analysis

In the residential sector 71.70 GWh energy savings was achieved at a cost of \$ 3,538,720. Figure 4-17 presents the energy savings and cost for each of the family types.

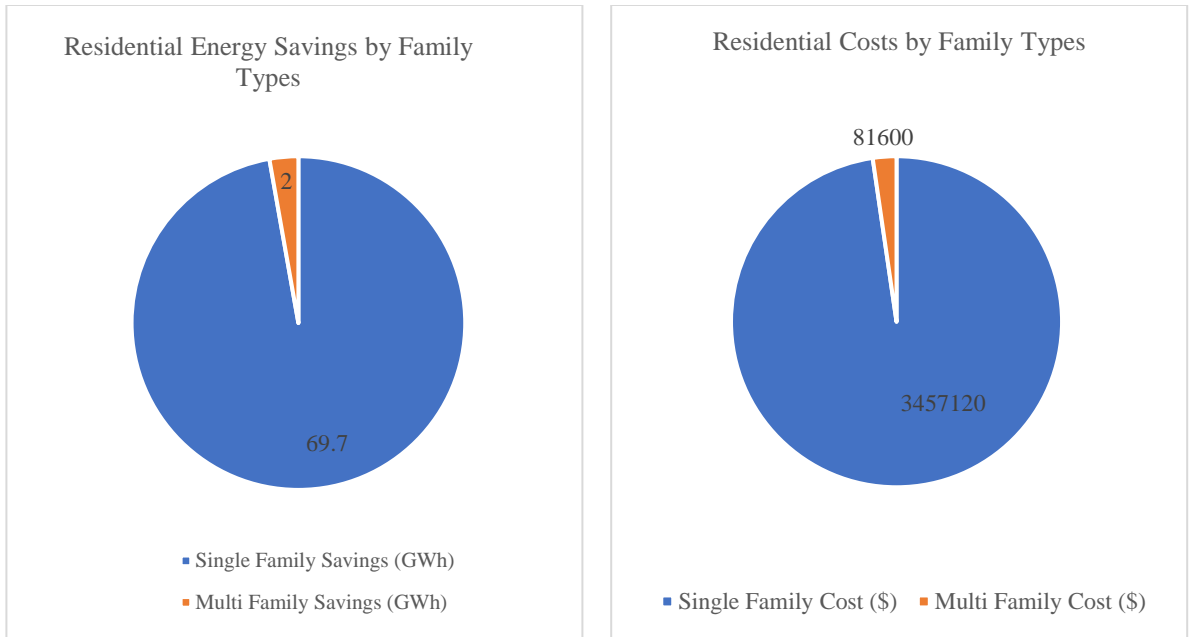


Figure 4-17: Case 5 Residential energy savings and costs by Family types

The savings and the corresponding values of costs attained under each end use category for the residential sector are shown in the Figure 4-18 refrigeration, whole house, and pool pump are the top three energy saving areas.

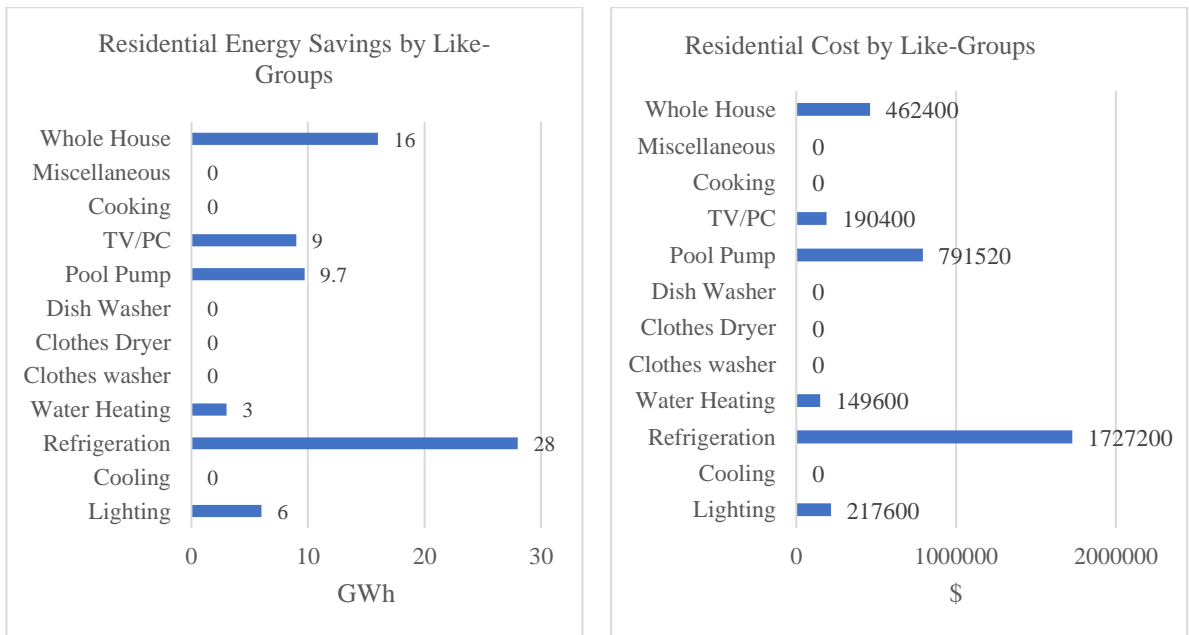


Figure 4-18: Case 5 Residential energy savings and cost by like-groups

In the C and I sector, 68.77 GWh energy savings was obtained at a cost of \$ 3,895,992. The Figure 4-19 presents the energy savings and cost for each of the building types.



Figure 4-19: Case 5 C&I savings and costs by building types

The savings and the corresponding values of costs attained under each end use category for C and I sector are shown in the Figure 4-20. Indoor lighting, office equipment, and cooking are the top three energy saving areas.

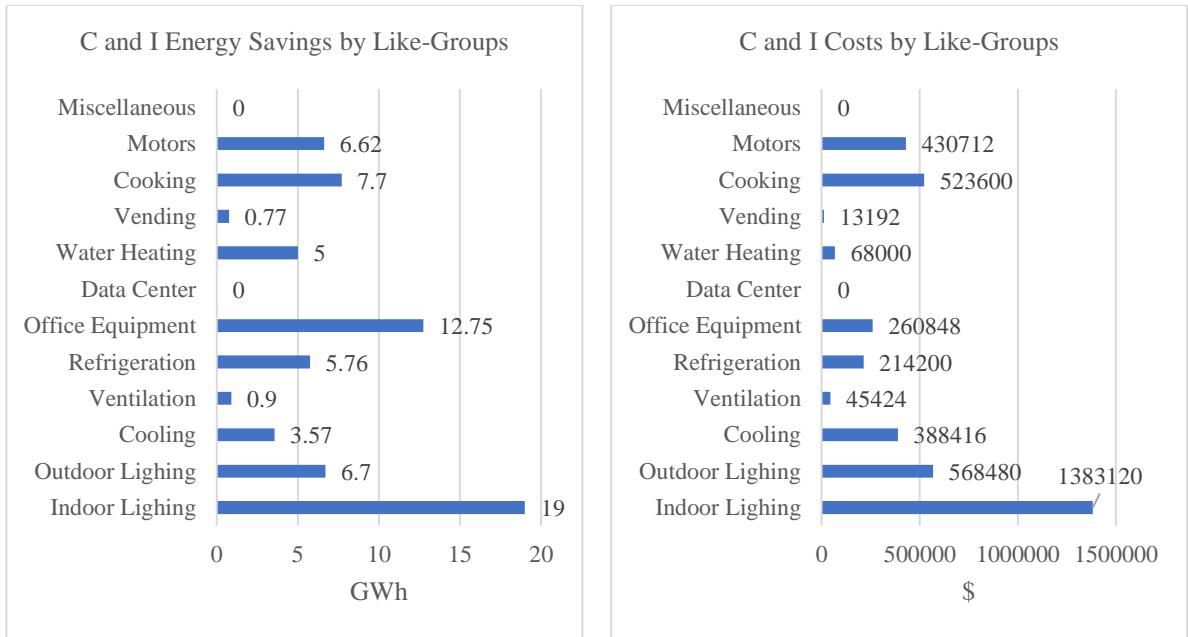


Figure 4-20: Case 5 C&I energy savings and costs by like-groups

140 measures with 9 different values of LCOE ranging from 0.01 to 0.12 \$/kWh are selected to obtain the target of 140.47 GWh. Appendix 6.5 presents the detail of maximum and achieved energy savings potential for each value of LCOE. We can observe that in three LCOE levels of 0.01, 0.08, and 0.12 kWh energy savings to the full potential cannot be achieved. This is because the program can choose any value of savings between zero to maximum potential (constraint 1) to best match the target.

Nine measures in different groups are not selected despite having a low value of LCOE because the maximum savings potential for respective end use category is already saturated (constraint 2) as shown in appendix 7.

#### 4.2.5. Summary of the Case Studies

The summary of the five cases is shown in the Table 4-7.

Table 4-7: Result summary of all cases

DSM					
Case	MW Savings	Achieved Total Energy Savings kWh	Total Cost (Optimized) \$	Peak Savings MW	Global LCOE \$/kWh
1	12.5	93,075,000.00	10,246,716.00	11.77	0.110
2	13	96,798,000.00	10,804,982.40	12.24	0.112
3	20	148,920,000.00	19,667,776.00	18.83	0.132
4	29.7	221,146,200.00	39,483,960.60	27.96	0.179
5	18.87	140,470,000.00	17,998,056.00	17.76	0.128

#### 4.3 Sensitivity Analysis

This section reflects the possibility of DSM through different arrays of choices. It is observed that the complexity of DSM implementation, which involves 351 measures, could be minimized by working on various focus areas of intervention. The sensitivity analysis is carried out for three different scenarios as follows.

##### 4.3.1 Potential of Top twenty Contributors

The Kema Report lists what they consider to be the top twenty measures contributing to economic energy savings potential for each of the residential and C and I sectors. However, it is observed that the measures with TRC values less than one are also included in the list which is not consistent with the use of only economic energy savings potential in this thesis. Because of these concerns, a new list of overall top twenty measures has been prepared for a sensitivity analysis. The total economic energy savings potential of this new group of measures is 208.14 GWh which is slightly less than Kema Report list and involves half the number of measures.

An analysis has been carried out to determine the economic combination among the top twenty energy savings measures. The details of these measures are shown in appendix 8. The optimization program was run for the five above cases considering the top twenty measures only. The results are shown in Table 4-8.

*Table 4-8: Result of Top twenty contributors*

Case	MW Savings	Achieved Total Energy Savings kWh	No. of Measures Chosen	Optimized Cost of energy Savings \$	Cost of Loss of ROI \$	Total Cost \$	Global LCOE \$/kWh	
1	12.5	93,075,000.00	11	8,966,344.00	6,999,240.00	15,965,584.00	0.172	
2	13	96,798,000.00	12	9,960,368.00	6,775,860.00	16,736,228.00	0.173	
3	20	148,920,000.00	16	26,310,016.00	11,198,784.00	37,508,800.00	0.252	
4	29.7	221,146,200.00	Not Feasible					
5	18.87	140,470,000.00	15	23,026,976.00	10,563,344.00	33,590,320.00	0.240	

From the results it can be seen that it is possible to replace three generators of capacities 12.5 MW, 13 MW and 20 MW. The target of 18.87 MW capacity for case 5 (IRRP target) could also be met. The total energy savings capacity of these twenty measures is 208.14 GWh. However, the maximum energy savings that could be achieved here is 174.09 GWh which is equivalent to only 23.38 MW. This is due to the constraints in like-groups. Therefore, the result for the generator of capacity of 29.7 MW (case 4) was obtained as infeasible.

#### **4.3.2 Potential of Three End Use Areas (Lighting, Cooling and Behavioural Program)**

The Ministry of Energy, Barbados has a target of achieving 20 MW of capacity savings from DSM. The report on “Barbados National Energy Policy, 2019 -2030” [47] shows the intervention in three energy efficiency areas: lighting, cooling, and behavioural program. The total economic energy savings potential of this group is 275.46 GWh.

A case study has been carried out to see the potential of intervention in only these three end use areas. The result obtained from optimization program for the five above cases is shown in Table 4-9.

*Table 4-9: Result of three end use area*

Case	MW Savings	Achieved Total Energy Savings kWh	No. of Measures Chosen	Optimized Cost of energy Savings \$	Cost of Loss of ROI \$	Total Cost \$	Global LCOE \$/kWh	
1	12.5	93,075,000.00	82	9,293,016.00	6,999,240.00	16,292,256.00	0.175	
2	13	96,798,000.00	88	10,072,676.80	7,279,209.60	17,351,886.40	0.179	
3	20	148,920,000.00	115	24,493,328.00	11,198,784.00	35,692,112.00	0.240	
4	29.7	221,146,200.00	Not feasible					
5	18.87	140,470,000.00	107	21,894,640.00	10,563,344.00	32,457,984.00	0.231	

It can be seen that except for case 4 (29.7 MW) all other 4 cases could be met. The total energy savings capacity of these three areas is 275.46 GWh. However, the maximum energy savings that could be achieved here is 166 GWh equivalent to 22.29 MW only. This is due to the constraints in like groups.

### **4.3.3 Potential of Lighting**

A study was carried out to explore the potential of lighting only. The total economic energy savings potential of lighting is 224.04 GWh. The results obtained from the optimization program for the above five cases are shown in Table 4-10.

Table 4-10: Result of lighting

Case	MW Savings	Achieved Total Energy Savings kWh	No. of Measures Chosen	Optimized Cost of energy Savings \$	Cost of Loss of ROI \$	Total Cost \$	Global LCOE \$/kWh	
1	12.5	93,075,000.00	85	13,343,980.00	6,999,240.00	20,343,220.00	0.219	
2	13	96,798,000.00	89	14,351,372.80	7,279,210.00	21,630,582.40	0.223	
3	20	148,920,000.00	98	32,526,712.00	11,198,784.00	43,725,496.00	0.294	
4	29.7	221,146,200.00	Not feasible					
5	18.87	140,470,000.00	98	28,964,192.00	10,563,344.00	39,527,536.00	0.281	

It can be seen that all the capacities could be achieved, except case 4 at 29.7 MW which could not be achieved. The total energy savings capacity of lighting is 224.04 GWh. However, the maximum energy savings that could be achieved here is 165.02 GWh which is equivalent to 22.16 MW only. As before this is due to the constraints in like-groups.

#### 4.4 Comparison

##### 4.4.1 Comparison of DSM Versus Renewables

A comparison of LCOE of DSM versus central PV and Wind is shown in Figure 4-21. In all the five cases, the costs of installing central PV and wind are more expensive than implementing DSM. The comparison of cost percentage for each of these cases can be seen in Table 4-11. On average central PV is 42.52% more expensive than DSM and wind is 52.79% more expensive than DSM.

Table 4-11: Comparison of DSM, Central PV and Wind

Case	MW Savings	Total Energy Savings (Optimized) kWh	DSM	Central PV		Wind	
			LCOE \$/kWh	LCOE \$/kWh	Central PV Vs DSM %	LCOE \$/kWh	Wind Vs DSM %
1	12.5	93,075,000.00	0.110	0.23	52.17%	0.28	60.71%
2	13	96,798,000.00	0.112	0.23	51.30%	0.28	60.00%
3	20	148,920,000.00	0.132	0.23	42.61%	0.28	52.86%
4	29.7	221,146,200.00	0.179	0.23	22.17%	0.28	36.07%
5	18.87	140,470,000.00	0.128	0.23	44.35%	0.28	54.29%

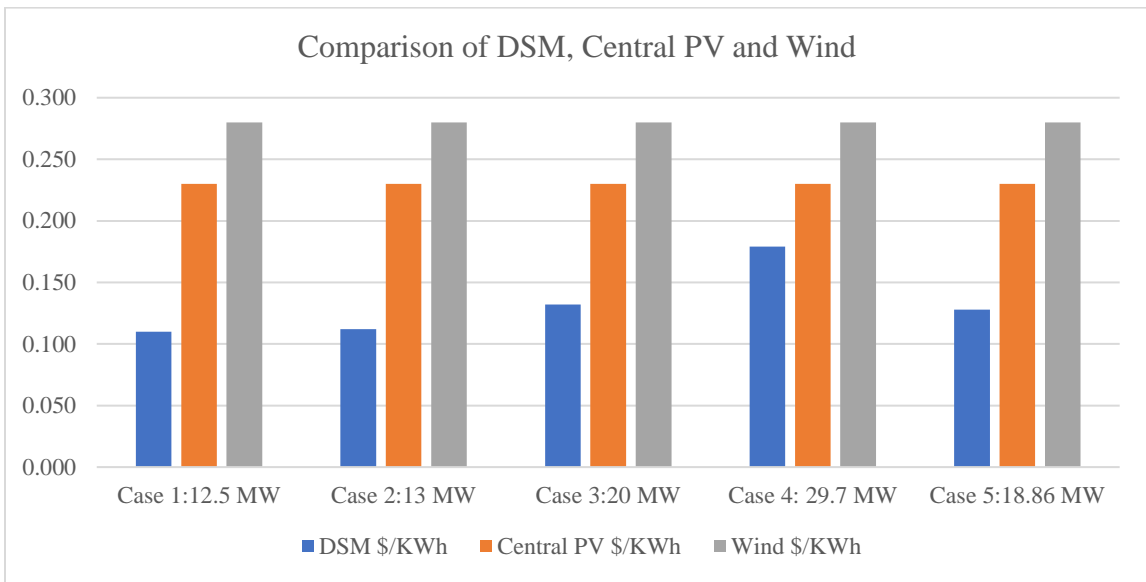


Figure 4-21: Comparison of DSM, Central PV and Wind

#### 4.4.2 Comparison of Top-Twenty Versus Renewables

A comparison of LCOE of the top-twenty measures versus central PV and wind is shown in Table 4-12. Out of five cases, four cases are feasible. In two cases, central PV is more expensive than the top 20 DSM (represented by green cells). In four cases, wind is more expensive than the top-20 DSM (represented by green cells). In two cases, the top-20 DSM is more expensive than solar (represented by red cells).

Table 4-12: Comparison of Top-twenty, Central PV and Wind

Case	MW Savings	Total Energy Savings (Optimized) kWh	Top 20	Central PV		Wind	
			LCOE \$/kWh	LCOE \$/kWh	Central PV Vs Top-20 %	LCOE \$/kWh	Wind Vs Top-20 %
1	12.5	93,075,000.00	0.172	0.23	25%	0.28	39%
2	13	96,798,000.00	0.173	0.23	25%	0.28	38%
3	20	148,920,000.00	0.252	0.23	-10%	0.28	10%
4	29.7	221,146,200.00	Infeasible				
5	18.87	140,470,000.00	0.240	0.23	-4%	0.28	14%

#### 4.4.3 Comparison of Three-areas Versus Renewables

A comparison of LCOE of the three-areas DSM versus central PV and wind is shown in Table 4-13. Out of five cases, four cases are feasible. In two cases, central PV is more expensive than the three-areas DSM (represented by green cells). In four cases, wind is more expensive than three-areas DSM (represented by green cells). In one case, the three-areas DSM is more expensive than central PV (represented by red cell). In one case, the three-areas DSM is equal to central PV (represented by blue cell).

Table 4-13: Comparison of Three-areas, Central PV and Wind

Case	MW Savings	Total Energy Savings (Optimized) kWh	3 areas	Central PV		Wind	
			LCOE \$/kWh	LCOE \$/kWh	Central PV Vs 3-areas %	LCOE \$/kWh	Wind Vs 3-areas %
1	12.5	93,075,000.00	0.175	0.23	24%	0.28	38%
2	13	96,798,000.00	0.179	0.23	22%	0.28	36%
3	20	148,920,000.00	0.240	0.23	-4%	0.28	14%
4	29.7	221,146,200.00	Infeasible				
5	18.87	140,470,000.00	0.231	0.23	0%	0.28	18%

#### 4.4.4 Comparison of Lighting Versus Renewables

A comparison of LCOE of the three-areas versus Central PV and Wind is shown in Table 4-13. Out of five cases, four cases are feasible. In two cases, central PV is more expensive than lighting DSM (represented by green cells). In two cases, wind is more expensive than lighting DSM (represented by green cells). In two cases, lighting DSM is more expensive than central PV (represented by red cells). In one case, lighting DSM is more expensive than wind (represented by red cells). In one case, lighting DSM is equal to wind (represented by blue cell).

Table 4-14: Comparison of Lighting, Central PV and Wind

Case	MW Savings	Total Energy Savings (Optimized) kWh	Lighting	Central PV		Wind	
			LCOE \$/kWh	LCOE \$/kWh	Central PV Vs Lighting %	LCOE \$/kWh	Wind Vs Lighting %
1	12.5	93,075,000.00	0.219	0.23	5%	0.28	22%
2	13	96,798,000.00	0.223	0.23	3%	0.28	20%
3	20	148,920,000.00	0.294	0.23	-28%	0.28	-5%
4	29.7	221,146,200.00	Infeasible				
5	18.87	140,470,000.00	0.281	0.23	-22%	0.28	0%

## CHAPTER 5

### 5. DATA AND MODELLING COMPLEXITIES

The purpose of this chapter is to highlight factors which went into decisions regarding data and modelling in this thesis.

#### 5.1 Number of Variables

DSM opportunities have the systematic structure already outlined of end uses, and various measures applied to each end use to reduce energy consumption. A very simple example is that of an occupancy sensor as a measure to reduce lighting energy costs. Its existing base end use is 1000 Base Fluorescent Fixture, 4L4'T8. The Kema Report develops residential measure capabilities based on an “average” house. There are only two family types and out of 34 only 4 measures are in the multi-family. Therefore, it is possible to use one single decision variable to represent this measure.

The C and I sector has to be treated differently. The values of savings potential, LCOE and TRC for this measure vary according to different building types as shown in the Table 5-1. Based on the TRC values each might or might not yield economic benefit.

*Table 5-1: Variation of energy savings, LCOE and TRC in a measure*

Measure No.	Measure Name	Building	Tech. Pot	Levelized Cost	TRC	Does it have Economic Potential?
			GWh	\$/kWh		
1060	Occupancy sensor	Office	4.31	0.37	1.15	Yes
		Restaurant	0.05	6.73	0.06	No
		Retail	4.02	0.1	4.38	Yes
		Grocery	1.92	0.21	2.07	Yes
		School	0.86	0.25	1.71	Yes
		Health	0.09	2.99	0.14	No
		Lodging	0.8	1.12	0.36	No

	Industrial	1.72	1.33	0.32	No
	WWT	0.09	1.33	0.32	No
	Ports	0.34	0.41	1.05	Yes
	Landlord	0.22	0.27	1.61	Yes
	Other	0.44	0.27	1.61	Yes

The Table 5-1 shows that application of the TRC test results in seven different building types where the occupancy sensor has Economic Potential, all having different energy savings potential and different LCOE costs. Therefore, it is necessary to define seven decision variables for this one simple measure.

## 5.2 Appendix F and Appendix G Differences

As described in Chapter 3, Appendix F of the Kema Report shows the Technical Potential, the associated LCOE, and the associated TRC value for each of the hundreds of possible DSM energy saving measures. The values of Technical Potential were achieved by repeated application of the fundamental equation (2.1) and (2.2).

It is important to note that the Savings Factor was applied to the base end use energy consumption at the time each facility was evaluated via surveys. For this reason, it can be considered that the energy savings act independently, with the technical terminology of the Kema Report being that the measures are non-additive.

Appendix G of the Kema Report seeks to develop a supply curve. As such, it first arranges all measures in increasing values of LCOE, that is they are stacked in ascending order of costs. Associated with each measure is an energy savings value, which is also cumulatively totalled as the process moves up the cost order. This is where the double counting of energy savings occurs. Suppose the lowest cost measure is applied to a particular end use. Then that end use energy consumption is reduced. As one moves up the stacking order, eventually one will arrive at another measure applicable to that end use.

However now the Technical Potential for that measure must be recalculated because the Savings Factor must be applied to the “reduced” energy consumption. Another way to describe this is to say that the application of the first measure has created a “new and different” building. Appendix G then takes the next logical step. As apparently is standard in the DSM industry, it argues that the capital and installation cost of the next measure has stayed the same, but the energy savings potential has been reduced, so it calculates a new and often much higher value of LCOE for that second measure. While this value of LCOE may seem artificial, nevertheless it is the value which the Kema Report uses in development of the supply curve. This process is repeated all the way up the stacking order of measures.

The distinction between non-additive and additives measures means that the Kema Report has presented to this research one set of measures with associated energy saving values and LCOE in Appendix F and the same set of measures with different associated savings value and different LCOE in Appendix G.

### **5.3 Avoiding Double Counting of Competitive Measures**

This complexity is best illustrated by an example. Take as an example of base end use the 1000 Base Ducted Split-System Air Conditioner (11 SEER). This end use has three higher efficiency measures, that is there are three competing measures to reduce energy consumption of the air conditioner.

- 1001 Split-System Air Conditioner 14 SEER (12.15 EER)
- 1002 Split-System Air Conditioner 15 SEER (12.72 EER)
- 1003 Split-System Air Conditioner 17 SEER (12.28 EER)

With higher efficiency, the cost of the unit would be expected to increase. If typical costs were considered, an optimization routine might improperly select more than one of these like, or competing, alternatives. The Kema Report handles this in a unique way by providing a total cost for the first alternative and the incremental cost for the other alternatives.

Total cost of 14 SEER = 304 \$/ton (and a savings of 7.1%).

Incremental cost of 15 SEER = 316 \$/ton (and a savings of 13.3%).

Incremental cost of 17 SEER = 589 \$/ton (and a savings of 23,5%).

Based on these cost values, an optimization routine would first select the cost of the 14 SEER, and if more energy savings were required would capture the total cost of the 15 SEER by adding its incremental cost to the base cost of the 14 SEER.

It should be noted that this approach only works if the costs as shown are monotonically increasing. It appears that this is the case in all circumstances in which there are like measures throughout the Kema Report.

#### **5.4 Establishing the relationship of Appendix F and G**

As we move from non-additive to additive data (Appendix F to G), we observe that the effective technical potential of energy savings is reduced. This can be considered as a “mathematical artifact” resulting from the fact the cost of a measure device and its installation has not changed, but the energy savings per measure is reduced. This means the “Apparent Cost” is greatly increased. It is this apparent cost on which the Supply Curve is developed. Therefore, Appendix F is used in the model to establish limits on energy savings potential at the individual measure level as “true, actual costs”. The values of

energy savings potential from Appendix G (additive) are used to set the limit on energy savings potential at the broad end use level.

When one looks into the relation of the values in Appendix F and G, the non-additive to additive (F to G) ratio for the total technical and economic energy savings potential is approximately equal i.e., 1.5.

Appendix F to Appendix G ratio:

$$\begin{aligned} \text{Technical potential} &= [\text{Technical Pot. Appendix F} / \text{Technical Pot. Appendix G}] \\ &= 564.61/370.8 \\ &= 1.517 = 1.5 \end{aligned}$$

$$\begin{aligned} \text{Economic potential} &= [\text{Economic Pot. Appendix F} / \text{Economic Pot. Appendix G}] \\ &= 414.05/277 \\ &= 1.494 = \text{approx. } 1.5 \end{aligned}$$

The F to G factor at all 12 end-uses category is obtained as shown in the Table 5-2.

*Table 5-2: Details of energy savings potential in appendix F and appendix G of Kema Report*

Like-Group	F			G			F to G factor
	R	C&I	Total	R	C&I	Total	F/G
Lighting	1400000	21000000	23025000	1000000	11100000	12100000	1.90
Cooling	200000	3404000	3342000	300000	2700000	3000000	1.20
Refrigeration	6200000	754000	6955000	4000000	700000	4700000	1.48
Ventilation		220000	220000		200000	200000	1.1
Water Heating	500000	861000	1361000	300000	500000	800000	1.70
Clothes Washer	0		0	0		0	0
Clothes Dryer	100000		100000	140000		140000	0.71
Pool Pump	1000000		1000000	970000		970000	1.03
TV/PC	1100000		1100000	1180000		1180000	0.93
Data Center		0	0		0	0	0
Office Equipment		1362000	1362000		1400000	1400000	0.97
Vending		84000	84000		100000	100000	0.84
Cooking	0	942000	942000	0	900000	900000	1.05
Motors		736000	736000		700000	700000	1.05

Miscellaneous	0	0	0	0	0	0	0
Whole House	16000000		14000000	16100000		16100000	0.87
Total	121000000	293050000	414050000	95000000	183000000	278000000	1.50

### **5.5 Acceptance of LCOE from Appendix F**

When the LCOE is calculated at a discount rate of 9.5 %, it does not match with the values of LCOE given in Appendix F (non-additive). We have used the values of LCOE from Appendix F as they are the value from the data management system of DNV GL’s Microsoft Excel based model called DSM Assyst™ – it uses scientific and behavioural data in their calculations considering load data, rate projection, saturation, and marginal cost. This research did not have access to DSM Assyst™, but the data calculated in this way is more realistic, so the LCOE values from Appendix F have been directly taken as input to the model developed in this study.

### **5.6 Choice of Implementation Year**

The LCOE is calculated for study year 2025 considering the inflation rate of 36 % from 2013. When one looks into the retirement schedule in Table 3-1, the first two generators of capacities 13 MW and 20 MW are going to be retired by 2023. It would be too early to implement DSM by 2023. Targeting the retirement of the next two generators of same capacities in 2026, requires that the LCOE values be calculated for 2025.

### **5.7 Loss of Return on Investment**

The rate for energy sales is fixed so as to meet the production cost and the profit for every kWh of energy sold. Whenever DSM is implemented, the demand is reduced due to which the revenue from the sale of certain kWh is also lost. This means that the profit for the energy not sold is lost. There will be a consequent reduction in dividends for

shareholders. There has to be a mechanism to deal with this loss of Return on Investment (ROI). Therefore, to adjust for this loss and to recover the lost profit, the ROI is treated as an additional cost of energy savings in the DSM calculation.

## **5.8 Optimization Conundrum**

Appendix F of the Kema Report shows the economic potential energy in kWh and the cost in \$/kWh for each of the hundreds of measures. At the same time, it also shows the capacity savings in kW and the capacity cost in \$/kW of kW saved for each of those measures. This suggests that the optimization formulation could have been done on an energy basis or on a capacity basis. The Kema Report itself states that the total capacity calculations have been done assuming that all the capacity savings occurred at the same time, and it is known that this would not happen given the diversity of measures. It was concluded it would be better to carry out the optimization on an energy basis, and that is what has been done.

## **5.9 Comparing Capacity Factors**

This concern is best addressed by a numerical example from page 57 of the Kema Report. For all the global measures available within BLPC, for the year 2025 the energy savings technical potential is 371 GWh while the peak demand technical potential is 48 MW. This results in an annual Capacity Factor of 88.2%, although this number is optimistic because of the failure to consider diversity in the measure peaks.

Basing this analysis on economic potential numbers, there are 277 GWh of energy savings and 35 MW of peak demand savings. This results in a Capacity Factor of 90.3%, which again is optimistic. However, both compare well with the assumed Capacity Factor of 85% for the rotational units being retired.

## **CHAPTER 6**

### **6. CONCLUSION**

#### **6.1 Summary**

An optimization model for DSM has been developed to identify the cheapest combination of measures that would contribute to energy savings equal to the energy production of a retiring rotational unit. The case studies and sensitivity analysis in Chapter 4 show that the optimization model developed here is flexible to operate at any target value of energy savings and for any group of measures.

The optimization result shows that it is feasible to replace all five capacities of retiring rotational units by implementing DSM strategies. The cost comparison among DSM and renewables (central PV and wind) shows that DSM is cheaper for all five cases. It has been observed that the average cost of installing central PV is 42.52% higher than implementing DSM and the cost of implementing wind generation is 52.79% higher than DSM.

The three sensitivity analysis scenarios have been carried out to see the prospects of applying DSM in different dynamics. The first sensitivity analysis shows the top-twenty measures have the potential to replace four rotational capacities. From the results, it is observed that top-twenty DSM measures are cheaper than wind in all four feasible cases. However, they are cheaper than central PV in only two out of four feasible cases.

The second sensitivity analysis shows the chosen three end use areas have the potential to replace four rotational capacities. From the results, it is observed that three-

areas DSM is cheaper than wind in all four feasible cases. However, it is cheaper than central PV in only two out of four feasible cases.

The third sensitivity analysis shows that lighting-only based DSM has the potential to replace four rotational capacities. From the results, it is observed that lighting is cheaper than wind in two out of four feasible cases. Similarly, it is cheaper than central PV in only two out of four feasible cases.

## **6.2 Limitations and future works**

Achievable potential has not been analysed as the implementation plan has not decided and therefore the data related to market are not available. The implementation plan is completely dependent upon BLPC's requirement. Also, the model is designed for the ideal incentive scenario of 100 % investment by BLPC.

Program Delivery/Implementation mechanism has a great impact on the output of the program. The results obtained here is for an ideal acceptance scenario, that is when there is 100% customer's participation. However, customer's acceptance is very challenging as the choice of equipment varies greatly among the customers' comfort and requirement. For an instance, the space for a refrigerator in a customer's home could be a reason for rejection of a proposed measure. There is a need to map all the factors influencing the adoption and reliability of measures. Also, the identification of the set of measures with high users' acceptance could be very useful for designing a target program.

The existing system could have numerous bottlenecks in the policies that could limit its implementation. Hence, it is important to identify all the barriers and the policy requirements that could bolster the program. This demands the active involvement of social

activists and policy makers. From a cursory view, some of the areas that require novel legislative policy could be:

- Review of import duties on measures
- Review on contractual complexities
- Regulations to intervene in the customer's house
- Return on Investment
- Disposal of replaced equipment

The data on base end uses represent the scenario of year 2013. Many existing base end uses could have been already replaced. Therefore, the energy savings potential could be a different value than that shown in the present context.

The cost of Implementing DSM could be further compared with other technologies such as battery storage.

### **6.3 Contribution**

- A methodology has been developed to answer a question posed by BLPC – Upon retirement of a rotational generating unit is it more cost effective to undertake a DSM program or to install renewable energy sources?
- A literature search appears to show that no such problem is addressed in the literature.
- The choice of optimal DSM combination is addressed through a linear programming formulation. While linear programming is common, the literature does not show where it has previously been used to select optimal DSM combinations.

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# Appendices

## APPENDIX 1

### Magnitude of the DSM energy savings possible for each of the measures

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential GWh	LCOE \$/kWh	TRC
Lighting	E <sub>R1</sub>	E <sub>1</sub>	1301	CFL (60W-equivalent), base inc <2 hrs/day	Single Family	1.00	0.05	15.10
		E <sub>2</sub>	1302	LEDs (60W-equivalent), base inc <2 hrs/day	Single Family	1.00	0.08	14.66
		E <sub>3</sub>	1401	CFL (60W-equivalent), base inc >2 hrs/day	Single Family	2.00	0.01	23.10
		E <sub>4</sub>	1402	LEDs (60W-equivalent), base inc >2 hrs/day	Single Family	2.00	0.03	47.45
		E <sub>5</sub>	1601	LEDs (60W-equivalent), base CFL >2 hrs/day	Single Family	4.00	0.30	3.48
		E <sub>6</sub>	1701	4' standard T-8 fluorescent fixtures	Single Family	1.00	0.57	2.06
		E <sub>7</sub>	1702	4' premium T-8 fluorescent fixtures	Single Family	1.00	0.63	1.87
		E <sub>8</sub>	1703	4' low-watt premium T-8 fluorescent fixtures	Single Family	1.00	0.54	2.16
		E <sub>9</sub>	1601	LEDs (60W-equivalent), base CFL >2 hrs/day	Multi-Family	1.00	0.30	3.48
Cooling	E <sub>R2</sub>	E <sub>10</sub>	1214	WINDOWS - Default With Sunscreen, Base Ductless	Single Family	2.00	0.54	1.08
Refrigeration	E <sub>R3</sub>	E <sub>11</sub>	1801	Refrigerator (Energy Star)	Single Family	11.00	0.27	3.50
		E <sub>12</sub>	1802	Refrigerator (CEE Tier 2)	Single Family	15.00	0.49	1.89
		E <sub>13</sub>	1901	Refrigerator (Energy Star) (2nd Refrigerator)	Single Family	1.00	0.27	3.50
		E <sub>14</sub>	1902	Refrigerator (CEE Tier 2) (2nd Refrigerator)	Single Family	2.00	0.49	1.89
		E <sub>15</sub>	1903	Refrigerator Recycling	Single Family	7.00	0.07	7.58
		E <sub>16</sub>	2001	Freezer (Energy Star)	Single Family	7.00	0.08	7.25
		E <sub>17</sub>	2101	Freezer (Energy Star) (2nd Freezer)	Single Family	2.00	0.10	6.98
		E <sub>18</sub>	2102	Freezer Recycling	Single Family	12.00	0.04	8.08
		E <sub>19</sub>	1801	Refrigerator (Energy Star)	Multi-Family	2.00	0.27	3.43
		E <sub>20</sub>	1802	Refrigerator (CEE Tier 2)	Multi-Family	3.00	0.49	1.89
Water Heating	E <sub>R4</sub>	E <sub>21</sub>	2203	Heat Pump Water Heater - Energy Star	Single Family	1.00	0.23	3.60
		E <sub>22</sub>	2204	Solar Domestic Water Heating with booster	Single Family	2.00	0.07	16.16
		E <sub>23</sub>	2205	DHW Tank Wrap	Single Family	1.00	0.01	32.61

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
		E <sub>24</sub>	2301	Low Flow Showerhead 1.5 Gal/Min, Base POU	Single Family	1.00	0.12	4.84
Clothes Dryer	E <sub>R6</sub>	E <sub>25</sub>	2601	High Efficiency CD (EF=3.01 w/moisture sensor)	Single Family	1.00	0.41	1.71
Pool Pump	E <sub>R8</sub>	E <sub>26</sub>	2802	Variable-Speed Pool Pump (<1 hp)	Single Family	10.00	0.08	6.95
TV/PC	E <sub>R9</sub>	E <sub>27</sub>	2901	Energy Star Plasma TV	Single Family	1.00	0.03	20.27
		E <sub>28</sub>	3001	Energy Star LCD TV	Single Family	4.00	0.01	42.81
		E <sub>29</sub>	3201	Energy Star LED TV	Single Family	2.00	0.20	2.18
		E <sub>30</sub>	3401	Energy Star DVD Player	Single Family	1.00	0.04	11.29
		E <sub>31</sub>	3501	Energy Star Desktop PC	Single Family	2.00	0.01	49.06
		E <sub>32</sub>	3601	Energy Star Laptop PC	Single Family	1.00	0.04	9.87
Whole House	E <sub>R12</sub>	E <sub>33</sub>	3901	OPower/Behavioural Program	Single Family	14.00	0.03	4.81
		E <sub>34</sub>	3901	OPower/Behavioural Program	Multi-Family	2.00	0.04	3.40
Indoor Lighting	E <sub>C1</sub>	E <sub>35</sub>	1010	ROB 4L4' High Performance T8 (86 W)	Office	1.42	0.19	2.59
		E <sub>36</sub>	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Office	3.13	0.30	1.68
		E <sub>37</sub>	1060	Occupancy Sensor	Office	4.31	0.50	1.15
		E <sub>38</sub>	1110	ROB High Performance T8 (base other fluorescent)	Office	4.45	0.22	2.21
		E <sub>39</sub>	1120	ROB Low Watt High Performance T8 (base other fluorescent)	Office	9.77	0.35	1.43
		E <sub>40</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Office	23.33	0.30	1.93
		E <sub>41</sub>	1310	Hardwired CFL fixture	Office	0.09	0.27	3.45
		E <sub>42</sub>	1310	Hardwired CFL fixture	Restaurant	0.04	0.15	6.04
		E <sub>43</sub>	1510	T5 (240W)	Restaurant	0.07	0.15	6.10
		E <sub>44</sub>	1520	Induction High Bay Lighting	Restaurant	0.05	0.97	1.04
		E <sub>45</sub>	1530	Pulse-start metal halide + electronic ballast	Restaurant	0.06	0.35	2.48
		E <sub>46</sub>	1540	Occupancy Sensor, High Bay T5	Restaurant	0.03	0.18	3.33
		E <sub>47</sub>	1010	ROB 4L4' High Performance T8 (86 W)	Retail	2.01	0.03	13.19
		E <sub>48</sub>	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Retail	4.40	0.05	8.55
		E <sub>49</sub>	1040	ROB 4L4' LED Tube	Retail	6.94	0.42	1.65
		E <sub>50</sub>	1050	LED Troffer (base 4L4'T8)	Retail	8.07	0.49	1.41
E <sub>51</sub>	1060	Occupancy Sensor	Retail	4.02	0.14	4.38		
E <sub>52</sub>	1110	ROB High Performance T8 (base other fluorescent)	Retail	1.29	0.22	2.07		
E <sub>53</sub>	1120	ROB Low Watt High Performance T8 (base other fluorescent)	Retail	2.83	0.33	1.34		

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Indoor Lighting	E <sub>C1</sub>	E <sub>54</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Retail	6.72	0.29	2.02
		E <sub>55</sub>	1210	CFL - 100W-equivalent	Retail	0.65	0.14	1.38
		E <sub>56</sub>	1220	LED screw-in - 100W-equivalent	Retail	0.40	0.15	2.64
		E <sub>57</sub>	1310	Hardwired CFL fixture	Retail	0.07	0.04	25.39
		E <sub>58</sub>	1320	Hardwired LED fixture	Retail	0.08	0.35	1.98
		E <sub>59</sub>	1010	ROB 4L4' High Performance T8 (86 W)	Grocery	0.91	0.08	4.15
		E <sub>60</sub>	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Grocery	1.91	0.12	2.70
		E <sub>61</sub>	1060	Occupancy Sensor	Grocery	1.92	0.29	2.07
		E <sub>62</sub>	1210	CFL - 100W-equivalent	Grocery	0.66	0.07	1.98
		E <sub>63</sub>	1220	LED screw-in - 100W-equivalent	Grocery	0.34	0.05	4.59
		E <sub>64</sub>	1310	Hardwired CFL fixture	Grocery	0.07	0.01	56.29
		E <sub>65</sub>	1320	Hardwired LED fixture	Grocery	0.08	0.16	3.13
		E <sub>66</sub>	1510	T5 (240W)	Grocery	0.57	0.87	1.07
		E <sub>67</sub>	1010	ROB 4L4' High Performance T8 (86 W)	School	0.49	0.08	8.85
		E <sub>68</sub>	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	School	1.02	0.12	5.76
		E <sub>69</sub>	1060	Occupancy Sensor	School	0.86	0.34	1.71
		E <sub>70</sub>	1110	ROB High Performance T8 (base other fluorescent)	School	0.88	0.18	3.94
		E <sub>71</sub>	1120	ROB Low Watt High Performance T8 (base other fluorescent)	School	1.83	0.27	2.56
		E <sub>72</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	School	4.00	0.26	2.24
		E <sub>73</sub>	1210	CFL - 100W-equivalent	School	0.22	0.08	3.77
		E <sub>74</sub>	1220	LED screw-in - 100W-equivalent	School	0.24	0.27	2.21
		E <sub>75</sub>	1310	Hardwired CFL fixture	School	0.02	0.03	42.09
		E <sub>76</sub>	1320	Hardwired LED fixture	School	0.03	0.22	4.63
		E <sub>77</sub>	1110	ROB High Performance T8 (base other fluorescent)	Health	0.62	0.23	2.12
		E <sub>78</sub>	1120	ROB Low Watt High Performance T8 (base other fluorescent)	Health	1.29	0.35	1.37
		E <sub>79</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Health	3.21	0.30	1.93
E <sub>80</sub>	1210	CFL - 100W-equivalent	Health	0.63	0.04	4.30		

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Indoor Lighting	E <sub>C1</sub>	E <sub>81</sub>	1220	LED screw-in - 100W-equivalent	Health	0.59	0.08	5.02
		E <sub>82</sub>	1310	Hardwired CFL fixture	Health	0.07	0.01	79.02
		E <sub>83</sub>	1320	Hardwired LED fixture	Health	0.07	0.11	6.96
		E <sub>84</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Lodging	1.80	0.53	1.10
		E <sub>85</sub>	1310	Hardwired CFL fixture	Lodging	0.28	0.24	3.84
		E <sub>86</sub>	1010	ROB 4L4' High Performance T8 (86 W)	Ports	0.17	0.14	3.15
		E <sub>87</sub>	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Ports	0.37	0.22	2.04
		E <sub>88</sub>	1060	Occupancy Sensor	Ports	0.34	0.56	1.05
		E <sub>89</sub>	1110	ROB High Performance T8 (base other fluorescent)	Ports	0.51	0.19	2.30
		E <sub>90</sub>	1120	ROB Low Watt High Performance T8 (base other fluorescent)	Ports	1.11	0.30	1.49
		E <sub>91</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Ports	2.64	0.26	2.25
		E <sub>92</sub>	1210	CFL - 100W-equivalent	Ports	0.33	0.10	2.00
		E <sub>93</sub>	1220	LED screw-in - 100W-equivalent	Ports	0.20	0.10	3.81
		E <sub>94</sub>	1010	ROB 4L4' High Performance T8 (86 W)	Landlord	0.10	0.10	4.95
		E <sub>95</sub>	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Landlord	0.22	0.15	3.22
		E <sub>96</sub>	1060	Occupancy Sensor	Landlord	0.22	0.37	1.61
		E <sub>97</sub>	1110	ROB High Performance T8 (base other fluorescent)	Landlord	0.24	0.10	5.10
		E <sub>98</sub>	1120	ROB Low Watt High Performance T8 (base other fluorescent)	Landlord	0.51	0.15	3.31
		E <sub>99</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Landlord	1.34	0.12	4.91
		E <sub>100</sub>	1210	CFL - 100W-equivalent	Landlord	1.18	0.08	2.53
		E <sub>101</sub>	1220	LED screw-in - 100W-equivalent	Landlord	1.07	0.14	2.79
		E <sub>102</sub>	1310	Hardwired CFL fixture	Landlord	0.13	0.01	46.55
		E <sub>103</sub>	1320	Hardwired LED fixture	Landlord	0.14	0.19	3.87
		E <sub>104</sub>	1510	T5 (240W)	Landlord	0.31	0.16	5.79
		E <sub>105</sub>	1530	Pulse-start metal halide + electronic ballast	Landlord	0.28	0.37	2.36
		E <sub>106</sub>	1540	Occupancy Sensor, High Bay T5	Landlord	0.14	0.16	3.55
		E <sub>107</sub>	1010	ROB 4L4' High Performance T8 (86 W)	Other	0.20	0.10	4.95
		E <sub>108</sub>	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Other	0.44	0.15	3.22

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Indoor Lighting	EC1	E <sub>109</sub>	1060	Occupancy Sensor	Other	0.44	0.37	1.61
		E <sub>110</sub>	1110	ROB High Performance T8 (base other fluorescent)	Other	0.47	0.10	5.10
		E <sub>111</sub>	1120	ROB Low Watt High Performance T8 (base other fluorescent)	Other	1.01	0.15	3.31
		E <sub>112</sub>	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Other	2.64	0.12	4.91
		E <sub>113</sub>	1210	CFL - 100W-equivalent	Other	2.33	0.08	2.53
		E <sub>114</sub>	1220	LED screw-in - 100W-equivalent	Other	2.11	0.14	2.79
		E <sub>115</sub>	1310	Hardwired CFL fixture	Other	0.26	0.01	46.55
		E <sub>116</sub>	1320	Hardwired LED fixture	Other	0.28	0.19	3.87
		E <sub>117</sub>	1510	T5 (240W)	Other	0.62	0.16	5.79
		E <sub>118</sub>	1530	Pulse-start metal halide + electronic ballast	Other	0.55	0.37	2.36
		E <sub>119</sub>	1540	Occupancy Sensor, High Bay T5	Other	0.28	0.16	3.55
Outdoor Lighting	EC2	E <sub>120</sub>	1610	LED Exit Sign	Office	0.46	0.05	8.61
		E <sub>121</sub>	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Office	4.38	0.10	9.28
		E <sub>122</sub>	1720	LED Outdoor Area Lighting	Office	14.99	0.16	4.57
		E <sub>123</sub>	1730	Bi-Level LED Outdoor Lighting	Office	22.27	0.42	1.81
		E <sub>124</sub>	1610	LED Exit Sign	Restaurant	0.02	0.04	9.83
		E <sub>125</sub>	1610	LED Exit Sign	Retail	0.05	0.07	6.73
		E <sub>126</sub>	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Retail	0.66	0.22	4.10
		E <sub>127</sub>	1720	LED Outdoor Area Lighting	Retail	2.19	0.37	2.07
		E <sub>128</sub>	1610	LED Exit Sign	Grocery	0.10	0.01	40.70
		E <sub>129</sub>	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Grocery	0.26	0.08	10.74
		E <sub>130</sub>	1720	LED Outdoor Area Lighting	Grocery	0.95	0.15	4.92
		E <sub>131</sub>	1730	Bi-Level LED Outdoor Lighting	Grocery	1.30	0.37	2.10
		E <sub>132</sub>	1610	LED Exit Sign	School	0.15	0.04	10.42

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Outdoor Lighting	Ec2	E133	1710	Outdoor Lighting Controls (Photocell/Timeclock)	School	0.19	0.67	1.39
		E134	1610	LED Exit Sign	Health	0.02	0.05	8.86
		E135	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Health	0.25	0.11	8.53
		E136	1720	LED Outdoor Area Lighting	Health	0.95	0.20	3.82
		E137	1730	Bi-Level LED Outdoor Lighting	Health	1.28	0.46	1.66
		E138	1610	LED Exit Sign	Lodging	0.42	0.04	9.84
		E139	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Lodging	2.16	0.14	6.52
		E140	1720	LED Outdoor Area Lighting	Lodging	7.51	0.24	3.17
		E141	1730	Bi-Level LED Outdoor Lighting	Lodging	10.98	0.60	1.27
		E142	1610	LED Exit Sign	Industrial	0.07	0.23	1.94
		E143	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Ports	0.23	0.22	4.10
		E144	1720	LED Outdoor Area Lighting	Ports	0.77	0.37	2.07
		E145	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Landlord	0.20	0.08	11.28
		E146	1720	LED Outdoor Area Lighting	Landlord	0.62	0.12	5.92
		E147	1730	Bi-Level LED Outdoor Lighting	Landlord	1.00	0.34	2.20
		E148	1710	Outdoor Lighting Controls (Photocell/Timeclock)	Other	0.39	0.08	11.28
E149	1720	LED Outdoor Area Lighting	Other	1.23	0.12	5.92		
E150	1730	Bi-Level LED Outdoor Lighting	Other	1.97	0.34	2.20		
Cooling	Ec3	E151	3220	DX Packaged System, EER=13.4, 10 tons	Office	2.40	0.41	2.02
		E152	3260	Ceiling/roof Insulation	Office	1.26	0.69	1.48
		E153	3270	Duct/Pipe Insulation	Office	0.21	0.44	1.92
		E154	3510	High-efficiency ductless split-system AC (20 SEER)	Office	1.96	0.48	1.78
		E155	3540	Ceiling/roof Insulation	Office	2.37	0.84	1.22
		E156	3220	DX Packaged System, EER=13.4, 10 tons	Restaurant	0.66	0.52	1.61
		E157	3270	Duct/Pipe Insulation	Restaurant	0.06	0.54	1.53
		E158	3290	Window Film (Standard)	Restaurant	0.12	0.27	2.20
		E159	3510	High-efficiency ductless split-system AC (20 SEER)	Restaurant	0.38	0.58	1.42
		E160	3550	Window Film (Standard)	Restaurant	0.16	0.27	2.20
		E161	3220	DX Packaged System, EER=13.4, 10 tons	Retail	1.90	0.31	2.67
		E162	3240	Cool Roof	Retail	0.74	0.41	1.48
		E163	3250	Prog. Thermostat	Retail	0.22	0.44	1.13

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Cooling	Ec3	E <sub>164</sub>	3270	Duct/Pipe Insulation	Retail	0.17	0.33	2.53
		E <sub>165</sub>	3510	High-efficiency ductless split-system AC (20 SEER)	Retail	0.62	0.35	2.34
		E <sub>166</sub>	3520	Cool Roof	Retail	0.55	0.41	1.48
		E <sub>167</sub>	3530	Prog. Thermostat	Retail	0.16	0.44	1.12
		E <sub>168</sub>	3210	DX Packaged System, EER=10.9, 10 tons	Grocery	0.65	0.35	2.33
		E <sub>169</sub>	3220	DX Packaged System, EER=13.4, 10 tons	Grocery	2.70	0.11	7.77
		E <sub>170</sub>	3240	Cool Roof	Grocery	1.81	0.16	3.60
		E <sub>171</sub>	3250	Prog. Thermostat	Grocery	0.64	0.11	4.21
		E <sub>172</sub>	3260	Ceiling/roof Insulation	Grocery	1.42	0.65	1.54
		E <sub>173</sub>	3270	Duct/Pipe Insulation	Grocery	0.23	0.11	7.37
		E <sub>174</sub>	3290	Window Film (Standard)	Grocery	0.36	0.12	4.87
		E <sub>175</sub>	3510	High-efficiency ductless split-system AC (20 SEER)	Grocery	0.28	0.12	6.82
		E <sub>176</sub>	3520	Cool Roof	Grocery	0.44	0.16	3.60
		E <sub>177</sub>	3530	Prog. Thermostat	Grocery	0.15	0.12	4.17
		E <sub>178</sub>	3540	Ceiling/roof Insulation	Grocery	0.34	0.79	1.28
		E <sub>179</sub>	3550	Window Film (Standard)	Grocery	0.09	0.12	4.87
		E <sub>180</sub>	3220	DX Packaged System, EER=13.4, 10 tons	Health	0.85	0.26	3.23
		E <sub>181</sub>	3250	Prog. Thermostat	Health	0.20	0.31	1.54
		E <sub>182</sub>	3260	Ceiling/roof Insulation	Health	0.45	0.39	2.62
		E <sub>183</sub>	3270	Duct/Pipe Insulation	Health	0.07	0.27	3.07
		E <sub>184</sub>	3510	High-efficiency ductless split-system AC (20 SEER)	Health	0.27	0.30	2.84
		E <sub>185</sub>	3530	Prog. Thermostat	Health	0.15	0.31	1.52
		E <sub>186</sub>	3540	Ceiling/roof Insulation	Health	0.33	0.48	2.16
		E <sub>187</sub>	3220	DX Packaged System, EER=13.4, 10 tons	Lodging	1.08	0.82	1.02
		E <sub>188</sub>	3260	Ceiling/roof Insulation	Lodging	0.57	0.88	1.16
		E <sub>189</sub>	3290	Window Film (Standard)	Lodging	0.16	0.34	1.79
		E <sub>190</sub>	3550	Window Film (Standard)	Lodging	0.79	0.34	1.79
		E <sub>191</sub>	3220	DX Packaged System, EER=13.4, 10 tons	Industrial	2.05	0.52	1.60
		E <sub>192</sub>	3270	Duct/Pipe Insulation	Industrial	0.18	0.54	1.52
		E <sub>193</sub>	3510	High-efficiency ductless split-system AC (20 SEER)	Industrial	0.82	0.58	1.41
E <sub>194</sub>	3220	DX Packaged System, EER=13.4, 10 tons	Ports	0.67	0.31	2.67		

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Cooling	EC3	E <sub>195</sub>	3250	Prog. Thermostat	Ports	0.08	0.44	1.13
		E <sub>196</sub>	3270	Duct/Pipe Insulation	Ports	0.06	0.33	2.53
		E <sub>197</sub>	3290	Window Film (Standard)	Ports	0.09	0.37	1.68
		E <sub>198</sub>	3510	High-efficiency ductless split-system AC (20 SEER)	Ports	0.22	0.35	2.34
		E <sub>199</sub>	3530	Prog. Thermostat	Ports	0.06	0.44	1.12
		E <sub>200</sub>	3550	Window Film (Standard)	Ports	0.07	0.37	1.68
		E <sub>201</sub>	3220	DX Packaged System, EER=13.4, 10 tons	Landlord	0.04	0.34	2.45
		E <sub>202</sub>	3250	Prog. Thermostat	Landlord	0.01	0.44	1.10
		E <sub>203</sub>	3290	Window Film (Standard)	Landlord	0.01	0.41	1.47
		E <sub>204</sub>	3510	High-efficiency ductless split-system AC (20 SEER)	Landlord	0.19	0.39	2.16
		E <sub>205</sub>	3530	Prog. Thermostat	Landlord	0.06	0.45	1.09
		E <sub>206</sub>	3550	Window Film (Standard)	Landlord	0.08	0.41	1.47
		E <sub>207</sub>	3220	DX Packaged System, EER=13.4, 10 tons	Other	0.08	0.34	2.45
		E <sub>208</sub>	3250	Prog. Thermostat	Other	0.01	0.44	1.10
		E <sub>209</sub>	3270	Duct/Pipe Insulation	Other	0.01	0.35	2.33
		E <sub>210</sub>	3290	Window Film (Standard)	Other	0.01	0.41	1.47
E <sub>211</sub>	3510	High-efficiency ductless split-system AC (20 SEER)	Other	0.37	0.39	2.16		
E <sub>212</sub>	3530	Prog. Thermostat	Other	0.13	0.45	1.09		
E <sub>213</sub>	3550	Window Film (Standard)	Other	0.15	0.41	1.47		
Ventilation	EC4	E <sub>214</sub>	4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Retail	0.10	0.14	6.19
		E <sub>215</sub>	4050	Separate Makeup Air / Exhaust Hoods AC	Retail	0.17	0.04	23.11
		E <sub>216</sub>	4020	Variable Speed Drive Control	Grocery	0.04	0.37	1.61
		E <sub>217</sub>	4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Grocery	0.02	0.03	24.45
		E <sub>218</sub>	4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Health	0.01	0.07	11.82
		E <sub>219</sub>	4050	Separate Makeup Air / Exhaust Hoods AC	Health	0.02	0.01	280.20
		E <sub>220</sub>	4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Lodging	0.68	0.48	1.72
		E <sub>221</sub>	4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Industrial	0.39	0.20	3.98
		E <sub>222</sub>	4050	Separate Makeup Air / Exhaust Hoods AC	Industrial	0.68	0.05	14.67
		E <sub>223</sub>	4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	WWT	0.03	0.52	1.58
		E <sub>224</sub>	4050	Separate Makeup Air / Exhaust Hoods AC	WWT	0.06	0.14	5.82

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Refrigeration	E <sub>C5</sub>	E <sub>225</sub>	5220	Auto-closer on main door to walk-in freezer (self-contained)	Restaurant	0.67	0.08	5.96
		E <sub>226</sub>	5230	Night covers for display cases (self-contained)	Restaurant	0.76	0.04	8.36
		E <sub>227</sub>	5240	Freezer-Cooler Replacement Gaskets (self-contained)	Restaurant	0.12	0.04	5.59
		E <sub>228</sub>	5290	Energy-Star Freezer, glass door	Restaurant	0.18	0.37	1.48
		E <sub>229</sub>	5310	Hydraulic-type door closer on reach-in cooler glass doors	Restaurant	0.35	0.05	8.25
		E <sub>230</sub>	5230	Night covers for display cases (self-contained)	Retail	0.02	0.15	2.10
		E <sub>231</sub>	5030	Auto-closer on main door to walk-in freezer (built-up)	Grocery	0.51	0.01	47.64
		E <sub>232</sub>	5040	Night covers for display cases	Grocery	0.08	0.01	108.74
		E <sub>232</sub>	5060	Electronically commutated evaporator fan motor	Grocery	0.45	0.01	137.41
		E <sub>234</sub>	5070	Efficient compressor motor	Grocery	0.01	0.26	2.24
		E <sub>235</sub>	5090	Refrigeration Commissioning	Grocery	0.16	0.01	16.49
		E <sub>236</sub>	5120	Anti-sweat (humidistat) controls	Grocery	0.09	0.68	1.00
		E <sub>237</sub>	5130	Freezer-Cooler Replacement Gaskets	Grocery	0.22	0.01	410.75
		E <sub>238</sub>	5140	High R-Value Glass Doors	Grocery	0.10	0.05	11.86
		E <sub>239</sub>	5220	Auto-closer on main door to walk-in freezer (self-contained)	Grocery	0.57	0.04	12.83
		E <sub>240</sub>	5230	Night covers for display cases (self-contained)	Grocery	0.15	0.01	1032.91
		E <sub>241</sub>	5240	Freezer-Cooler Replacement Gaskets (self-contained)	Grocery	0.09	0.01	23.07
		E <sub>242</sub>	5270	Energy-Star Freezer, solid door	Grocery	0.16	0.31	1.70
		E <sub>243</sub>	5280	Energy-Star Refrigerator, glass door	Grocery	0.01	0.45	1.32
		E <sub>244</sub>	5290	Energy-Star Freezer, glass door	Grocery	0.39	0.12	4.22
		E <sub>245</sub>	5310	Hydraulic-type door closer on reach-in cooler glass doors	Grocery	0.30	0.01	178.11
		E <sub>246</sub>	5220	Auto-closer on main door to walk-in freezer (self-contained)	School	0.02	0.27	1.84
		E <sub>247</sub>	5230	Night covers for display cases (self-contained)	School	0.02	0.04	7.04
		E <sub>248</sub>	5310	Hydraulic-type door closer on reach-in cooler glass doors	School	0.01	0.08	5.58
		E <sub>249</sub>	5230	Night covers for display cases (self-contained)	Health	0.02	0.03	14.77
		E <sub>250</sub>	5260	Energy-Star Refrigerator, solid door	Health	0.01	0.45	1.32
		E <sub>251</sub>	5280	Energy-Star Refrigerator, glass door	Health	0.01	0.44	1.35
		E <sub>252</sub>	5310	Hydraulic-type door closer on reach-in cooler glass doors	Health	0.01	0.05	9.63
E <sub>253</sub>	5220	Auto-closer on main door to walk-in freezer (self-contained)	Lodging	0.64	0.12	3.79		
E <sub>254</sub>	5230	Night covers for display cases (self-contained)	Lodging	0.72	0.01	51.73		
E <sub>255</sub>	5240	Freezer-Cooler Replacement Gaskets (self-contained)	Lodging	0.10	0.01	20.83		
E <sub>256</sub>	5260	Energy-Star Refrigerator, solid door	Lodging	0.09	0.38	1.54		
E <sub>257</sub>	5270	Energy-Star Freezer, solid door	Lodging	0.13	0.27	1.97		

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Refrigeration	EC5	E <sub>258</sub>	5290	Energy-Star Freezer, glass door	Lodging	0.32	0.11	4.87
		E <sub>259</sub>	5230	Night covers for display cases (self-contained)	Ports	0.01	0.15	2.10
		E <sub>260</sub>	5220	Auto-closer on main door to walk-in freezer (self-contained)	Landlord	0.01	0.45	1.09
		E <sub>261</sub>	5230	Night covers for display cases (self-contained)	Landlord	0.02	0.01	19.93
		E <sub>262</sub>	5310	Hydraulic-type door closer on reach-in cooler glass doors	Landlord	0.01	0.03	23.32
Office Equipment	EC6	E <sub>263</sub>	6010	Energy Star or Better PC	Office	3.18	0.01	18.27
		E <sub>264</sub>	6110	Energy Star or Better Monitor – CRT	Office	0.92	0.03	11.98
		E <sub>265</sub>	6210	Energy Star or Better Monitor – LCD	Office	1.31	0.01	18.27
		E <sub>266</sub>	6310	Energy Star or Better Copier	Office	0.23	0.30	1.27
		E <sub>267</sub>	6410	ENERGY STAR Printer	Office	0.38	0.08	3.86
		E <sub>268</sub>	6010	Energy Star or Better PC	Retail	0.92	0.01	58.69
		E <sub>269</sub>	6110	Energy Star or Better Monitor – CRT	Retail	0.29	0.01	28.13
		E <sub>270</sub>	6210	Energy Star or Better Monitor – LCD	Retail	0.30	0.01	62.54
		E <sub>271</sub>	6310	Energy Star or Better Copier	Retail	0.17	0.04	10.23
		E <sub>272</sub>	6410	ENERGY STAR Printer	Retail	0.24	0.01	27.24
		E <sub>273</sub>	6010	Energy Star or Better PC	Grocery	0.14	0.01	26.28
		E <sub>274</sub>	6110	Energy Star or Better Monitor – CRT	Grocery	0.05	0.03	8.55
		E <sub>275</sub>	6210	Energy Star or Better Monitor – LCD	Grocery	0.09	0.01	27.35
		E <sub>276</sub>	6310	Energy Star or Better Copier	Grocery	0.03	0.07	5.21
		E <sub>277</sub>	6410	ENERGY STAR Printer	Grocery	0.03	0.03	10.46
		E <sub>278</sub>	6010	Energy Star or Better PC	School	0.38	0.01	18.77
		E <sub>279</sub>	6110	Energy Star or Better Monitor – CRT	School	0.27	0.03	8.68
		E <sub>280</sub>	6210	Energy Star or Better Monitor – LCD	School	0.21	0.01	22.23
		E <sub>281</sub>	6310	Energy Star or Better Copier	School	0.04	0.16	2.30
		E <sub>282</sub>	6410	ENERGY STAR Printer	School	0.04	0.07	4.44
E <sub>283</sub>	6010	Energy Star or Better PC	Health	0.56	0.01	16.43		
E <sub>284</sub>	6110	Energy Star or Better Monitor – CRT	Health	0.15	0.03	9.87		

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Office Equipment	EC6	E <sub>285</sub>	6210	Energy Star or Better Monitor - LCD	Health	0.22	0.01	16.92
		E <sub>286</sub>	6310	Energy Star or Better Copier	Health	0.08	0.14	2.80
		E <sub>287</sub>	6410	ENERGY STAR Printer	Health	0.09	0.05	6.13
		E <sub>288</sub>	6010	Energy Star or Better PC	Lodging	0.19	0.18	1.52
		E <sub>289</sub>	6210	Energy Star or Better Monitor - LCD	Lodging	0.08	0.18	1.47
		E <sub>290</sub>	6010	Energy Star or Better PC	Industrial	1.00	0.03	11.42
		E <sub>291</sub>	6110	Energy Star or Better Monitor - CRT	Industrial	0.24	0.04	6.65
		E <sub>292</sub>	6210	Energy Star or Better Monitor - LCD	Industrial	0.43	0.03	10.77
		E <sub>293</sub>	6310	Energy Star or Better Copier	Industrial	0.11	0.37	1.04
		E <sub>294</sub>	6410	ENERGY STAR Printer	Industrial	0.14	0.12	2.76
		E <sub>295</sub>	6010	Energy Star or Better PC	WWT	0.02	0.03	11.42
		E <sub>296</sub>	6110	Energy Star or Better Monitor - CRT	WWT	0.01	0.04	6.65
		E <sub>297</sub>	6210	Energy Star or Better Monitor - LCD	WWT	0.01	0.03	10.77
		E <sub>298</sub>	6010	Energy Star or Better PC	Ports	0.33	0.01	58.69
		E <sub>299</sub>	6110	Energy Star or Better Monitor - CRT	Ports	0.10	0.01	28.13
		E <sub>300</sub>	6210	Energy Star or Better Monitor - LCD	Ports	0.11	0.01	62.54
		E <sub>301</sub>	6310	Energy Star or Better Copier	Ports	0.06	0.04	10.23
		E <sub>302</sub>	6410	ENERGY STAR Printer	Ports	0.09	0.01	27.24
		E <sub>303</sub>	6010	Energy Star or Better PC	Landlord	0.19	0.01	31.21
		E <sub>304</sub>	6110	Energy Star or Better Monitor - CRT	Landlord	0.05	0.01	17.44
E <sub>305</sub>	6210	Energy Star or Better Monitor - LCD	Landlord	0.08	0.01	30.39		
E <sub>306</sub>	6310	Energy Star or Better Copier	Landlord	0.02	0.08	5.05		
E <sub>307</sub>	6410	ENERGY STAR Printer	Landlord	0.04	0.03	10.40		
Water Heating	EC8	E <sub>308</sub>	8020	High Efficiency Water Heater (electric)	Office	0.01	0.23	3.48
		E <sub>309</sub>	8040	Tankless Water Heater	Office	0.04	0.45	2.26
		E <sub>310</sub>	8050	Heat Pump Water Heater (air source)	Office	0.08	0.53	1.12
		E <sub>311</sub>	8070	Heat Trap	Office	0.03	0.11	5.14

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Water Heating	EC8	E <sub>312</sub>	8080	Solar Water Heater	Office	0.27	0.38	2.66
		E <sub>313</sub>	8010	Demand controlled circulating systems	Restaurant	0.06	0.42	1.97
		E <sub>314</sub>	8020	High Efficiency Water Heater (electric)	Restaurant	0.03	0.05	13.54
		E <sub>315</sub>	8040	Tankless Water Heater	Restaurant	0.13	0.11	8.78
		E <sub>316</sub>	8050	Heat Pump Water Heater (air source)	Restaurant	0.26	0.14	4.34
		E <sub>317</sub>	8070	Heat Trap	Restaurant	0.09	0.03	19.99
		E <sub>318</sub>	8080	Solar Water Heater	Restaurant	0.40	0.05	20.96
		E <sub>319</sub>	8010	Demand controlled circulating systems	Grocery	0.31	0.01	127.49
		E <sub>320</sub>	8020	High Efficiency Water Heater (electric)	Grocery	0.13	0.01	278.65
		E <sub>321</sub>	8030	Hot Water Pipe Insulation	Grocery	0.12	0.01	135.45
		E <sub>322</sub>	8040	Tankless Water Heater	Grocery	0.64	0.01	180.73
		E <sub>323</sub>	8050	Heat Pump Water Heater (air source)	Grocery	1.28	0.01	89.31
		E <sub>324</sub>	8070	Heat Trap	Grocery	0.44	0.01	411.32
		E <sub>325</sub>	8080	Solar Water Heater	Grocery	3.73	0.01	259.41
		E <sub>326</sub>	8080	Solar Water Heater	School	0.01	0.34	3.00
		E <sub>327</sub>	8010	Demand controlled circulating systems	Lodging	0.05	0.79	1.03
		E <sub>328</sub>	8020	High Efficiency Water Heater (electric)	Lodging	0.02	0.64	1.26
		E <sub>329</sub>	8070	Heat Trap	Lodging	0.07	0.31	1.87
		E <sub>330</sub>	8080	Solar Water Heater	Lodging	0.32	0.50	1.98
		E <sub>331</sub>	8010	Demand controlled circulating systems	Industrial	0.01	0.76	1.08
E <sub>332</sub>	8050	Heat Pump Water Heater (air source)	Industrial	0.04	0.29	2.04		
E <sub>333</sub>	8070	Heat Trap	Industrial	0.01	0.07	9.42		
E <sub>334</sub>	8080	Solar Water Heater	Industrial	0.03	0.08	11.96		

**Appendix 1: Magnitude of the DSM energy savings possible for each of the measures (Continued)**

Like-Group	Group	Decision Variables	Measure No	Measure Name	Family/Building	Energy Savings Potential	LCOE	TRC
Vending	EC9	E <sub>335</sub>	8101	Vending Misers	Office	0.04	0.01	131.01
		E <sub>336</sub>	8101	Vending Misers	Retail	0.07	0.01	44.83
		E <sub>337</sub>	8101	Vending Misers	Grocery	0.46	0.01	20.90
		E <sub>338</sub>	8101	Vending Misers	School	0.07	0.03	9.43
		E <sub>339</sub>	8101	Vending Misers	Health	0.01	0.03	9.93
		E <sub>340</sub>	8101	Vending Misers	Lodging	0.07	0.12	2.68
		E <sub>341</sub>	8101	Vending Misers	Industrial	0.02	0.10	3.14
		E <sub>342</sub>	8101	Vending Misers	Landlord	0.10	0.01	188.07
Cooking	EC10	E <sub>343</sub>	8510	ENERGY STAR Commercial Oven	Grocery	0.02	0.45	1.52
		E <sub>344</sub>	8530	ENERGY STAR Steamer	Grocery	0.05	0.48	1.43
		E <sub>345</sub>	8510	ENERGY STAR Commercial Oven	Lodging	1.54	0.12	5.84
		E <sub>346</sub>	8530	ENERGY STAR Steamer	Lodging	7.70	0.07	9.81
		E <sub>347</sub>	8530	ENERGY STAR Steamer	Industrial	0.01	0.39	1.74
		E <sub>348</sub>	8530	ENERGY STAR Steamer	Landlord	0.10	0.30	2.27
Motors	EC11	E <sub>349</sub>	9102	Variable Speed Drive Control	WWT	5.01	0.08	7.30
		E <sub>350</sub>	9103	Motors - Maintenance (Cost is for predictive maintenance)	WWT	1.61	0.01	6.80
		E <sub>351</sub>	9104	Motors- System Optimization and sizing	WWT	0.74	0.14	6.24

## APPENDIX 2

### Magnitude of the DSM energy savings capability of like- groups

Like-Group Name	Symbol	Subset of Decision Variables	Number of Measures	Energy Savings Potential GWh	Like-Group Name	Symbol	Subset of Decision Variables	Number of Measures	Energy Savings Potential GWh
Lighting	ER1	E1 to E9	9	14	Indoor Lighting	EC1	E35 to E119	85	132
Cooling	ER2	E10	1	2	Outdoor Lighting	EC2	E120 to E150	31	78
Refrigeration	ER3	E11 to E20	10	62	Cooling	EC3	E151 to E213	63	33.42
Water Heating	ER4	E21 to E24	4	5	Ventilation	EC4	E214 to E224	11	2.2
Clothes Washer	ER5	-	-	0	Refrigeration	EC5	E225 to E262	38	7.54
Clothes Dryer	ER6	E25	1	1	Office Equipment	EC6	E263 to E307	45	13.62
Dish Washer	ER7	-	-	0	Data Centre	EC7	-	-	0
Pool Pump	ER8	E26	1	10	Water Heating	EC8	E308 to E334	27	8.61
TV/PC	ER9	E27 to E32	6	11	Vending	EC9	E335 to E342	8	0.84
Cooking	ER10	-	-	0	Cooking	EC10	E343 to E348	6	9.42
Miscellaneous	ER11	-	-	0	Motors	EC11	E349 to E351	3	7.36
Whole House	ER12	E33 to E34	2	16	Miscellaneous	EC12	-	-	0
			34	121				317	293.05

### APPENDIX 3

#### Inflation rate from year 2013 to 2025

Year	Inflation %	Bd\$
2013		1
2014	1.77%	1.0177
2015	-1.11%	1.006404
2016	1.51%	1.0216
2017	4.41%	1.0667
2018	3.69%	1.1060
2019	4.10%	1.1514
2020	2.88%	1.1845
2021	2.47%	1.2138
2022	4.36%	1.2667
2023	2.47%	1.2980
2024	2.41%	1.3293
2025	2.31%	1.3600
	Inflation rate 2013-2025	36.00%

## APPENDIX 4

### Measures with the value of LCOE as zero

S.N.	Measure No.	Measure Name	Building Type	Like-Group	Symbol	Energy Savings Potential GWh
1	4050	Separate Makeup Air / Exhaust Hoods AC	Health	Ventilation	EC4	0.02
2	5040	Night covers for display cases	Grocery	Refrigeration	EC5	0.08
3	5060	Electronically commutated evaporator fan motor	Grocery	Refrigeration	EC5	0.45
4	5130	Freezer-Cooler Replacement Gaskets	Grocery	Refrigeration	EC5	0.22
5	5230	Night covers for display cases (self-contained)	Grocery	Refrigeration	EC5	0.15
6	5310	Hydraulic-type door closer on reach-in cooler glass doors	Grocery	Refrigeration	EC5	0.30
7	5230	Night covers for display cases (self-contained)	Lodging	Refrigeration	EC5	0.72
8	6010	Energy Star or Better PC	Retail	Office equipment	EC6	0.92
9	6210	Energy Star or Better Monitor - LCD	Retail	Office equipment	EC6	0.30
10	6010	Energy Star or Better PC	Ports	Office equipment	EC6	0.33
11	6210	Energy Star or Better Monitor - LCD	Ports	Office equipment	EC6	0.11
12	8010	Demand controlled circulating systems	Grocery	Water Heating	EC8	0.31
13	8020	High Efficiency Water Heater (electric)	Grocery	Water Heating	EC8	0.13
14	2030	Hot Water Pipe Insulation	Grocery	Water Heating	EC8	0.12
15	8040	Tankless Water Heater	Grocery	Water Heating	EC8	0.64

**Appendix 4: Measures with the value of LCOE as zero (Continued)**

<b>S.N.</b>	<b>Measure No.</b>	<b>Measure Name</b>	<b>Building type</b>	<b>Like-Group</b>	<b>Symbol</b>	<b>Energy Savings potential GWh</b>
16	8050	Heat Pump Water Heater (air source)	Grocery	Water Heating	EC8	1.28
17	8070	Heat Trap	Grocery	Water Heating	EC8	0.44
18	8080	Solar Water Heater	Grocery	Water Heating	EC8	3.73
19	8101	Vending Misers	Office	Vending	EC9	0.04
Total						10.29

**APPENDIX 5**

**Measures distribution and energy savings potential for different values of LCOE**

S.N.	LCOE	No. of Measure			Energy savings Potential (GWh)		
	Bd/kWh	R	C&I	Total	R	C&I	Total
1	0.01	4	48	52	9	21.17	30.17
2	0.03	3	18	21	17	5.17	22.17
3	0.04	4	14	18	16	3.41	19.41
4	0.05	1	11	12	1	6.88	7.88
5	0.07	2	7	9	9	8.5	17.5
6	0.08	3	15	18	18	12.69	30.69
7	0.10	1	8	9	2	5.94	7.94
8	0.11	-	8	8	-	4.37	4.37
9	0.12	1	15	16	1	12.42	13.42
10	0.14	-	11	11	-	11.42	11.42
11	0.15	-	10	10	-	3.67	3.67
12	0.16	-	9	9	-	18.71	18.71
13	0.18	-	4	4	-	1.18	1.18
14	0.19	-	4	4	-	2.35	2.35
15	0.20	1	2	3	2	1.34	3.34

**Appendix 5: Measures distribution and energy savings potential for different values of LCOE (Continued)**

S.N.	LCOE	No. of Measure	Energy savings Potential (GWh)				
	Bd/kWh	R	C&I	Total	R	C&I	Total
16	0.22	-	6	6	-	7.03	7.03
17	0.23	1	3	4	1	0.7	1.7
18	0.24	-	2	2	-	7.79	7.79
19	0.26	-	4	4	-	7.5	7.5
20	0.27	3	8	11	14	2.66	16.66
21	0.29	-	3	3	-	8.68	8.68
22	0.30	2	7	9	5	31.38	36.38
23	0.31	-	6	6	-	3.15	3.15
24	0.33	-	3	3	-	3.06	3.06
25	0.34	-	8	8	-	4.91	4.91
26	0.35	-	8	8	-	12.7	12.7
27	0.37	-	12	12	-	6.24	6.24
28	0.38	-	2	2	-	0.36	0.36
29	0.39	-	4	4	-	1.02	1.02
30	0.41	1	7	8	1	3.94	4.94

**Appendix 5: Measures distribution and energy savings potential for different values of LCOE (Continued)**

<b>S.N.</b>	<b>LCOE</b>	<b>No. of Measure</b>	<b>Energy savings Potential (GWh)</b>				
	<b>Bd/kWh</b>	<b>R</b>	<b>C&amp;I</b>	<b>Total</b>	<b>R</b>	<b>C&amp;I</b>	<b>Total</b>
31	0.42	-	3	3	-	29.27	29.27
32	0.44	-	8	8	-	0.76	0.76
33	0.45	-	7	7	-	0.28	0.28
34	0.46	-	1	1	-	1.28	1.28
35	0.48	-	4	4	-	3.02	3.02
36	0.49	3	1	4	20	8.07	28.07
37	0.50	-	2	2	-	4.63	4.63
38	0.52	-	3	3	-	2.74	2.74
39	0.53	-	2	2	-	1.88	1.88
40	0.54	2	2	4	3	0.24	3.24
41	0.56	-	1	1	-	0.34	0.34
42	0.57	1	-	1	1	-	1
43	0.58	-	2	2	-	1.2	1.2
44	0.60	-	1	1	-	10.98	10.98
45	0.63	1	-	1	1	-	1

**Appendix 5: Measures distribution and energy savings potential for different values of LCOE (Continued)**

<b>S.N.</b>	<b>LCOE</b>	<b>No. of Measure</b>	<b>Energy savings Potential (GWh)</b>				
	<b>Bd/kWh</b>	<b>R</b>	<b>C&amp;I</b>	<b>Total</b>	<b>R</b>	<b>C&amp;I</b>	<b>Total</b>
46	0.64	-	1	1	-	0.02	0.02
47	0.65	-	1	1	-	1.42	1.42
48	0.67	-	1	1	-	0.19	0.19
49	0.68	-	1	1	-	0.09	0.09
50	0.69	-	1	1	-	1.26	1.26
51	0.76	-	1	1	-	0.01	0.01
52	0.79	-	2	2	-	0.39	0.39
53	0.82	-	1	1	-	1.08	1.08
54	0.84	-	1	1	-	2.37	2.37
55	0.87	-	1	1	-	0.57	0.57
56	0.88	-	1	1	-	0.57	0.57
57	0.97	-	1	1	-	0.05	0.05
		34	317	351	121	293.05	414.05

## APPENDIX 6

Details of LCOE and measures for different cases.

**Appendix 6.1: Details of LCOE and measures chosen for Case 1; 12.5 MW.**

S.N.	No. of Measure	LCOE	Maximum energy savings potential GWh	Achieved energy savings kWh
1	50	0.01	29.42	28520000
2	20	0.03	22.08	22080000
3	18	0.04	19.41	19410000
4	10	0.05	7.45	7450000
5	5	0.07	17.37	15615000
<b>Total</b>	<b>103</b>		<b>95.73</b>	<b>93075000</b>

**Appendix 6.2: Details of LCOE and measures chosen for Case 2; 13 MW.**

S.N.	No. of Measure	LCOE	Maximum energy savings potential GWh	Achieved energy savings kWh
1	50	0.01	29.42	28520000
2	20	0.03	22.08	22080000
3	18	0.04	19.41	19410000
4	10	0.05	7.45	7450000
5	8	0.07	17.49	17490000
6	1	0.08	7	1848000
<b>Total</b>	<b>107</b>		<b>102.85</b>	<b>96798000</b>

**Appendix 6.3: Details of LCOE and measures chosen for Case 3; 20 MW.**

S.N.	No. of Measure	LCOE	Maximum energy savings potential GWh	Achieved energy savings kWh
1	50	0.01	29.42	28520000
2	20	0.03	22.08	22080000
3	18	0.04	19.41	19410000
4	10	0.05	7.45	7450000
5	8	0.07	17.49	17490000
6	17	0.08	30.66	30360000
7	9	0.10	7.94	7940000
8	6	0.11	4.21	4210000
9	12	0.12	11.82	11460000
<b>Total</b>	<b>150</b>		<b>150.48</b>	<b>148920000</b>

**Appendix 6.4: Details of LCOE and measures chosen for Case 4; 29.7 MW.**

S.N.	No. of Measure	LCOE	Maximum energy savings potential GWh	Achieved energy savings kWh
1	50	0.01	29.42	28520000
2	20	0.03	22.08	22080000
3	18	0.04	19.41	19410000
4	10	0.05	7.45	7450000
5	8	0.07	17.49	17490000
6	17	0.08	30.66	30360000
7	9	0.10	7.94	7940000
8	6	0.11	4.21	4210000
9	15	0.12	12.42	12180000
10	10	0.14	11.16	10800000
11	10	0.15	3.67	3670000
12	9	0.16	18.71	18710000
13	4	0.18	1.18	1180000
14	4	0.19	2.35	2350000
15	3	0.20	3.34	3340000
16	6	0.22	7.03	7030000
17	2	0.23	0.69	690000
18	2	0.24	7.79	5720000
19	4	0.26	7.5	7500000
20	1	0.27	11	10516200
<b>Total</b>	<b>208</b>		<b>225.5</b>	<b>221146200</b>

**Appendix 6.5: Details of LCOE and measures chosen for Case 5; 18.87 MW.**

S.N.	No. of Measure	LCOE	Maximum energy savings potential GWh	Achieved energy savings kWh
1	50	0.01	29.42	28520000
2	20	0.03	22.08	22080000
3	18	0.04	19.41	19410000
4	10	0.05	7.45	7450000
5	8	0.07	17.49	17490000
6	17	0.08	30.66	30360000
7	9	0.1	7.94	7940000
8	6	0.11	4.21	4210000
9	2	0.12	3.25	3010000
<b>Total</b>	<b>140</b>		<b>141.91</b>	<b>140470000</b>

## APPENDIX 7

### Measures not selected while running the optimization program

S.N.	Measure no.	Measure Name	Building/ Family	Energy savings	LCOE	Cases MW				
				GWh	Bd\$/kWh	12.5	13	20	29.7	18.87
1	8010	Demand controlled circulating systems	Grocery	0.31	0.01					
2	8070	Heat Pump Water Heater	Grocery	0.44	0.01					
3	8070	Heat Pump Water Heater	Restaurant	0.09	0.03					
4	8020	High Efficiency Water Heater	Restaurant	0.03	0.05					
5	8080	Solar Water Heater	Restaurant	0.4	0.05					
6	8070	Heat Trap	Industrial	0.01	0.07					
7	8080	Solar Water Heater	Industrial	0.03	0.08					
8	8070	Heat Trap	Office	0.03	0.11					
9	8040	Tankless Water Heater	Restaurant	0.13	0.11					
10	2301	Low Flow Showerhead 1.5 Gal/Min	Single Family	1	0.12					
11	8050	Heat Pump Water Heater (air source)	Restaurant	0.26	0.14					
12	2203	Heat Pump Water Heater Energy Star	Single Family	1	0.23					
13	8020	High Efficiency Water Heater (electric),	Office	0.01	0.23					

## APPENDIX 8

### Top twenty energy savings measures

S.N.	Measure No.	Measure name	Family/Building	Energy savings Potential GWh	LCOE \$/kWh	TRC
1	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Office	23.33	0.30	1.93
2	1730	Bi-Level LED Outdoor Lighting	Office	22.27	0.42	1.81
3	1802	Refrigerator (CEE Tier 2)	Single Family	15	0.49	1.89
4	1720	LED Outdoor Area Lighting	Office	14.99	0.16	4.57
5	3901	OPower/Behavioral Program	Single Family	14	0.03	4.81
6	2102	Freezer Recycling	Single Family	12	0.04	8.08
7	1801	Refrigerator (Energy Star)	Single Family	11	0.27	3.5
8	1730	Bi-Level LED Outdoor Lighting	Lodging	10.98	0.60	1.27
9	2802	Variable-Speed Pool Pump (<1 hp)	Single Family	10	0.08	6.95
10	1120	ROB Low Watt High Performance T8 (base other fluorescent)	Office	9.77	0.35	1.43
11	1050	LED Troffer (base 4L4'T8)	Retail	8.07	0.49	1.41
12	8530	ENERGY STAR Steamer	Lodging	7.7	0.07	9.81
13	1720	LED Outdoor Area Lighting	Lodging	7.51	0.24	3.17
14	1903	Refrigerator Recycling	Single Family	7	0.07	7.58
15	2001	Freezer (Energy Star)	Single Family	7	0.08	7.25
16	1040	ROB 4L4' LED Tube	Retail	6.94	0.42	1.65
17	1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Retail	6.72	0.29	2.02
18	9102	Variable Speed Drive Control	WWT	5.01	0.08	7.3
19	1110	ROB High Performance T8 (base other fluorescent)	Office	4.45	0.22	2.21
20	1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Retail	4.4	0.05	8.55
				208.14		

# APPENDIX 9

## Sample optimization model for 12.5 MW

Index

	Base end-uses
	Measures
	Total in one Family/Building Type
	Total in Group
	Total in a customer type (R/C&I)
	Grand Total
Blue Font	Optimized value chosen by the program

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Residential End Uses ER</b>													
<b>Lighting ERI</b>													
1300	Base Incandescent Lighting, <2 hrs/day	Single Family											
1301	CFL (60W-equivalent), base inc <2 hrs/day	Single Family	1.00	0.05	1000000	54400.00	0.00	>=	=<=	1000000			
1302	LEDs (60W-equivalent), base inc <2 hrs/day	Single Family	1.00	0.08	0	0.00	0.00	=>=	<=	1000000			
1400	Base Incandescent Lighting, >=2 hrs/day	Single Family											
1401	CFL (60W-equivalent), base inc >2 hrs/day	Single Family	2.00	0.01	2000000	27200.00	0.00	>=	=<=	2000000			
1402	LEDs (60W-equivalent), base inc >2 hrs/day	Single Family	2.00	0.03	2000000	54400.00	0.00	>=	=<=	2000000			
1500	Base Lighting 15 Watt CFL, <2 hrs/day	Single Family											
1600	Base Lighting 15 Watt CFL, >2 hrs/day	Single Family											
1601	LEDs (60W-equivalent), base CFL >2 hrs/day	Single Family	4.00	0.30	0	0.00	0.00	=>=	<=	4000000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Lower Limit			Upper Limit	Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
1700	Base Fluorescent Fixture 1.8 hrs/day	Single Family											
1701	4' standard T-8 fluorescent fixtures	Single Family	1.00	0.57	0	0.00	0.00	=>=	<=	1000000			
1702	4' premium T-8 fluorescent fixtures	Single Family	1.00	0.63	0	0.00	0.00	=>=	<=	1000000			
1703	4' low-watt premium T-8 fluorescent fixtures	Single Family	1.00	0.54	0	0.00	0.00	=>=	<=	1000000			
			13.00		5000000	136000.00				13000000			
<b>Lighting ER1</b>													
1300	Base Incandescent Lighting, <2 hrs/day	Multi-Family											
1400	Base Incandescent Lighting, >=2 hrs/day	Multi-Family											
1500	Base Lighting 15 Watt CFL, <2 hrs/day	Multi-Family											
1600	Base Lighting 15 Watt CFL, >2 hrs/day	Multi-Family											
1601	LEDs (60W-equivalent), base CFL >2 hrs/day	Multi-Family	1.00	0.30	0	0.00	0.00	=>=	<=	1000000			
1700	Base Fluorescent Fixture 1.8 hrs/day	Multi-Family											
			1.00		0	0.00				1000000			
			14.00		5000000	136000.00				14000000	10000000.00	<=	
<b>Cooling ER2</b>													
1000	Base Ducted Split-System Air Conditioner (11 SEER)	Single Family											
1100	Base Room Air Conditioner - EER 9.7	Single Family											
1200	Base Ductless Split-System Air Conditioner	Single Family											
1214	WINDOWS - Default With Sunscreen, Base Ductless	Single Family	2.00	0.54	0	0.00	0.00	=>=	<=	2000000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Lower Limit			Upper Limit	Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
			2.00		0	0.00	2000000						
<b>Cooling ER2</b>													
1000	Base Ducted Split-System Air Conditioner (11 SEER)	Multi-Family											
1100	Base Room Air Conditioner - EER 9.7	Multi-Family											
1200	Base Ductless Split-System Air Conditioner	Multi-Family											
			0.00		0	0.00	0						
			2.00		0	0.00				2000000	3000000.00	<=	
<b>Refrigeration ER3</b>													
1800	Base Refrigerator	Single Family											
1801	Refrigerator (Energy Star)	Single Family	11.00	0.27	0	0.00	0.00	=>=	<=	11000000			
1802	Refrigerator (CEE Tier 2)	Single Family	15.00	0.49	0	0.00	0.00	=>=	<=	15000000			
1900	Base Second Refrigerator	Single Family											
1901	Refrigerator (Energy Star) (2nd Refrigerator)	Single Family	1.00	0.27	0	0.00	0.00	=>=	<=	1000000			
1902	Refrigerator (CEE Tier 2) (2nd Refrigerator)	Single Family	2.00	0.49	0	0.00	0.00	=>=	<=	2000000			
1903	Refrigerator Recycling	Single Family	7.00	0.07	7000000	476000.00	0.00	>=	=<=	7000000			
2000	Base Freezer	Single Family											
2001	Freezer (Energy Star)	Single Family	7.00	0.08	0	0.00	0.00	=>=	<=	7000000			
2100	Base Second Freezer	Single Family											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh						
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh	
2101	Freezer (Energy Star) (2nd Freezer)	Single Family	2.00	0.10	0	0.00	0.00	=>=	<=	2000000			
2102	Freezer Recycling	Single Family	12.00	0.04	12000000	489600.00	0.00	>=	=<=	12000000			
			57.00		19000000	965600.00				57000000			
<b>Refrigeration ER3</b>													
1800	Base Refrigerator	Multi-Family											
1801	Refrigerator (Energy Star)	Multi-Family	2.00	0.27	0	0.00	0.00	=>=	<=	2000000			
1802	Refrigerator (CEE Tier 2)	Multi-Family	3.00	0.49	0	0.00	0.00	=>=	<=	3000000			
1900	Base Second Refrigerator	Multi-Family											
2000	Base Freezer	Multi-Family											
2100	Base Second Freezer	Multi-Family											
			5.00		0	0.00				5000000			
			62.00		19000000	965600.00				62000000	40000000.00	<=	
<b>Water Heating ER4</b>													
2200	Base 40 gal. Water Heating (EF=0.88)	Single Family											
2203	Heat Pump Water Heater - Energy Star	Single Family	1.00	0.23	0	0.00	0.00	=>=	<=	1000000			
2204	Solar Domestic Water Heating with booster	Single Family	2.00	0.07	2000000	136000.00	0.00	>=	=<=	2000000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Lower Limit			Upper Limit	Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
2205	DHW Tank Wrap	Single Family	1.00	0.01	1000000	13600.00	0.00	>=	<=	1000000			
2300	Base POU Water Heater	Single Family											
2301	Low Flow Showerhead 1.5 Gal/Min, Base POU	Single Family	1.00	0.12	0	0.00	0.00	=>=	<=	1000000			
2400	Base Booster Water Heater (with solar system)	Single Family											
			5.00		3000000	149600.00				5000000			
<b>Water Heating ER4</b>													
2200	Base 40 gal. Water Heating (EF=0.88)	Multi-Family											
2300	Base POU Water Heater	Multi-Family											
2400	Base Booster Water Heater (with solar system)	Multi-Family											
			0.00		0	0.00				0			
			5.00		3000000	149600.00				5000000	3000000.00	=<=	
<b>Clothes Washer ER5</b>													
2500	Base Clotheswasher (MEF=1.26)	Single Family											
			0.00		0	0.00				0	0.00		
<b>Clothes Dryer ER6</b>													
2600	Base Clothes Dryer (EF=3.01)	Single Family											
2601	High Efficiency CD (EF=3.01 w/moisture sensor)	Single Family	1.00	0.41	0	0.00	0.00	=>=	<=	1000000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3	
							Lower Limit			Upper Limit	Additive Energy Savings		Global Energy Saving Target
							kWh			kWh	kWh		kWh
			1.00		0	0.00			1000000				
<b>Clothes Dryer ER6</b>													
2600	Base Clothes Dryer (EF=3.01)	Multi-Family											
			0.00		0	0.00			0				
			1.00		0	0.00			1000000	1400000.00	<=		
<b>Dish Washer ER7</b>													
2700	Base Dishwasher (EF=0.65)	Single Family											
<b>Dish Washer ER7</b>													
2700	Base Dishwasher (EF=0.65)	Multi-Family											
			0.00		0	0.00			0	0.00			
<b>Pool Pump ER8</b>													
2800	Base Pool Pump (RET)	Single Family											
2802	Variable-Speed Pool Pump (<1 hp)	Single Family	10.00	0.08	0	0.00	0.00	=>=	<=	10000000			
			10.00		0	0.00			10000000				
<b>Pool Pump ER8</b>													
2800	Base Pool Pump (RET)	Multi-Family											
			0.00		0	0.00			0				
			10.00		0	0.00			10000000	9700000.00	<=		

Appendix 9: Sample optimization model for 12.5 MW (Continued)

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>TV/PC ER9</b>													
2900	Base Plasma TV	Single Family											
2901	Energy Star Plasma TV	Single Family	1.00	0.03	1000000	27200.00	0.00	>=	=<=	1000000			
3000	Base LCD TV	Single Family											
3001	Energy Star LCD TV	Single Family	4.00	0.01	4000000	54400.00	0.00	>=	=<=	4000000			
3100	Base LED TV	Single Family											
3200	Base CRT TV	Single Family											
3201	Energy Star LED TV	Single Family	2.00	0.20	0	0.00	0.00	=>=	<=	2000000			
3300	Base Set-Top Box	Single Family											
3400	Base DVD Player	Single Family											
3401	Energy Star DVD Player	Single Family	1.00	0.04	1000000	40800.00	0.00	>=	=<=	1000000			
3500	Base Desktop PC	Single Family											
3501	Energy Star Desktop PC	Single Family	2.00	0.01	2000000	27200.00	0.00	>=	=<=	2000000			
3600	Base Laptop PC	Single Family											
3601	Energy Star Laptop PC	Single Family	1.00	0.04	1000000	40800.00	0.00	>=	=<=	1000000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3	
							Lower Limit			Upper Limit	Additive Energy Savings		Global Energy Saving Target
							GWh	B\$/kWh	kWh	B\$	kWh		kWh
			11.00		9000000	190400.00				11000000			
<b>TV/PC ER9</b>													
2900	Base Plasma TV	Multi-Family											
3000	Base LCD TV	Multi-Family											
3100	Base LED TV	Multi-Family											
3200	Base CRT TV	Multi-Family											
3300	Base Set-Top Box	Multi-Family											
3400	Base DVD Player	Multi-Family											
3500	Base Desktop PC	Multi-Family											
3600	Base Laptop PC	Multi-Family											
			0.00		0	0.00				0			
			11.00		9000000	190400.00				11000000	11800000.00	<=	
<b>Cooking ER10</b>													
3700	Base Cooking	Single Family											
<b>Cooking ER10</b>													
3700	Base Cooking	Multi-Family											
			0.00		0	0.00				0	0.00		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Miscellaneous ER11</b>													
3800	Base Miscellaneous	Single Family											
<b>Miscellaneous ER11</b>													
3800	Base Miscellaneous	Multi-Family											
			0.00		0	0.00				0	0.00		
<b>Whole House Practices ER12</b>													
3900	Base House Practices	Single Family											
3901	OPower/Behavioral Program	Single Family	14.00	0.03	14000000	380800.00	0.00	>=	=<=	14000000			
			14.00		14000000	380800.00				14000000			
<b>Whole House Practices ER12</b>													
3900	Base House Practices	Multi-Family											
3901	OPower/Behavioral Program	Multi-Family	2.00	0.04	2000000	81600.00	0.00	>=	=<=	2000000			
			2.00		2000000	81600.00				2000000			
			16.00		16000000	462400.00				16000000	16100000.00	<=	
			121.00		52000000	1904000.00				121000000	95000000.00		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings	Global Energy Saving Target	
													kWh
<b>Commercial And Industrial End Uses EC</b>													
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4'T8	Office											
1010	ROB 4L4' High Performance T8 (86 W)	Office	1.42	0.19	0	0.00	0.00	=>=	<=	1420000			
1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Office	3.13	0.30	0	0.00	0.00	=>=	<=	3130000			
1060	Occupancy Sensor	Office	4.31	0.50	0	0.00	0.00	=>=	<=	4310000			
1100	Base Other Fluorescent Fixture	Office											
1110	ROB High Performance T8 (base other fluorescent)	Office	4.45	0.22	0	0.00	0.00	=>=	<=	4450000			
1120	ROB Low Watt High Performance T8 (base other fluorescent)	Office	9.77	0.35	0	0.00	0.00	=>=	<=	9770000			
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Office	23.33	0.30	0	0.00	0.00	=>=	<=	23330000			
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Office											
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Office											
1310	Hardwired CFL fixture	Office	0.09	0.27	0	0.00	0.00	=>=	<=	90000			
1400	Base CFL (assuming 18w)	Office											
1500	Base High Bay Metal Halide, 400W	Office											
			46.50		0	0.00				46500000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
<b>Indoor Lighting EC1</b>												
1000	Base Fluorescent Fixture, 4L4T8	Restaurant										
1100	Base Other Fluorescent Fixture	Restaurant										
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Restaurant										
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Restaurant										
1310	Hardwired CFL fixture	Restaurant	0.04	0.15	0	0.00	0.00	=>=	<=	40000		
1400	Base CFL (assuming 18w)	Restaurant										
1500	Base High Bay Metal Halide, 400W	Restaurant										
1510	T5 (240W)	Restaurant	0.07	0.15	0	0.00	0.00	=>=	<=	70000		
1520	Induction High Bay Lighting	Restaurant	0.05	0.97	0	0.00	0.00	=>=	<=	50000		
1530	Pulse-start metal halide + electronic ballast	Restaurant	0.06	0.35	0	0.00	0.00	=>=	<=	60000		
1540	Occupancy Sensor, High Bay T5	Restaurant	0.03	0.18	0	0.00	0.00	=>=	<=	30000		
			0.25		0	0.00				250000		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh	
			0.25		0	0.00				250000			
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4'T8	Retail											
1010	ROB 4L4' High Performance T8 (86 W)	Retail	2.01	0.03	2010000	54672.00	0.00	>=	=<=	2010000			
1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Retail	4.40	0.05	4400000	239360.00	0.00	>=	=<=	4400000			
1040	ROB 4L4' LED Tube	Retail	6.94	0.42	0	0.00	0.00	=>=	<=	6940000			
1050	LED Troffer (base 4L4'T8)	Retail	8.07	0.49	0	0.00	0.00	=>=	<=	8070000			
1060	Occupancy Sensor	Retail	4.02	0.14	0	0.00	0.00	=>=	<=	4020000			
1100	Base Other Fluorescent Fixture	Retail											
1110	ROB High Performance T8 (base other fluorescent)	Retail	1.29	0.22	0	0.00	0.00	=>=	<=	1290000			
1120	ROB Low Watt High Performance T8 (base other fluorescent)	Retail	2.83	0.33	0	0.00	0.00	=>=	<=	2830000			
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Retail	6.72	0.29	0	0.00	0.00	=>=	<=	6720000			
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Retail											
1210	CFL - 100W-equivalent	Retail	0.65	0.14	0	0.00	0.00	=>=	<=	650000			
1220	LED screw-in - 100W-equivalent	Retail	0.40	0.15	0	0.00	0.00	=>=	<=	400000			
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Retail											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh	
1310	Hardwired CFL fixture	Retail	0.07	0.04	70000	2856.00	0.00	>=	=<=	70000			
1320	Hardwired LED fixture	Retail	0.08	0.35	0	0.00	0.00	=>=	<=	80000			
1400	Base CFL (assuming 18w)	Retail											
1500	Base High Bay Metal Halide, 400W	Retail											
			37.48		6480000	296888.00				37480000			
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4'T8	Grocery											
1010	ROB 4L4' High Performance T8 (86 W)	Grocery	0.91	0.08	0	0.00	0.00	=>=	<=	910000			
1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Grocery	1.91	0.12	0	0.00	0.00	=>=	<=	1910000			
1060	Occupancy Sensor	Grocery	1.92	0.29	0	0.00	0.00	=>=	<=	1920000			
1100	Base Other Fluorescent Fixture	Grocery											
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Grocery											
1210	CFL - 100W-equivalent	Grocery	0.66	0.07	660000	44880.00	0.00	>=	=<=	660000			
1220	LED screw-in - 100W-equivalent	Grocery	0.34	0.05	340000	18496.00	0.00	>=	=<=	340000			
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Grocery											
1310	Hardwired CFL fixture	Grocery	0.07	0.01	70000	952.00	0.00	>=	=<=	70000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
1320	Hardwired LED fixture	Grocery	0.08	0.16	0	0.00	0.00	=>=	<=	80000			
1400	Base CFL (assuming 18w)	Grocery											
1500	Base High Bay Metal Halide, 400W	Grocery											
1510	T5 (240W)	Grocery	0.57	0.87	0	0.00	0.00	=>=	<=	570000			
			6.46		1070000	64328.00				6460000			
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4'T8	School											
1010	ROB 4L4' High Performance T8 (86 W)	School	0.49	0.08	0	0.00	0.00	=>=	<=	490000			
1020	ROB 4L4' Low Watt High Performance T8 (75 W)	School	1.02	0.12	0	0.00	0.00	=>=	<=	1020000			
1060	Occupancy Sensor	School	0.86	0.34	0	0.00	0.00	=>=	<=	860000			
1100	Base Other Fluorescent Fixture	School											
1110	ROB High Performance T8 (base other fluorescent)	School	0.88	0.18	0	0.00	0.00	=>=	<=	880000			
1120	ROB Low Watt High Performance T8 (base other fluorescent)	School	1.83	0.27	0	0.00	0.00	=>=	<=	1830000			
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	School	4.00	0.26	0	0.00	0.00	=>=	<=	4000000			
1200	Base Incandescent lamp, 75W to Screw-in Replacement	School											
1210	CFL - 100W-equivalent	School	0.22	0.08	0	0.00	0.00	=>=	<=	220000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings	Global Energy Saving Target	
							kWh						kWh
1220	LED screw-in - 100W-equivalent	School	0.24	0.27	0	0.00	0.00	=>=	<=	240000			
1300	Base Incandescent Flood, 75W to Hardwired Replacement	School											
1310	Hardwired CFL fixture	School	0.02	0.03	20000	544.00	0.00	>=	=<=	20000			
1320	Hardwired LED fixture	School	0.03	0.22	0	0.00	0.00	=>=	<=	30000			
1400	Base CFL (assuming 18w)	School											
1500	Base High Bay Metal Halide, 400W	School											
			9.59		20000	544.00				9590000			
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4'T8	Health											
1100	Base Other Fluorescent Fixture	Health											
1110	ROB High Performance T8 (base other fluorescent)	Health	0.62	0.23	0	0.00	0.00	=>=	<=	620000			
1120	ROB Low Watt High Performance T8 (base other fluorescent)	Health	1.29	0.35	0	0.00	0.00	=>=	<=	1290000			
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Health	3.21	0.30	0	0.00	0.00	=>=	<=	3210000			
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Health											
1210	CFL - 100W-equivalent	Health	0.63	0.04	630000	25704.00	0.00	>=	=<=	630000			
1220	LED screw-in - 100W-equivalent	Health	0.59	0.08	0	0.00	0.00	=>=	<=	590000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Health											
1310	Hardwired CFL fixture	Health	0.07	0.01	70000	952.00	0.00	>=	=<=	70000			
1320	Hardwired LED fixture	Health	0.07	0.11	0	0.00	0.00	=>=	<=	70000			
1400	Base CFL (assuming 18w)	Health											
1500	Base High Bay Metal Halide, 400W	Health											
			6.48		700000	26656.00				6480000			
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4T8	Lodging											
1100	Base Other Fluorescent Fixture	Lodging											
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Lodging	1.80	0.53	0	0.00	0.00	=>=	<=	1800000			
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Lodging											
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Lodging											
1310	Hardwired CFL fixture	Lodging	0.28	0.24	0	0.00	0.00	=>=	<=	280000			
1400	Base CFL (assuming 18w)	Lodging											
1500	Base High Bay Metal Halide, 400W	Lodging											
			2.08		0	0.00				2080000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
			GWh	B\$/kWh	kWh	B\$						
<b>Indoor Lighting EC1</b>												
1000	Base Fluorescent Fixture, 4L4'T8	Industrial										
1100	Base Other Fluorescent Fixture	Industrial										
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Industrial										
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Industrial										
1400	Base CFL (assuming 18w)	Industrial										
1500	Base High Bay Metal Halide, 400W	Industrial										
			0.00		0	0.00				0		
<b>Indoor Lighting EC1</b>												
1000	Base Fluorescent Fixture, 4L4'T8	WWT										
1100	Base Other Fluorescent Fixture	WWT										
1200	Base Incandescent lamp, 75W to Screw-in Replacement	WWT										
1300	Base Incandescent Flood, 75W to Hardwired Replacement	WWT										
1400	Base CFL (assuming 18w)	WWT										
1500	Base High Bay Metal Halide, 400W	WWT										
			0.00		0	0.00				0		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
<b>Indoor Lighting EC1</b>												
1000	Base Fluorescent Fixture, 4L4'T8	Ports										
1010	ROB 4L4' High Performance T8 (86 W)	Ports	0.17	0.14	0	0.00	0.00	=>=	<=	170000		
1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Ports	0.37	0.22	0	0.00	0.00	=>=	<=	370000		
1060	Occupancy Sensor	Ports	0.34	0.56	0	0.00	0.00	=>=	<=	340000		
1100	Base Other Fluorescent Fixture	Ports										
1110	ROB High Performance T8 (base other fluorescent)	Ports	0.51	0.19	0	0.00	0.00	=>=	<=	510000		
1120	ROB Low Watt High Performance T8 (base other fluorescent)	Ports	1.11	0.30	0	0.00	0.00	=>=	<=	1110000		
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Ports	2.64	0.26	0	0.00	0.00	=>=	<=	2640000		
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Ports										
1210	CFL - 100W-equivalent	Ports	0.33	0.10	0	0.00	0.00	=>=	<=	330000		
1220	LED screw-in - 100W-equivalent	Ports	0.20	0.10	0	0.00	0.00	=>=	<=	200000		
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Ports										
1400	Base CFL (assuming 18w)	Ports										
1500	Base High Bay Metal Halide, 400W	Ports										
			5.67		0	0.00				5670000		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4'T8	Landlord											
1010	ROB 4L4' High Performance T8 (86 W)	Landlord	0.10	0.10	0	0.00	0.00	=>=	<=	100000			
1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Landlord	0.22	0.15	0	0.00	0.00	=>=	<=	220000			
1060	Occupancy Sensor	Landlord	0.22	0.37	0	0.00	0.00	=>=	<=	220000			
1100	Base Other Fluorescent Fixture	Landlord											
1110	ROB High Performance T8 (base other fluorescent)	Landlord	0.24	0.10	0	0.00	0.00	=>=	<=	240000			
1120	ROB Low Watt High Performance T8 (base other fluorescent)	Landlord	0.51	0.15	0	0.00	0.00	=>=	<=	510000			
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Landlord	1.34	0.12	0	0.00	0.00	=>=	<=	1340000			
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Landlord											
1210	CFL - 100W-equivalent	Landlord	1.18	0.08	0	0.00	0.00	=>=	<=	1180000			
1220	LED screw-in - 100W-equivalent	Landlord	1.07	0.14	0	0.00	0.00	=>=	<=	1070000			
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Landlord											
1310	Hardwired CFL fixture	Landlord	0.13	0.01	130000	1768.00	0.00	>=	=<=	130000			
1320	Hardwired LED fixture	Landlord	0.14	0.19	0	0.00	0.00	=>=	<=	140000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
1400	Base CFL (assuming 18w)	Landlord											
1500	Base High Bay Metal Halide, 400W	Landlord											
1510	T5 (240W)	Landlord	0.31	0.16	0	0.00	0.00	=>=	<=	310000			
1530	Pulse-start metal halide + electronic ballast	Landlord	0.28	0.37	0	0.00	0.00	=>=	<=	280000			
1540	Occupancy Sensor, High Bay T5	Landlord	0.14	0.16	0	0.00	0.00	=>=	<=	140000			
			5.88		130000	1768.00				5880000			
<b>Indoor Lighting EC1</b>													
1000	Base Fluorescent Fixture, 4L4'T8	Other											
1010	ROB 4L4' High Performance T8 (86 W)	Other	0.20	0.10	0	0.00	0.00	=>=	<=	200000			
1020	ROB 4L4' Low Watt High Performance T8 (75 W)	Other	0.44	0.15	0	0.00	0.00	=>=	<=	440000			
1060	Occupancy Sensor	Other	0.44	0.37	0	0.00	0.00	=>=	<=	440000			
1100	Base Other Fluorescent Fixture	Other											
1110	ROB High Performance T8 (base other fluorescent)	Other	0.47	0.10	0	0.00	0.00	=>=	<=	470000			
1120	ROB Low Watt High Performance T8 (base other fluorescent)	Other	1.01	0.15	0	0.00	0.00	=>=	<=	1010000			
1130	Occupancy Sensor, 4L8' Fluorescent Fixtures	Other	2.64	0.12	0	0.00	0.00	=>=	<=	2640000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
1200	Base Incandescent lamp, 75W to Screw-in Replacement	Other											
1210	CFL - 100W-equivalent	Other	2.33	0.08	0	0.00	0.00	=>=	<=	2330000			
1220	LED screw-in - 100W-equivalent	Other	2.11	0.14	0	0.00	0.00	=>=	<=	2110000			
1300	Base Incandescent Flood, 75W to Hardwired Replacement	Other											
1310	Hardwired CFL fixture	Other	0.26	0.01	260000	3536.00	0.00	>=	=<=	260000			
1320	Hardwired LED fixture	Other	0.28	0.19	0	0.00	0.00	=>=	<=	280000			
1400	Base CFL (assuming 18w)	Other											
1500	Base High Bay Metal Halide, 400W	Other											
1510	T5 (240W)	Other	0.62	0.16	0	0.00	0.00	=>=	<=	620000			
1530	Pulse-start metal halide + electronic ballast	Other	0.55	0.37	0	0.00	0.00	=>=	<=	550000			
1540	Occupancy Sensor, High Bay T5	Other	0.28	0.16	0	0.00	0.00	=>=	<=	280000			
			11.63		260000	3536.00				11630000			
			132.02		8660000	393720.00				132020000	77000000.00	<=	

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Office											
1610	LED Exit Sign	Office	0.46	0.05	460000	25024.00	0.00	>=	=<=	460000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	Office											
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Office	4.38	0.10	0	0.00	0.00	=>=	<=	4380000			
1720	LED Outdoor Area Lighting	Office	14.99	0.16	0	0.00	0.00	=>=	<=	14990000			
1730	Bi-Level LED Outdoor Lighting	Office	22.27	0.42	0	0.00	0.00	=>=	<=	22270000			
1800	Base Streetlighting High Pressure Sodium	Office											
			42.10		460000	25024.00				42100000			
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Restaurant											
1610	LED Exit Sign	Restaurant	0.02	0.04	20000	816.00	0.00	>=	=<=	20000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	Restaurant											
1800	Base Streetlighting High Pressure Sodium	Restaurant											
			0.02		20000	816.00				20000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Retail											
1610	LED Exit Sign	Retail	0.05	0.07	0	0.00	0.00	=>=	<=	50000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	Retail											
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Retail	0.66	0.22	0	0.00	0.00	=>=	<=	660000			
1720	LED Outdoor Area Lighting	Retail	2.19	0.37	0	0.00	0.00	=>=	<=	2190000			
1800	Base Streetlighting High Pressure Sodium	Retail											
			2.90		0	0.00				2900000			
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Grocery											
1610	LED Exit Sign	Grocery	0.10	0.01	100000	1360.00	0.00	>=	=<=	100000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	Grocery											
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Grocery	0.26	0.08	0	0.00	0.00	=>=	<=	260000			
1720	LED Outdoor Area Lighting	Grocery	0.95	0.15	0	0.00	0.00	=>=	<=	950000			
1730	Bi-Level LED Outdoor Lighting	Grocery	1.30	0.37	0	0.00	0.00	=>=	<=	1300000			
1800	Base Streetlighting High Pressure Sodium	Grocery											
			2.61		100000	1360.00				2610000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	School											
1610	LED Exit Sign	School	0.15	0.04	150000	6120.00	0.00	>=	=<=	150000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	School											
1710	Outdoor Lighting Controls (Photocell/Timeclock)	School	0.19	0.67	0	0.00	0.00	=>=	<=	190000			
1800	Base Streetlighting High Pressure Sodium	School											
			0.34		150000	6120.00				340000			
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Health											
1610	LED Exit Sign	Health	0.02	0.05	20000	1088.00	0.00	>=	=<=	20000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	Health											
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Health	0.25	0.11	0	0.00	0.00	=>=	<=	250000			
1720	LED Outdoor Area Lighting	Health	0.95	0.20	0	0.00	0.00	=>=	<=	950000			
1730	Bi-Level LED Outdoor Lighting	Health	1.28	0.46	0	0.00	0.00	=>=	<=	1280000			
1800	Base Streetlighting High Pressure Sodium	Health											
			2.50		20000	1088.00				2500000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Lodging											
1610	LED Exit Sign	Lodging	0.42	0.04	420000	17136.00	0.00	>=	=<=	420000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	Lodging											
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Lodging	2.16	0.14	0	0.00	0.00	=>=	<=	2160000			
1720	LED Outdoor Area Lighting	Lodging	7.51	0.24	0	0.00	0.00	=>=	<=	7510000			
1730	Bi-Level LED Outdoor Lighting	Lodging	10.98	0.60	0	0.00	0.00	=>=	<=	10980000			
1800	Base Streetlighting High Pressure Sodium	Lodging											
			21.07		420000	17136.00				21070000			
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Industrial											
1610	LED Exit Sign	Industrial	0.07	0.23	0	0.00	0.00	=>=	<=	70000			
1700	Base Outdoor High Pressure Sodium 250W Lamp	Industrial											
1800	Base Streetlighting High Pressure Sodium	Industrial											
			0.07		0	0.00				70000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
<b>Outdoor Lighting EC2</b>												
1600	Base Exit Sign	WWT										
1700	Base Outdoor High Pressure Sodium 250W Lamp	WWT										
1800	Base Streetlighting High Pressure Sodium	WWT										
			0.00		0	0.00			0			
<b>Outdoor Lighting EC2</b>												
1600	Base Exit Sign	Ports										
1700	Base Outdoor High Pressure Sodium 250W Lamp	Ports										
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Ports	0.23	0.22	0	0.00	0.00	=>=	<=	230000		
1720	LED Outdoor Area Lighting	Ports	0.77	0.37	0	0.00	0.00	=>=	<=	770000		
1800	Base Streetlighting High Pressure Sodium	Ports										
			1.00		0	0.00				1000000		
<b>Outdoor Lighting EC2</b>												
1600	Base Exit Sign	Landlord										
1700	Base Outdoor High Pressure Sodium 250W Lamp	Landlord										
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Landlord	0.20	0.08	0	0.00	0.00	=>=	<=	200000		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
1720	LED Outdoor Area Lighting	Landlord	0.62	0.12	0	0.00	0.00	=>=	<=	620000			
1730	Bi-Level LED Outdoor Lighting	Landlord	1.00	0.34	0	0.00	0.00	=>=	<=	1000000			
1800	Base Streetlighting High Pressure Sodium	Landlord											
			1.82		0	0.00				1820000			
<b>Outdoor Lighting EC2</b>													
1600	Base Exit Sign	Other											
1700	Base Outdoor High Pressure Sodium 250W Lamp	Other											
1710	Outdoor Lighting Controls (Photocell/Timeclock)	Other	0.39	0.08	0	0.00	0.00	=>=	<=	390000			
1720	LED Outdoor Area Lighting	Other	1.23	0.12	0	0.00	0.00	=>=	<=	1230000			
1730	Bi-Level LED Outdoor Lighting	Other	1.97	0.34	0	0.00	0.00	=>=	<=	1970000			
1800	Base Streetlighting High Pressure Sodium	Other											
			3.59		0	0.00				3590000			
			78.02		1170000	51544.00				78020000	34000000.00	<=	
			210.04		9830000	445264.00				210040000	111000000.00		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Cooling EC3</b>			<b>GWh</b>	<b>B\$/kWh</b>	<b>kWh</b>	<b>B\$</b>	<b>kWh</b>			<b>kWh</b>	<b>kWh</b>		
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Office											
3200	Base DX Packaged System, EER=10.3, 10 tons	Office											
3220	DX Packaged System, EER=13.4, 10 tons	Office	2.40	0.41	0	0.00	0.00	=>=	<=	2400000			
3260	Ceiling/roof Insulation	Office	1.26	0.69	0	0.00	0.00	=>=	<=	1260000			
3270	Duct/Pipe Insulation	Office	0.21	0.44	0	0.00	0.00	=>=	<=	210000			
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Office											
3510	High-efficiency ductless split-system AC (20 SEER)	Office	1.96	0.48	0	0.00	0.00	=>=	<=	1960000			
3540	Ceiling/roof Insulation	Office	2.37	0.84	0	0.00	0.00	=>=	<=	2370000			
3700	Base PTAC, EER=8.3, 1 ton	Office											
			8.20		0	0.00				8200000			
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Restaurant											
3200	Base DX Packaged System, EER=10.3, 10 tons	Restaurant											
3220	DX Packaged System, EER=13.4, 10 tons	Restaurant	0.66	0.52	0	0.00	0.00	=>=	<=	660000			
3270	Duct/Pipe Insulation	Restaurant	0.06	0.54	0	0.00	0.00	=>=	<=	60000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
3290	Window Film (Standard)	Restaurant	0.12	0.27	0	0.00	0.00	=>=	<=	120000			
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Restaurant											
3510	High-efficiency ductless split-system AC (20 SEER)	Restaurant	0.38	0.58	0	0.00	0.00	=>=	<=	380000			
3550	Window Film (Standard)	Restaurant	0.16	0.27	0	0.00	0.00	=>=	<=	160000			
3700	Base PTAC, EER=8.3, 1 ton	Restaurant											
			1.38		0	0.00				1380000			
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Retail											
3200	Base DX Packaged System, EER=10.3, 10 tons	Retail											
3220	DX Packaged System, EER=13.4, 10 tons	Retail	1.90	0.31	0	0.00	0.00	=>=	<=	1900000			
3240	Cool Roof	Retail	0.74	0.41	0	0.00	0.00	=>=	<=	740000			
3250	Prog. Thermostat	Retail	0.22	0.44	0	0.00	0.00	=>=	<=	220000			
3270	Duct/Pipe Insulation	Retail	0.17	0.33	0	0.00	0.00	=>=	<=	170000			
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Retail											
3510	High-efficiency ductless split-system AC (20 SEER)	Retail	0.62	0.35	0	0.00	0.00	=>=	<=	620000			
3520	Cool Roof	Retail	0.55	0.41	0	0.00	0.00	=>=	<=	550000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
3530	Prog. Thermostat	Retail	0.16	0.44	0	0.00	0.00	=>=	<=	160000			
3700	Base PTAC, EER=8.3, 1 ton	Retail		0.00									
			4.36		0	0.00				4360000			
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Grocery											
3200	Base DX Packaged System, EER=10.3, 10 tons	Grocery											
3210	DX Packaged System, EER=10.9, 10 tons	Grocery	0.65	0.35	0	0.00	0.00	=>=	<=	650000			
3220	DX Packaged System, EER=13.4, 10 tons	Grocery	2.70	0.11	0	0.00	0.00	=>=	<=	2700000			
3240	Cool Roof	Grocery	1.81	0.16	0	0.00	0.00	=>=	<=	1810000			
3250	Prog. Thermostat	Grocery	0.64	0.11	0	0.00	0.00	=>=	<=	640000			
3260	Ceiling/roof Insulation	Grocery	1.42	0.65	0	0.00	0.00	=>=	<=	1420000			
3270	Duct/Pipe Insulation	Grocery	0.23	0.11	0	0.00	0.00	=>=	<=	230000			
3290	Window Film (Standard)	Grocery	0.36	0.12	0	0.00	0.00	=>=	<=	360000			
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Grocery											
3510	High-efficiency ductless split-system AC (20 SEER)	Grocery	0.28	0.12	0	0.00	0.00	=>=	<=	280000			
3520	Cool Roof	Grocery	0.44	0.16	0	0.00	0.00	=>=	<=	440000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh	
3530	Prog. Thermostat	Grocery	0.15	0.12	0	0.00	0.00	=>=	<=	150000			
3540	Ceiling/roof Insulation	Grocery	0.34	0.79	0	0.00	0.00	=>=	<=	340000			
3550	Window Film (Standard)	Grocery	0.09	0.12	0	0.00	0.00	=>=	<=	90000			
3700	Base PTAC, EER=8.3, 1 ton	Grocery											
			9.11		0	0.00				9110000			
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	School											
3200	Base DX Packaged System, EER=10.3, 10 tons	School											
3500	Base Ductless Split-System Air Conditioner (18 SEER)	School											
3700	Base PTAC, EER=8.3, 1 ton	School											
			0.00		0	0.00							
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Health											
3200	Base DX Packaged System, EER=10.3, 10 tons	Health											
3220	DX Packaged System, EER=13.4, 10 tons	Health	0.85	0.26	0	0.00	0.00	=>=	<=	850000			
3250	Prog. Thermostat	Health	0.20	0.31	0	0.00	0.00	=>=	<=	200000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
			GWh	B\$/kWh	kWh	B\$						
3260	Ceiling/roof Insulation	Health	0.45	0.39	0	0.00	0.00	=>=	<=	450000		
3270	Duct/Pipe Insulation	Health	0.07	0.27	0	0.00	0.00	=>=	<=	70000		
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Health										
3510	High-efficiency ductless split-system AC (20 SEER)	Health	0.27	0.30	0	0.00	0.00	=>=	<=	270000		
3530	Prog. Thermostat	Health	0.15	0.31	0	0.00	0.00	=>=	<=	150000		
3540	Ceiling/roof Insulation	Health	0.33	0.48	0	0.00	0.00	=>=	<=	330000		
3700	Base PTAC, EER=8.3, 1 ton	Health		0.00								
			2.32		0	0.00				2320000		
<b>Cooling EC3</b>												
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Lodging										
3200	Base DX Packaged System, EER=10.3, 10 tons	Lodging										
3220	DX Packaged System, EER=13.4, 10 tons	Lodging	1.08	0.82	0	0.00	0.00	=>=	<=	1080000		
3260	Ceiling/roof Insulation	Lodging	0.57	0.88	0	0.00	0.00	=>=	<=	570000		
3290	Window Film (Standard)	Lodging	0.16	0.34	0	0.00	0.00	=>=	<=	160000		
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Lodging										
3550	Window Film (Standard)	Lodging	0.79	0.34	0	0.00	0.00	=>=	<=	790000		
3700	Base PTAC, EER=8.3, 1 ton	Lodging										
			2.60		0	0.00				2600000		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Industrial											
3200	Base DX Packaged System, EER=10.3, 10 tons	Industrial											
3220	DX Packaged System, EER=13.4, 10 tons	Industrial	2.05	0.52	0	0.00	0.00	=>=	<=	2050000			
3270	Duct/Pipe Insulation	Industrial	0.18	0.54	0	0.00	0.00	=>=	<=	180000			
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Industrial											
3510	High-efficiency ductless split-system AC (20 SEER)	Industrial	0.82	0.58	0	0.00	0.00	=>=	<=	820000			
3700	Base PTAC, EER=8.3, 1 ton	Industrial											
			3.05		0	0.00				3050000			
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	WWT											
3200	Base DX Packaged System, EER=10.3, 10 tons	WWT											
3500	Base Ductless Split-System Air Conditioner (18 SEER)	WWT											
3700	Base PTAC, EER=8.3, 1 ton	WWT											
			0.00		0	0.00				0			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
<b>Cooling EC3</b>			<b>GWh</b>	<b>B\$/kWh</b>	<b>kWh</b>	<b>B\$</b>						
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Ports										
3200	Base DX Packaged System, EER=10.3, 10 tons	Ports										
3220	DX Packaged System, EER=13.4, 10 tons	Ports	0.67	0.31	0	0.00	0.00	=>=	<=	670000		
3250	Prog. Thermostat	Ports	0.08	0.44	0	0.00	0.00	=>=	<=	80000		
3270	Duct/Pipe Insulation	Ports	0.06	0.33	0	0.00	0.00	=>=	<=	60000		
3290	Window Film (Standard)	Ports	0.09	0.37	0	0.00	0.00	=>=	<=	90000		
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Ports										
3510	High-efficiency ductless split-system AC (20 SEER)	Ports	0.22	0.35	0	0.00	0.00	=>=	<=	220000		
3530	Prog. Thermostat	Ports	0.06	0.44	0	0.00	0.00	=>=	<=	60000		
3550	Window Film (Standard)	Ports	0.07	0.37	0	0.00	0.00	=>=	<=	70000		
3700	Base PTAC, EER=8.3, 1 ton	Ports										
			1.25		0	0.00				1250000		
<b>Cooling EC3</b>												
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Landlord										
3200	Base DX Packaged System, EER=10.3, 10 tons	Landlord										

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
3220	DX Packaged System, EER=13.4, 10 tons	Landlord	0.04	0.34	0	0.00	0.00	=>=	<=	40000			
3250	Prog. Thermostat	Landlord	0.01	0.44	0	0.00	0.00	=>=	<=	10000			
3290	Window Film (Standard)	Landlord	0.01	0.41	0	0.00	0.00	=>=	<=	10000			
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Landlord											
3510	High-efficiency ductless split-system AC (20 SEER)	Landlord	0.19	0.39	0	0.00	0.00	=>=	<=	190000			
3530	Prog. Thermostat	Landlord	0.06	0.45	0	0.00	0.00	=>=	<=	60000			
3550	Window Film (Standard)	Landlord	0.08	0.41	0	0.00	0.00	=>=	<=	80000			
3700	Base PTAC, EER=8.3, 1 ton	Landlord											
			0.39		0	0.00				390000			
<b>Cooling EC3</b>													
3000	Base Centrifugal Chiller, 0.58 kW/ton, 500 tons	Other											
3200	Base DX Packaged System, EER=10.3, 10 tons	Other											
3220	DX Packaged System, EER=13.4, 10 tons	Other	0.08	0.34	0	0.00	0.00	=>=	<=	80000			
3250	Prog. Thermostat	Other	0.01	0.44	0	0.00	0.00	=>=	<=	10000			
3270	Duct/Pipe Insulation	Other	0.01	0.35	0	0.00	0.00	=>=	<=	10000			
3290	Window Film (Standard)	Other	0.01	0.41	0	0.00	0.00	=>=	<=	10000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
3500	Base Ductless Split-System Air Conditioner (18 SEER)	Other											
3510	High-efficiency ductless split-system AC (20 SEER)	Other	0.37	0.39	0	0.00	0.00	=>=	<=	370000			
3530	Prog. Thermostat	Other	0.13	0.45	0	0.00	0.00	=>=	<=	130000			
3550	Window Film (Standard)	Other	0.15	0.41	0	0.00	0.00	=>=	<=	150000			
3700	Base PTAC, EER=8.3, 1 ton	Other											
			0.76		0	0.00				760000			
			33.42		0	0.00				33420000	27000000.00	<=	
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Office											
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Restaurant											
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Retail											
4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Retail	0.10	0.14	0	0.00	0.00	=>=	<=	100000			
4050	Separate Makeup Air / Exhaust Hoods AC	Retail	0.17	0.04	170000	6936.00	0.00	>=	=<=	170000			
			0.27		170000	6936.00				270000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Grocery											
4020	Variable Speed Drive Control	Grocery	0.04	0.37	0	0.00	0.00	=>=	<=	40000			
4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Grocery	0.02	0.03	20000	544.00	0.00	>=	=<=	20000			
			0.06		20000	544.00				60000			
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	School											
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Health											
4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Health	0.01	0.07	10000	680.00	0.00	>=	=<=	10000			
4050	Separate Makeup Air / Exhaust Hoods AC	Health	0.02	0.01	20000	272.00	0.00	>=	=<=	20000			
			0.03		30000	952.00				30000			
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Lodging											
4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Lodging	0.68	0.48	0	0.00	0.00	=>=	<=	680000			
			0.68		0	0.00				680000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Industrial											
4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	Industrial	0.39	0.20	0	0.00	0.00	=>=	<=	390000			
4050	Separate Makeup Air / Exhaust Hoods AC	Industrial	0.68	0.05	680000	36992.00	0.00	>=	=<=	680000			
			1.07		680000	36992.00				1070000			
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	WWT											
4040	Electronically Commutated Motors (ECM) on an Air Handler Unit	WWT	0.03	0.52	0	0.00	0.00	=>=	<=	30000			
4050	Separate Makeup Air / Exhaust Hoods AC	WWT	0.06	0.14	0	0.00	0.00	=>=	<=	60000			
			0.09		0	0.00				90000			
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Ports											
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Landlord											
<b>Ventilation EC4</b>													
4000	Base Fan Motor, 5-75 hp	Other											
			0.00		0	0.00				0			
			2.20		900000	45424.00				2200000	2000000.00	<=	

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Office											
5100	Demand Hot Gas Defrost	Office											
5200	Base Self-Contained Refrigeration	Office											
5300	Energy Star Ice Machines	Office											
			0.00		0	0.00				0			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Restaurant											
5200	Base Self-Contained Refrigeration	Restaurant											
5220	Auto-closer on main door to walk-in freezer (self-contained)	Restaurant	0.67	0.08	0	0.00	0.00	=>=	<=	670000			
5230	Night covers for display cases (self-contained)	Restaurant	0.76	0.04	760000	31008.00	0.00	>=	=<=	760000			
5240	Freezer-Cooler Replacement Gaskets (self-contained)	Restaurant	0.12	0.04	120000	4896.00	0.00	>=	=<=	120000			
5290	Energy-Star Freezer, glass door	Restaurant	0.18	0.37	0	0.00	0.00	=>=	<=	180000			
5300	Energy Star Ice Machines	Restaurant											
5310	Hydraulic-type door closer on reach-in cooler glass doors	Restaurant	0.35	0.05	350000	19040.00	0.00	>=	=<=	350000			
			2.08		1230000	54944.00				2080000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Refrigeration EC5</b>			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh	
5000	Base Built-Up Refrigeration System	Retail											
5100	Demand Hot Gas Defrost	Retail											
5200	Base Self-Contained Refrigeration	Retail											
5230	Night covers for display cases (self-contained)	Retail	0.02	0.15	0	0.00	0.00	=>=	<=	20000			
5300	Energy Star Ice Machines	Retail											
			0.02		0	0.00				20000			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Grocery											
5030	Auto-closer on main door to walk-in freezer (built-up)	Grocery	0.51	0.01	510000	6936.00	0.00	>=	=<=	510000			
5040	Night covers for display cases	Grocery	0.08	0.01	80000	1088.00	0.00	>=	=<=	80000			
5060	Electronically commutated evaporator fan motor	Grocery	0.45	0.01	450000	6120.00	0.00	>=	=<=	450000			
5070	Efficient compressor motor	Grocery	0.01	0.26	0	0.00	0.00	=>=	<=	10000			
5090	Refrigeration Commissioning	Grocery	0.16	0.01	160000	2176.00	0.00	>=	=<=	160000			
5100	Demand Hot Gas Defrost	Grocery											
5120	Anti-sweat (humidistat) controls	Grocery	0.09	0.68	0	0.00	0.00	=>=	<=	90000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh						
5130	Freezer-Cooler Replacement Gaskets	Grocery	0.22	0.01	220000	2992.00	0.00	>=	=<=	220000			
5140	High R-Value Glass Doors	Grocery	0.10	0.05	100000	5440.00	0.00	>=	=<=	100000			
5200	Base Self-Contained Refrigeration	Grocery											
5220	Auto-closer on main door to walk-in freezer (self-contained)	Grocery	0.57	0.04	570000	23256.00	0.00	>=	=<=	570000			
5230	Night covers for display cases (self-contained)	Grocery	0.15	0.01	150000	2040.00	0.00	>=	=<=	150000			
5240	Freezer-Cooler Replacement Gaskets (self-contained)	Grocery	0.09	0.01	90000	1224.00	0.00	>=	=<=	90000			
5270	Energy-Star Freezer, solid door	Grocery	0.16	0.31	0	0.00	0.00	=>=	<=	160000			
5280	Energy-Star Refrigerator, glass door	Grocery	0.01	0.45	0	0.00	0.00	=>=	<=	10000			
5290	Energy-Star Freezer, glass door	Grocery	0.39	0.12	0	0.00	0.00	=>=	<=	390000			
5300	Energy Star Ice Machines	Grocery		0.00									
5310	Hydraulic-type door closer on reach-in cooler glass doors	Grocery	0.30	0.01	300000	4080.00	0.00	>=	=<=	300000			
			3.29		2630000	55352.00				3290000			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	School											
5200	Base Self-Contained Refrigeration	School											
5220	Auto-closer on main door to walk-in freezer (self-contained)	School	0.02	0.27	0	0.00	0.00	=>=	<=	20000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
5230	Night covers for display cases (self-contained)	School	0.02	0.04	20000	816.00	0.00	>=	=<=	20000			
5300	Energy Star Ice Machines	School											
5310	Hydraulic-type door closer on reach-in cooler glass doors	School	0.01	0.08	0	0.00	0.00	=>=	<=	10000			
			0.05		20000	816.00				50000			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Health											
5200	Base Self-Contained Refrigeration	Health											
5230	Night covers for display cases (self-contained)	Health	0.02	0.03	20000	544.00	0.00	>=	=<=	20000			
5260	Energy-Star Refrigerator, solid door	Health	0.01	0.45	0	0.00	0.00	=>=	<=	10000			
5280	Energy-Star Refrigerator, glass door	Health	0.01	0.44	0	0.00	0.00	=>=	<=	10000			
5300	Energy Star Ice Machines	Health											
5310	Hydraulic-type door closer on reach-in cooler glass doors	Health	0.01	0.05	10000	544.00	0.00	>=	=<=	10000			
			0.05		30000	1088.00				50000			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Lodging											
5200	Base Self-Contained Refrigeration	Lodging											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
5220	Auto-closer on main door to walk-in freezer (self-contained)	Lodging	0.64	0.12	0	0.00	0.00	=>=	<=	640000			
5230	Night covers for display cases (self-contained)	Lodging	0.72	0.01	720000	9792.00	0.00	>=	=<=	720000			
5240	Freezer-Cooler Replacement Gaskets (self-contained)	Lodging	0.10	0.01	100000	1360.00	0.00	>=	=<=	100000			
5260	Energy-Star Refrigerator, solid door	Lodging	0.09	0.38	0	0.00	0.00	=>=	<=	90000			
5270	Energy-Star Freezer, solid door	Lodging	0.13	0.27	0	0.00	0.00	=>=	<=	130000			
5290	Energy-Star Freezer, glass door	Lodging	0.32	0.11	0	0.00	0.00	=>=	<=	320000			
5300	Energy Star Ice Machines	Lodging											
			2.00		820000	11152.00				2000000			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Industrial											
5200	Base Self-Contained Refrigeration	Industrial											
5300	Energy Star Ice Machines	Industrial											
			0.00		0	0.00				0			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	WWT											
5200	Base Self-Contained Refrigeration	WWT											
			0.00		0	0.00				0			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Ports											
5200	Base Self-Contained Refrigeration	Ports											
5230	Night covers for display cases (self-contained)	Ports	0.01	0.15	0	0.00	0.00	=>=	<=	10000			
5300	Energy Star Ice Machines	Ports											
			0.01		0	0.00				10000			
<b>Refrigeration EC5</b>													
5000	Base Built-Up Refrigeration System	Landlord											
5100	Demand Hot Gas Defrost	Landlord											
5200	Base Self-Contained Refrigeration	Landlord											
5220	Auto-closer on main door to walk-in freezer (self-contained)	Landlord	0.01	0.45	0	0.00	0.00	=>=	<=	10000			
5230	Night covers for display cases (self-contained)	Landlord	0.02	0.01	20000	272.00	0.00	>=	=<=	20000			
5300	Energy Star Ice Machines	Landlord											
5310	Hydraulic-type door closer on reach-in cooler glass doors	Landlord	0.01	0.03	10000	272.00	0.00	>=	=<=	10000			
			0.04		30000	544.00				40000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh
<b>Refrigeration EC5</b>												
5000	Base Built-Up Refrigeration System	Other										
5100	Demand Hot Gas Defrost	Other										
5200	Base Self-Contained Refrigeration	Other										
5300	Energy Star Ice Machines	Other										
			0.00		0	0.00				0		
			7.54		4760000	123896.00		0.00	0.00	7540000	7000000.00	<=
<b>Office Equipment EC6</b>												
6000	Base Desktop PC	Office										
6010	Energy Star or Better PC	Office	3.18	0.01	3180000	43248.00	0.00	>=	=<=	3180000		
6100	Base Monitor, CRT	Office										
6110	Energy Star or Better Monitor - CRT	Office	0.92	0.03	920000	25024.00	0.00	>=	=<=	920000		
6200	Base Monitor, LCD	Office										
6210	Energy Star or Better Monitor - LCD	Office	1.31	0.01	1310000	17816.00	0.00	>=	=<=	1310000		
6300	Base Copier	Office										
6310	Energy Star or Better Copier	Office	0.23	0.30	0	0.00	0.00	=>=	<=	230000		
6400	Base Printer	Office										
6410	ENERGY STAR Printer	Office	0.38	0.08	0	0.00	0.00	=>=	<=	380000		
			6.02		5410000	86088.00				6020000		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Restaurant											
6100	Base Monitor, CRT	Restaurant											
6200	Base Monitor, LCD	Restaurant											
6300	Base Copier	Restaurant											
6400	Base Printer	Restaurant											
			0.00		0	0.00				0			
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Retail											
6010	Energy Star or Better PC	Retail	0.92	0.01	920000	12512.00	0.00	>=	=<=	920000			
6100	Base Monitor, CRT	Retail											
6110	Energy Star or Better Monitor - CRT	Retail	0.29	0.01	290000	3944.00	0.00	>=	=<=	290000			
6200	Base Monitor, LCD	Retail											
6210	Energy Star or Better Monitor - LCD	Retail	0.30	0.01	300000	4080.00	0.00	>=	=<=	300000			
6300	Base Copier	Retail											
6310	Energy Star or Better Copier	Retail	0.17	0.04	170000	6936.00	0.00	>=	=<=	170000			
6400	Base Printer	Retail											
6410	ENERGY STAR Printer	Retail	0.24	0.01	240000	3264.00	0.00	>=	=<=	240000			
			1.92		1920000	30736.00				1920000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Grocery											
6010	Energy Star or Better PC	Grocery	0.14	0.01	140000	1904.00	0.00	>=	=<=	140000			
6100	Base Monitor, CRT	Grocery											
6110	Energy Star or Better Monitor - CRT	Grocery	0.05	0.03	50000	1360.00	0.00	>=	=<=	50000			
6200	Base Monitor, LCD	Grocery											
6210	Energy Star or Better Monitor - LCD	Grocery	0.09	0.01	90000	1224.00	0.00	>=	=<=	90000			
6300	Base Copier	Grocery											
6310	Energy Star or Better Copier	Grocery	0.03	0.07	0	0.00	0.00	=>=	<=	30000			
6400	Base Printer	Grocery											
6410	ENERGY STAR Printer	Grocery	0.03	0.03	30000	816.00	0.00	>=	=<=	30000			
			0.34		310000	5304.00				340000			
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	School											
6010	Energy Star or Better PC	School	0.38	0.01	380000	5168.00	0.00	>=	=<=	380000			
6100	Base Monitor, CRT	School											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
6110	Energy Star or Better Monitor - CRT	School	0.27	0.03	270000	7344.00	0.00	>=	=<=	270000			
6200	Base Monitor, LCD	School											
6210	Energy Star or Better Monitor - LCD	School	0.21	0.01	210000	2856.00	0.00	>=	=<=	210000			
6300	Base Copier	School											
6310	Energy Star or Better Copier	School	0.04	0.16	0	0.00	0.00	=>=	<=	40000			
6400	Base Printer	School											
6410	ENERGY STAR Printer	School	0.04	0.07	0	0.00	0.00	=>=	<=	40000			
			0.94		860000	15368.00				940000			
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Health											
6010	Energy Star or Better PC	Health	0.56	0.01	560000	7616.00	0.00	>=	=<=	560000			
6100	Base Monitor, CRT	Health											
6110	Energy Star or Better Monitor - CRT	Health	0.15	0.03	150000	4080.00	0.00	>=	=<=	150000			
6200	Base Monitor, LCD	Health											
6210	Energy Star or Better Monitor - LCD	Health	0.22	0.01	220000	2992.00	0.00	>=	=<=	220000			
6300	Base Copier	Health											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings	Global Energy Saving Target	
							kWh						kWh
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh	
6310	Energy Star or Better Copier	Health	0.08	0.14	0	0.00	0.00	=>=	<=	80000			
6400	Base Printer	Health											
6410	ENERGY STAR Printer	Health	0.09	0.05	90000	4896.00	0.00	>=	=<=	90000			
			1.10		1020000	19584.00				1100000			
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Lodging											
6010	Energy Star or Better PC	Lodging	0.19	0.18	0	0.00	0.00	=>=	<=	190000			
6100	Base Monitor, CRT	Lodging											
6200	Base Monitor, LCD	Lodging											
6210	Energy Star or Better Monitor - LCD	Lodging	0.08	0.18	0	0.00	0.00	=>=	<=	80000			
6300	Base Copier	Lodging											
6400	Base Printer	Lodging											
			0.27		0	0.00				270000			
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Industrial											
6010	Energy Star or Better PC	Industrial	1.00	0.03	1000000	27200.00	0.00	>=	=<=	1000000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
6100	Base Monitor, CRT	Industrial										
6110	Energy Star or Better Monitor - CRT	Industrial	0.24	0.04	240000	9792.00	0.00	>=	=<=	240000		
6200	Base Monitor, LCD	Industrial										
6210	Energy Star or Better Monitor - LCD	Industrial	0.43	0.03	430000	11696.00	0.00	>=	=<=	430000		
6300	Base Copier	Industrial										
6310	Energy Star or Better Copier	Industrial	0.11	0.37	0	0.00	0.00	=>=	<=	110000		
6400	Base Printer	Industrial										
6410	ENERGY STAR Printer	Industrial	0.14	0.12	0	0.00	0.00	=>=	<=	140000		
			1.92		1670000	48688.00				1920000		
<b>Office Equipment EC6</b>												
6000	Base Desktop PC	WWT										
6010	Energy Star or Better PC	WWT	0.02	0.03	20000	544.00	0.00	>=	=<=	20000		
6100	Base Monitor, CRT	WWT										
6110	Energy Star or Better Monitor - CRT	WWT	0.01	0.04	10000	408.00	0.00	>=	=<=	10000		
6200	Base Monitor, LCD	WWT										
6210	Energy Star or Better Monitor - LCD	WWT	0.01	0.03	10000	272.00	0.00	>=	=<=	10000		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
6300	Base Copier	WWT											
6400	Base Printer	WWT											
			0.04		40000	1224.00			40000				
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Ports											
6010	Energy Star or Better PC	Ports	0.33	0.01	330000	4488.00	0.00	>=	=<=	330000			
6100	Base Monitor, CRT	Ports											
6110	Energy Star or Better Monitor - CRT	Ports	0.10	0.01	100000	1360.00	0.00	>=	=<=	100000			
6200	Base Monitor, LCD	Ports											
6210	Energy Star or Better Monitor - LCD	Ports	0.11	0.01	110000	1496.00	0.00	>=	=<=	110000			
6300	Base Copier	Ports											
6310	Energy Star or Better Copier	Ports	0.06	0.04	60000	2448.00	0.00	>=	=<=	60000			
6400	Base Printer	Ports											
6410	ENERGY STAR Printer	Ports	0.09	0.01	90000	1224.00	0.00	>=	=<=	90000			
			0.69		690000	11016.00				690000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh						
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Landlord											
6010	Energy Star or Better PC	Landlord	0.19	0.01	190000	2584.00	0.00	>=	=<=	190000			
6100	Base Monitor, CRT	Landlord											
6110	Energy Star or Better Monitor - CRT	Landlord	0.05	0.01	50000	680.00	0.00	>=	=<=	50000			
6200	Base Monitor, LCD	Landlord											
6210	Energy Star or Better Monitor - LCD	Landlord	0.08	0.01	80000	1088.00	0.00	>=	=<=	80000			
6300	Base Copier	Landlord											
6310	Energy Star or Better Copier	Landlord	0.02	0.08	0	0.00	0.00	=>=	<=	20000			
6400	Base Printer	Landlord											
6410	ENERGY STAR Printer	Landlord	0.04	0.03	40000	1088.00	0.00	>=	=<=	40000			
			0.38		360000	5440.00				380000			
<b>Office Equipment EC6</b>													
6000	Base Desktop PC	Other											
6100	Base Monitor, CRT	Other											
6200	Base Monitor, LCD	Other											
6300	Base Copier	Other											
6400	Base Printer	Other											
			0.00		0	0.00				0			
			13.62		12280000	223448.00				13620000	14000000.00	<=	

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Office										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Restaurant										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Retail										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Grocery										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	School										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Health										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Lodging										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Industrial										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	WWT										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Ports										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Landlord										
<b>Data Center EC7</b>												
7000	Base Data Center/Server Room	Other										
			0.00		0	0.00				0		

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Water Heating EC8</b>													
8000	Base Water Heating	Office											
8020	High Efficiency Water Heater (electric)	Office	0.01	0.23	0	0.00	0.00	=>=	<=	10000			
8040	Tankless Water Heater	Office	0.04	0.45	0	0.00	0.00	=>=	<=	40000			
8050	Heat Pump Water Heater (air source)	Office	0.08	0.53	0	0.00	0.00	=>=	<=	80000			
8070	Heat Trap	Office	0.03	0.11	0	0.00	0.00	=>=	<=	30000			
8080	Solar Water Heater	Office	0.27	0.38	0	0.00	0.00	=>=	<=	270000			
			0.43		0	0.00				430000			
<b>Water Heating EC8</b>													
8000	Base Water Heating	Restaurant											
8010	Demand controlled circulating systems	Restaurant	0.06	0.42	0	0.00	0.00	=>=	<=	60000			
8020	High Efficiency Water Heater (electric)	Restaurant	0.03	0.05	0	0.00	0.00	=>=	<=	30000			
8040	Tankless Water Heater	Restaurant	0.13	0.11	0	0.00	0.00	=>=	<=	130000			
8050	Heat Pump Water Heater (air source)	Restaurant	0.26	0.14	0	0.00	0.00	=>=	<=	260000			
8070	Heat Trap	Restaurant	0.09	0.03	0	0.00	0.00	=>=	<=	90000			
8080	Solar Water Heater	Restaurant	0.40	0.05	0	0.00	0.00	=>=	<=	400000			
			0.97		0	0.00				970000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Water Heating EC8</b>													
8000	Base Water Heating	Retail											
<b>Water Heating EC8</b>													
8000	Base Water Heating	Grocery											
8010	Demand controlled circulating systems	Grocery	0.31	0.01	0	0.00	0.00	=>=	<=	310000			
8020	High Efficiency Water Heater (electric)	Grocery	0.13	0.01	130000	1768.00	0.00	>=	=<=	130000			
8030	Hot Water Pipe Insulation	Grocery	0.12	0.01	120000	1632.00	0.00	>=	=<=	120000			
8040	Tankless Water Heater	Grocery	0.64	0.01	640000	8704.00	0.00	>=	=<=	640000			
8050	Heat Pump Water Heater (air source)	Grocery	1.28	0.01	380000	5168.00	0.00	>=	<=	1280000			
8070	Heat Trap	Grocery	0.44	0.01	0	0.00	0.00	=>=	<=	440000			
8080	Solar Water Heater	Grocery	3.73	0.01	3730000	50728.00	0.00	>=	=<=	3730000			
			6.65		5000000	68000.00				6650000			
<b>Water Heating EC8</b>													
8000	Base Water Heating	School											
8080	Solar Water Heater	School	0.01	0.34	0	0.00	0.00	=>=	<=	10000			
			0.01		0	0.00				10000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
<b>Water Heating EC8</b>													
8000	Base Water Heating	Health											
<b>Water Heating EC8</b>													
8000	Base Water Heating	Lodging											
8010	Demand controlled circulating systems	Lodging	0.05	0.79	0	0.00	0.00	=>=	<=	50000			
8020	High Efficiency Water Heater (electric)	Lodging	0.02	0.64	0	0.00	0.00	=>=	<=	20000			
8070	Heat Trap	Lodging	0.07	0.31	0	0.00	0.00	=>=	<=	70000			
8080	Solar Water Heater	Lodging	0.32	0.50	0	0.00	0.00	=>=	<=	320000			
			0.46		0	0.00				460000			
<b>Water Heating EC8</b>													
8000	Base Water Heating	Industrial											
8010	Demand controlled circulating systems	Industrial	0.01	0.76	0	0.00	0.00	=>=	<=	10000			
8050	Heat Pump Water Heater (air source)	Industrial	0.04	0.29	0	0.00	0.00	=>=	<=	40000			
8070	Heat Trap	Industrial	0.01	0.07	0	0.00	0.00	=>=	<=	10000			
8080	Solar Water Heater	Industrial	0.03	0.08	0	0.00	0.00	=>=	<=	30000			
			0.09		0	0.00				90000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Water Heating EC8</b>													
8000	Base Water Heating	WWT											
<b>Water Heating EC8</b>													
8000	Base Water Heating	Ports											
<b>Water Heating EC8</b>													
8000	Base Water Heating	Landlord											
<b>Water Heating EC8</b>													
8000	Base Water Heating	Other											
			8.61		5000000	68000.00				8610000	5000000.00	=<=	
<b>Vending EC9</b>													
8100	Base Vending Machines	Office											
8101	Vending Misers	Office	0.04	0.01	40000	544.00	0.00	>=	=<=	40000			
			0.04		40000	544.00				40000			
<b>Vending EC9</b>													
8100	Base Vending Machines	Restaurant											
<b>Vending EC9</b>													
8100	Base Vending Machines	Retail											
8101	Vending Misers	Retail	0.07	0.01	70000	952.00	0.00	>=	=<=	70000			
			0.07		70000	952.00				70000			

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Global Energy Saving Target
							Lower Limit				Additive Energy Savings		
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh	
<b>Vending EC9</b>													
8100	Base Vending Machines	Grocery											
8101	Vending Misers	Grocery	0.46	0.01	460000	6256.00	0.00	>=	=<=	460000			
			0.46		460000	6256.00				460000			
<b>Vending EC9</b>													
8100	Base Vending Machines	School											
8101	Vending Misers	School	0.07	0.03	70000	1904.00	0.00	>=	=<=	70000			
			0.07		70000	1904.00				70000			
<b>Vending EC9</b>													
8100	Base Vending Machines	Health											
8101	Vending Misers	Health	0.01	0.03	10000	272.00	0.00	>=	=<=	10000			
			0.01		10000	272.00				10000			
<b>Vending EC9</b>													
8100	Base Vending Machines	Lodging											
8101	Vending Misers	Lodging	0.07	0.12	0	0.00	0.00	=>=	<=	70000			
			0.07		0	0.00				70000			

Appendix 9: Sample optimization model for 12.5 MW (Continued)

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Vending EC9</b>													
8100	Base Vending Machines	Industrial											
8101	Vending Misers	Industrial	0.02	0.10	0	0.00	0.00	=>=	<=	20000			
			0.02		0	0.00				20000			
<b>Vending EC9</b>													
8100	Base Vending Machines	WWT											
<b>Vending EC9</b>													
8100	Base Vending Machines	Landlord											
8101	Vending Misers	Landlord	0.10	0.01	100000	1360.00	0.00	>=	=<=	100000			
			0.10		100000	1360.00				100000			
<b>Vending EC9</b>													
8100	Base Vending Machines	Other											
			0.84		750000	11288.00				840000	1000000.00	<=	
<b>Cooking EC10</b>													
8500	Base Cooking	Office											
9000	Base Compressed Air	Office											
<b>Cooking EC10</b>													
8500	Base Cooking	Restaurant											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
							kWh			kWh	kWh	kWh
9000	Base Compressed Air	Restaurant										
<b>Cooking EC10</b>												
8500	Base Cooking	Retail										
9000	Base Compressed Air	Retail										
<b>Cooking EC10</b>												
8500	Base Cooking	Grocery										
8510	ENERGY STAR Commercial Oven	Grocery	0.02	0.45	0	0.00	0.00	=>=	<=	20000		
8530	ENERGY STAR Steamer	Grocery	0.05	0.48	0	0.00	0.00	=>=	<=	50000		
9000	Base Compressed Air	Grocery										
			0.07		0	0.00				70000		
<b>Cooking EC10</b>												
8500	Base Cooking	School										
9000	Base Compressed Air	School										
<b>Cooking EC10</b>												
8500	Base Cooking	Health										
9000	Base Compressed Air	Health										

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Cooking EC10</b>													
8500	Base Cooking	Lodging											
8510	ENERGY STAR Commercial Oven	Lodging	1.54	0.12	0	0.00	0.00	=>=	<=<	1540000			
8530	ENERGY STAR Steamer	Lodging	7.70	0.07	5945000	404260.00	0.00	>=	<=<	7700000			
9000	Base Compressed Air	Lodging											
			9.24		5945000	404260.00				9240000			
<b>Cooking EC10</b>													
8500	Base Cooking	Industrial											
8530	ENERGY STAR Steamer	Industrial	0.01	0.39	0	0.00	0.00	=>=	<=<	10000			
9000	Base Compressed Air	Industrial											
			0.01		0	0.00				10000			
<b>Cooking EC10</b>													
8500	Base Cooking	WWT											
9000	Base Compressed Air	WWT											
<b>Cooking EC10</b>													
8500	Base Cooking	Ports											
9000	Base Compressed Air	Ports											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
							kWh				kWh		kWh
<b>Cooking EC10</b>													
8500	Base Cooking	Landlord											
8530	ENERGY STAR Steamer	Landlord	0.10	0.30	0	0.00	0.00	=>=	<=	100000			
9000	Base Compressed Air	Landlord											
			0.10		0	0.00				100000			
<b>Cooking EC10</b>													
8500	Base Cooking	Other											
9000	Base Compressed Air	Other											
			9.42		5945000	404260.00				9420000	9000000.00	<=	
<b>Motors EC11</b>													
9100	Base Motors	Office											
<b>Motors EC11</b>													
9100	Base Motors	Restaurant											
<b>Motors EC11</b>													
9100	Base Motors	Retail											
<b>Motors EC11</b>													
9100	Base Motors	Grocery											
<b>Motors EC11</b>													
9100	Base Motors	School											

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Upper Limit	Constraint 2		Constraint 3
							Lower Limit				Additive Energy Savings		Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh		kWh
<b>Motors EC11</b>													
9100	Base Motors	Health											
<b>Motors EC11</b>													
9100	Base Motors	Lodging											
<b>Motors EC11</b>													
9100	Base Motors	Industrial											
<b>Motors EC11</b>													
9100	Base Motors	WWT											
9102	Variable Speed Drive Control	WWT	5.01	0.08	0	0.00	0.00	=>=	<=	5010000			
9103	Motors - Maintenance (Cost is for predictive maintenance)	WWT	1.61	0.01	1610000	21896.00	0.00	>=	=<=	1610000			
9104	Motors- System Optimization and sizing	WWT	0.74	0.14	0	0.00	0.00	=>=	<=	740000			
			7.36		1610000	21896.00				7360000			
<b>Motors EC11</b>													
9100	Base Motors	Ports											
<b>Motors EC11</b>													
9100	Base Motors	Landlord											
<b>Motors EC11</b>													
9100	Base Motors	Other											
			7.36		1610000	21896.00				7360000	7000000.00	<=	

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Office										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Restaurant										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Retail										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Grocery										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	School										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Health										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Lodging										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Industrial										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	WWT										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Ports										
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Landlord										

**Appendix 9: Sample optimization model for 12.5 MW (Continued)**

Measure Number	Measure	Building Type	Technical Potential	LCOE 2025	Optimized Energy Savings	Optimized Cost	Constraint 1			Constraint 2		Constraint 3
							Lower Limit			Upper Limit	Additive Energy Savings	Global Energy Saving Target
			GWh	B\$/kWh	kWh	B\$	kWh			kWh	kWh	kWh
<b>Miscellaneous EC12</b>												
9500	Base Miscellaneous	Other										
			0.00		0	0.00				0		
			293.05		41075000	1343476.00				293050000	183000000.00	
			414.05		93075000	<b>3247476.00</b>				414050000	278000000.00	=>=

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Total Energy Savings (Optimized) kWh	93,075,000.00
Total Cost (Optimized) B\$	3247476.00
MW Savings	12.50
Average Cost per kWh of energy B\$/kWh	0.752
Loss of ROI (10%) = 0.7*10%* total optimized energy B\$	6,999,240.00
Total cost after ROI B\$	10,246,716.00
Global LCOE B\$/kWh after ROI	0.110090959

## **CURRICULUM VITAE**

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