HOUSEHOLD ELECTRICITY USE ANALYSIS AND FORECASTING: THE CASE OF PHNOM PENH, CAMBODIA

MR. NOU SOVANNDARA
ID: 0111090

A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE
IN ENERGY TECHNOLOGY

THE JOINT GRADUATE SCHOOL OF ENERGY AND ENVIRONMENT
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ABSTRACT

The major electrical energy consumer in Cambodia is the residential sector and constitutes 54% of the overall electricity consumption requirements of Phnom Penh City. Electricity demand in Cambodia is concentrated in Phnom Penh, which accounts for 80% of the country's electricity consumption. In 2001, total energy billed was 364.15 GWh or 13.70 percent from the sale; in 2000 it was 320.28 GWh. At the same time 2001, the energy consumption was 196.80 GWh for residential sector, 66.00 GWh for commercial and service sectors, 43.35 GWh for industrial sector, and 58.00 GWh for public sector.

The residential sector in Phnom Penh is divided into three major household income levels, namely low income level, medium income level, and high income level. The household income level is a dominant factor of electricity demand in the residential sector, since the rates of ownership of electric appliances vary by the income levels of household.

According to the real data that were collected they show that the pattern of energy consumption in each household is different based on the variety income level of household occupation and the type of private home; the households in high income level consumed higher electricity to be 401 kWh/HH/Month or 71%; the average energy consumption for the households in medium and low income levels are 125 kWh/HH/Month or 22% and 42 kWh/HH/Month or 7%, respectively.

The end-use model will be developed to project the household electricity demand in the residential sector in Phnom Penh by using the real data from fieldwork survey. The electricity demand projection for the residential sector of the base case of 5.5% GDP growth is projected to grow from 263.68 GWh in 2002 to 511.75 GWh in 2012, which accounted for an annual growth rate 6.86%, while the electricity demand projection for the energy efficiency case of 5.5% GDP growth is projected to grow from 263.68 GWh in 2002 to 490.29 GWh in 2012, accounting for an annual growth rate of 6.40%. Thus, the efficiency appliance program in the energy efficiency case has potential to reduce the electricity demand by 21.46 GWh, accounting for 4.38% of the total demand in the base case of 5.5% GDP growth.

Therefore, the end-use models characterize the long-term structure of electricity consumption in homes under differing assumptions, scenarios, and policies. Due to the end-use model being a flexible model that can support the change in both macro economic parameters such as Gross Domestic Product and energy intensity and end-use technical parameters such as the device' s efficiency.

From this study, the developed model (end-use model) could be a good sample model for energy demand forecasting in all sectors such as residential, commercial, industrial, and public sectors in Cambodia.

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CHAPTER 1

INTRODUCTION

1.1 Background

The success of the United Nations in organizing a fair election in Cambodia brought Peace to Cambodia. After the election in the year 1993, normal economic activities restarted in Cambodia, which led to an increase in the demand for electricity. But the supply of electricity in Phnom Penh was inadequate, which resulted in poor quality of supply and lows power generation units.

At present, EDC has started to increase the power supply by installing new generators and purchasing electricity from Thailand and Vietnam. Thus, they should know what factors influence the electricity demand? And, how much electricity will be consumed in the future?

Electricity consumption occurs in three primary sectors. Electricity consumed in private homes is included in the residential sector. Electricity consumed in manufacturing business activities is included in the industrial sector. The commercial sector includes electricity consumed in non-manufacturing business activities and includes electricity consumed in office buildings, hospitals, retail stores, restaurants, warehouses etc…

Electricity is important for all sectors of the national economy; it is one of the principal production factors to satisfy basic human needs. The past, present and future growth of each activity in the economy has an impact on electricity demand.

Electricity forecasting in a developing country is very important, it can become the major factor of economic development. Electricity projects often involve large instruments for developing countries and such projects have long gestation periods. Therefore, forecasting becomes important.

Phnom Penh is the center of economic and commercial activities in Cambodia. Thus, the need for electricity is more important for this city than the province. Electricity demand in Cambodia is concentrated in Phnom Penh, which accounts for 80% of the country's electricity consumption. The government of Cambodia considers Phnom Penh first and then other provinces. The importance of Phnom Penh in this Cambodian economy

is significant.

Therefore, the analysis and forecasting of electricity demand considered only the Phnom Penh area and covered the residential sector because this sector is the first largest electricity demand consumer (54% of energy sales in 2001). For the other sectors, such as commercial and industrial sectors, most use their own generator to run their business. This study focuses only on the electricity consumption (GWh) in the household electricity use in Phnom Penh. There is a lack of adequate studies on electricity demand in Cambodia.

An accurate forecast in Phnom Penh requires adequate data, especially the data of electric appliance penetration in the private household, for without it, the results of the forecast are unreliable. However, the data available for electricity demand studies are often insufficient to meet the needs of the forecast.

Therefore, a model to determine electricity demand should be developed. This model should be a detail end-use model so that it is based on the premise that the demand for electricity is derived demand. That is, the demand for electricity is derived from customers' demand for lighting, cooking, heating hot water, refrigeration, and so on.

Data were collected for the development of segment profiles that describe how customers use energy today. The end-use model combines this type of information with planning assumptions about technology changes and models of customer behavior to develop forecasts of future customer needs and uses of energy.

1.2 Statement of the Problem

Unfortunately, Cambodia has passed through a political crisis and this current reconstruction has started only since 1993. Not many systematic studies are available for electricity demand in Cambodia. This lack of data presents a number of theoretical and practical problems.

According to the lack of data, in this study we chose only the residential sector in Phnom Penh to be a main input, because the residential sector comprises the electricity consumption of private homes as it results from cooking, hot water, lighting and the use of electrical appliances, such as ventilation fan, television set, radio/tape player or VCD/CD

-player and some for refrigeration and air conditioning purposes. A particular feature observed in Phnom Penh is that the household energy assessment is often combined with the commercial sector (business household). The industrial and commercial sectors are omitted.

Previous electricity forecasts for Cambodia do not provide any reasonable information on the energy demand and for electricity forecasting for individual areas, as their data is not adequately disaggregated. The present system of keeping records of generation and consumption in the Phnom Penh city is also non-existent or is completely inadequate, and cannot be used as a basis for the electricity forecast.

From this above discussion it becomes clear that there is a lack of systematic electricity demand analysis and forecasting. Given this present shortage situation and the economic condition of this country, it is desirable to understand the factors affecting electricity demand and develop an appropriate method for forecasting demand. The present study focuses on this issue and would address the following problems that concern the EDC:

- What are the major determinants of household electricity use in Phnom Penh?
- How does electricity demand grow?
- What will influence the household electricity demand in the future?

1.3 Objectives of the Study

The goal of this study is to develop an electricity demand model for EDC's service area in Phnom Penh. The results of data analysis will be a main input of the model.

Therefore, in short, the objectives of the study are:

1- To analyze the household electricity use patterns in different consumer categories;

2- To highlight the main driving forces in electricity demand for each household income level in the residential sector in Phnom Penh; and

3- To forecast household electricity demand in Phnom Penh. The methodologies used to forecast the household electricity demand will be the end-use models.

1.4 Scope of the study

To achieve the above objectives of this study, the following contents are to be studied only:

1- The planning period of this study is 10 years. The base year of this study is in 2002;

2- The Gross Domestic Product (GDP) projection at three growth rates of 3%, 5.5% and 8%, the number of households projection, number and capacity of electric appliances, and the usage hour of each electric appliance per day are used to develop the electricity demand model for only the residential sector in Phnom Penh; and

3- The study analyzes the household electricity use, forecasts the household electricity demand by using the primary data and a good set of information in the base year, containing data on current end-use, and to highlight the impact of factors that might influence the future electricity demand for the residential sector in Phnom Penh city.

1.5 Keywords

Household electricity demand, End-use model, Base case and Energy efficiency case, Number of electrified households, Income level, Number of electric appliances, Capacity of electric appliances, Usage hours.

1.6 Organization of the study

This study divides into seven chapters: The First Chapter presents introduction. Chapter 2 provides and discuses the literature review of household electricity supply, household electricity use analysis, electricity demand forecast, and household electricity demand forecasting models. Chapter 3 presents an overview of the power sector in Cambodia. Chapter 4 presents the overall methodologies. Chapter 5 presents the household electricity use Analysis. Chapter 6 presents the household electricity demand forecasting. Chapter 7 presents the final conclusion and recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1 Conceptual Background

The literature review section presents various methods of energy modeling that have been developed through the years to determine household electricity demand and supply analysis, and decision analysis for electricity demand forecasting.

2.2 Household Electricity Supply

Gregory North, (2001). Improving the understanding of electricity consumption characteristics within the residential sector and the way in which to control them can reduce the ever-present risk of energy shortages and can also provide benefits for the residential customer and the supplying utility by more optimally managing the consumption of electricity.

Prime Minister Hun Sen, (29/5/2002). Energy electricity is an important need to serve every day the standard living of people and to serve the process of other fields of the national economy, and the stability of enough and cheap electric supply, which is a catalyst to push ahead development of other national economic fields.

Bente Halvorsen and Bodil M. Larsen, (2001). Presents that political signals indicate that the growth in Norwegian residential energy consumption should be reduced, and that it may be necessary to increase energy taxes.

Ith Praing, (1994). To overcome this " Power Crisis" it is necessary to improve the quality of our decision making in optimally and efficiently utilizing the limited energy resources for expansion of the electric power system so as to meet, reliably the future power demand at minimum cost.

Rudolf K. H. Dennerlein, (1987). The description and the forecast of residential electricity consumption is not only important for many areas of economic policy but also for the long-term investment plans of enterprises supplying electrical power.

A.S. Farag, et al, (1999). The energy plan is a key element in the utilities' process for integrating demand-side and supply-side resource options into plans that provide reliable service at the lowest reasonable cost under a range of uncertain future conditions within reliability, flexibility and financial constrains.

World Bank, (1999). Developing power infrastructure can alleviate poverty by providing the poor with access to a more efficient and cheaper energy, and it can mitigate environmental degradation by encouraging a shift from traditional to commercial energy and by increasing the supply of clean fuels. The efficient development of the power sector, open to private participation, is a critical requirement to support Cambodia's goal to generate sustainable economic growth and social development.

P. Balachandra and Vijay Chandru, (1999). In addition to list types of planning, electricity systems constrained by both power and capital shortages require effective supply-demand matching. Due to severe shortages of supply, large electricity demands remain unmet. Through supply interruptions and power rationing, utilities avoid supplying part of the electricity demanded by consumers. Thus, managing the system requires planning for non-supply and supply of electricity.

Bente Halvorsen and Bodil M. Larsen, (2001). The Norwegian residential electricity consumption increased by an average of 3% annually during the period 1976-1993. Political signals indicate that the growth in Norwegian residential energy consumption should be reduced, and that it may be necessary to increase energy taxes.

2.3 Household Electricity Use

Falong Yan, (1995). Since 1980, with reform of economic structure and opening to the outside world, urban household real income has increased rapidly. After having only enough food and clothing, urban residents want to achieve a relatively comfortable standard of living. Therefore, less electricity-intensive appliances entered urban households rapidly. First, electric fans, tape recorders and black-and-white TV sets, then color-TV sets, washing machines and refrigerators represented the primary electric load. Since 1990, electricity use has grown continuously with resident income rise. At the same time, income disparity has gradually widened. Electricity-intensive appliances such as air conditioners and electric heaters have begun to enter primary the high- and middle-income

households. In 1993, urban households consumed 57.14% of the electricity used by all households, although the urban population was only 28.14% of the total.

A.S. Fung, et al, (year: N/A). Energy consumption in a house is due to four major categories of end-uses: space heating, water heating, appliances and lighting, and space cooling.

Genevieve Mcnnes, et al, (1991). Development in electricity demand is the result of a range of very diverse factors, including energy policy measures, disposable income levels and consumer behavior. Governments have in some cases encouraged the use of electricity as a substitute for oil for energy security reasons. Structural changes in the economies of the OECD countries also have a strong influence on electricity demand, through the effects of increased personal income, changes in lifestyle, and shifts in the composition of industrial output and developments in production technologies. In addition, electricity is a particularly versatile form of energy, it is clean at the place of its use and its prices are generally less volatile than those of hydrocarbons. In some countries, electricity tariffs have been designed to support and attract electricity-intensive industries.

Joseph C. Lam, et al, (2002). The total building electrical load was broken down into four major electricity end-uses, namely heating, ventilation and air-conditioning (HVAC), lighting, small power and lift/escalator. During the hot summer months, it was found that HVAC was the single largest electricity end-user, accounting for 30-60%, lighting was second with 20-35% and small power third with 15-25%, lift/escalator accounted for a few percent of the total building load.

ESCAP, (1996). Sectoral energy demand of residential sector refers to the energy demand of building used for the purpose of residence for the following end-uses: cooking, lighting, space heating and cooling, hot water production, and electrical appliances.

Joseph C. Lam, (1998). He presented that with the economic growth and improvement in living standards, there has been a substantial increase in energy consumption during the eighties in Hong Kong. The electricity consumption rose from 1,059 GWh in 1971 to 6,692 GWh in 1993, an increase of 632%. It can be seen that there are two parts in the electricity consumption seasonal-variation and yearly. Besides climatic

influences, residential electricity consumption is affected by the social, economic and demographic conditions.

Xavier Chen, (1995). The electricity demand in the residential sector of Thailand comprises electricity requirements of the households' activities such as cooking, lighting, air conditioning, refrigeration and use of electrical appliances. Moreover, it also depends on the population, urbanization ratio, household income, end-use efficiencies of electrical appliances and unit consumption.

G.E. Nasr, et al, (2000). Moreover, electricity demand varies during different periods of the year. During the hot and humid summer, substantial use of air-conditioning equipments is required in the coastal and heavily populated areas to maintain comfortable indoor spaces.

E. Raphael Branch, (1993). The demand for residential electricity is derived from the demand for services, such as heating, cooling, and cooking, which are produced by using electric appliances. Therefore, the use of appliances and the stock of appliances are major determinants of the demand for residential electricity. In the short run, the intensity with which consumers use electric appliances depends on their income, the price of electricity, housing unit structure, demographic characteristics, seasonal variation, and weather.

Debbie Hollen, (2001). Total population and total households in the region are broad indicators of the potential for overall economic growth and energy demand. Total population helps determine the available labor force and the total number of households in the region, which is the primary indicator of residential energy demand.

Bilal A. Akash, et al, (1999). In recent years, concern about energy consumption in Jordan has been growing. The residential sector has probably been affected by the economic and technological changes that the country has been experiencing.

2.4 Electricity Demand Forecasting

Mohammed A. Al-Sahlawi, (year: N/A). Forecasting electricity demand is vital for planning and investment purposes. In estimating future electricity demand, it is important

to assure high responsibility that there will be no supply shortages.

Christian von Hirschhausen and Michael Andres, (2000). Energy demand forecasts have traditionally played a key role in the Chinese development planning process. The government uses aggregate approaches to determine future energy consumption.

Peter Choynowski, (2002). Proposed the functional form for measuring willingness to pay for electricity demand for households and firms. The measuring willingness to pay for electricity relies critically on a reliable estimate of the demand for electricity function. The usual approach is to calculate consumer surplus (CS) on the basis of a linear electricity demand function. This function is often selected because only two data points are needed to estimate its parameters. One data point is the price and quantity of an alternative source of energy consumed; the other data point is the quantity of electricity consumed by the representative household and the corresponding average price paid for the consumption.

S. C. Tripathy, (1997). The forecast of energy requirements is a complex exercise. To date, no specific methodology has been developed by which projections regarding anticipated electricity consumption can be made accurately, especially over the long-term time frame. The job of load forecasting is more difficult when the likely scenario of the country in the years to come is equally difficult to predict.

P. Balachandra and Vijay Chandru, (1999). Estimates of electricity demand that are based on annual or normalized load-duration curves tend to be highly approximate but are adequate for long term strategic planning. In order to plan in advance for both the supply and non-supply of electricity, utilities need to forecast the levels of demand and shortages and their times of occurrence in terms of hour of the day and day of the year. With this type of planning, the modeled demand has to encompass all variations.

Bente Halvorsen and Bodil M. Larsen, (2001). Studied factors that are of importance in explaining the growth in the Norwegian residential electricity demand during the period 1976-1993. They carried out several econometric analyses to identify the factors determining residential electricity consumption. In analyses of the sensitivity of residential electricity demand with respect to price changes, a number of modeling options applying either data of individual household behavior or macro data may be used. The results show that nearly half of household electricity consumption has increased due to an

increase in the number of households, and is thus not a result of changes in household behavior. These results suggest that changes in the electricity price have a substantial influence on the consumption level, and that increased electricity taxes is an effective instrument for reducing household electricity consumption, and also find that the electricity consumption varies relatively little with income, that is electricity is considered a necessity for good.

LR Jones J Griesel, et al, (1999). Long term forecasts by straight line or time series techniques can overstate future load requirements, as an implicit assumption is that load would continue to grow as it has in the past. However, loads tend to saturate with time. Typically, a customer would experience rapid growth while implementing new processes based on electrical energy consumption.

2.5 Household Electricity Demand Forecasting Models

C.W. Gellings, et al, (1991). Presented that the choice among aggregate and disaggregate methods or models is not an absolute one, but should be made in the context of a definite objective. If the objective is the capability to turn around a forecast quickly and have a model that is easily and transparently described in terms of the key sensitivities (e.g., elasticities), then an aggregate econometric model may be appropriate. If the need is to develop a detailed demand-side plan in which various DSM strategies are evaluated and incorporated into the forecast, then a structurally detailed end-use model is almost a requirement. In fact, most advanced end-use models developed in recent years are hybrid or integrated end-use and econometric models in which disaggregate econometric analysis is used to develop some or many of the specific forecasting elements of end-use model, which is an attempt to better represent patterns of consumer behavior in an otherwise engineering-based approach.

MIME's Final Report, (1998). Presented that the econometric approach is based on a set of data of the historical development of power consumption and explanatory variables in the power sector. This set of data should cover a period of at least the past eight to ten years. Given the many structural changes in the Cambodian economy over the last decade and the lack of information and data collected in the past, this is a prerequisite that cannot be met at present. It is therefore most prudent in the present context to use the end-use

approach, which is predominately based on the end-use of the various consumer categories. This report projected the electricity demand for the residential sector in 8 Provincial Towns in Cambodia by using the end-use model. The electricity demand was calculated by taking the number of electrified households and multiplying by the growth of annual electricity consumption per household.

Xavier Chen, (1995). Presented that the foundation of forecasting electricity demand in the residential sector lies in the base year period. But unlike the industrial sector, the residential electricity consumption is driven mainly by the growth in the number of households as well as the rise in living standards. Moreover, it also depends on the population, urbanization ratio, household income, end-use efficiencies of electrical appliances, and unit consumption.

Bajay, (1983). Classified the energy demand forecasting techniques in four broad categories: extrapolative, correlation, direct inquiry (End-use) or any combination of these. The End-use approach is suitable for the longer term forecasting. The input/output method, according to the author, required huge data, which made it prohibitive for application by smaller utilities.

To obtain good forecasting results, the following conditions are necessary:

- Comprehensive understanding of energy demand generation mechanism,
- Deep study of past energy consumption behavior,
- Clear identification of principle influencing factors that includes:

  - National energy and environmental policy,
  - Economic growth and demographical changes,
  - Structure changes of the economy,
  - Consistent scenarios with pertinence, coherence, transparency and realisticity.

So we see that in fact, forecasting of electricity demand is mostly an exercise of predicting the future evolution of its determining socio-economic and technical variables. Numerous methods have been developed for power or electricity demand forecasting purposes.

In this study we considered three models for carrying out electricity forecasts. None of these three can be considered as universally superior to the others. It is rather that a decision amongst them has to be made on the basis of the available data and information and the particular circumstances of this study. The general characterization of these models is presented in table 2.1.

These three models for energy demand forecasting are comprised:

- Time series model,
- Econometric model,
- End-use model.

Table 2.1: General characterization of forecasting.

Characteristic	Time series model	Econometric model	End-use model
- Data requirement	- Minimal energy/load only (for small areas)	- 8 to 12 years time series for several independent variables	- 10 to 30 years proportional to desired detail of model
- Computer requirement	- Trivial for trend models, significant for complex models	- Moderate, many models can be run on microcomputer	- Most models can be run on microcomputer
- Specialized skills	- Trivial for trend models, significant for complex models	- Relatively easy to build model-experience and training need to solve the problem	- No specialized training except for optimization model
- Suitability for analysis of system	- Suitable for small forecasted area	- Good for variables explicity in model	- Generally the best method of all

C.W. Gellings, et al, (1991). The End-use models for electricity demand focus on the various uses of electricity in the residential, commercial, and industrial sectors of the economy, each major electricity-using activity, space heating, air conditioning, refrigeration, cloths washing, etc, are identified and the corresponding energy consumption is specified.

Harry G. Stoll, et al, (1989). End-use electricity models are physical engineering-based methods often used in forecasting the residential, and sometimes commercial and industrial, service classes. The basic concept of end-use methodology is forecasting the

annual number of additions of electricity-consuming devices and electricity energy consumption per device.

Robert Bartels, et al, (2000). End-use energy models explain the demand for energy by households at the level of specific end uses, such as heating, cooking, water heating, dishwashing, etc.

Jerason Santisirisomboon, (2001). Presented a detailed end-use model to project the electricity demand of Thailand households. This model is able to capture the differences in socio-economic characteristic and patterns of electricity demand; the residential sector is classified into six income classes. The electricity demand of households in each income class was projected by multiplying the total number of households belonging to each income class by the average number of appliances owned in each income level, average capacities, and the average number of usage hours per year.

Nimol Por, (1996). Presented the forecasting of power demand of households in Siam Reap city of Cambodia by using the end-use model. The demand is calculated on the basis of the number of electrified households in each income level and is multiplied by the average equipment owned in each income level, average capacities, and the average usage hours per year. This forecast assumed the growth rate of average demand per household is 10% for the high scenario case, and 7% for the low scenario case.

Joel N. Swisher, et al, (1997). End-use projection models (or engineering models) are much more detailed than econometric models; though their analytical formulation can be quite simple. The end-use approach is very well suited to the purpose of energy-efficiency projections because it is possible to explicitly consider changes in technology and service levels. The electricity demand in the residential sector is formulated as a function of the number of households, number of electric appliances, usage hours and capacity of electric appliances. The model of the residential sector is illustrated in Figure 2.1. As residential energy services requirements vary across income classes, the end-use model can be formulated at the appropriate level of detail by both end-use and income level.

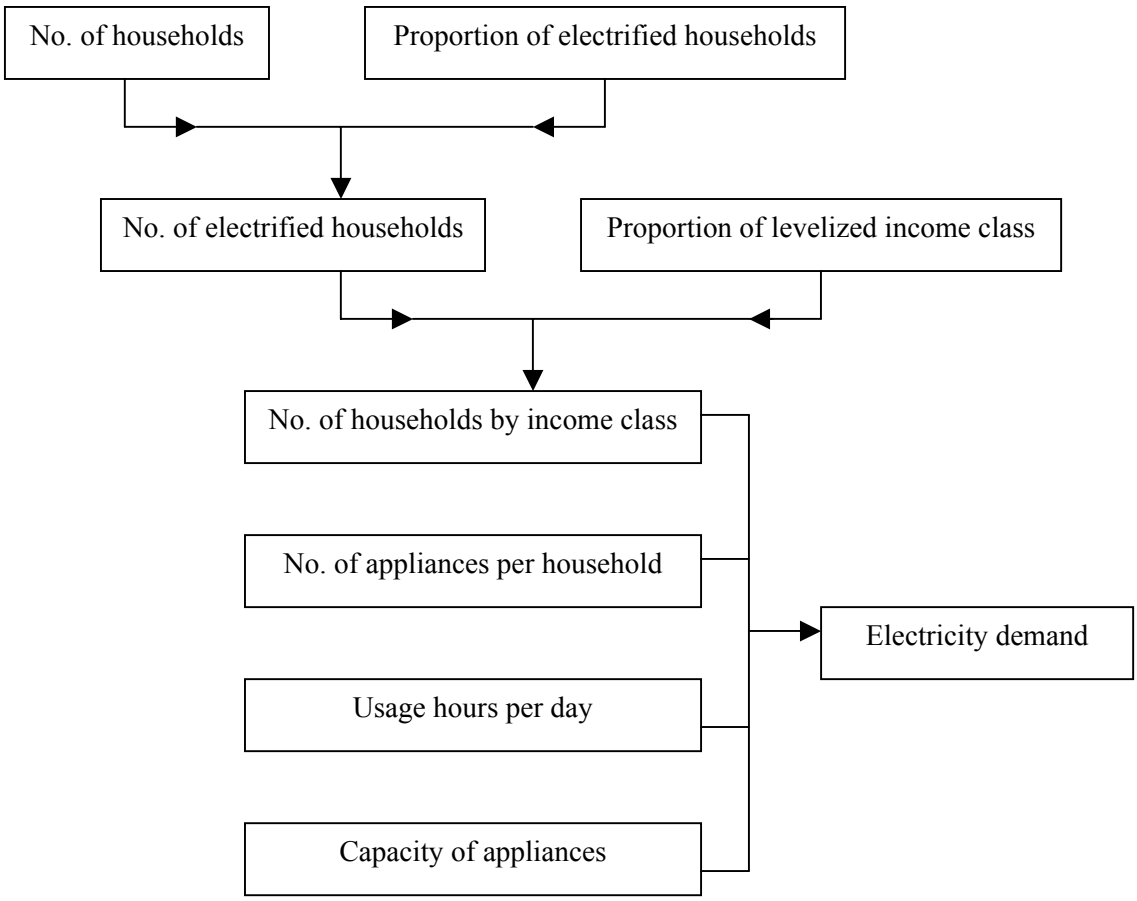

Figure 2.1: Model of the residential electric sector.

2.6 Conclusions

The literature review could be concluded as follows:

- The households do not demand electricity in itself, or the appliances that use electricity. What they demand is the services that are produced by these appliances. These services could be lighting, space cooling or some other kind of comfort or service. This means that in the end the households' electricity demand can be derived from the stock of electricity consuming appliances and from the other kind of household specific characteristics such as the household size and the household income levels. Therefore, the stock of appliances and the use of these can be affected by the different household income levels.

- The household electricity demand could indirectly or directly be influenced by the factors as follows: the electricity prices, population (household size), income

(number of electrified households in each income class), the economy (the economic changes), and the specific characteristics of appliances (the number of appliances and the use of these owned by each household income level, or appliance prices), etc.

- Energy planners often make the different projections of electricity demand for the future by using scenarios based on different assumptions such as about economic or political events. These scenarios allow planners to see how electricity demand might change if the different assumed economic and political events actually occur. In practice, a variety of problems with limited data measurement, theoretical variables and different purposes have led to a wide range of variety of approaches.
- The choice of the methodology for electricity demand projections makes the job of accurate forecasting rather difficult. Assumptions have also been made about the anticipated growth of the variables so that electricity demand forecasts are appropriate. Accordingly, different electricity demand models have been adopted in different variables for projecting a realistic forecast of electricity demand under reference. All of the forecasting methods are capable of looking at different scenarios and do so by changing their basic assumption.

2.7 Selection Household Electricity Demand Forecasting Model

From the above conclusions, the purpose of the study, and according to the characteristic of data and the condition of household electricity demand in the residential sector in Phnom Penh, the End-use model is suitable for the study. The number of electric appliances owned by the electrified households in each income level, capacity of electric appliances, and the usage hours of electric appliances per year could be the variables used for the function of the household electricity demand projection. To achieve the analysis of this projection, the variables of the function should be based on the actual data collected from the base year.

CHAPTER 3

OVERVIEW OF POWER SECTOR IN CAMBODIA

3.1 Country Profile

Cambodia lies in Southeast Asia (longitude 102°-108°, Latitude 10°-15°) and occupies an area of 181,035 square kilometers. The country's coastline along the gulf of Thailand runs for 389 kilometers (in the Southwest of the country). Cambodia shares its total international land boundary of 2,326 kilometers with three countries: the borders on Laos in the North and Northeast (541 kilometers), Thailand in the West and Northwest (803 kilometers), Vietnam in the East and Southeast (982 kilometers). The central part of the country, bordered by the Mekong River and Tonle Sap Lake, is a level basin covering three-quarters of Cambodia. The dominant geographical feature of Cambodia is the Mekong River, one of the longest rivers of the world with a length of 4,334 kilometers. On reaching the Cambodian plain it becomes broad, and near the delta it is 5 kilometers wide and deep enough to accommodate ocean steamers. Tonle Sap, an inland Lake in the central region acts as a natural reservoir for the Mekong River. Its Capital is Phnom Penh, which is the political, cultural and economic center. Cambodia has a tropical climate with two distinct seasons, wet and dry, the wet season is characterized by heavy monsoon rains (is Southwest monsoon) and the dry season (is Southeast monsoon), and humidity is high throughout the year. The average temperature is about 27°C in Phnom Penh area and high temperature in the region of 35^{o}C - 38^{o}C is common before the start of the rainy season.

3.2 Review of Electricity Service in Cambodia

Electricity service in Cambodia began in 1906. Up to 1958, supply was provided by three private companies: Compagnie de Eaux et Electricite (CEE) serving Phnom Penh area, the Union d' Electricite d' Indochine (UNEDI) serving other provinces, except Battambang, and the Compagnie Franco-Khmere d' Electricite (CFKE) serving the city Battambang. On 10 October 1958, CEE and UNEDI were merged to become Electricite du Cambodge (EdC), later Electricite de Phnom Penh (to serve only the Phnom Penh area) and now again Electricite du Cambodge (EdC).

Due to the severe damage by years of war and neglect, the power system was

unable to supply the demand for electricity from conventional grid connections. A large amount of demand was supplied from large and small generators owned by large, medium and small consumers. Since 1995 there has been a gradual normalization of supplies from EDC and the very small generators (such as gasoline powered sets) are no longer being used, except for a few backup units. However, there remains a substantial capacity of generation sets owned and operated by large industrial and commercial enterprises, which either use EDC supplies as secondary backup or are not connected to the grid. The reasons for not using EDC supplies are related to reliability and/or cost, including unit price as well as connection costs.

The Royal Government of Cambodia (RGC) aims to rapidly develop the electricity sector as a major contributor to balanced social and economic growth. Electricity reforms will be purposed to enhance the involvement of the private sector towards efficiency and competitiveness of the electricity industry.

In March 1996, the Royal Government of Cambodia created a wholly state-owned limited liability company named Electricite du Cambodge (EDC) to generate, transmit and distribute electric power throughout Cambodia. EDC is juridical organisation with administrative, financial and managerial authority, possessing civil right and responsibility according to the law and the pursuit of commercial objectives, with responsibility for its profit and losses and liable for its debts to the extent of the value of its assets. It has its own board of directors and operates, as an independent agency but has no authority over the electricity tariff.

In Cambodia, electricity is generated in 22 small isolated power systems, mostly from diesel generators. These systems are divided into two parts: Phnom Penh and six provincial towns served by EDC, and the remainder is served by the Ministry of Industry, Mines and Energy (MIME). In 2000 the total installed capacity of electricity generation in Cambodia was 145 MW, as shown in Fig. 3.1 and Table 3.1. As a result of the small size of generation units (300kW to 6MW), dependence on oil-based generation, and large distribution losses, the unit cost of electricity in Cambodia is among the highest in the region. Only 13% of the households in Cambodia have access to electricity and, per capita of the energy consumption, accounted for 48 kWh per annum. It is the lowest ratio among ASEAN countries, as shown in Table 3.2.

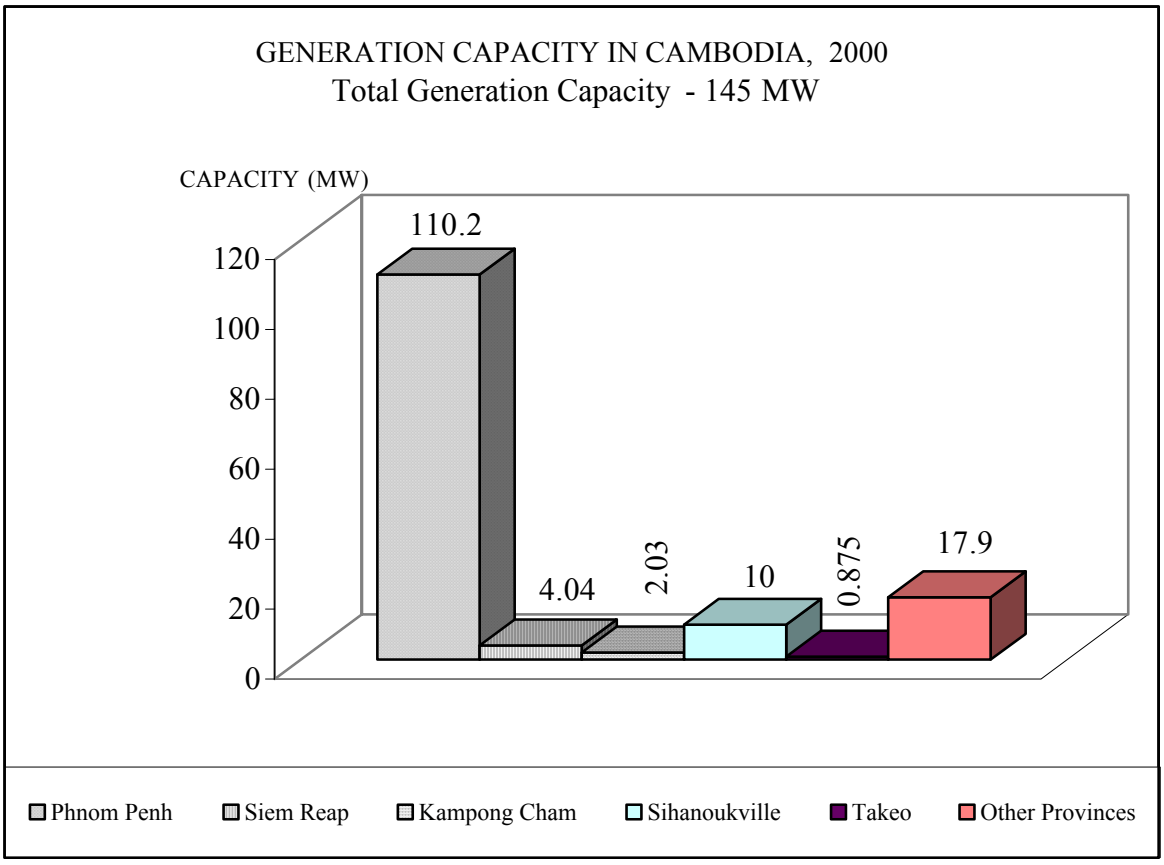

Figure 3.1: Power Generation Capacity in Cambodia

Table 3.1: Generation Capacity in Phnom Penh and EDC's coverage areas, (MW)

No	Area	Power Plant	Capacity, [MW]
1	Phnom Penh	C1 (IPP-Jupiter)	15
		C2 + IPP1	53
		C3	14.20
		C4	00
		C5	10
		C6	18
	TOTAL		110.20
2	Siem Reap	-	4.04
3	Kampong Cham	-	2.03
4	Sihanoukville	-	10
5	Takeo	-	0.875
6	Other provinces	-	17.90
	TOTAL		34.845
GRAND TOTAL			145.045

Source: EDC's Report (2000)

Table 3.2: Electrification Rate and Electricity Consumption per Capita in ASEAN.

Countries	Electrification, [%]	Consumption, [kWh/y/cap]
Brunei	-	-
Cambodia	13	48
Indonesia	-	329
Lao	18	94
Malaysia	-	2,352
Myanmar	-	57
Philippines	-	432
Singapore	100	6,451
Thailand	98	1,360
Vietnam	30	203

Source: Compiled from Country Report (1999), and MIME, EDC and JICA Report (2001)

3.3 Review of Electricity Service in Phnom Penh

Phnom Penh is the center of political, cultural, economic and commercial activities in Cambodia. Thus, the need of electricity is an important issue for this city than the other provincial towns. Electricity demand in Cambodia is concentrated in Phnom Penh, which accounts for 80% of the country's electricity consumption.

3.3.1 Power Generation in Phnom Penh

Nowadays, Phnom Penh's system and some areas located around this city are supplied the electricity from seven power stations, and one Kirirom-I hydro power station, which was opened again on May 29, 2002, produces 12 MW of power, which is also distributed to Phnom Penh and Kampong Speu city with an overhead transmission line of 115kV. These figures are shown in table 3.3.

Table 3.3: Power Stations for Phnom Penh's system, (MW)

Power Plant	Installed Capacity, [MW]	Engine Type	Fuel Use
C1 (IPP-Jupiter)	15.00	Diesel	DO
C2 (EDC)	18.00	Thermal	HFO
C2 (IPP-1)	35.00	Diesel	HFO
C3	14.20	Diesel	DO
C4	0.00	Diesel (out of service)	N/A
C5	10.00	Diesel	DO
C6	18.00	Diesel	HFO
Kirirom-I	12.00	Hydro-turbine	Hydraulic
Total Capacity	122.20 MW		

Source: EDC's Report (2002)

3.3.2 Distribution Networks in Phnom Penh

The capability of the new distribution system in Phnom Penh is 700 GWh to 800GWh. Voltage levels of 115 kV, 22 kV, and 6.3 kV are used in Phnom Penh's system. EDC's design standard requires upgrading the medium voltage levels to 22 kV from 15kV and 6.3 kV levels, in order to increase the system reliability, minimize system losses and to adapt the voltage level with neighboring countries. The low-tension level is 380/220 V.

In Phnom Penh's system, a 23cct-km of 115 kV ring bus line and its three-grid substations (GS1, GS2 and GS3) have been energized since late 1999. The main purpose of the ring bus line is to increase to reliability of Phnom Penh's system by connection between three main sources of power generation from Northwest and South. GS1, located in the North of Phnom Penh, is reserved for the power supply from IPP-2, while the GS2 in the South of Phnom Penh is reserved for the power transmission 115 kV/230 kV from the Southern supply line and the west grid substation GS3 is reserved for 115 kV transmission line from the BOT project of 12 MW Kirirom-I Hydro Power Station.

3.3.3 Energy Sales in Phnom Penh

In Phnom Penh's system, to ease understanding, groups of customers are grouped: The Residential sectors, comprising of domestic customers and the wholesale customers; Industrial sector includes industrial consumers and the water department; Commercial and Service sectors consisting of Hotels/Guest-houses; Public sector includes EDC service, government and municipality services, non-government and embassy services, public lighting and other services.

In 2001, total energy billed was 364.15 GWh or 13.70 percent from the sale in 2000 was 320.28 GWh. The production in Phnom Penh's system increased from 380.00 GWh in 2000 to 433.01 GWh in 2001 or 13.95 percent in 2001. For the Phnom Penh's system, power consumption was utilized for residential purposes and light loads only. In 2001, the energy consumption was 196.80 GWh for the residential sector, 66.00 GWh for the commercial and service sectors, 43.35 GWh for the industrial sector, and 58.00 GWh for the public sector. A breakdown of energy sold by sectors in 2001 is illustrated in figure 3.2, and the previous energy sold by sector from 1991 to 2001 is illustrated in table 3.4 and 3.5.

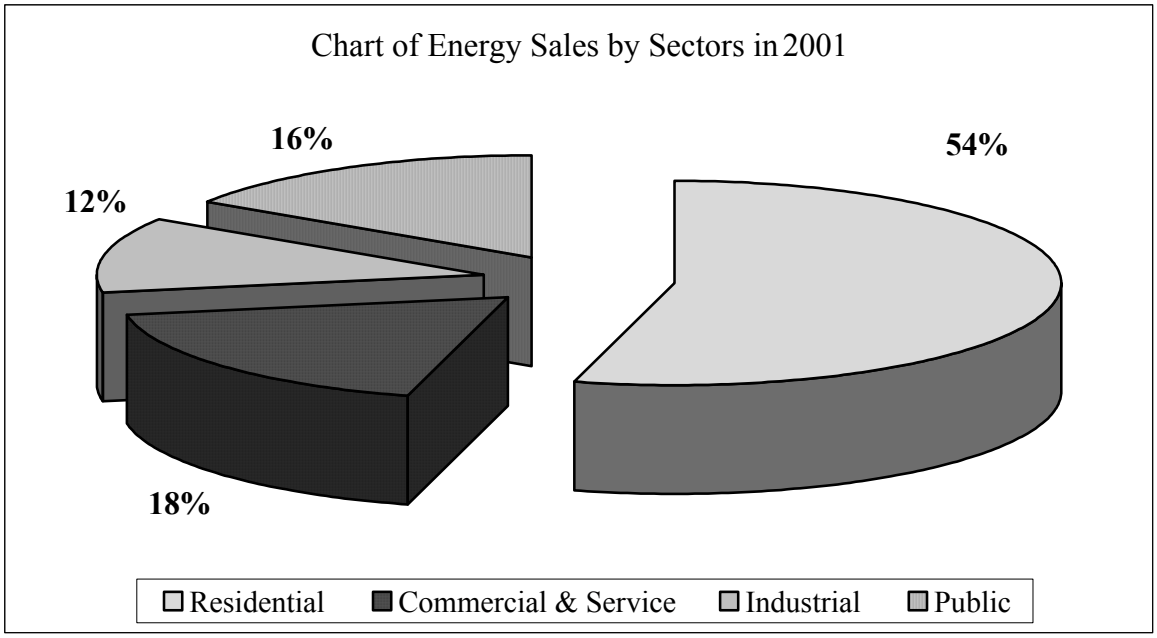

Figure 3.2: Energy Sales by Sector in Phnom Penh, 2001

Table 3.4: Energy Sales by Sector in Phnom Penh, 2001, (GWh)

Year	Residential	Comm. & Serv.	Industry	Public	Total	Gr. Rate
1991	14.81	4.17	35.82	5.09	59.89	-
1992	28.50	7.89	36.91	19.42	92.72	54.82
1993	35.28	12.94	2.37	28.01	78.60	-15.23
1994	42.16	14.35	7.28	18.45	82.24	4.63
1995	51.60	13.92	12.94	15.35	93.81	14.07
1996	99.00	19.57	18.40	31.39	168.36	79.47
1997	132.50	21.57	23.58	38.77	216.42	28.55
1998	152.70	31.94	31.87	52.89	269.40	24.48
1999	165.30	32.79	32.40	40.83	271.32	0.71
2000	183.60	49.32	35.60	51.79	320.28	18.05
2001	196.80	66.00	43.35	58.00	364.15	13.70

Source: EDC's Report (2001)

Table 3.5: Energy Sales shares by Sector in Phnom Penh, 2001, (%**)**

Year	Residential	Comm. & Serv.	Industry	Public	Total
1991	24.73	6.96	59.81	8.50	100
1992	30.74	8.51	39.81	20.94	100
1993	44.89	16.46	3.02	35.64	100
1994	51.26	17.45	8.85	22.43	100
1995	55.00	14.84	13.79	16.36	100
1996	58.80	11.62	10.93	18.64	100
1997	61.22	9.97	10.90	17.91	100
1998	56.68	11.86	11.83	19.63	100
1999	60.92	12.09	11.94	15.05	100
2000	57.32	15.40	11.12	16.16	100
2001	54.04	18.12	11.90	15.93	100

Source: EDC's Report (2001)

3.4 Household Electricity Supply in Phnom Penh

3.4.1 Previous Supply

Cambodia's power sector was severely damaged by years of war and neglect. In spite of the Government's efforts of past years, its institutions remain weak, and power supply is unreliable, costly, and mostly limited to urban areas. Consequently, demand for electricity within the country severely suppressed. Only 13% of the households have access to electricity, the lowest electrification ratio among ASEAN countries.

Due to years of neglect, the power system was unable to supply the demand for electricity from conventional grid connections. A large amount of demand was supplied from large and small generators owned by large, medium and small consumers. Since 1995 there has been a gradual normalization of supplies from EDC and the very small generators (such as gasoline powered sets) are no longer being used, except for a few backup units. However, there remains a substantial capacity of generation sets owned and operated by large industrial and commercial enterprises, which either use EDC supplies as secondary backup or are not connected to the grid. The reasons for not using EDC supplies are related to reliability and/or cost, including unit prices as well as connection cost.

3.4.2 Future Supply

The Royal Government of Cambodia formulated an energy sector development policy in October 1994, which aims:

- To provide an adequate supply of energy throughout Cambodia at a reasonable and affordable price;
- To ensure a reliable, secure electricity supply and prices, which facilitate investment in Cambodia and development of the national economy;
- To encourage exploration and environmentally and socially acceptable development of energy resources need for supply to all sectors of the Cambodian economy; and
- To encourage efficient use of energy and to minimize environmental effects resulting from energy supply and use.

The Government's policy for the rehabilitation and development of the power sector, as stated in late 1994, recognized the need to undertake sector reform to strengthen institutions and attract private sector investment. The Government of Cambodia (GOC) has acted on this, with the support of multilateral and bilateral agencies, aiming to: (a) re-establish an adequate supply of electricity in the main urban centers; (b) strengthen sector managerial and implementing capability; and (c) initiate efforts to create the environment required for a sustained and efficient development of the power sector, open to competition and private participation. During the last years, the Government of Cambodia (GOC) has been partially successful in meeting its objectives. Power supply in Phnom Penh has improved in generation, and distribution is complemented by a private independent power producer (IPP). Following a commercialization plan, EDC was established as a separate entity in March 1996 and EDC's Board of Directors was appointed in August 1997.

3.5 Household Electricity Demand in Phnom Penh

Between 1993 and 1996, Cambodia managed to maintain high economic growth with an annual average of 6.1 percent. After a two-year (1997-1998) economic slowdown caused by a long political stalemate and East Asia's financial crisis, political stability is emerging and Cambodia appears to be ready to resume a sustained economic growth.

During the last two years, in 1999 and 2000, GDP growth rebounded to 4.5% (as opposed to 1% in 1998) and 5.0% respectively. In 2001 the Cambodian economy performed reasonably well with a GDP growth rate of 5.3% while Cambodia initiates a new era as a member of ASEAN. According to the Socio-Economic Development Plan of the Ministry of Planning (MOP), the long-term prospects, sustainable economic growth at an annual growth rate of 6% to 7%, with the Government aiming for a 5% to 6% in GDP. An important part of this growth was associated to industrial expansion stemming from regional trade opportunities and located mostly in Phnom Penh. Therefore, the next 5 to 10 years will be characterized by an increasing demand for infrastructure in this area.

Since the mid-1990s, the garment industry recorded a dramatic growth rate, creating employment for tens of thousands of workers, many of whom come from the rural areas. Industrial sector growth provides income generating opportunities and the resources to fund swifter improvements in human standards of living.

The electric sales in 1996 reached 99.01 GWh for the residential sector in Phnom Penh, and in 2001 reached to 196.8GWh. The energy sale increased because of a reduction in system losses, renovation of the selling and management system, rapid growth of customers, etc. The average annual growth rate of energy sale was 29%; the average annual growth rate of customers was 10%; the average annual growth rate of energy consumption per household per month was 16%; and electrified households increased from 35% to 65% in the period of years 1991-2001. Table 3.6 presents the household electricity consumption in Phnom Penh in the period of years 1991-2001.

Table 3.6: Household Electricity Consumption in Phnom Penh, 1991-2001

Year	Energy Sales [GWh]	Growth Rate [%]	No. of Customers [HH]	Growth Rate [%]	Energy per HH [kWh/M]	Growth Rate [%]	No. of HH [HH]	El-HH [%]
1991	14.81	-	39,600	-	31.16	-	111,889	35
1992	28.50	92	53,740	36	44.19	42	119,864	45
1993	32.59	14	55,400	3	49.02	11	121,134	46
1994	42.16	29	59,860	8	58.69	20	136,800	44
1995	55.00	30	65,626	10	69.84	19	139,735	47
1996	99.01	80	89,200	36	92.50	32	150,280	59
1997	132.50	34	93,766	5	117.76	27	168,200	56
1998	152.70	15	98,857	5	128.72	9	173,678	57
1999	165.30	8	104,257	5	132.13	3	174,000	60
2000	184.00	11	109,538	5	139.98	6	174,859	63
2001	196.80	7	114,203	4	143.60	3	175,400	65

Source: Compiled from other Sources, MIME and EDC's Report (1991-2001)

3.6 Electricity Charge

The existing electricity charge of EDC varies depending on the customer groups. The payment is made in local currency (Riel) and US Dollar, by direct payment to EDC and through the regional electricity wholesalers. The tariff of 350 Riel/kWh was charged to some types of the Residential sector, Industrial sector, Public lighting, and some types of the Commercial sector. Some areas of the residential sector, such as house leasing to foreigners, some kind of the commercial and services sector (non government offices) the charge rate is 0.21 US$/kWh, and this rate was charged to some areas of the commercial sector, such as some hotels/guesthouses, and embassies. Table 3.7 shows the average old tariff.

Table 3.7: The Average Old Tariff for Customer Groups in Phnom Penh, [US Cent/kWh]

Year	1995	1996	1997	1998
Residential Sector	14.58	14.44	13.39	12.19
Industrial Sector	13.83	12.96	11.21	9.21
Commercial & Service Sector	16.70	14.09	13.00	11.89
Public Lighting	13.83	12.96	11.21	9.21
Average Annual Tariff	14.74	13.61	12.20	10.63

Source: EDC's Report (1998)

In 2001, to improve the financial performance of the EDC, the Board implemented the new tariff structure, which recognized the need for the electrification of lower income group, as shown in table 3.8.

Table 3.8: The New Tariff for Customer Groups in Phnom Penh, [Riel/kWh]

Customer Groups		New Price, [Riel/kWh]
Residential Sector	≤ 50 kWh/M 51 – 100 kWh/M 100 kWh/M ≤	350 550 650
Public Sector		700
Non government offices, Embassies, and House leasing to foreigners		800
Commercial Offices, Hotels/Guesthouses, Private Banks, Night Clubs…	Small Business Medium Business Large Business Use on Medium Voltage	650 600 500 480
Industrial Sector	Small Industry Medium Industry Large Industry Use on Medium Voltage	600 550 500 480

Source: EDC's Report (2001)

CHAPTER 4

OVERALL METHODOLOGIES

4.1 General

In this study, the analysis and forecasting of electricity demand covered only the residential sector in Phnom Penh city. Final electricity demand is simulated separately for each household income level on the basis of common macroeconomic and demographic projections.

The electricity demand in the residential sector can be estimated by using the end use model. This model needs detailed data, such as the number of electric devices, hours of usage, capacity, etc. Since such data are not available, a field survey of energy consumption in the residential sector needs to be conducted.

The political and economic changes in Cambodia have begun not long ago. Therefore, it is too early to say what the future shape of economy will be like, or how soon there will be noticeable results. The current uncertainties and critical situation make it extremely difficult to estimate forecasts. Therefore, scenario analyses are the only reasonable approach. Different assumptions on the results of economic and social reforms and other factors will deeply affect the changes within the energy sector.

4.2 Methodology

In this study, two case studies; namely, the base case and the energy efficient appliances case are used to analyze the household electricity demand projection.

The base case does not include the application of efficiency improvement of electric appliances; it relies on baseline projections of economic structure and growth (i.e. macroeconomic) to project demand for energy services. Three alternative macroeconomic scenarios are based on the national economic depend on the annual Gross Domestic Product (GDP) growth rate at 3%, 5.5%, and 8%. This allows us to perform sensitivity analyses on the socio-economic parameters, which can have a factor that influences energy demand.

The inefficient fluorescent lamps (conventional ballast and fluorescent lamp) are used in the residential sector in Phnom Penh. The energy efficient lighting equipments and refrigerators are introduced in the energy efficient appliances case to examine the hypothetical saving that could be achieved if all systems were replaced with more efficient ones. To achieve the analysis of the energy efficiency case, suppose that if the policy options of Government forces people to replace the inefficient appliances after the base year until the forecasted target year.

4.3 Model Development

Electricity demand forecasting can be determined on the basis of interview on the electrical equipment of households. The methodology used to forecast household electricity demand is the *End-Use Model*. The end-use model makes projections for each important end-use, using as input variables information on the level of energy service required and the technical efficiency needed. Figure 4.1 illustrates the end-use model for forecasting electricity demand in the residential sector in this study.

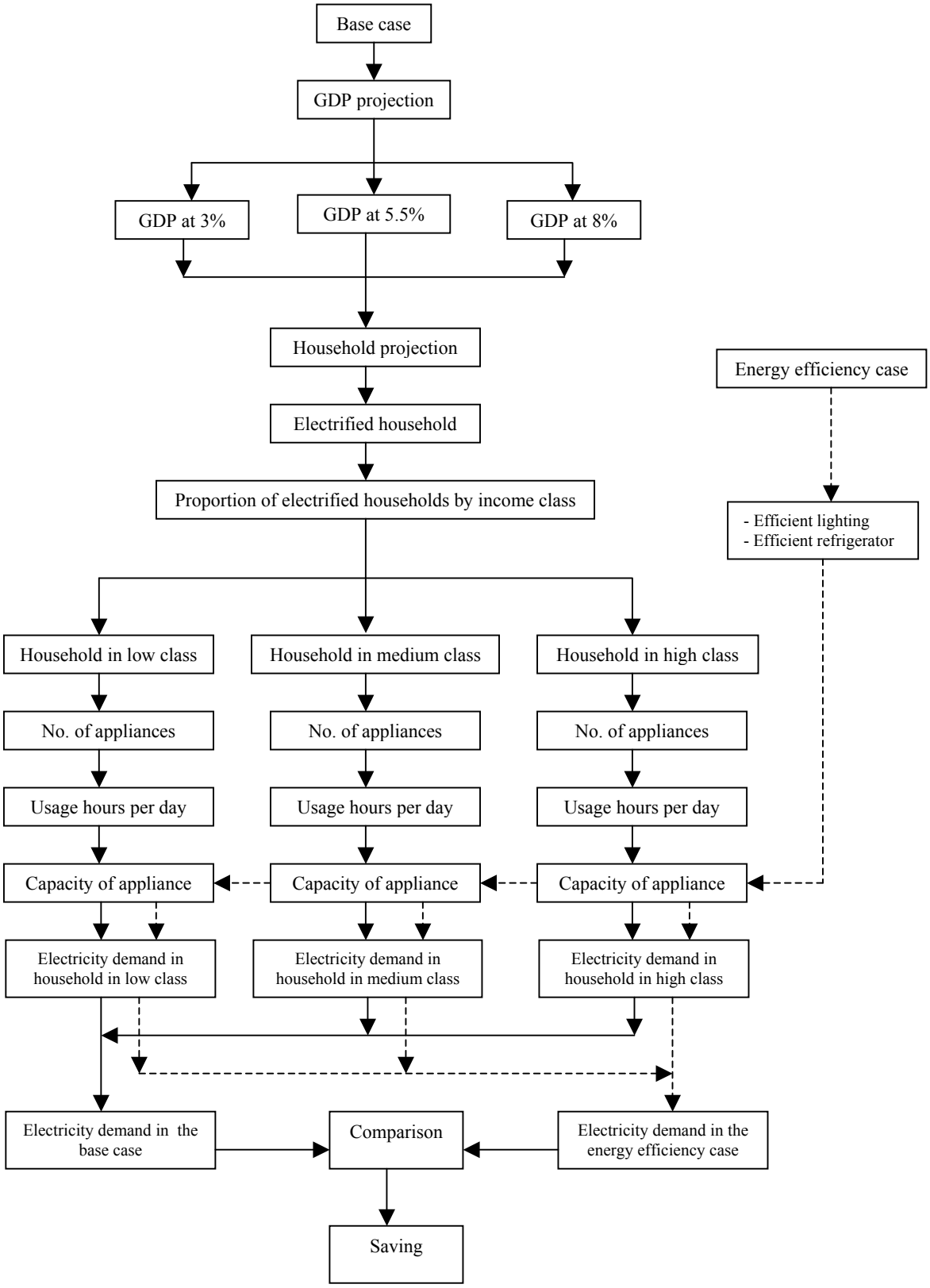

Figure 4.1: End-use model for household electricity demand forecasting.

4.4 Gross Domestic Product (GDP) Projection in Cambodia

In this study, the Gross Domestic Product (GDP) projection is depended on the statistical data from the Ministry of Planning (MOP). This GDP will be projected by the three cases of annual growth rate of GDP at 3%, 5.5%, and 8%. Table 4.1 presents the GDP projection from 2002 to 2012. The equation used for the Gross Domestic Product (GDP) projection, can be written as follows:

$$GDP_t = GDP_0 \times (1 + GDP\%)^t \qquad (4.1)$$

Where: GDP_t – Gross Domestic Product at year t=1…n, [Billion Riels]

GDP_0 – Gross Domestic Product at the base year, [Billion Riels]

GDP% – The Average Annual Growth Rate of GDP, [%]

Table 4.1: GDP Projection in Cambodia from 2002 to 2012, [Billion Riels]

Year	GDP at 3%	GDP at 5.5%	GDP at 8%
2002	10,476	10,730	10,985
2003	10,790	11,321	11,863
2004	11,114	11,943	12,813
2005	11,448	12,600	13,838
2006	11,791	13,293	14,945
2007	12,145	14,024	16,140
2008	12,509	14,796	17,431
2009	12,884	15,609	18,826
2010	13,271	16,468	20,332
2011	13,669	17,374	21,958
2012	14,079	18,329	23,715

Source: Compiled from Statistical Data of Ministry of Planning, Year Book 2001

4.5 Number of Households Projection

The number of population projection in Phnom Penh, which was projected by the Ministry of Planning (MOP) and National Institute of Statistics (NIS) covers up to the year 2021. However, the study period of this study covers up to the year 2012. But the number of households was not projected. Due to the statistical data of the number of population and the number of households was a similar linear function. Therefore, the number of household projection can be a function of population as follows:

$$HHNot = A + B * PoPt \qquad (4.2)$$

Where: HHNot – Number of households in year t

PoPt – Number of population in year t

A – Constant term for household size

B – Coefficient term for household size

Table 4.2 presents the constant term for household size, coefficient term for household size, and the correlation coefficient (R^2) of equation (4.2).

Table 4.2: Constant and Coefficient for Equation (4.2)

Item	A	B	R^2
Coefficient	-5257.337	0.184	0.970

Source: Computed from Statistical Data by using SPSS.

The correlation coefficient (R^2) of equation (4.2) is 0.970. Using a statistical tool called the F-test tests the significance of R^2. With a confidence level of 95% it can be concluded that the value of R^2 is significant. Table 4.3 shows the number of household projection in Phnom Penh in the period of years 2002-2012.

Table 4.3: Projection Number of Households in Phnom Penh, 2002-2012

Year	Population, [Person]	Number of Households	Household Size, [Per/HH]
2002	1,234,000	221,799	5.56
2003	1,283,000	230,815	5.56
2004	1,335,000	240,383	5.55
2005	1,387,000	249,951	5.55
2006	1,442,000	260,071	5.54
2007	1,493,000	269,455	5.54
2008	1,546,000	279,207	5.54
2009	1,600,000	289,143	5.53
2010	1,656,000	299,447	5.53
2011	1,714,000	310,119	5.53
2012	1,767,000	319,871	5.52

Source: Compiled from Report 6 “Population Projections 2001-2021”, Year Book 2001

4.6 Proportion of Electrified Households

Regarding to the residential customers in Phnom Penh, the percentage of electrified households was 65% of the total households in 2001. Electricite du Cambodge’s (EDC) power supply planning is aiming for a 95% increase in the residential sector up to year the 2016 in Phnom Penh. Therefore, the annual growth rate of electrified households will be 2%. Table 4.4 shows the number of electrified households in Phnom Penh from 2002 to 2012.

Table 4.4: Number of Electrified Households in Phnom Penh from 2002 to 2012

Year	Total Household	Electrified Household	% Electrified Household
2002	221,799	148,605	67
2003	230,815	159,262	69
2004	240,383	170,672	71
2005	249,951	182,464	73
2006	260,071	195,053	75
2007	269,455	207,480	77
2008	279,207	220,574	79
2009	289,143	234,206	81
2010	299,447	248,541	83
2011	310,119	263,601	85
2012	319,871	278,288	87

Source: Compiled from Table 4.2 and EDC's Power Strategy Report, 2000

The number of electrified households is expected to grow from 148,605 in 2002 to 278,288 in 2012, while the number of total households grows from 221,799 in 2002 to 319,871 in 2012 or by an average growth rate of 3.73% per year.

4.7 Household Classification

The Planning Department of Phnom Penh and Municipality of Phnom Penh have classified the household income levels in Phnom Penh into three categories based on the US dollar accounting constantly at the 1993 price. Table 4.5 presents the household income levels, namely, low income level (L), medium income level (M), and high income level (H).

Table 4.5: Household Income Level at 1993 Constant Price in Phnom Penh

Currency in Riel	Currency in US$	Exchange Rate in 2002
(L) < 784,200 1,960,500 > (M) > 784,200 (H) > 1,960,500	(L) < 200 500 > (M) > 200 (H) > 500	3,921 Riels/ 1US$

Source: Draft Report of Planning Department of Phnom Penh, 2002

The household income level is a dominant factor of electricity demand in the residential sector since the rates of ownership of electric devices vary by the income levels of household. Using the statistical data of the number of households and the percentage of household income level projects the number of households in each income level.

4.8 Projection of Percentage of Household Income Level

The percentage of number of households in each income level is estimated by using

the statistical data of the percentage of households in each income level. The percentages of number of households in each income level are projected as a function of GDP.

$$PIncL_{t,i} = A_i + B_i * GDP_t \qquad (4.3)$$

Where: $PIncL_{t,i}$ – Percentage of number of households in the income level i in year t,

GDP_t – Gross domestic products in year t,

A_i – Constant term for income level i,

B_i – Coefficient term for income level i, and

i – Income level 1, 2, and 3.

Table 4.6: Constants and Coefficients for Equation (4.3)

Income Level	A	B	R^2
1 – Low	44.376	$- 4.60 \times 10^{-4}$	0.969
2 – Medium	37.461	3.456×10^{-4}	0.971
3 – High	18.164	1.149×10^{-5}	0.962

Source: Computed from Statistical Data by using SPSS.

The number of electrified households and the percentage of household income levels in each case of GDP growth rate are shown in tables: 4.7, 4.8, and 4.9. It is estimated that the proportion of households in the low income level will gradually decrease and shift to the medium and high levels.

Table 4.7: Percentage and Number of Electrified Households in the Case of GDP at 3%

Year	Low Income		Medium Income		High Income	
	Percentage	No. of HH	Percentage	No. of HH	Percentage	No. of HH
2002	39.56	58,788	41.08	61,047	19.36	28,770
2003	39.41	62,765	41.19	65,600	19.40	30,897
2004	39.26	67,006	41.30	70,488	19.44	33,178
2005	39.11	71,362	41.42	75,577	19.47	35,525
2006	38.95	75,973	41.54	81,025	19.51	38,055
2007	38.79	80,481	41.66	86,436	19.55	40,563
2008	38.62	85,186	41.78	92,156	19.60	43,232
2009	38.45	90,052	41.91	98,156	19.64	45,998
2010	38.27	95,117	42.05	104,511	19.68	48,913
2011	38.09	100,406	42.19	111,213	19.72	51,982
2012	37.90	105,471	42.33	117,799	19.77	55,018

Source: Compiled from Statistical Data of Planning Department of Phnom Penh, 2002

Table 4.8: Percentage and Number of Electrified Households in the Case of GDP at 5.5%

Year	Low Income		Medium Income		High Income	
	Percentage	No. of HH	Percentage	No. of HH	Percentage	No. of HH
2002	39.44	58,610	41.17	61,181	19.39	28,814
2003	39.17	62,383	41.37	65,887	19.46	30,992
2004	38.88	66,357	4159	70,983	19.53	33,332
2005	38.58	70,395	41.82	76,306	19.60	35,763
2006	38.26	74,627	42.06	82,039	19.68	38,387
2007	37.92	78,676	42.31	87,785	19.77	41,019
2008	37.57	82,870	42.57	93,898	19.86	43,806
2009	37.20	87,125	42.85	100,357	19.95	46,724
2010	36.80	91,463	43.15	107,245	20.05	49,833
2011	36.38	95,898	43.47	114,587	20.15	53,116
2012	35.94	100,017	43.80	121,890	20.26	56,381

Source: Compiled from Statistical Data of Planning Department of Phnom Penh, 2002

Table 4.9: Percentage and Number of Electrified Households in the Case of GDP at 8%

Year	Low Income		Medium Income		High Income	
	Percentage	No. of HH	Percentage	No. of HH	Percentage	No. of HH
2002	39.32	58,431	41.26	61,314	19.42	28,860
2003	38.92	61,985	41.56	66,189	19.52	31,088
2004	38.48	65,675	41.89	71,495	19.63	33,502
2005	38.01	69,355	42.24	77,073	19.75	36,036
2006	37.50	73,145	42.63	83,151	19.87	38,757
2007	36.95	76,664	43.04	89,299	20.01	41,517
2008	36.36	80,201	43.48	95,906	20.16	44,467
2009	35.72	83,658	43.96	102,957	20.32	47,591
2010	35.02	87,039	44.49	110,576	20.49	50,926
2011	34.28	90,362	45.04	118,726	20.68	54,513
2012	33.47	93,143	45.65	127,038	20.88	58,107

Source: Compiled from Statistical Data of Planning Department of Phnom Penh, 2002

4.9 Average Number of Electric Appliances per Household

The average number of electric appliances used in each household income level is a parameter that can be used to estimate the household electricity consumption. The average number of electric appliances can be estimated by an equation as follows:

$$APNoi,j = \frac{TAPNoi,j}{TNHHi} \qquad (4.4)$$

Where: APNoi;j – Average number of electric appliance j kind in household income level i, [Unit/HH]

TAPNoi;j – Total number of electric appliance j kind in household income level i, [Unit]

TNHHj – Total number of households in household income level i, [HH]

The average number of electric appliances is adopted from the field survey of electricity consumption in the residential sector. These parameters are classified on the basis of income levels. Table 4.10 shows the average number of electric appliances per household by income class.

Table 4.10: Average Number of Electric Appliances per Household by Income Level

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	0.840	0.561	0.424
Fluorescent (20 W)	3.211	7.494	11.376
Fluorescent (32 W)	-	0.244	1.729
Fluorescent (40 W)	0.411	1.472	2.847
Incandescent (5 W)	1.149	1.350	0.459
Incandescent (25 W)	-	0.522	3.824
Compact Fluorescent (9 W)	0.234	1.178	3.000
Radio/Tape/VCD/CD-player	0.954	1.117	1.424
Television	0.891	1.033	1.459
Electric Fan	1.124	3.133	4.035
Air-conditioner	-	0.130	2.152
Refrigerator	0.090	0.585	1.181
Iron	0.731	1.000	1.000
Rice Cooker	0.063	0.428	0.459
Electric Stove	-	0.278	0.341
Electric Pot	0.166	0.606	0.741
Microwave	-	-	0.082
Vacuum	-	-	0.259
Aspirator	-	0.100	1.024
Electric Pump	0.063	0.083	0.188
Water Heater	-	-	0.812
Washing Machine	0.052	0.540	0.715
Computer	0.029	0.178	0.482
Other	0.531	0.622	0.813

Source: Results from Actual Data Analysis, (2002).

4.10 Average Usage Hours per Electric Appliance

The average of usage hours per electric appliance is a parameter to be used to estimate the household electricity consumption. To estimate this parameter we can use the equation:

$$AUHi;j = \frac{TUHi;j}{TAPNoi;j} \qquad (4.5)$$

Where: AUHi,j – Average usage hours per electric appliance j kind in household income level i, [h/Unit]

TUHi;j – Total usage hours of electric appliances j kind in household income level i, [h]

TAPNoi;j – Total number of electric appliances j kind in household income level i, [Unit]

The average usage hours per day of each kind of electric appliance are classified on the basis of income levels. Table 4.11 presents the average usage hour per day of electric appliances by income class.

Table 4.11: Average Usage Hours per Day of Electric Appliances by Income Level, [Hour]

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	3.833	4.713	4.261
Fluorescent (20 W)	3.108	2.790	2.518
Fluorescent (32 W)	-	1.273	2.014
Fluorescent (40 W)	2.143	3.435	2.079
Incandescent (5 W)	7.925	8.319	8.205
Incandescent (25 W)	-	1.000	1.000
Compact Fluorescent (9 W)	7.624	7.991	8.035
Radio/Tape/VCD/CD-player	5.496	5.315	5.583
Television	5.644	5.738	5.608
Electric Fan	5.272	5.195	5.755
Air-conditioner	-	4.000	5.693
Refrigerator	12	12.000	12.000
Iron	0.251	0.282	0.287
Rice Cooker	0.603	0.720	0.703
Electric Stove	-	0.901	0.989
Electric Pot	0.402	0.527	0.495
Microwave	-	-	0.322
Vacuum	-	-	0.281
Aspirator	-	1.000	0.960
Electric Pump	0.255	0.250	0.250
Water Heater	-	-	0.527
Washing Machine	0.250	0.285	0.277
Computer	1.600	1.906	2.122
Other	0.430	0.500	0.642

Source: Results from Actual Data Analysis, (2002).

4.11 Average Capacity per Electric Appliance

The average capacity per electric appliance is estimated by two ways. First can be estimated by a unit group. Second we estimate in a combined group. In this study, the

combined group of electric appliances such as electric fan, TV, radio/CD/VCD/tape-player, air conditioner, refrigerator, and other electric devices. Table 4.12 presents the average capacity of electric appliances per household by income class. The equation used for estimation of the capacity per electric appliance is as follows:

$$ACAPi,j = \frac{\sum_{j=1}^{n} CAPi,j * APNoi,j}{TAPNoi,j} \quad (4.6)$$

Where: ACAPi,j – Average capacity per electric appliance j kind in household income level i, [W/Unit]

CAPi,j – Capacity of electric appliances j kind in household income level i, [W]

APNoi;j – Number of electric appliances j kind in household income level i, [Unit]

TAPNoi;j – Total number of electric appliances j kind in household income level i, [Unit]

Table 4.12: Average Capacity of Electric Appliances per Household by Income Level, [W]

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	16.000	16.000	16.000
Fluorescent (20 W)	28.000	28.000	28.000
Fluorescent (32 W)	-	39.000	39.000
Fluorescent (40 W)	47.000	47.000	47.000
Incandescent (5 W)	5.000	5.000	5.000
Incandescent (25 W)	-	25.000	25.000
Compact Fluorescent (9 W)	9.000	9.000	9.000
Radio/Tape/VCD/CD-player	11.835	21.169	26.942
Television	51.026	53.871	56.048
Electric Fan	45.930	50.780	50.933
Air-conditioner	-	508.000	553.314
Refrigerator	68.700	69.400	70.790
Iron	1000.000	1000.000	1000.000
Rice Cooker	600.000	600.000	600.000
Electric Stove	-	1000.000	1000.000
Electric Pot	600.000	600.000	600.000
Microwave	-	-	700.000
Vacuum	-	-	1000.000
Aspirator	-	45.000	45.000
Electric Pump	368.000	368.000	368.000
Water Heater	-	-	1200.000
Washing Machine	300.000	270.000	275.000
Computer	300.000	300.000	300.000
Other	142.656	161.672	170.624

Source: Results from Actual Data Analysis, (2002).

4.12 Conventional Lighting Equipment

Inefficient lighting is low efficient lighting equipment such as inefficient fluorescent lamp and high loss ballast. Table 4.13 presents the low efficient lighting equipment.

Table 4.13: Conventional Lighting Equipments

Capacity Bulb [W]	Ballast Loss [W]	Total Capacity [W/Lamp]
10	6	16
20	8	28
32	7	39
40	7	47

Source: Field Work Survey 2002 and Official Journal of the European Communities 2000

4.13 High Efficient Lighting Equipment

Efficient lighting is high efficient lighting equipment such as efficient fluorescent lamp, and electronic ballast. Table 4.14 presents the high efficient lighting equipment.

Table 4.14: High Efficiency Lighting Equipments

Capacity Bulb [W]	Electronic Ballast [W]	Total Capacity [W/Lamp]
10	3	13
18	3	21
32	3	35
36	3	39

Source: Department of Energy Development and Promotion, 1999, Thailand.

4.14 Refrigerator Classification

According to the actual data from the survey consisting of more than 440 observations on individual households and the primary source of information on refrigerators used in the residential sector in Phnom Penh is similar to the efficiency label program of the Demand Side Management (DSM) program of the Department of Energy Development (EDD) in 2000, Cambodia. The characteristic refrigerators' efficiency label has been estimated on the basis of experience from the other companies produced refrigerators and the neighboring countries, as the database of the refrigerators' efficiency standard regulated by the Electricity Generating Authority of Thailand (EGAT) in 1996. Table 4.15 shows the characteristics of refrigerators used in each household income level in Phnom Penh.

Table 4.15 Characteristics of Refrigerators

Income Level	Volume [ft^3]	Power [W]	Consumption [kWh/year]
Low	4.6 – 5.2	68 – 65	298 – 285
Medium	5.9 – 6.3	100 – 65	438 – 285
High	6.4 – 8.8	100 – 62	438 – 272

Source: Field Work Survey 2002 and Energy Development Department 2000, Cambodia

4.15 Air-Conditioner Classification

Air-Conditioner use in the residential sector in Phnom Penh is similar to the efficiency label program of Demand Side Management (DSM) program of EDD in 2000. The characteristic of air-conditioner has been assumed as in the case of refrigerators' characteristics. According to the results from the actual data, they show that air-conditioner use in each household income level to be mostly at the efficiency standard. Table 4.16 shows the characteristic of air-conditioner use in medium and high income levels in Phnom Penh.

Table 4.16 Characteristics of Air-Conditioners

Capacity [Btu/h]	Efficiency Level		
	1	2	3
	Electricity Power [W]		
9,000	400	380	370
12,000	800	760	740
13,000	1,200	1,140	1,110
15,000	1,600	1,520	1,480

Source: Field Work Survey 2002 and Energy Development Department 2000, Cambodia

4.16 Other Electric Appliances

The other electric appliance uses in each household income level in Phnom Penh are shown in table 4.17.

Table 4.17 Characteristics of Other Electric Appliances

Item	Capacity	Electricity Power [W]		
Hand Phone Charger	1 unit	4	5.5	-
Battery Charger	2-4 units	3	5.5	-
Blender	1-3 liters	400	350	300
Bread Heater	4 slices	650	700	750
Coffee Maker	7 cups	750	800	850
Suki Pot	N/A	1,000	1,200	1,300
Hair Dryer	N/A	300	400	500
Shaver	N/A	20	30	40
Sewing Machine	N/A	200	250	300
Drill Machine	N/A	500	650	740
Soldering Iron	N/A	80	100	150
Video Game	N/A	50	100	150
Music Instrument	N/A	150	200	300
Christmas Lighting	50-150 bulbs	50	100	150
Candle lighting	1-3 bulbs	2	4	6
Printer	N/A	300	500	800
Copy Machine	N/A	1,500	2,000	2,500

Source: Field Work Survey 2002 and Energy Development Department 2000, Cambodia

The other electric appliances are not permanently used in each household income level. They were used for only the need or entertaining day, and exclude hand phone, battery charger and hair dryer.

4.17 Case Study Approach

The case of annual GDP growth rate at 3% tries to express a future development that is characterized by an unfavorable economic and social performance of the country. The reasons for such an unsatisfactory development could be of political or economical nature and it could also be caused, at least partly, by natural disasters and the like. As a consequence of such a development, the growth rate of the domestic economic environment would be lower than at present and it is expected in future that the percentage of household income level would be slightly flexible.

The case of annual GDP growth rate at 5.5% expects a future economic activity that would be the same as the economic development at present and the percentage of household income level would be normally flexible over the next decade.

The case of annual GDP growth rate at 8% reflects a favorable future development of the Cambodian economy and the standard of living of its population. Its underlying

assumptions are a stable political situation and prudent economic policy. In this case, the growth rate of the economy expressed by GDP would be above present expectations, consequently income of the population would rise and more money would be available for private consumer spending. Therefore, the percentage of household income level, in this case, would be more flexible than both the cases of GDP growth at 3% and 5.5%.

The energy efficiency (EE) case tries to examine future electricity demand in the residential sector due to the high efficiency technologies of electric appliances being introduced. In this case, it assumes major government intervention in more rational energy planning and policy to promote energy efficiency and energy conservation, to propose replacement of inefficient lighting and refrigerators by efficient lighting and refrigerators. The inefficient lighting will be replaced by the efficient lighting in all households after the base year, and new households will use efficient refrigerators after the base year, otherwise old households will replace inefficient refrigerators by efficient refrigerators by the target year of projection.

4.18 Electricity Demand Projection

The electricity demand for the residential sector is a function of the total number of customers (electrified households), average number of appliances, average usage hours of appliances, and average capacity of appliances. Therefore, using the following equation projects the electricity demand:

$$ENDt = \sum_{i=1}^{m}\sum_{j=1}^{n} [ELHHNot,i * APNot,i,j * AUHt,i,j * ACAPt,i,j * 365days/1000] \quad (4.7)$$

Where: ENDt – Electricity demand in year t, (kWh)

APNot,i,j – Average number of appliances type j owned by household income level i in year t, (Unit/HH)

AUHt,i,j – Average usage hours of appliances type j owned by household income level i in year t, (h/day)

ACAPt,i,j – Average capacity of appliances type j owned by household income level i in year t, (W/Unit)

ELHHNot,i – Number of electrified households in income level i in year t, (HH)

$$ELHHNot,i = TNHHt * PELt * PincLt,i \quad (4.8)$$

Where: $TNHH_t$ – Number of households in year t, [HH]

PEL_t – Percentage of electrified households in year t, [%]

$PIncL_{t;j}$ – Percentage of household income level i in year t, [%]

In the equation (4.7), the number of electrified households, the average number of appliances, the average usage hours of appliances, and the average capacity of appliances are the determinants of household electricity demand. Based on the model structure and formula, many parameters are needed for the electricity demand projection. The detailed description and methodologies used for the estimation of these parameters are described in the above subtitles.

According to the rates of ownership of electric appliances varying by the income levels of household, two alternative analysis methods, aggregate and disaggregate version, are available to us. The aggregate version considers the electricity consumption by types of appliance for all households. The disaggregate version makes a distinction between the households by income level. The electricity price and electric appliance price do not appeared in the model formula, even though they are a dominant factor of electricity demand in the residential sector. Otherwise, they would be shown through the total electricity demand, which is derived from average share of households owning each type of electric appliance, and the relative unit consumption evolved according to the household income levels.

CHAPTER 5

HOUSEHOLD ELECTRICITY USE ANALYSIS

5.1 General

Phnom Penh is the Capital City of the Kingdom of Cambodia. This city is the center of the commercial, economic, political, and cultural activities in Cambodia. The city covers a land area of 375 km^2 and is divided into seven districts with a total population of 986,750 people composed 175,400 households and the household size was 5.79 Per/HH. The population growth rate was estimated by the National Institute of Statistics of Cambodia to be decreased from 4.2% to 2.45% in 2002 and 2021, respectively.

Through the field work survey it was seen that in Phnom Penh city, as in Cambodia and also the same as in Thailand, the climate is the same, hot in the summer season and cold in the winter season. When the summer arrives the consumers will use a lot of electric power because at that time they use air-conditioners or electric fans for about 10 hours per day, while they cut down usage hours for other appliances. For the winter season the consumers will cut down usage hours of appliances, which means they use air-conditioners or electric fans only 2 or 3 hours per day, 1 hour at noon and 2 hours at night before going to bed for comfort in their rooms. Other electric appliances such as lighting, iron, washing machine, TV, radio/VCD/tape-player…etc are used the same for all seasons in the year.

5.2 Actual Data Analysis

The parameters related to the household electricity consumption were estimated by using the methodologies in Chapter 4. The results of each parameter were found out from the actual data. In this study, the household electricity consumption can be projected by using these results.

There are 2,518 people living in 440 households, and the average number of people per household is 5.72 Per/HH. The minimum household size is 2 Per/HH and the maximum household size is 15 Per/HH. In all household income levels, the numbers of 440 households were occupied in 356 flat houses, 47 wooden houses, and 37 villas. The results from analysis of actual data were separated into three household income levels that

are shown in the following.

For the households in the low income level there are 922 people living in 175 households. The average number of people per household is 5.27 Per/HH. There are 156 flat houses, and 19 wooden houses. The average electricity consumption per household per day is 1,402 Wh, per month it is 42 kWh, and per capita per month is 8 kWh. The amount of 1,237 W is the average number of installed electrical power per household, and the average installed electrical power per capita is 235 W.

1,062 people are living in 180 households that are in the medium income level. The average number of people per household is 5.90 Per/HH. These households are occupied in 149 flat houses, 22 wooden houses, and 9 villas. The average electricity consumption per household per day is 4,169 Wh, per month it is 125 kWh, and per capita per month is 21 kWh. The average installed electrical power per household is 2,906 W, and 493 W is the average installed electrical power per capita.

There are 85 households in the high income level combined from 534 people that are distributed in 51 flat houses, 6 wooden houses, and 28 villas. The average number of people per household is 6.28 Per/HH. The amount of 13,369 Wh is the average energy consumption per household per day, 401 kWh is the average electricity consumption per household per month, and per capita per month is 64 kWh. The average installed electrical power per household is 6,198 W, and 987 W is the average installed electrical power per capita.

5.3 Household Electricity Use Analysis

The characteristic of the electricity use in the residential sector is specified for the time period of the individual electric appliances put into operation according to the specific operation patterns of households in each income level.

Households in all income levels use lighting at night time, the duration of operation is from 18:00 to 23:00 hour for fluorescent lamps of 10W, 20W, and 40W. The fluorescent lamps of 32W and incandescent lamps or spotlight of 25W are used for outdoor lighting

and decoration lighting at the relaxing time from 19:00 to 20:00 hour in some households in the medium and high income levels. The incandescent lamp of 5W or compact fluorescent lamp of 9W are used for midnight lighting from 24:00 to 6:00 hour; some households use in the toilet or bathroom and the usage hour could be estimated at 4 hours per day, and some household use for outdoor or garden lighting from 18:00 to 6:00 hour.

TV/Radio/Tape/VCD players are used for entertainment time for all household income levels. The period of usage hours are from 12:00 to 13:00 in the day time and 18:00 to 23:00 hour in the evening.

Air-conditioners are used for cooling condition in households of a high income level and some households in the medium income level. The periods of usage hours are two times a day: 12:00 to 14:00 hour and 23:00 to 3:00 hour.

Electric fans are used as the principal appliances for cooling condition for households in all income levels, even though air-conditioners are used by households with high income. The periods of usage hours are 12:00 to 14:00 hour and 23:00 to 6:00 hour, but some households use from 18:00 to 23:00 hour.

Refrigerators are used for freezing food and beverages, and making ice. According to the high efficient end-use technologies, the process of the refrigerator is not operated in the full period of hours, even though the refrigerator is plugged in 24 hours a day. In fact, the operation hours of refrigerators could be estimated at 12 hours per day.

At present, electric rice cookers and pots are high efficient appliances. Households in all income levels use rice cookers at the cooking times, around 6:00 or 7:00 hour, 10:00 or 11:00 hour and 16:00 or 17:00 hour. The usage time is 15 to 20 minutes per time or 30 to 40 minutes per day. Electric pots are used for the same time of using rice cookers or at any time of the day, especially before breakfast, lunch, and dinner times with usage times of 30 to 40 minutes per day. Electric stoves are used by households in the medium and high income levels. The operation hour is the same time of using rice cooker and the usage time could be estimated to be 30 to 50 minutes per day.

Electric irons and washing machines are used at any time in the day. They mostly

use these appliances in the morning from 8:00 to 9:00 hour or in the afternoon from 13:00 to 14:00 hour. Some households use any day in the week, especially on Sunday, which is the day they have free time. These appliances are also high efficiency.

Water heaters are used by households in the high income level. The operation hour is dependent on the time they have a bath, which can be at 6:00, 13:30 and 20:00 hour. The usage hours can be estimated from 30 to 40 minutes per day. Aspirators are used in the bathroom or kitchen, the usage hour is accorded to the time they have a bath or cooking.

Almost all households in the high income level use electric vacuum cleaners for cleaning in their house or car. This appliance is used any time, especially on Sunday. The usage hours are 1 or 2 hours a week.

Electric pumps are still used by households in all income levels, especially for the households that have no access to the city's water supply. There are 42% of households that have access to the city's water supply, and 47% of households have access to water supply from private suppliers. Therefore, 89% of households have access to a water supply. Some households use electric pumps for irrigation of their garden's flowers, such as households in the high income level. The operation hour is at 7:00 or 8:00 hour in the morning and 17:00 or 18:00 hour in the afternoon with the usage hours 10 to 20 minutes per day. Some households have no access to a water supply and use an electric pump for water pumping at any time in a day or any day in a week, and the usage hour is 15 to 20 minutes per day.

The usage hours of computers can be estimated from 1 to 3 hours per day. They use computers for preparing homework or documents at 20:00 to 22:00 hour.

Microwaves are used by some households in the high income level. They use microwaves for warming some food before eating, the usage hour is 10 to 20 minutes per day. But some households use these in an entertaining day of the weekend.

Other electric appliances such as hand phone and battery chargers, sewing machine, hair dryer, coffee maker, suki pot, and blender…etc can be used for the need or the entertaining time. The usage hour is at least 30 minutes to 5 hours. The characteristic and classification of other electric appliances are shown in table 4.14.

All electric appliances are not used at the same time, even though there are a lot of them. For example, a lamp was turned on for only the time they stayed at that place, or decoration lighting was turned on in the sitting room at the same time they turn off the principle lamp.

The result of a field survey conducted for the study shows that the incandescent lamp with high capacity: 40W, 60W, 75W, 100W…are not used in the residential sector, because people have already known that the capacity of these lamp is two or three times more than a fluorescent lamp. But people are still using inefficient lighting equipments, because the price of efficient lighting equipments is 20% higher than the inefficient equipments and there is the lack of these equipments in the markets.

5.4 Household Electricity Use in the Low Income Level

The results of the low income level were analyzed from actual data. Table 5.1 presents the estimation of the electricity consumption of each type of appliance use in the households in the low income level. The average number of fluorescent lamps of 20 W is 3.211 Unit/HH, consumed energy 279.434 Wh/day, and higher than other types of appliance, even though the capacity of electric irons is 1,000 W/Unit, which is high, but the number and the usage hours are low. It means that the lighting to be used by households in the low income level is important. Otherwise, the electric appliances that are not important, of high capacity, and high price such as air-conditioners, water heaters, electric stoves, microwaves, vacuums, aspirators, and incandescent lamps with high capacity, compact fluorescent lamps of 32 W were not used. All households have electric lighting, 95% have Radio/Tape/Video/CD-player, 89% have TV, 82% have electric fan, 73% have iron, 53% have other electric appliances, 17% have electric pot, 8% have refrigerator, 6% have rice cooker, 6% have electric pump, 5% have washing machine, and 3% of all households have computer. Table 4.10 shows the average number of electric appliances per household by income level.

Table 5.1: Electricity Consumption by Type of Appliance in the Low Income Level

Electric Appliances	Average Energy, [Wh/HH-Day]
Lighting	433.931
Electric Fan	272.168
Television	256.600
Electric Iron	183.481
Refrigerator	74.169
Radio/Tape/VCD/CD-player	62.053
Electric Pot	40.039
Other Appliances	32.573
Rice Cooker	22.793
Computer	13.920
Electric Pump	5.912
Washing Machine	3.900
Total Average Energy	1,401.567

Source: Compiled Real Data from Field Work Survey

As in the Table 5.1, the electricity consumption in households in the low income level is mainly used in lighting, followed by electric fan, television, electric iron, refrigerator, radio/tape/VCD/CD-player, electric pot, other appliances, rice cooker, computer, electric pump, and clothing washing machine, respectively.

5.5 Household Electricity Use in the Medium Income Level

The results of the medium income level were analyzed from actual data. Table 5.2 presents the estimation of the electricity consumption of each type of appliance use in the households in the medium income level. The average number of fluorescent lamps of 20 W is 7.494 Unit/HH and they consume energy at 1031 Wh/day, followed by the energy demand of electric fan, which is 826.492 Wh/day, higher than the other types of appliance, even though the capacity of electric iron and electric stove is 1,000 W/Unit but the usage hours and the numbers are low. It means that the lighting use in households in the medium income level is important, and the electric fan is used as a comfortable appliance for cooling. Otherwise, the electric appliances that are not important, high capacity, and high price such as water heater, microwave, and vacuum were not used. All households have electric lighting, electric fans, Radio/Tape/Video/CD-players, TVs, iron, 72% have other electric appliances, 65% have refrigerator, 60% have electric pot, 58% have washing machine, 43% have rice cooker, 28% have electric stove, 18% have computer, 13% have air-conditioner, 10% have aspirator, and 8% of all households have electric pump (See Table 4.10).

Table 5.2: Electricity Consumption by Type of Appliance in the Medium Income Level

Electric Appliances	Average Energy, [Wh/HH-Day]
Lighting	1,031.420
Electric Fan	826.492
Refrigerator	487.188
Television	319.312
Electric Iron	282.00
Air-Conditioner	264.160
Electric Stove	250.478
Electric Pot	191.617
Rice Cooker	184.896
Radio/Tape/VCD/CD-player	125.667
Computer	101.780
Other Appliances	50.280
Washing Machine	41.553
Electric Pump	7.636
Aspirator	4.500
Total Average Energy	4,168.990

Source: Compiled Real Data from Field Work Survey

As in the Table 5.2, the electricity consumption in households in the medium income level is mainly used in lighting, followed by electric fan, refrigerator, television, electric iron, air-conditioner, electric stove, electric pot, rice cooker, radio/tape/VCD/CD-player, computer, other appliances, clothing washing machine, electric pump, and aspirator, respectively.

5.6 Household Electricity Use in the High Income Level

The results of the high income level were analyzed from actual data. Table 5.3 presents the estimation of the electricity consumption of the each type of appliance use in the households in the high income level. The air-conditioner consumes energy of 6,778.836 Wh/day, followed by the lighting; especially the average number of fluorescent lamps of 20 W is more than the other types of appliance at 11.376 Unit/HH. The electric appliances that consumed high energy are electric fan and then the refrigerator: 1,182.737 Wh/day and 1,003.236 Wh/day, respectively. Even though water heater, electric iron, electric stove, and vacuum are electric appliances that have high capacity: 1,200 W/Unit, and 1,000 W/Unit, respectively, but the number and the usage hours of these appliances are low. It means that the air-conditioner and the lighting are important for use in the households in the high income level; electric fan, and refrigerator are used as a comfortable appliance for cooling. All households have electric lighting, electric fans, air-conditioners,

Radio/Tape/Video/CD-players, TVs, refrigerators, iron, 98% have washing machine, 98% have other electric appliances, 70% have electric pot, 67% have aspirator, 52% have water heater, 46% have rice cooker, 41% have computer, 34% have electric stove, 26% have vacuum, 19% have electric pump, and 8% of all households have microwave (See Table 4.10).

Table 5.3: Electricity Consumption by Type of Appliance in the High Income Level

Electric Appliances	Average Energy, [Wh/HH-Day]
Air-Conditioner	6,778.836
Lighting	1,576.331
Electric Fan	1,182.737
Refrigerator	1,003.236
Water Heater	513.509
Television	458.589
Electric Stove	337.249
Computer	306.841
Electric Iron	287.000
Electric Pot	220.077
Radio/Tape/VCD/CD-player	214.194
Rice Cooker	193.606
Other Appliances	89.057
Vacuum	72.779
Washing Machine	54.465
Aspirator	44.237
Microwave	18.483
Electric Pump	17.296
Total Average Energy	13,368.520

Source: Compiled Real Data from Field Work Survey

As in the Table 5.3, the electricity consumption in households in the high income level is mainly used in air-conditioners, followed by lighting, electric fan, refrigerator, water heater, television, electric stove, computer, electric iron, electric pot, radio/tape/VCD/CD-player, rice cooker, other appliances, vacuum, washing machine, aspirator, microwave, and electric pump.

5.7 Household Electricity Use in the Residential Sector

Table 5.4 and Table 5.5 presents the estimation of household electricity consumption of each type of appliance use by each household income level in the residential sector in Phnom Penh. The major dominant of household electricity consumption is air-conditioners, followed by lighting, electric fan, refrigerator, television,

electric irons, electric stove, water heater, electric pot, computer, radio/tape/VCD/CD-player, rice cooker, other appliances, washing machine, vacuum, aspirator, electric pump, and microwave.

Table 5.4: Household Electricity Consumption by Type of Appliance in the Residential Sector, [Wh/HH-Day]

Appliances	Income Level			Total
	High	Medium	Low	
Air-conditioner	6,779.00	264.00	0.00	7,043.00
Lighting	1,576.00	1,031.00	433.00	3,040.00
Electric Fan	1,183.00	826.00	272.00	2,281.00
Refrigerator	1,003.00	487.00	74.00	1,564.00
Television	459.00	319.00	257.00	1,035.00
Electric Iron	287.00	282.00	183.00	752.00
Electric Stove	337.00	250.00	0.00	587.00
Water Heater	514.00	0.00	0.00	514.00
Electric Pot	220.00	192.00	40.00	452.00
Computer	307.00	102.00	14.00	423.00
Radio/tape/VCD/CD-player	214.00	126.00	62.00	402.00
Rice Cooker	194.00	185.00	23.00	402.00
Other Appliances	89.00	50.00	33.00	172.00
Washing Machine	54.00	42.00	4.00	100.00
Vacuum	73.00	0.00	0.00	73.00
Aspirator	44.00	5.00	0.00	49.00
Electric Pump	17.00	8.00	6.00	31.00
Microwave	18.00	0.00	0.00	18.00
Total electricity consumption	13,368.00	4.169.00	1,401.00	18,938.00

Source: Compiled from Tables 5.1, 5.2, and 5.3

Table 5.5: The Share of Household Electricity Consumption by Type of Appliance in the Residential Sector, [%]

Appliances	Income Level			Total
	High	Medium	Low	
Air-conditioner	50.71	6.33	0.00	37.19
Lighting	11.79	24.73	30.91	16.05
Electric Fan	8.85	19.81	19.41	12.04
Refrigerator	7.50	11.68	5.28	8.26
Television	3.43	7.65	18.34	5.47
Electric Iron	2.15	6.76	13.06	3.97
Electric Stove	2.52	6.00	0.00	3.10
Water Heater	3.85	0.00	0.00	2.71
Electric Pot	1.65	4.61	2.86	2.39
Computer	2.30	2.45	1.00	2.23
Radio/tape/VCD/CD-player	1.60	3.02	4.43	2.12
Rice Cooker	1.45	4.44	1.64	2.12
Other Appliances	0.67	1.20	2.36	0.91
Washing Machine	0.40	1.01	0.29	0.53
Vacuum	0.55	0.00	0.00	0.39
Aspirator	0.33	0.12	0.00	0.26
Electric Pump	0.13	0.19	0.43	0.16
Microwave	0.13	0.00	0.00	0.10
Total	100.00	100.00	100.00	100.00

Source: Compiled from Table 5.4

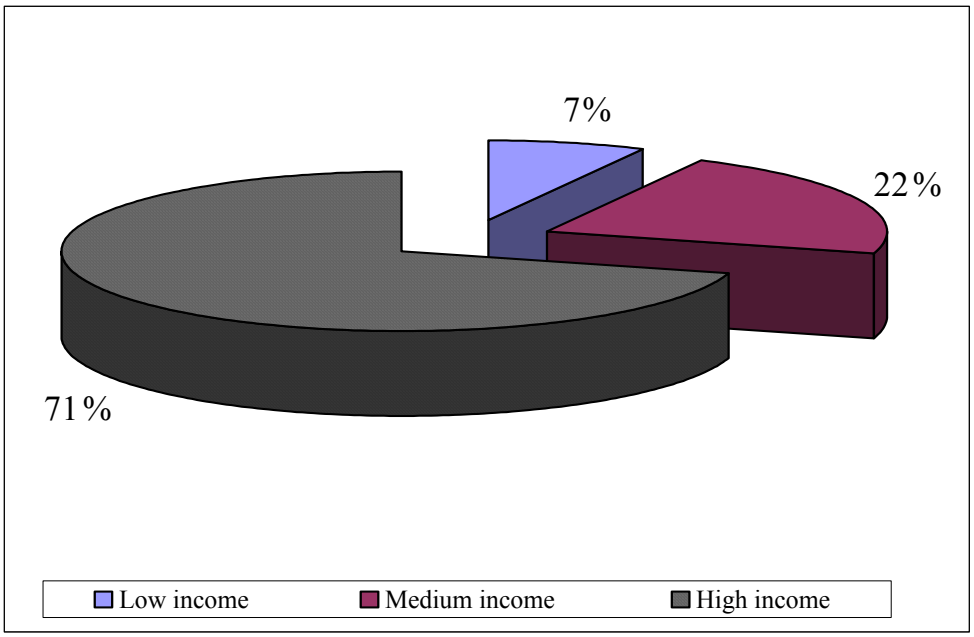

Figure 5.1: Share of Average Electricity Consumption in Each Income Level, [%]

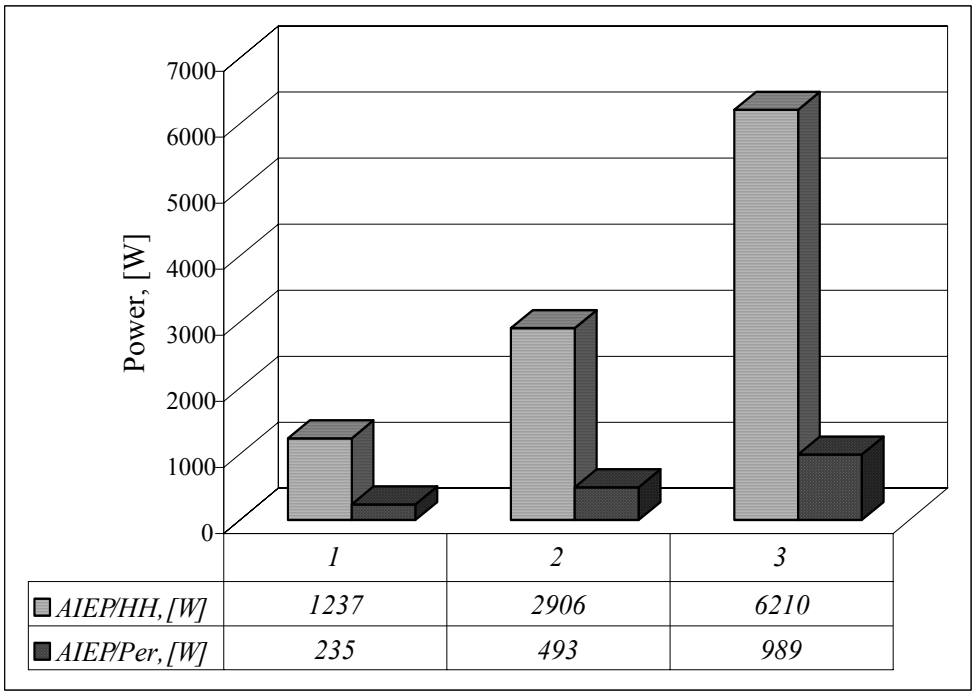

Figure 5.2: Electrical Installed Power per Each Household Income Level and per Capita.

Note: *1* represents the households in the low income level;

2 represents the households in the medium income level; and

3 represents the households in the high income level.

AIEP/HH is the average installed electrical power per household; and

AIEP/Per is the average installed electrical power per capita.

5.8 Conclusion

As in the above results, it can be concluded that the higher electricity demand is in the households in the high income level followed by the medium and low income levels. The stock of appliances and use of these can affect the household energy demand by different household income factors. The figures 5.1 and 5.2 show the different energy demand and electrical installed power in each household income level, respectively.

The above results also show that lighting is the important use of electricity in each household income level in the residential sector in Phnom Penh, while the Radio/Tape/CD-player, TV, electric fan, iron, refrigerator, air-conditioner, and so on are second uses for entertainment and comfort of living. The characteristic of the dwelling were related to the household electricity demand such as villas and some beautiful wooden houses are large houses and belonging to almost all the households in the high income level. Moreover,

the number of people in households in the high income level is also high, so that the need for electricity is high too. Therefore, the electricity consumption in households in the high income level is higher than the other two income levels, even though the number of households in the high income level is small. It means that the households in the high income level use many kinds of electric appliances to be serviced for their entertainment and comfort of living, while the households in the low income level uses the only important electric appliances for their living because of the electricity price and electric appliance price are a barrier to their electricity use.

CHAPTER 6

HOUSEHOLD ELECTRICITY DEMAND FORECASTING

6.1 General

As in the conclusion in chapter 5, the influence of different factors on the electricity demand is modeled given the following: category of household income level, electricity price and other parameters, which influence electricity demand both directly and indirectly: Indirectly through the electricity price and electric appliance price, and directly through the household income level, number of appliances, usage hours, and capacity of appliances.

As regarding in the past trend of the proportion of households in the low income level, this gradually decreased and shifted to the medium and high levels. Moreover, the number of population growth every year causes the number of households to increase. Therefore, improvements in the living standards of the people cause the household electricity demand to increase in the residential sector in Phnom Penh.

In this study, the household electricity demand in the residential sector in Phnom Penh for the next decade in the period 2002-2012 will be projected in the two case studies; namely, the base case and the energy efficiency case are used to analyze the household electricity demand projection.

The base case does not include the implication of efficiency improvement of electric appliances. In this case, the household electricity demand would be considered through the changes of economic growth. The method of the projection was discussed in chapter 4.

In the case of lighting being the main use of electricity in the residential sector in Phnom Penh, and the people are still using the inefficient lighting equipments, the energy efficient lighting equipments and refrigerators are introduced in the energy efficiency case. The method of the projection was discussed in chapter 4. According to the limited time and the scope of study, this case considers only the electricity demand, and the replacement rates of efficient household lighting equipments and refrigerators are omitted.

6.2 Electricity Demand Projection in the Base Case

The results of electricity demand projection by type of appliance and the total electricity demand projection by household income level in the base case of 3% GDP growth, 5.5% GDP growth, and 8% GDP growth are shown in Table 6.1 to Table 6.6, respectively. Table 6.7 shows the total electricity demand in each household income level in the base case. Table 6.8 and the Figure 6.1 show the total electricity demand projection in the base case of each GDP growth.

Table 6.1: Electricity Demand Projection by Type of Appliance in the Base Case of 3% GDP Growth, [GWh]

Appliances	Electricity demand by appliance in selected years					
	2002	2004	2006	2008	2010	2012
Fluorescent (10 W)	2.35	2.70	3.08	3.48	3.92	4.38
Fluorescent (20 W)	27.46	31.61	36.20	41.04	46.35	52.04
Fluorescent (32 W)	1.70	1.96	2.24	2.55	2.89	3.25
Fluorescent (40 W)	9.10	10.50	12.04	13.67	15.47	17.40
Incandescent (5 W)	2.43	2.79	3.18	3.60	4.06	4.55
Incandescent (25 W)	1.29	1.49	1.71	1.95	2.20	2.48
Compact Fluorescent (9 W)	4.51	5.20	5.96	6.77	7.66	8.62
Radio/Tape/VCD/CD-player	6.38	7.34	8.41	9.54	10.77	12.09
Television	17.44	20.04	22.93	25.96	29.28	32.82
Electric Fan	36.68	42.24	48.42	54.93	62.09	69.77
Air-conditioner	77.07	88.89	101.97	115.85	131.10	147.49
Refrigerator	22.98	26.50	30.40	34.52	39.07	43.95
Electric Iron	13.23	15.22	17.41	19.72	22.25	24.95
Rice Cooker	6.64	7.66	8.79	9.98	11.30	12.72
Electric Stove	9.12	10.53	12.09	13.75	15.58	17.54
Electric Pot	7.44	8.57	9.83	11.16	12.63	14.20
Microwave	0.19	0.22	0.26	0.29	0.33	0.37
Vacuum	0.76	0.88	1.01	1.15	1.30	1.46
Aspirator	0.56	0.65	0.75	0.85	0.96	1.08
Electric Pump	0.48	0.55	0.63	0.71	0.81	0.90
Water Heater	5.39	6.22	7.13	8.10	9.17	10.31
Washing Machine	1.58	1.82	2.09	2.38	2.69	3.03
Computer	5.79	6.67	7.66	8.70	9.84	11.07
Other	2.75	3.17	3.63	4.11	4.64	5.20
Total electricity demand	263.35	303.43	347.85	394.76	446.36	501.67

Table 6.2: Total Electricity Demand Projection by Household Income Levels in the Base Case of 3% GDP Growth, [GWh]

Year	Low Income	Medium Income	High Income	Total
2002	30.07	92.89	140.38	263.35
2003	32.11	99.82	150.76	282.69
2004	34.28	107.26	161.89	303.43
2005	36.51	115.00	173.34	324.85
2006	38.86	123.29	185.69	347.85
2007	41.17	131.53	197.93	370.63
2008	43.58	140.23	210.95	394.76
2009	46.07	149.36	224.45	419.88
2010	48.66	159.03	238.67	446.36
2011	51.36	169.23	253.65	474.24
2012	53.95	179.25	268.46	501.67

Table 6.3: Electricity Demand Projection by Type of Appliance in the Base Case of 5.5% GDP Growth, [GWh]

Appliances	Electricity demand by appliance in selected years					
	2002	2004	2006	2008	2010	2012
Fluorescent (10 W)	2.35	2.70	3.08	3.47	3.90	4.36
Fluorescent (20 W)	27.49	31.69	36.38	41.34	46.83	52.75
Fluorescent (32 W)	1.70	1.97	2.27	2.59	2.94	3.33
Fluorescent (40 W)	9.12	10.54	12.14	13.84	15.74	17.81
Incandescent (5 W)	2.43	2.79	3.19	3.60	4.06	4.55
Incandescent (25 W)	1.30	1.50	1.73	1.98	2.25	2.55
Compact Fluorescent (9 W)	4.52	5.22	6.01	6.86	7.80	8.82
Radio/Tape/VCD/CD-player	6.39	7.37	8.45	9.61	10.89	12.26
Television	17.44	20.07	22.98	26.04	29.41	33.01
Electric Fan	36.72	42.39	48.73	55.47	62.95	71.05
Air-conditioner	77.19	89.32	102.89	117.44	133.64	151.25
Refrigerator	23.02	26.62	30.67	34.98	39.79	45.03
Iron	13.24	15.24	17.46	19.80	22.38	25.15
Rice Cooker	6.65	7.70	8.87	10.12	11.52	13.04
Electric Stove	9.14	10.59	12.23	13.98	15.94	18.08
Electric Pot	7.45	8.61	9.91	11.30	12.84	14.52
Microwave	0.19	0.22	0.26	0.30	0.34	0.38
Vacuum	0.77	0.89	1.02	1.16	1.32	1.50
Aspirator	0.57	0.65	0.75	0.86	0.98	1.11
Electric Pump	0.48	0.55	0.63	0.72	0.81	0.91
Water Heater	5.40	6.25	7.19	8.21	9.34	10.57
Washing Machine	1.58	1.83	2.11	2.41	2.75	3.11
Computer	5.80	6.71	7.73	8.82	10.03	11.35
Other	2.79	3.18	3.64	4.13	4.68	5.26
Total electricity demand	263.68	304.60	350.32	399.03	453.14	511.75

Table 6.4: Total Electricity Demand Projection by Household Income Levels in the Base Case of 5.5% GDP Growth, [GWh]

Year	Low Income	Medium Income	High Income	Total
2002	29.98	93.10	140.60	263.68
2003	31.91	100.26	151.23	283.40
2004	33.95	108.01	162.64	304.60
2005	36.01	116.11	174.51	326.63
2006	38.18	124.84	187.31	350.32
2007	40.25	133.58	200.15	373.98
2008	42.39	142.88	213.75	399.03
2009	44.57	152.71	227.99	425.27
2010	46.79	163.19	243.16	453.14
2011	49.06	174.36	259.18	482.60
2012	51.16	185.48	275.11	511.75

Table 6.5: Electricity Demand Projection by Type of Appliance in the Base Case of 8% GDP Growth, [GWh]

Appliances	Electricity demand by appliance in selected years					
	2002	2004	2006	2008	2010	2012
Fluorescent (10 W)	2.35	2.69	3.07	3.46	3.88	4.33
Fluorescent (20 W)	27.51	31.78	36.57	41.69	47.41	53.66
Fluorescent (32 W)	1.70	1.98	2.29	2.63	3.01	3.44
Fluorescent (40 W)	9.13	10.60	12.25	14.05	16.08	18.33
Incandescent (5 W)	2.43	2.79	3.19	3.60	4.06	4.55
Incandescent (25 W)	1.30	1.51	1.75	2.01	2.30	2.63
Compact Fluorescent (9 W)	4.52	5.25	6.07	6.96	7.96	9.08
Radio/Tape/VCD/CD-player	6.39	7.39	8.50	9.69	11.03	12.48
Television	17.45	20.09	23.03	26.13	29.56	33.26
Electric Fan	36.76	42.55	49.08	56.10	63.99	72.66
Air-conditioner	77.32	89.79	103.91	119.27	136.67	156.02
Refrigerator	23.05	26.76	30.96	35.51	40.67	46.39
Iron	13.25	15.27	17.52	19.90	22.55	25.40
Rice Cooker	6.66	7.74	8.96	10.28	11.79	13.45
Electric Stove	9.16	10.66	12.37	14.24	16.38	18.77
Electric Pot	7.46	8.65	10.00	11.45	13.10	14.91
Microwave	0.19	0.23	0.26	0.30	0.34	0.39
Vacuum	0.77	0.89	1.03	1.18	1.35	1.54
Aspirator	0.57	0.66	0.76	0.88	1.00	1.15
Electric Pump	0.48	0.55	0.63	0.72	0.82	0.92
Water Heater	5.41	6.28	7.26	8.33	9.55	10.89
Washing Machine	1.59	1.84	2.14	2.45	2.81	3.21
Computer	5.81	6.74	7.80	8.95	10.25	11.70
Other	2.76	3.18	3.66	4.16	4.72	5.33
Total electricity demand	264.01	305.86	353.06	403.94	461.28	524.49

Table 6.6: Total Electricity Demand Projection by Household Income Levels in the Base Case of 8% GDP Growth, [GWh]

Year	Low Income	Medium Income	High Income	Total
2002	29.89	93.30	140.82	264.01
2003	31.71	100.72	151.69	284.12
2004	33.60	108.79	163.47	305.86
2005	35.48	117.28	175.84	328.60
2006	37.42	126.53	189.12	353.06
2007	39.22	135.88	202.58	377.69
2008	41.03	145.94	216.98	403.94
2009	42.80	156.67	232.22	431.68
2010	44.53	168.26	248.49	461.28
2011	46.23	180.66	266.00	492.89
2012	47.65	193.31	283.53	524.49

Table 6.7: Electricity Demand Projection by Each Income Level in the Base Case, [GWh]

Year	3% GDP Growth			5.5% GDP Growth			8% GDP Growth		
	L-Inc	M-Inc	H-Inc	L-Inc	M-Inc	H-Inc	L-Inc	M-Inc	H-Inc
2002	30.07	92.89	140.38	29.98	93.10	140.60	29.89	93.30	140.82
2003	32.11	99.82	150.76	31.91	100.26	151.23	31.71	100.72	151.69
2004	34.28	107.26	161.89	33.95	108.01	162.64	33.60	108.79	163.47
2005	36.51	115.00	173.34	36.01	116.11	174.51	35.48	117.28	175.84
2006	38.86	123.29	185.69	38.18	124.84	187.31	37.42	126.53	189.12
2007	41.17	131.53	197.93	40.25	133.58	200.15	39.22	135.88	202.58
2008	43.58	140.23	210.95	42.39	142.88	213.75	41.03	145.94	216.98
2009	46.07	149.36	224.45	44.57	152.71	227.99	42.80	156.67	232.22
2010	48.66	159.03	238.67	46.79	163.19	243.16	44.53	168.26	248.49
2011	51.36	169.23	253.65	49.06	174.36	259.18	46.23	180.66	266.00
2012	53.95	179.25	268.46	51.16	185.48	275.11	47.65	193.31	283.53

The results show that the electricity demand in the households in the low income level decrease, while the economic growth increases, and the electricity demand in households in the medium and high income levels increases. The high economic growth causes the change of household income level. Therefore, the households in the low income level would decrease and shift to the medium or high income level.

The results also show that the electricity demand in the households in the high income level is higher than the electricity demand in the households in the medium and low income levels.

Table 6.8: Electricity Demand Projection in the Residential Sector in the Base Case

Year	Electricity demand, [GWh]		
	GDP growth rate of 3%	GDP growth rate of 5.5%	GDP growth rate of 8%
2002	263.35	263.68	264.01
2003	282.69	283.40	284.12
2004	303.43	304.60	305.86
2005	324.85	326.63	328.60
2006	347.85	350.32	353.06
2007	370.63	373.98	377.69
2008	394.76	399.03	403.94
2009	419.88	425.27	431.68
2010	446.36	453.14	461.28
2011	474.24	482.60	492.89
2012	501.67	511.75	524.49

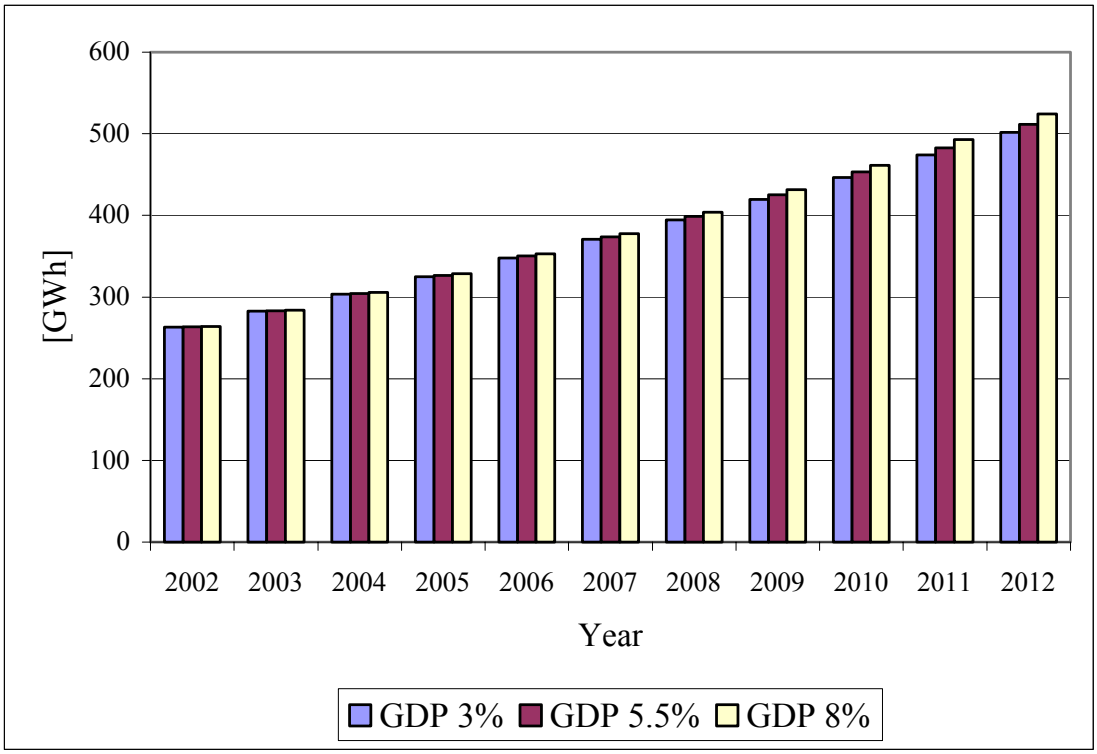

Figure 6.1: Electricity Demand Projection in the Base Case of Each GDP Growth Rate.

In the residential sector, the electricity demand projection in the base case is projected to grow from 263.35 GWh, 263.68 GWh, and 264.01 GWh in 2002 to 501.67 GWh, 511.75 GWh, and 524.49 GWh in 2012, accounted at 6.66%, 6.86%, and 7.11% per year in the cases of 3% GDP growth, 5.5% GDP growth, and 8% GDP growth, respectively. The results show as nearly the same for electricity demand among the three cases of GDP growth in 2002 to 2005. From 2006 to 2012, we could begin to see a minor difference in electricity demand. Thus, high economic growth implies improvement in household income. The increase of appliance ownership is regarded as mainly determined by the increase in household income.

6.3 Electricity Demand Projection in the Energy Efficiency (EE) Case

This case assumes major government intervention in more rational energy planning and policy to promote energy efficiency and energy conservation. The efficiency for lighting and refrigeration would be proposed by replacing inefficient lighting equipment, and refrigerators. The efficient lighting equipment is the efficient fluorescent lamp: 18W and 36W, and the electronic ballast: 3W. This case considers the replacement of existing inefficient lighting equipment with high efficient equipment after the base year. Efficient refrigerators would be used for the new households after the base year, and the old households in the base year would use inefficient refrigerators until the target year of projection because the lifetime of refrigerators is 10 years.

The results of the electricity demand projection by type of appliance and the total electricity demand projection by household income level in the energy efficiency case of 3% GDP growth, 5.5% GDP growth, and 8% GDP growth are shown in Table 6.9 to Table 6.14, respectively. Table 6.15 shows the total electricity demand in each household income level in the energy efficiency case. Table 6.16 and the Figure 6.2 show the total electricity demand projection in the energy efficiency case of each GDP growth rate.

Table 6.9: Electricity Demand Projection by Type of Appliance in the Energy Efficiency Case of 3% GDP Growth, [GWh]

Appliances	Electricity demand by appliance in selected years					
	2002	2004	2006	2008	2010	2012
Fluorescent (10 W)	2.35	2.19	2.50	2.83	3.18	3.56
Fluorescent (18 W)	27.46	23.71	27.15	30.78	34.76	39.03
Fluorescent (32 W)	1.70	1.76	2.01	2.29	2.59	2.91
Fluorescent (36 W)	9.10	8.71	9.99	11.34	12.84	14.44
Incandescent (5 W)	2.43	2.79	3.18	3.60	4.06	4.55
Incandescent (25 W)	1.29	1.49	1.71	1.95	2.20	2.48
Compact Fluorescent (9 W)	4.51	5.20	5.96	6.77	7.66	8.62
Radio/Tape/VCD/CD-player	6.38	7.34	8.41	9.54	10.77	12.09
Television	17.44	20.04	22.93	25.96	29.28	32.82
Electric Fan	36.68	42.24	48.42	54.93	62.09	69.77
Air-conditioner	77.07	88.89	101.97	115.85	131.10	147.49
Refrigerator	22.98	26.18	29.73	33.48	37.61	39.97
Electric Iron	13.23	15.22	17.41	19.72	22.25	24.95
Rice Cooker	6.64	7.66	8.79	9.98	11.30	12.72
Electric Stove	9.12	10.53	12.09	13.75	15.58	17.54
Electric Pot	7.44	8.57	9.83	11.16	12.63	14.20
Microwave	0.19	0.22	0.26	0.29	0.33	0.37
Vacuum	0.76	0.88	1.01	1.15	1.30	1.46
Aspirator	0.56	0.65	0.75	0.85	0.96	1.08
Electric Pump	0.48	0.55	0.63	0.71	0.81	0.90
Water Heater	5.39	6.22	7.13	8.10	9.17	10.31
Washing Machine	1.58	1.82	2.09	2.38	2.69	3.03
Computer	5.79	6.67	7.66	8.70	9.84	11.07
Other	2.75	3.17	3.63	4.11	4.64	5.20
Total electricity demand	263.35	292.72	335.27	380.21	429.65	480.56

Table 6.10: Total Electricity Demand Projection by Household Income Levels in the Energy Efficiency Case of 3% GDP Growth, [GWh]

Year	Low Income	Medium Income	High Income	Total
2002	30.07	92.89	140.38	263.35
2003	30.12	95.08	147.65	272.85
2004	32.15	102.11	158.46	292.72
2005	34.23	109.43	169.57	313.24
2006	36.44	117.27	181.56	335.27
2007	38.60	125.06	193.44	357.09
2008	40.85	133.29	206.08	380.21
2009	43.18	141.92	219.18	404.28
2010	45.60	151.07	232.98	429.65
2011	48.13	160.71	247.52	456.36
2012	50.47	169.50	260.59	480.56

Table 6.11: Electricity Demand Projection by Type of Appliance in the Energy Efficiency Case of 5.5% GDP Growth, [GWh]

Appliances	Electricity demand by appliance in selected years					
	2002	2004	2006	2008	2010	2012
Fluorescent (10 W)	2.35	2.19	2.50	2.82	3.17	3.54
Fluorescent (18 W)	27.49	23.77	27.28	31.01	35.13	39.56
Fluorescent (32 W)	1.70	1.76	2.03	2.32	2.64	2.99
Fluorescent (36 W)	9.12	8.75	10.07	11.49	13.06	14.78
Incandescent (5 W)	2.43	2.79	3.19	3.60	4.06	4.55
Incandescent (25 W)	1.30	1.50	1.73	1.98	2.25	2.55
Compact Fluorescent (9 W)	4.52	5.22	6.01	6.86	7.80	8.82
Radio/Tape/VCD/CD-player	6.39	7.37	8.45	9.61	10.89	12.26
Television	17.44	20.07	22.98	26.04	29.41	33.01
Electric Fan	36.72	42.39	48.73	55.47	62.95	71.05
Air-conditioner	77.19	89.32	102.89	117.44	133.64	151.25
Refrigerator	23.02	26.30	29.97	33.90	38.27	40.95
Iron	13.24	15.24	17.46	19.80	22.38	25.15
Rice Cooker	6.65	7.70	8.87	10.12	11.52	13.04
Electric Stove	9.14	10.59	12.23	13.98	15.94	18.08
Electric Pot	7.45	8.61	9.91	11.30	12.84	14.52
Microwave	0.19	0.22	0.26	0.30	0.34	0.38
Vacuum	0.77	0.89	1.02	1.16	1.32	1.50
Aspirator	0.57	0.65	0.75	0.86	0.98	1.11
Electric Pump	0.48	0.55	0.63	0.72	0.81	0.91
Water Heater	5.40	6.25	7.19	8.21	9.34	10.57
Washing Machine	1.58	1.83	2.11	2.41	2.75	3.11
Computer	5.80	6.71	7.73	8.82	10.03	11.35
Other	2.79	3.18	3.64	4.13	4.68	5.26
Total electricity demand	263.68	293.85	337.66	384.33	436.20	490.29

Table 6.12: Total Electricity Demand Projection by Household Income Levels in the Energy Efficiency Case of 5.5% GDP Growth, [GWh]]

Year	Low Income	Medium Income	High Income	Total
2002	29.98	93.10	140.60	263.68
2003	29.94	95.49	148.10	273.53
2004	31.84	102.83	159.19	293.85
2005	33.77	110.48	170.70	314.96
2006	35.80	118.73	183.13	337.66
2007	37.73	127.00	195.60	360.33
2008	39.74	135.80	208.80	384.33
2009	41.78	145.09	222.62	409.49
2010	43.85	155.00	237.34	436.20
2011	45.97	165.57	252.89	464.43
2012	47.86	175.38	267.05	490.29

Table 6.13: Electricity Demand Projection by Type of Appliance in the Energy Efficiency Case of 8% GDP Growth, [GWh]

Appliances	Electricity demand by appliance in selected years					
	2002	2004	2006	2008	2010	2012
Fluorescent (10 W)	2.35	2.19	2.49	2.81	3.15	3.51
Fluorescent (18 W)	27.51	23.84	27.43	31.27	35.56	40.24
Fluorescent (32 W)	1.70	1.77	2.05	2.36	2.70	3.09
Fluorescent (36 W)	9.13	8.79	10.17	11.66	13.34	15.21
Incandescent (5 W)	2.43	2.79	3.19	3.60	4.06	4.55
Incandescent (25 W)	1.30	1.51	1.75	2.01	2.30	2.63
Compact Fluorescent (9 W)	4.52	5.25	6.07	6.96	7.96	9.08
Radio/Tape/VCD/CD-player	6.39	7.39	8.50	9.69	11.03	12.48
Television	17.45	20.09	23.03	26.13	29.56	33.26
Electric Fan	36.76	42.55	49.08	56.10	63.99	72.66
Air-conditioner	77.32	89.79	103.91	119.27	136.67	156.02
Refrigerator	23.05	24.67	30.24	34.38	39.07	42.18
Iron	13.25	15.27	17.52	19.90	22.55	25.40
Rice Cooker	6.66	7.74	8.96	10.28	11.79	13.45
Electric Stove	9.16	10.66	12.37	14.24	16.38	18.77
Electric Pot	7.46	8.65	10.00	11.45	13.10	14.91
Microwave	0.19	0.23	0.26	0.30	0.34	0.39
Vacuum	0.77	0.89	1.03	1.18	1.35	1.54
Aspirator	0.57	0.66	0.76	0.88	1.00	1.15
Electric Pump	0.48	0.55	0.63	0.72	0.82	0.92
Water Heater	5.41	6.28	7.26	8.33	9.55	10.89
Washing Machine	1.59	1.84	2.14	2.45	2.81	3.21
Computer	5.81	6.74	7.80	8.95	10.25	11.70
Other	2.76	3.18	3.66	4.16	4.72	5.33
Total electricity demand	264.01	295.07	340.31	389.08	444.05	502.59

Table 6.14: Total Electricity Demand Projection by Household Income Levels in the Energy Efficiency Case of 8% GDP Growth, [GWh]

Year	Low Income	Medium Income	High Income	Total
2002	29.89	93.30	140.82	264.01
2003	29.75	95.93	148.56	274.24
2004	31.51	103.56	159.99	295.07
2005	33.27	111.59	172.00	316.86
2006	35.09	120.33	184.89	340.31
2007	36.77	129.18	197.96	363.91
2008	38.46	138.69	211.93	389.08
2009	40.12	148.83	226.73	415.68
2010	41.73	159.80	242.52	444.05
2011	43.32	171.52	259.51	474.36
2012	44.57	182.79	275.22	502.59

Table 6.15: Electricity Demand Projection by Each Income Level in the Energy Efficiency Case, [GWh]

Year	3% GDP Growth			5.5% GDP Growth			8% GDP Growth		
	L-Inc	M-Inc	H-Inc	L-Inc	M-Inc	H-Inc	L-Inc	M-Inc	H-Inc
2002	30.07	92.89	140.38	29.98	93.10	140.60	29.89	93.30	140.82
2003	30.12	95.08	147.65	29.94	95.49	148.10	29.75	95.93	148.56
2004	32.15	102.11	158.46	31.84	102.83	159.19	31.51	103.56	159.99
2005	34.23	109.43	169.57	33.77	110.48	170.70	33.27	111.59	172.00
2006	36.44	117.27	181.56	35.80	118.73	183.13	35.09	120.33	184.89
2007	38.60	125.06	193.44	37.73	127.00	195.60	36.77	129.18	197.96
2008	40.85	133.29	206.08	39.74	135.80	208.80	38.46	138.69	211.93
2009	43.18	141.92	219.18	41.78	145.09	222.62	40.12	148.83	226.73
2010	45.60	151.07	232.98	43.85	155.00	237.34	41.73	159.80	242.52
2011	48.13	160.71	247.52	45.97	165.57	252.89	43.32	171.52	259.51
2012	50.47	169.50	260.59	47.86	175.38	267.05	44.57	182.79	275.22

For the Table 6.15, the results show that the electricity demand in the households in the low income level decrease, while the economic growth increases, and the electricity demand in households in the medium and high income levels increase. The high economic growth causes the change of household income level. Therefore, the households in the low income level would decrease and shift to the medium or high income level.

The results also show that the electricity demand in the households in the high income level is higher than the electricity demand in the households in the medium and low income levels. Thus, if economic growth increased then the electricity demand would increase.

Table 6.16: Electricity Demand Projection in the Residential Sector in the Energy Efficiency Case

Year	Electricity demand, [GWh]		
	GDP growth rate of 3%	GDP growth rate of 5.5%	GDP growth rate of 8%
2002	263.35	263.68	264.01
2003	272.85	273.53	274.24
2004	292.72	293.85	295.07
2005	313.24	314.96	316.86
2006	335.27	337.66	340.31
2007	357.09	360.33	363.91
2008	380.21	384.33	389.08
2009	404.28	409.49	415.68
2010	429.65	436.20	444.05
2011	456.36	464.43	474.36
2012	480.56	490.29	502.59

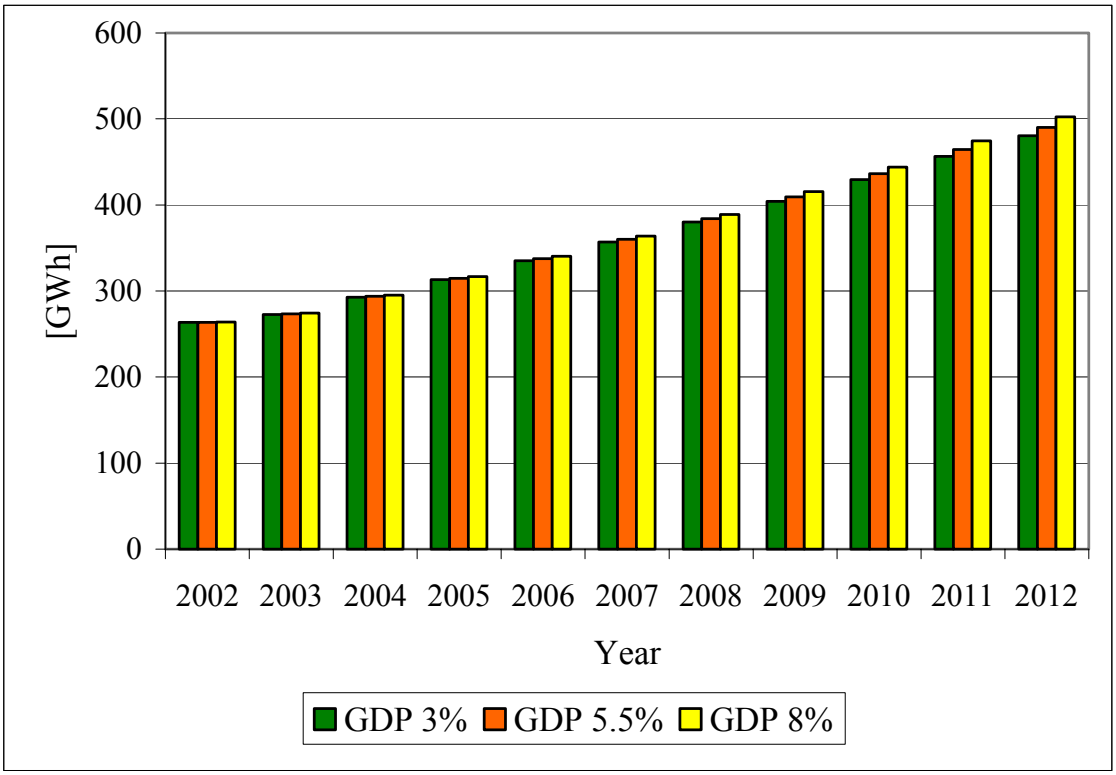

Figure 6.2: Electricity Demand Projection in the Energy Efficiency Case of Each GDP Growth Rate.

In the residential sector, the electricity demand projection in the energy efficiency (EE) case is projected to grow from 263.35 GWh, 263.68 GWh, and 264.01 GWh in 2002 to 480.56 GWh, 490.29 GWh, and 502.59 GWh in 2012, accounted at 6.20%, 6.40%, and 6.65% per year in the cases of 3% GDP growth, 5.5% GDP growth, and 8% GDP growth, respectively. The results show only minor differences in electricity demand among the three cases of GDP growth in 2002 to 2012. Thus, high economic growth implies an improvement in household income. An increase of appliance ownership is regarded as mainly determined by an increase in household income.

6.4 Comparison of Electricity Demand among the Base Case and the EE Case

The electricity demand in the energy efficiency case would be lower than the electricity demand in the base case (BC), due to a reduced capacity of lighting equipment and refrigerators. The saving in energy can be calculated by the equation (6.1). Table 6.17 to Table 6.19 show the results of electricity demand and the energy saving between the base case and the energy efficiency case. Figure 6.3 shows the comparison of electricity demands among the base case and the energy efficiency case.

$$SE_t = EDBC_t - EDEE_t \qquad (6.1)$$

Where: SE_t – Saving in energy in year t,

$EDBC_t$ – Energy demand in the base case in year t,

$EDEE_t$ – Energy demand in the energy efficiency case in year t.

Table 6.17: Comparison of Electricity Demand Projection in the Residential Sector in the Case of 3% GDP Growth.

Year	Electricity demand in the case of 3% GDP growth, [GWh]		
	Base case	Energy efficiency case	Saving
2002	263.35	263.35	0.00
2003	282.69	272.85	9.84
2004	303.43	292.72	10.71
2005	324.85	313.24	11.16
2006	347.85	335.27	12.58
2007	370.63	357.09	13.54
2008	394.76	380.21	14.55
2009	419.88	404.28	15.60
2010	446.36	429.65	16.71
2011	474.24	456.36	17.88
2012	501.67	480.56	21.11

Table 6.18: Comparison of Electricity Demand Projection in the Residential Sector in the Case of 5.5% GDP Growth.

Year	Electricity demand in the case of 5.5% GDP growth, [GWh]		
	Base case	Energy efficiency case	Saving
2002	263.68	263.68	0.00
2003	283.40	273.53	9.87
2004	304.60	293.85	10.75
2005	326.63	314.96	11.67
2006	350.32	337.66	12.66
2007	373.98	360.33	13.65
2008	399.03	384.33	14.70
2009	425.27	409.49	15.78
2010	453.14	436.20	16.94
2011	482.60	464.43	18.17
2012	511.75	490.29	21.46

Table 6.19: Comparison of Electricity Demand Projection in the Residential Sector in the Case of 8% GDP Growth.

Year	Electricity demand in the case of 8% GDP growth, [GWh]		
	Base case	Energy efficiency case	Saving
2002	264.01	264.01	0.00
2003	284.12	274.24	9.88
2004	305.86	295.07	10.79
2005	328.60	316.86	11.74
2006	353.06	340.31	12.75
2007	377.69	363.91	13.78
2008	403.94	389.08	14.86
2009	431.68	415.68	15.60
2010	461.28	444.05	17.23
2011	492.89	474.36	18.53
2012	524.49	502.59	21.90

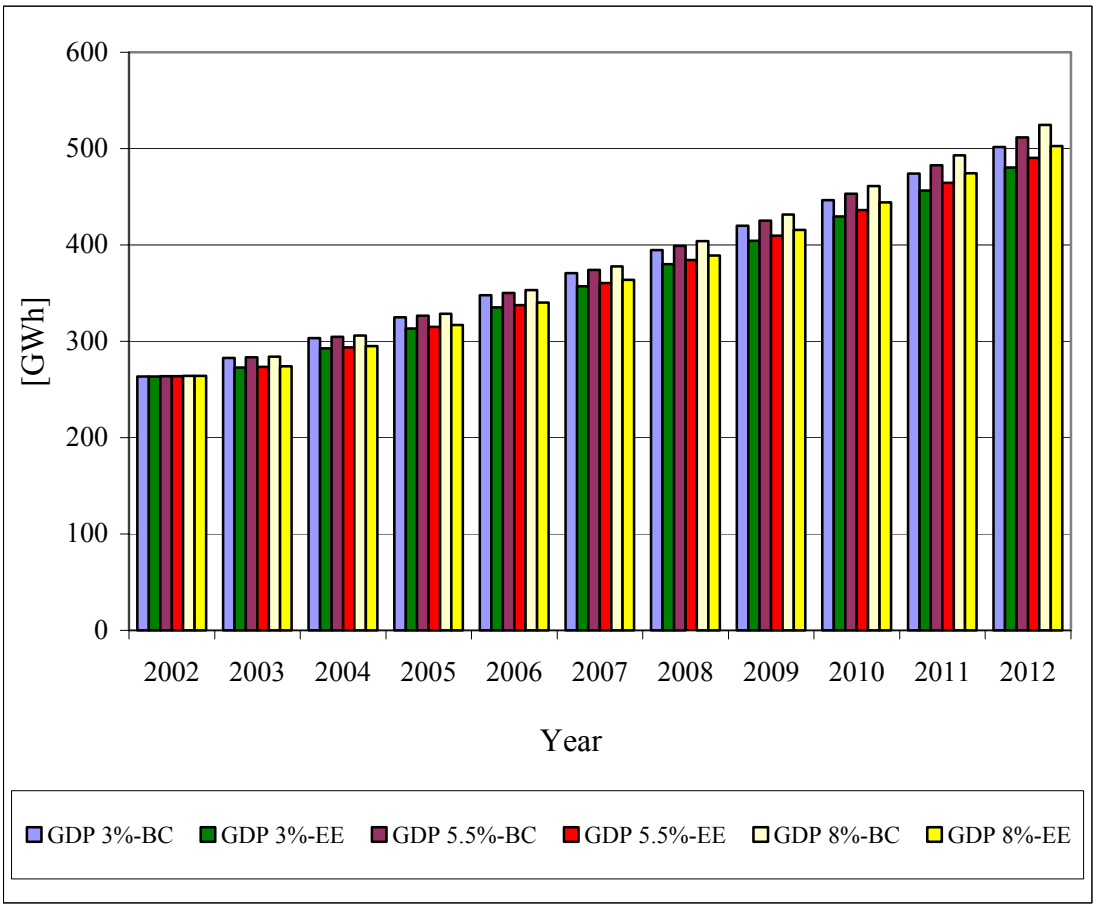

Figure 6.3: Comparison of Electricity Demand among the Base Case and the Energy Efficiency Case

The results show that the appliance efficiency improvement in the energy efficiency case have potential to reduce the electricity demand by 21.46 GWh in 2012 or accounting for 4.38% of the total demand in the base case of 5.5% GDP growth. In the energy efficiency case, the lighting efficiency improvement have potential to reduce the electricity demand by 17.38 GWh in 2012 or accounted for 3.55% of the total demand in the base case of 5.5% GDP growth, while the refrigerator efficiency improvement have the ability to reduce the electricity demand by 4.08 GWh, accounting for 0.83% of the total demand in the base case of the same GDP growth.

CHAPTER 7

FINAL CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The number of electrified households is a factor that affects the electricity demand in the residential sector. The stock of appliances and the use of these can affect household electricity demand by different household income factors in the residential sector. The air-conditioner and lighting are the major dominant uses of electricity in the residential sector, accounting for 37.19% and 16.05%, respectively, followed by electric fan, refrigerator, television, electric iron, electric stove, water heater, electric pot, computer, radio/tape/VCD/CD-player, rice cooker, other appliances, washing machine, vacuum, aspirator, electric pump, and microwave.

The household income level is a dominant factor of electricity demand in the residential sector, since the rates of ownership of electric appliances vary by the income levels of household. The higher electricity use is in the households in the high income level, accounted at 71%, while the households in the medium and low income levels consume low levels of electricity, accounted at 21% and 7%, respectively.

In the economic changes, the household income levels would be changed. They would be gradually changed or rapidly changed according to the economic growth. Therefore, the electricity demand for the residential could be changed in line with the change of household income level. In the base case of 8% GDP growth, the electricity demand projection could be different by 22.82 GWh and 12.74 GWh in 2012 or accounted at 4.55% and 2.49% of the total demand in the base case of 3% GDP growth and 5.5% GDP growth, respectively.

The high efficiency technology of electric appliances is able to reduce the electricity demand. The electricity demand projection in the energy efficiency case could be able to reduce the electricity demand by around 21 GWh in 2012 or account for 4% of the total demand in the base case of each GDP growth rate.

The magnitude of the real savings depends on consumers, government, and utilities. Government and utilities can deploy a rage of policy measures to overcome market barriers to increase efficiency.

7.2 Recommendations

The high efficiency technology of electric appliances conserves high electricity consumption in the households. But the price of the high efficiency electric appliances is mostly expensive. Therefore, energy planners should consider the least cost of these appliances because the decision of consumers is based only on the minimum cost of appliances and electricity cost. Nevertheless, improvements in electricity end-use efficiency could make a significant contribution to meeting environmental and energy conservation objectives, while at the same time supporting economic well being.

Governments should intervene in more rational energy planning and policy to promote energy efficiency and energy conservation. This policy should incorporate other social constraints such as the willingness of replacing or buying of a more efficient appliance with higher cost.

The end-use model is a significant model to project the future electricity demand in the residential sector. The model is able to reflect the change in electricity demand from the replacement by energy efficient appliances. However, a large number of survey data needs to verify the model and needs to be updated from time to time.

There is an urgent need of review, gathering and documentation of an energy database in the residential sector identifying information gaps, which need to be filled. It is recommended to continuously update the database by official statistics and small-scale surveys. These concerns should be especially recommended to the Energy Development Department of the Ministry of Industry, Mines and Energy, and Electricite du Cambodge.

Due to the end-use model being a flexible model that can support the change in both macro economic parameters, such as Gross Domestic Product, and energy intensity and end-use technical parameters, such as the device’s efficiency, I hope that further study would be achieved and the accuracy of the forecasts of the electricity demand in the

residential sector in Phnom Penh improved, if there are adequate data such as the quality and the quantity of the historical data. However, this study is a first sample to develop the models of energy demand forecasting in the residential sector in Phnom Penh.

The end-use model can be used to analyze and forecast the electricity demand in all economic sectors, such as residential, commercial, industrial, and public sectors, etc. Therefore, the further study should consider the energy demand in all sectors in Phnom Penh.

The scope of future study should use another method to find out the other factors such as energy price, substituted price, population, output or income, technology, etc. which are all indirect and direct influences on the energy demand in residential, commercial, transport, industrial, and agricultural sectors in Cambodia. The analysis of demand side management in improving the efficiency of electricity and policy option with the least cost concept is needed.

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APPENDICES

APPENDIX – A

QUESTIONNAIRE SHEET

Phnom Penh City Surveyor…….
Khan…..……Date…….…../……...……/2002
Quarter…….……..Sheet N^{o}…….
Road N^{o}……House N^{o}……

Income/house	500US$>[ ]	500-200US$[ ]	200US$<[ ]	
House Type	Flat [ ]	W-H [ ]	Villa [ ]	
Number of People per Household				
Energy Consumption			KWh/Month	
Item	**N^{o} of Item**	**Wattage**	**Hour/day**	**Other**
Fluorescent Lamps 10W				
Fluorescent Lamps 20W				
Fluorescent Lamps 32W				
Fluorescent Lamps 40W				
Fluorescent Compact Lamp 9W				
Incandescent Lamps 5W				
Incandescent Lamps 25W				
Radio/tape Player, VCD/CD Player				
Television 1st Type				
Television 2nd Type				
Television 3rd Type				
Electric Fan 1st Type				
Electric Fan 2nd Type				
Electric Fan 3rd Type				
Air-cond.: 740W (9,000Btu/hr)				
Air-cond.: 1,120W (12,000Btu/hr)				
Air-cond.: 1,480W (13,000Btu/hr)				
Air-cond.: 1,850W (15,000Btu/hr)				
Refrigerator 1st Type				
Refrigerator 2nd Type				
Refrigerator 3rd Type				
Electric Iron				
Electric Rice Cooker				
Electric Stove				
Electric Pot				
Microwave				
Vacuum				
Aspirator				
Electric Pump				
Water Heater				
Washing Machine				
Computer				
Other Appliances				

Source: Established by Author, (2002).

APPENDIX – B

SPECIFICATION OF COLLECTED DATA

Table B.1: Specification of Collected Data

N°	Item	Kind of Item	Capacity of Item	Other
1	House Type	Villa	Number of people Per house: From: 2p…15p	Average per HH 5.72 Per.
		Flat		
		Wooden house		
2	Lighting	Fluorescent	From: 10-40W	5min…10h/d
		Incandescent	From: 5-100W	5min…10h/d
		Compact Fluorescent	From: 9-13W	5min…10h/d
3	Cooling	Air conditioner	From: 368-1,500W	1h…10h/d
		Electric Fan	From: 45-110W	1h…10h/d
4	Heating	Water heater	Almost: 1,000W	3min…1h/d
		Electric Pot	From: 800-1,000W	15min…2h/d
5	Freezing	Refrigerator	From: 45-125W	10h…12h/d
6	Cooking	Rice cooker	From: 400-800W	20min…1h/d
		Microwave	From: 700-800W	5min…1h/d
		Electric Stove	Almost: 1,000W	5min…1h/d
7	Entertainment	Television	From: 45-110W	30min…8h/d
		VCD, CD, VCR player	From: 20-110W	30min…8h/d
		Radio/Tape player	From: 5W…20W	10min…10h/d
8	Cleaning	Washing machine	From: 200-380W	20min…2h/d
		Vacuum machine	From: 368-2000W	30min…1h/d
		Electric Iron	Almost: 1,000W	5min…2h/d
		Aspirator	From: 25-80W	5min…2h/d
9	Studying	Computer	From: 80-500W	30min…3h/d
10	Pumping	Electric Motor	From: 368-1200W	10min…3h/d
11	Other	Electric Sewing Machine	From: 200-300W	30min…2h/d
		Battery Charger	From: 3-5.5W	1h…4h/d
		Hand Phone Charger	From: 3-5.5W	1h…5h/d
		Blender	From: 300-400W	10…20min/d
		Bread Heater	From: 650-750W	10…20min/d
		Coffee Maker	From: 750-850W	5…10min/d

Source: Fieldwork Survey, (2002).

APPENDIX – C

OVERVIEW OF SOCIO-ECONOMIC AND DEMOGRAPHY

Table C.1: Demography and Economics in Phnom Penh (2001)

N^{o}	Description	Amount
1	Total Surface Area (Km^2)	375
2	Density (Pers/Km^2)	2,565
3	Number of Districts	7
4	Number of Communes	76
5	Number of Villages	637
6	Total of Population	986,750
7	Total Number of Households	175,400
8	Household Size	5.62
9	Concrete Building (Villages-Flat)	63,336
10	Wooden Houses	57,194
11	Thatch Houses	27,947
12	Number of Households that Have Access to Electricity Use	127,749
13	Number of Households that Have Access to Water Use	70,000
14	Rate of Total Employed People (%)	12.60
15	Rate of Employed People in Commercial Sector (%)	70.30
16	Rate of Employed People in Industrial Sector (%)	21.40
17	Rate of Employed People in Agriculture Sector (%)	8.30
18	Per Capita GDP in US$	280
19	Income/person/month in (Riels)	219,771
20	Income/HH/month in (Riels)	1,139,553
21	Government Radio Stations	2
22	Government TV Station	1
23	Private Radio Stations	13
24	Private TV Stations	6
25	Cable TV Stations	3

Source: Planning Department of Phnom Penh, (2002).

Table C.2: GDP Deflators of Cambodia, 1991-2001, (Billion Riels)

Year	GDP in current prices	Growth Rate, [%]	GDP in constant 1993 prices	Growth Rate, [%]	GDP Deflator
1991	1,336.00	-	280.00	-	4.7714
1992	2,508.00	87.7	302.00	7.9	8.3046
1993	6,545.00	161.0	6,545.00	2067.2	1.0000
1994	6,812.00	4.1	7,047.00	7.7	0.9666
1995	8,111.00	19.1	7,464.00	5.9	1.0867
1996	8,886.00	9.6	7,808.00	4.6	1.1380
1997	9,778.00	10.0	8,143.00	4.3	1.2008
1998	11,364.00	16.2	8,318.00	2.1	1.3662
1999	12,587.00	10.8	8,889.00	6.9	1.4160
2000	12,932.00	2.7	9,570.00	7.7	1.3513
2001	13,357.00	3.3	10,171.00	6.3	1.3132

Source: NIS and MOP, (Year Book 2001).

Table C.3: The Percentage of Number of Households' Income Level in Phnom Penh.

Year	Income Levels, [%]			Total Number of Households, [HH]	Exchange Rate (Riel/US$)
	High	Medium	Low		
1993	18.89	39.68	41.43	121,134.00	2,747.00
1994	18.95	39.85	41.20	136,800.00	2,570.00
1995	19.02	40.00	40.98	139,735.00	2,467.00
1996	19.07	40.16	40.77	150,280.00	2,640.00
1997	19.12	40.31	40.57	168,200.00	2,991.00
1998	19.16	40.46	40.38	173,678.00	3,774.00
1999	19.21	40.61	40.18	174,000.00	3,814.00
2000	19.26	40.76	39.98	174,854.00	3,859.00
2001	19.29	40.87	39.84	175,400.00	3,926.00

Source: Planning Department of Phnom Penh, (2002).

Table C.4: Population and Demography in Phnom Penh (1991 – 2001)

Year	Number of Population	Number of Household	Average Household Size
	[Person]	[HH]	[Person/HH]
1991	632,142.00	111,889.00	5.65
1992	668,593.00	119,864.00	5.57
1993	717,261.00	121,134.00	5.92
1994	793,400.00	136,800.00	5.80
1995	795,600.00	139,735.00	5.60
1996	796,936.00	150,280.00	5.30
1997	925,289.00	168,200.00	5.50
1998	999,804.00	173,678.00	5.75
1999	958,578.00	174,000.00	5.50
2000	961,578.00	174,859.00	5.50
2001	986,750.00	175,400.00	5.62

Source: Planning Department of Phnom Penh, (2002).

Table C.5: Population Projections and Annual Growth Rate 2001-2021

Year	Number of Population	Annual Growth Rate
	[Person]	[%]
2001	1,185,000	-
2002	1,234,000	4.13
2003	1,283,000	3.97
2004	1,335,000	4.05
2005	1,387,000	3.89
2006	1,442,000	3.96
2007	1,493,000	3.53
2008	1,546,000	3.55
2009	1,600,000	3.50
2010	1,656,000	3.50
2011	1,714,000	3.50
2012	1,767,000	3.09
2013	1,821,000	3.05
2014	1,876,000	3.02
2015	1,932,000	2.98
2016	1,990,000	3.00
2017	2,042,000	2.61
2018	2,094,000	2.54
2019	2,147,000	2.53
2020	2,200,000	2.46
2021	2,254,000	2.45

Source: NIS and MOP, (July, 2000).

APPENDIX – D

SPECIFICATION OF ELECTRIC APPLIANCE USE IN CAMBODIA

Table D.1: Specification of Electric Appliances Usage in Cambodia

Item	Capacity	Specific	Power [W]
Fluorescent Lamp	1 Bulb	1 2 3 4	10 20 32 40
Incandescent Lamp	1 Bulb	1 2 3 4	5 25 40 60
Compact Fluorescent Lamp	1 Bulb	1 2	9 13
Spotlight	1 Bulb	1 2	25 45
TV	14”	1 2 3	50 60 70
	21”	1 2 3	60 70 90
	29”	1 2 3	70 90 100
CD/VCD/DVD	Modern	1 2 3	20-30 30-50 60-150
Radio/Tape Player	Simple	1 2 3	5-10 10-15 15-20
Fan	12”	1 2 3	45 50 60
	14”	1 2 3	55 65 75
	16”	1 2 3	54 60-65-66 88
Electric Pot	2.2 L 2.5 L 3.3 L	1 2 3	600 600 600
Rice Cooker	1.8 L 2.2 L 4.0 L	1 2 3	600 600 600

Source: Department of Energy Development, MIME, Cambodia, (2000).

Table D.2: Specification of Electric Appliances Usage in Cambodia, (Cont'd)

Item	Capacity	Specific	Power [W]
Iron	N/A	1	1,000
Washing Machine	5.5 kg	1	270
		2	300
		3	335
	6.0 kg	1	270
		2	300
		3	370
	7.0 kg	1	275
		2	300
		3	340
Microwave	N/A	1	600
		2	700
		3	800
Bread Heater	4.0 Slices	1	650
		2	700
		3	750
Blender	3.0 L	1	300
	1.0 L	2	350
	1.5 L – 2.0 L	3	400
Coffee Maker	7 Cups	1	750
		2	800
		3	850
Cooker Stove	N/A	1	1,000
		2	1,200
		3	1,300
Water Heater	N/A	1	1,200
		2	1,500
		3	2,000
Vacuum Cleaner	N/A	1	1,000
		2	1,200
		3	1,400
Aspirator	8"	1	25
	9"	2	35
	10"	3	45
Suki Pot	N/A	1	800
		2	1,000
		3	1,200
Hair Dryer	N/A	1	200
		2	300
		3	400
Shaver	N/A	1	15
		2	20
		3	30

Source: Department of Energy Development, MIME, Cambodia, (2000)

Table D.3: Specification of Electric Appliances Usage in Cambodia, (Cont'd)

Item	Capacity	Specific	Power [W]
Refrigerator	5.2 ft^3	1	65
	4.6 ft^3	2	68
	6.0 ft^3	3	79
	6.2 ft^3 – 6.9 ft^3	1	65 – 69
	7.2 ft^3 – 8.1 ft^3	2	82 – 96
	10.0 ft^3 – 15.2 ft^3	3	175
Air-conditioner	9,000 Btu/hr	1	740
		2	760
		3	800
	12,000 Btu/hr	1	1,110
		2	1,140
		3	1,200
	13,000 Btu/hr	1	1,480
		2	1,520
		3	1,600
	15,000 Btu/hr	1	1,850
		2	1,900
		3	2,000
Hand Phone Charger	1 Unit	1	4
		2	5.5
Battery Charger	2 Units	1	3
	4 Units	2	5.5
Electric Pump	10 m^3/hr	1	368
	20 m^3/hr	2	750
	25 m^3/hr	3	900
Sewing Machine	N/A	1	200
		2	250
		3	300
Computer	15"	1	300
	17"	2	500
Printer	N/A	1	500
		2	800
Copy Machine	N/A	1	1,500
		2	2,500
		3	3,000
		4	5,000
Drill Machine	N/A	1	370
		2	500
		3	650
		4	740
Soldering Iron	N/A	1	80
		2	150
		3	300

Source: Department of Energy Development, MIME, Cambodia, (2000).

APPENDIX – E

DETAILS OF RESULTS FROM DATA ANALYSIS

Table E.1: Average Number of Electric Appliances per Household by Income Level

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	0.840	0.561	0.424
Fluorescent (20 W)	3.211	7.494	11.376
Fluorescent (32 W)	-	0.244	1.729
Fluorescent (40 W)	0.411	1.472	2.847
Incandescent (5 W)	1.149	1.350	0.459
Incandescent (25 W)	-	0.522	3.824
Compact Fluorescent (9 W)	0.234	1.178	3.000
Radio/Tape/VCD/CD-player	0.954	1.117	1.424
Television	0.891	1.033	1.459
Electric Fan	1.124	3.133	4.035
Air-conditioner	-	0.130	2.152
Refrigerator	0.090	0.585	1.181
Iron	0.731	1.000	1.000
Rice Cooker	0.063	0.428	0.459
Electric Stove	-	0.278	0.341
Electric Pot	0.166	0.606	0.741
Microwave	-	-	0.082
Vacuum	-	-	0.259
Aspirator	-	0.100	1.024
Electric Pump	0.063	0.083	0.188
Water Heater	-	-	0.812
Washing Machine	0.052	0.540	0.715
Computer	0.029	0.178	0.482
Other	0.531	0.622	0.813

Source: Results from Actual Data Analysis, (2002).

The capacity of fluorescent lamps and refrigerators was collected from fieldwork survey and shown to be inefficient. Capacity of inefficient lighting equipment is assumed for fluorescent lamps and capacity of inefficient refrigerator is assumed to be high capacity but small volume. Table E.2 presents inefficient capacity of fluorescent lamps and refrigerators, and Table E.3 presents efficient capacity of fluorescent lamps and refrigerators.

Table E.2: Average Capacity of Electric Appliances per Household by Income Level, [W]

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	16.000	16.000	16.000
Fluorescent (20 W)	28.000	28.000	28.000
Fluorescent (32 W)	-	39.000	39.000
Fluorescent (40 W)	47.000	47.000	47.000
Incandescent (5 W)	5.000	5.000	5.000
Incandescent (25 W)	-	25.000	25.000
Compact Fluorescent (9 W)	9.000	9.000	9.000
Radio/Tape/VCD/CD-player	11.835	21.169	26.942
Television	51.026	53.871	56.048
Electric Fan	45.930	50.780	50.933
Air-conditioner	-	508.000	553.314
Refrigerator	68.700	69.400	70.790
Iron	1000.000	1000.000	1000.000
Rice Cooker	600.000	600.000	600.000
Electric Stove	-	1000.000	1000.000
Electric Pot	600.000	600.000	600.000
Microwave	-	-	700.000
Vacuum	-	-	1000.000
Aspirator	-	45.000	45.000
Electric Pump	368.000	368.000	368.000
Water Heater	-	-	1200.000
Washing Machine	300.000	270.000	275.000
Computer	300.000	300.000	300.000
Other	142.656	161.672	170.624

Source: Results from Actual Data Analysis, (2002).

Table E.3: Average Capacity of Electric Appliances per Household by Income Level, [W]

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	13.000	13.000	13.000
Fluorescent (18 W)	21.000	21.000	21.000
Fluorescent (32 W)	-	35.000	35.000
Fluorescent (36 W)	49.000	39.000	39.000
Incandescent (5 W)	5.000	5.000	5.000
Incandescent (25 W)	-	25.000	25.000
Compact Fluorescent (9 W)	9.000	9.000	9.000
Radio/Tape/VCD/CD-player	11.835	21.169	26.942
Television	51.026	53.871	56.048
Electric Fan	45.930	50.780	50.933
Air-conditioner	-	508.000	553.314
Refrigerator	65.000	65.000	62.000
Iron	1000.000	1000.000	1000.000
Rice Cooker	600.000	600.000	600.000
Electric Stove	-	1000.000	1000.000
Electric Pot	600.000	600.000	600.000
Microwave	-	-	700.000
Vacuum	-	-	1000.000
Aspirator	-	45.000	45.000
Electric Pump	368.000	368.000	368.000
Water Heater	-	-	1200.000
Washing Machine	300.000	270.000	275.000
Computer	300.000	300.000	300.000
Other	142.656	161.672	170.624

Source: Results from Actual Data Analysis, (2002).

Table E.4: Average Usage Hours per Day of Electric Appliances by Income Level, [Hour]

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	3.833	4.713	4.261
Fluorescent (20 W)	3.108	2.790	2.518
Fluorescent (32 W)	-	1.273	2.014
Fluorescent (40 W)	2.143	3.435	2.079
Incandescent (5 W)	7.925	8.319	8.205
Incandescent (25 W)	-	1.000	1.000
Compact Fluorescent (9 W)	7.624	7.991	8.035
Radio/Tape/VCD/CD-player	5.496	5.315	5.583
Television	5.644	5.738	5.608
Electric Fan	5.272	5.195	5.755
Air-conditioner	-	4.000	5.693
Refrigerator	12.000	12.000	12.000
Iron	0.251	0.282	0.287
Rice Cooker	0.603	0.720	0.703
Electric Stove	-	0.901	0.989
Electric Pot	0.402	0.527	0.495
Microwave	-	-	0.322
Vacuum	-	-	0.281
Aspirator	-	1.000	0.960
Electric Pump	0.255	0.250	0.250
Water Heater	-	-	0.527
Washing Machine	0.250	0.285	0.277
Computer	1.600	1.906	2.122
Other	0.430	0.500	0.642

Source: Results from Actual Data Analysis, (2002).

Table E.5 presents average energy consumption per day per household by income level using inefficient lighting equipments and refrigerators. Table E.6 presents average energy consumption per day per household by income level using efficient lighting equipments and refrigerators.

Table E.5: Average Energy Consumption per Day per Household by Income Level, [Wh]

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	51.516	42.304	28.907
Fluorescent (20 W)	279.434	585.431	802.054
Fluorescent (32 W)	-	12.114	135.806
Fluorescent (40 W)	41.396	237.647	278.189
Incandescent (5 W)	45.529	56.153	18.830
Incandescent (25 W)	-	13.050	95.600
Compact Fluorescent (9 W)	16.056	84.721	216.945
Radio/Tape/VCD/CD-player	62.053	125.677	214.194
Television	256.600	319.312	458.589
Electric Fan	272.168	826.492	1182.737
Air-conditioner	-	264.160	6778.836
Refrigerator	74.169	487.188	1,003.236
Iron	183.481	282.000	287.000
Rice Cooker	22.793	184.896	193.606
Electric Stove	-	250.478	337.249
Electric Pot	40.039	191.617	220.077
Microwave	-	-	18.483
Vacuum	-	-	72.779
Aspirator	-	4.500	44.237
Electric Pump	5.912	7.636	17.296
Water Heater	-	-	513.509
Washing Machine	3.900	41.553	54.465
Computer	13.920	101.780	306.841
Other	32.573	50.280	89.057
Total Energy Consumption per Day	1,401.567	4,168.990	13,3368.520

Source: Results from Actual Data Analysis, (2002).

Table E.6: Average Energy Consumption per Day per Household by Income Level, [Wh]

Appliances	Income Level		
	Low	Medium	High
Fluorescent (10 W)	41.856	34.372	23.487
Fluorescent (18 W)	209.576	439.073	601.540
Fluorescent (32 W)	-	10.871	121.877
Fluorescent (36 W)	34.350	197.196	230.838
Incandescent (5 W)	45.529	56.153	18.830
Incandescent (25 W)	-	13.050	95.600
Compact Fluorescent (9 W)	16.056	84.721	216.945
Radio/Tape/VCD/CD-player	62.053	125.677	214.194
Television	256.600	319.312	458.589
Electric Fan	272.168	826.492	1182.737
Air-conditioner	-	264.160	6778.836
Refrigerator	70.200	456.300	878.664
Iron	183.481	282.000	287.000
Rice Cooker	22.793	184.896	193.606
Electric Stove	-	250.478	337.249
Electric Pot	40.039	191.617	220.077
Microwave	-	-	18.483
Vacuum	-	-	72.779
Aspirator	-	4.500	44.237
Electric Pump	5.912	7.636	17.296
Water Heater	-	-	513.509
Washing Machine	3.900	41.553	54.465
Computer	13.920	101.780	306.841
Other	32.573	50.280	89.057
Total Energy Consumption per Day	1,311.007	3,942.119	12,976.735

Source: Results from Actual Data Analysis, (2002).

Table E.7: Electricity Consumption by Type of Appliance in the Low Income Level

Electric Appliances	Average Energy, [Wh/HH/Day]
Lighting	433.931
Electric Fan	272.168
Television	256.600
Electric Iron	183.481
Refrigerator	74.169
Radio/Tape/VCD/CD-player	62.053
Electric Pot	40.039
Other Appliances	32.573
Rice Cooker	22.793
Computer	13.920
Electric Pump	5.912
Washing Machine	3.900
Total Average Energy	1,401.567

Source: Compiled Real Data from Field Work Survey

Table E.8: Electricity Consumption by Type of Appliance in the Medium Income Level

Electric Appliances	Average Energy, [Wh/HH/Day]
Lighting	1,031.420
Electric Fan	826.492
Refrigerator	487.188
Television	319.312
Electric Iron	282.000
Air-Conditioner	264.160
Electric Stove	250.478
Electric Pot	191.617
Rice Cooker	184.896
Radio/Tape/VCD/CD-player	125.667
Computer	101.780
Other Appliances	50.280
Washing Machine	41.553
Electric Pump	7.636
Aspirator	4.500
Total Average Energy	4,168.990

Source: Compiled Real Data from Field Work Survey

Table E.9: Electricity Consumption by Type of Appliance in the High Income Level

Electric Appliances	Average Energy, [Wh/HH/Day]
Air-Conditioner	6,778.836
Lighting	1,576.331
Electric Fan	1,182.737
Refrigerator	1,003.236
Water Heater	513.509
Television	458.589
Electric Stove	337.249
Computer	306.841
Electric Iron	287.000
Electric Pot	220.077
Radio/Tape/VCD/CD-player	214.194
Rice Cooker	193.606
Other Appliances	89.057
Vacuum	72.779
Washing Machine	54.465
Aspirator	44.237
Microwave	18.483
Electric Pump	17.296
Total Average Energy	13,368.520

Source: Compiled Real Data from Field Work Survey

Table E.10: Household Electricity Consumption by Type of Appliance in the Residential Sector, [Wh/HH/Day]

Appliances	Income Level			Total
	High	Medium	Low	
Air-conditioner	6,779.00	264.00	0.00	7,043.00
Lighting	1,576.00	1,031.00	433.00	3,040.00
Electric Fan	1,183.00	826.00	272.00	2,281.00
Refrigerator	1,003.00	487.00	74.00	1,564.00
Television	459.00	319.00	257.00	1,035.00
Electric Iron	287.00	282.00	183.00	752.00
Electric Stove	337.00	250.00	0.00	587.00
Water Heater	514.00	0.00	0.00	514.00
Electric Pot	220.00	192.00	40.00	452.00
Computer	307.00	102.00	14.00	423.00
Radio/tape/VCD/CD-player	214.00	126.00	62.00	402.00
Rice Cooker	194.00	185.00	23.00	402.00
Other Appliances	89.00	50.00	33.00	172.00
Washing Machine	54.00	42.00	4.00	100.00
Vacuum	73.00	0.00	0.00	73.00
Aspirator	44.00	5.00	0.00	49.00
Electric Pump	17.00	8.00	6.00	31.00
Microwave	18.00	0.00	0.00	18.00
Total electricity consumption	13,368.00	4.169.00	1,401.00	18,938.00

Source: Compiled from Tables E.7, E.8, and E.9

Table E.11: The Share of Household Electricity Consumption by Type of Appliance in the Residential Sector, [%]

Appliances	Income Level			Total
	High	Medium	Low	
Air-conditioner	50.71	6.33	0.00	37.19
Lighting	11.79	24.73	30.91	16.05
Electric Fan	8.85	19.81	19.41	12.04
Refrigerator	7.50	11.68	5.28	8.26
Television	3.43	7.65	18.34	5.47
Electric Iron	2.15	6.76	13.06	3.97
Electric Stove	2.52	6.00	0.00	3.10
Water Heater	3.85	0.00	0.00	2.71
Electric Pot	1.65	4.61	2.86	2.39
Computer	2.30	2.45	1.00	2.23
Radio/tape/VCD/CD-player	1.60	3.02	4.43	2.12
Rice Cooker	1.45	4.44	1.64	2.12
Other Appliances	0.67	1.20	2.36	0.91
Washing Machine	0.40	1.01	0.29	0.53
Vacuum	0.55	0.00	0.00	0.39
Aspirator	0.33	0.12	0.00	0.26
Electric Pump	0.13	0.19	0.43	0.16
Microwave	0.13	0.00	0.00	0.10
Total	100.00	100.00	100.00	100.00

Source: Compiled from Table E.10

APPENDIX – F

DETAILS OF RESULTS FROM FORECASTING

Table F.1: Electricity Demand Projection by Type of Appliance in Low Income Level in the Base Case of All GDP Growths, [GWh]

Appliances	Electricity demand by appliance in selected years								
	3% GDP growth			5.5% GDP growth			8% GDP growth		
	2002	2007	2012	2002	2007	2012	2002	2007	2012
Fl (10 W)	1.11	1.51	1.98	1.10	1.48	1.88	1.10	1.44	1.75
Fl (20 W)	6.00	8.21	10.76	5.98	8.02	10.20	5.96	7.82	9.50
Fl (32 W)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fl (40 W)	0.89	1.22	1.59	0.89	1.19	1.51	0.88	1.16	1.40
Inc (5 W)	0.98	1.34	1.75	0.97	1.31	1.66	0.97	1.27	1.55
Inc (25 W)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C Fl (9 W)	0.34	0.47	0.62	0.34	0.46	0.59	0.34	0.45	0.55
Radio/Player	1.33	1.82	2.39	1.33	1.78	2.27	1.32	1.74	2.11
Television	5.51	7.54	9.88	5.49	7.37	9.37	5.47	7.18	8.72
Electric Fan	5.84	8.00	10.48	5.82	7.82	9.94	5.80	7.62	9.25
Air-conditioner	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Refrigerator	1.59	2.18	2.86	1.59	2.13	2.71	1.58	2.08	2.52
Electric Iron	3.94	5.39	7.06	3.93	5.27	6.70	3.91	5.13	6.24
Rice Cooker	0.49	0.67	0.88	0.49	0.65	0.83	0.49	0.64	0.77
Electric Stove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electric Pot	0.86	1.18	1.54	0.86	1.15	1.46	0.85	1.12	1.36
Microwave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vacuum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspirator	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electric Pump	0.13	0.17	0.23	0.13	0.17	0.22	0.13	0.17	0.20
Water Heater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wash. Machine	0.08	0.11	0.15	0.08	0.11	0.14	0.08	0.11	0.13
Computer	0.30	0.41	0.54	0.30	0.40	0.51	0.30	0.39	0.47
Other	0.70	0.96	1.25	0.70	0.94	1.19	0.69	0.91	1.11
Total Energy	30.07	41.17	53.95	29.98	40.25	51.16	29.89	39.22	47.65

Table F.2: Electricity Demand Projection by Type of Appliance in Medium Income Level in the Base Case of All GDP Growths, [GWh]

Appliances	Electricity demand by appliance in selected years								
	3% GDP growth			5.5% GDP growth			8% GDP growth		
	2002	2007	2012	2002	2007	2012	2002	2007	2012
Fl (10 W)	0.94	1.33	1.82	0.94	1.36	1.88	0.95	1.38	1.96
Fl (20 W)	13.04	18.47	25.17	13.07	18.76	26.05	13.10	19.08	27.15
Fl (32 W)	0.27	0.38	0.52	0.27	0.39	0.54	0.27	0.39	0.56
Fl (40 W)	5.30	7.50	10.22	5.31	7.61	10.57	5.32	7.75	11.02
Inc (5 W)	1.25	1.77	2.41	1.25	1.80	2.50	1.26	1.83	2.60
Inc (25 W)	0.29	0.41	0.56	0.29	0.42	0.58	0.29	0.43	0.61
C Fl (9 W)	1.89	2.67	3.64	1.89	2.71	3.77	1.90	2.76	3.93
Radio/Player	2.80	3.97	5.40	2.81	4.03	5.59	2.81	4.10	5.83
Television	7.11	10.07	13.73	7.13	10.23	14.21	7.15	10.41	14.81
Electric Fan	18.42	26.08	35.54	18.46	26.48	36.77	18.50	26.94	38.32
Air-conditioner	5.89	8.33	11.36	5.90	8.46	11.75	5.91	8.61	12.25
Refrigerator	10.86	15.37	20.95	10.88	15.61	21.67	10.90	15.88	22.59
Electric Iron	6.28	8.90	12.13	6.30	9.04	12.55	6.31	9.19	13.08
Rice Cooker	4.12	5.83	7.95	4.13	5.92	8.23	4.14	6.03	8.57
Electric Stove	5.58	7.90	10.77	5.59	8.03	11.14	5.61	8.16	11.61
Electric Pot	4.27	6.05	8.24	4.28	6.14	8.53	4.29	6.25	8.89
Microwave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vacuum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspirator	0.10	0.14	0.19	0.10	0.14	0.20	0.10	0.15	0.21
Electric Pump	0.17	0.24	0.33	0.17	0.24	0.34	0.17	0.25	0.35
Water Heater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wash. Machine	0.93	1.31	1.79	0.93	1.33	1.85	0.93	1.35	1.93
Computer	2.27	3.21	4.38	2.27	3.26	4.53	2.28	3.32	4.72
Other	1.12	1.59	2.16	1.12	1.61	2.24	1.13	1.64	2.33
Total Energy	92.89	131.53	179.25	93.10	133.58	185.48	93.30	135.88	193.31

Table F.3: Electricity Demand Projection by Type of Appliance in High Income Level in the Base Case of All GDP Growths, [GWh]

Appliances	Electricity demand by appliance in selected years								
	3% GDP growth			5.5% GDP growth			8% GDP growth		
	2002	2007	2012	2002	2007	2012	2002	2007	2012
Fl (10 W)	0.30	0.43	0.58	0.30	0.43	0.59	0.30	0.44	0.61
Fl (20 W)	8.42	11.87	16.11	8.44	12.01	16.51	8.45	12.15	17.01
Fl (32 W)	1.43	2.01	2.73	1.43	2.03	2.79	1.43	2.06	2.88
Fl (40 W)	2.92	4.12	5.59	2.93	4.17	5.72	2.93	4.22	5.90
Inc (5 W)	0.20	0.28	0.38	0.20	0.28	0.39	0.20	0.29	0.40
Inc (25 W)	1.00	1.42	1.92	1.01	1.43	1.97	1.01	1.45	2.03
C Fl (9 W)	2.28	3.21	4.36	2.28	3.25	4.46	2.29	3.29	4.60
Radio/Player	2.25	3.17	4.30	2.25	3.21	4.41	2.26	3.25	4.54
Television	4.82	6.79	9.21	4.82	6.87	9.44	4.83	6.95	9.73
Electric Fan	12.42	17.51	23.75	12.44	17.71	24.34	12.46	17.92	25.08
Air-conditioner	71.18	100.36	136.13	71.29	101.49	139.50	71.41	102.77	143.77
Refrigerator	10.54	14.85	20.15	10.55	15.02	20.65	10.57	15.20	21.28
Electric Iron	3.01	4.25	5.76	3.02	4.30	5.91	3.02	4.35	6.09
Rice Cooker	2.03	2.87	3.89	2.04	2.90	3.98	2.04	2.93	4.11
Electric Stove	3.54	4.99	6.77	3.55	5.05	6.94	3.55	5.11	7.15
Electric Pot	2.31	3.26	4.42	2.31	3.29	4.53	2.32	3.33	4.67
Microwave	0.19	0.27	0.37	0.19	0.28	0.38	0.19	0.28	0.39
Vacuum	0.76	1.08	1.46	0.77	1.09	1.50	0.77	1.10	1.54
Aspirator	0.46	0.65	0.89	0.47	0.66	0.91	0.47	0.67	0.94
Electric Pump	0.18	0.26	0.35	0.18	0.26	0.36	0.18	0.26	0.37
Water Heater	5.39	7.60	10.31	5.40	7.69	10.57	5.41	7.78	10.89
Wash. Machine	0.57	0.81	1.09	0.57	0.82	1.12	0.57	0.83	1.16
Computer	3.22	4.54	6.16	3.23	4.59	6.31	3.23	4.65	6.51
Other	0.94	1.32	1.79	0.94	1.33	1.83	0.94	1.35	1.89
Total Energy	140.38	197.93	268.46	140.60	200.15	275.11	140.82	202.58	283.53

Note: The underlined word and number are used by a small font.

Table F.4: Electricity Demand Projection by Type of Appliance in Low Income Level in the Energy Efficiency Case of All GDP Growths, [GWh]

Appliances	Electricity demand by appliance in selected years								
	3% GDP growth			5.5% GDP growth			8% GDP growth		
	2002	2007	2012	2002	2007	2012	2002	2007	2012
Fl (10 W)	*1.11*	*1.23*	*1.61*	*1.10*	*1.20*	*1.53*	*1.10*	*1.17*	*1.42*
Fl (20 W)	*6.00*	*6.16*	*8.07*	*5.98*	*6.02*	*7.65*	*5.96*	*5.86*	*7.12*
Fl (32 W)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fl (40 W)	*0.89*	*1.01*	*1.32*	*0.89*	*0.99*	*1.25*	*0.88*	*0.96*	*1.17*
Inc (5 W)	0.98	1.34	1.75	0.97	1.31	1.66	0.97	1.27	1.55
Inc (25 W)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C Fl (9 W)	0.34	0.47	0.62	0.34	0.46	0.59	0.34	0.45	0.55
Radio/Player	1.33	1.82	2.39	1.33	1.78	2.27	1.32	1.74	2.11
Television	5.51	7.54	9.88	5.49	7.37	9.37	5.47	7.18	8.72
Electric Fan	5.84	8.00	10.48	5.82	7.82	9.94	5.80	7.62	9.25
Air-conditioner	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Refrigerator	*1.59*	*2.15*	*2.70*	*1.59*	*2.10*	*2.56*	*1.58*	*2.05*	*2.39*
Electric Iron	3.94	5.39	7.06	3.93	5.27	6.70	3.91	5.13	6.24
Rice Cooker	0.49	0.67	0.88	0.49	0.65	0.83	0.49	0.64	0.77
Electric Stove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electric Pot	0.86	1.18	1.54	0.86	1.15	1.46	0.85	1.12	1.36
Microwave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vacuum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspirator	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electric Pump	0.13	0.17	0.23	0.13	0.17	0.22	0.13	0.17	0.20
Water Heater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wash. Machine	0.08	0.11	0.15	0.08	0.11	0.14	0.08	0.11	0.13
Computer	0.30	0.41	0.54	0.30	0.40	0.51	0.30	0.39	0.47
Other	0.70	0.96	1.25	0.70	0.94	1.19	0.69	0.91	1.11
Total Energy	30.07	38.60	50.47	29.98	40.25	51.16	29.89	39.22	47.65

Table F.5: Electricity Demand Projection by Type of Appliance in Medium Income Level in the Energy Efficiency Case of All GDP Growths, [GWh]

Appliances	Electricity demand by appliance in selected years								
	3% GDP growth			5.5% GDP growth			8% GDP growth		
	2002	2007	2012	2002	2007	2012	2002	2007	2012
Fl (10 W)	*0.94*	*1.08*	*1.48*	*0.94*	*1.10*	*1.53*	*0.95*	*1.12*	*1.59*
Fl (20 W)	*13.04*	*13.85*	*18.88*	*13.07*	*14.07*	*19.53*	*13.10*	*14.31*	*20.36*
Fl (32 W)	*0.27*	*0.34*	*0.47*	*0.27*	*0.35*	*0.48*	*0.27*	*0.35*	*0.50*
Fl (40 W)	*5.30*	*6.22*	*8.48*	*5.31*	*6.32*	*8.77*	*5.32*	*6.43*	*9.14*
Inc (5 W)	1.25	1.77	2.41	1.25	1.80	2.50	1.26	1.83	2.60
Inc (25 W)	0.29	0.41	0.56	0.29	0.42	0.58	0.29	0.43	0.61
C Fl (9 W)	1.89	2.67	3.64	1.89	2.71	3.77	1.90	2.76	3.93
Radio/Player	2.80	3.97	5.40	2.81	4.03	5.59	2.81	4.10	5.83
Television	7.11	10.07	13.73	7.13	10.23	14.21	7.15	10.41	14.81
Electric Fan	18.42	26.08	35.54	18.46	26.48	36.77	18.50	26.94	38.32
Air-conditioner	5.89	8.33	11.36	5.90	8.46	11.75	5.91	8.61	12.25
Refrigerator	*10.86*	*15.08*	*19.62*	*10.88*	*15.31*	*20.30*	*10.90*	*15.56*	*21.16*
Electric Iron	6.28	8.90	12.13	6.30	9.04	12.55	6.31	9.19	13.08
Rice Cooker	4.12	5.83	7.95	4.13	5.92	8.23	4.14	6.03	8.57
Electric Stove	5.58	7.90	10.77	5.59	8.03	11.14	5.61	8.16	11.61
Electric Pot	4.27	6.05	8.24	4.28	6.14	8.53	4.29	6.25	8.89
Microwave	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vacuum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspirator	0.10	0.14	0.19	0.10	0.14	0.20	0.10	0.15	0.21
Electric Pump	0.17	0.24	0.33	0.17	0.24	0.34	0.17	0.25	0.35
Water Heater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wash. Machine	0.93	1.31	1.79	0.93	1.33	1.85	0.93	1.35	1.93
Computer	2.27	3.21	4.38	2.27	3.26	4.53	2.28	3.32	4.72
Other	1.12	1.59	2.16	1.12	1.61	2.24	1.13	1.64	2.33
Total Energy	92.89	131.53	179.25	93.10	133.58	185.48	93.30	135.88	193.31

Table F.6: Electricity Demand Projection by Type of Appliance in High Income Level in the Energy Efficiency Case of All GDP Growths, [GWh]

Appliances	Electricity demand by appliance in selected years								
	3% GDP growth			5.5% GDP growth			8% GDP growth		
	2002	2007	2012	2002	2007	2012	2002	2007	2012
Fl (10 W)	*0.30*	*0.35*	*0.47*	*0.30*	*0.35*	*0.48*	*0.30*	*0.36*	*0.50*
Fl (20 W)	*8.42*	*8.91*	*12.08*	*8.44*	*9.01*	*12.38*	*8.45*	*9.12*	*12.76*
Fl (32 W)	*1.43*	*1.80*	*2.45*	*1.43*	*1.82*	*2.51*	*1.43*	*1.85*	*2.58*
Fl (40 W)	*2.92*	*3.42*	*4.64*	*2.93*	*3.46*	*4.75*	*2.93*	*3.50*	*4.90*
Inc (5 W)	0.20	0.28	0.38	0.20	0.28	0.39	0.20	0.29	0.40
Inc (25 W)	1.00	1.42	1.92	1.01	1.43	1.97	1.01	1.45	2.03
C Fl (9 W)	2.28	3.21	4.36	2.28	3.25	4.46	2.29	3.29	4.60
Radio/Player	2.25	3.17	4.30	2.25	3.21	4.41	2.26	3.25	4.54
Television	4.82	6.79	9.21	4.82	6.87	9.44	4.83	6.95	9.73
Electric Fan	12.42	17.51	23.75	12.44	17.71	24.34	12.46	17.92	25.08
Air-conditioner	71.18	100.36	136.13	71.29	101.49	139.50	71.41	102.77	143.77
Refrigerator	*10.54*	*14.32*	*17.64*	*10.55*	*14.47*	*18.08*	*10.57*	*14.63*	*18.64*
Electric Iron	3.01	4.25	5.76	3.02	4.30	5.91	3.02	4.35	6.09
Rice Cooker	2.03	2.87	3.89	2.04	2.90	3.98	2.04	2.93	4.11
Electric Stove	3.54	4.99	6.77	3.55	5.05	6.94	3.55	5.11	7.15
Electric Pot	2.31	3.26	4.42	2.31	3.29	4.53	2.32	3.33	4.67
Microwave	0.19	0.27	0.37	0.19	0.28	0.38	0.19	0.28	0.39
Vacuum	0.76	1.08	1.46	0.77	1.09	1.50	0.77	1.10	1.54
Aspirator	0.46	0.65	0.89	0.47	0.66	0.91	0.47	0.67	0.94
Electric Pump	0.18	0.26	0.35	0.18	0.26	0.36	0.18	0.26	0.37
Water Heater	5.39	7.60	10.31	5.40	7.69	10.57	5.41	7.78	10.89
Wash. Machine	0.57	0.81	1.09	0.57	0.82	1.12	0.57	0.83	1.16
Computer	3.22	4.54	6.16	3.23	4.59	6.31	3.23	4.65	6.51
Other	0.94	1.32	1.79	0.94	1.33	1.83	0.94	1.35	1.89
Total Energy	140.38	197.93	268.46	140.60	200.15	275.11	140.82	202.58	283.53

APPENDIX – G

ANSWERS TO EXTERNAL EXAMINER'S COMMENTS

G.1 Literature Review

George S. Donatos and George J. Mergoes, (1991). Examined the factors that determine the electricity demand in the residential sector starting with an overview of the evolution of consumption and then with the econometric estimation single equation demand model using time-series data for the period 1961-1986 in Greece. Used the ridge regression technique, which gave efficient estimation results to overcome the problem of multicolinearity. The results show that the residential electricity demand in Greece is price inelastic and income elastic, and the number of customers has a strong positive impact on demand.

Joseph C. Lam, (1998). Performed regression and correlation analyses to investigate the relationships between residential electricity consumption and economic variables and climatic factors for Hong Kong. Economic and energy data from 1971 to 1993 were analyzed and it was found that both the seasonal and yearly electricity use in the residential sector can be estimated based on four independent variables, namely average household income, household size, electricity price and cooling degree-days. The first three variables relate to economic conditions and living standard and the last variable accounts for seasonal variation due to the air-conditioning equipment. He presented that besides climatic influences, residential electricity consumption is affected by the social, economic and demographic conditions.

Walker, J.M., (1979). Reported the results of monthly electricity demand for residential customers during the summer months of 1972-1975. Factors influencing electricity use were weather, the real price of electricity, and appeals for energy conservation. This study has used an econometric model with log linear demand function. The model can be specified as:

$$\ln U_{it} = A_0 + A_i + B_1 \ln C_{it} + B_2 \ln Y_t + B_3 E_t + B_4 \ln MP_{t-1} + e_{it}$$

where: $\ln U_{it}$ = log of monthly use for individual i in month t

A_0 = overall model intercept

A_i = subject i's intercept variation from the model intercept

$\ln C_{it}$ = log of the number of cooling degree days during month t for individual i

$\ln Y_t$ = the log of estimated real disposable income

E_t = a two-level dummy variable with a value of 0 for 1972, 1973 and 1 for 1974, 1975.

$\ln MP_{t-1}$ = the log of the real marginal price of electricity in period t-1

e_{it} = a random error term

The results offer a test of those parameter estimates obtained using data aggregated over households as well as further evidence of the short-run demand for electricity in the residential sector.

Chern and Bouis (1988), investigated the structural changes in residential electricity demand by using pooled time-series and cross-section data for the USA from 1955-78. The results show that there have been significant structural changes in demand elasticities for several independent variables. These changes can be best explained by changes in household stocks of major electric appliances as new technologies have been developed, improvements in consumer lifestyles and preference functions over time. Price and income elasticities of residential electricity demand are essential for projecting future electricity demand growth and for managing effectively various energy pricing and conservation policies.

Huang J.P, (1993). Examined the relationship between electricity consumption and economic growth in China during 1950-80. This study used two models, the first one is the energy intensity model (electricity-GDP ratio) and the second one is the elasticity model (income elasticities of electricity). Electricity-GDP ratio is defined as the amount of electricity consumed per dollar of GDP. The results of this study show that the electricity-GDP ratio increased over time with a growth rate of 7.3% in this period. The study used the following for income elasticites:

$$\ln E_t = a + b \ln Y_t \qquad (1)$$

$$\ln E_t = a + b \ln Y_t + c \ln E_{t-1} \qquad (2)$$

where E_t, Y_t are respectively per capita total electricity consumption and per capita GDP; subscript -1 represents one year lagged value. The parameters a, b, and c are regression equations that can be estimated using ordinary least squares fit. In equation (1) b is the income elasticity and in equation (2) income elasticity should be estimated by computing b/(1-c). The results of income elasticity of electricity consumption show that income elasticity is significantly greater than 1, ranging from 2.33 to 2.72 in this period.

Mohammed A. Al-Sahlawi, (N/A). Estimated the demand for electricity and used the bootstrap technique to forecast, for the first time, the peak electricity demand of Saudi Arabia in 1995, and estimate its probability distribution. The assumption of the average demand for electricity is given as a constant proportion of the peak demand, which can be specified in a general log-linear relationship:

$$\text{Log } Y_t = a + \beta \text{ Log } Z_t \qquad (1)$$

Where: $Y_t = a + \beta \text{ Log } Z_t$

Z_t = average demand per year in mW

a, β = parameters

Average demand is determined by real gross domestic product (RGDP), lagged average demand ($Z_t - 1$), and time trend (T). The price of electricity is omitted from the analysis since it did not change over the estimated period and had no significant effect on electricity consumption. The average demand equation is:

$$\text{Log } Z_t = \gamma_0 + \gamma_1 \text{ Log RGDP}_t + a + \gamma_2 \text{ Log } Z_{t-1} + \gamma_3 \text{ Log T} \qquad (2)$$

The study presented income elasticity of the demand for electricity, which is very important for forecasting and planning. Average demand for electricity in Saudi Arabia is income inelastic in the short run but is slightly elastic in the long run.

Sensitivity analysis indicates that a 2% annual growth rate in RGDP from 1985 to 1995 would yield average demand of 29,971 mW and a consequent peak load of 63,797 mW, while higher income elasticity of 1.5 would increase average demand and peak load by 1995 substantially to 63,664 mW and 137,678 mW, respectively.

G.2 Factors Influencing Electricity Demand

According to the empirical analyses, the factors or parameters influencing electricity demand in the residential sector are household characteristics, price of electricity, changes of the socio-economy, income level, characteristics of electric appliances, climatic variations, etc. Subtitles presenting the empirical analyses of these factors are as follows:

G.2.1 Household Characteristics

- The growth in total residential electricity consumption is due to an increase in the number of households. The growth in the number of households is a result of population growth (Bente Halvorson, Bodil M. Larsen, 2001).
- Household size, and housing unit size have a significant affect on electricity consumption. Large household sizes consume more electricity than small household sizes. The large size of the housing unit on electricity use consumes more electricity than the small size of the housing unit. (Raphael Branch E., 1993).
- The elasticity coefficient for the household size is 0.9, and a 1% increase will cause 0.9% rise in consumption (Joseph C. Lam, 1998).
- When the household size increases, the electricity consumption also increases. The greater the number of rooms the more is the requirement of electrical fixtures (Piyush Tiwari, 2000).

G.2.2 Price of Electricity

- The changes in electricity price have a substantial influence on the consumption level, and the increasing of electricity taxes is an effective instrument for reducing household electricity consumption (Bente Halvorsen, Bodil M. Larsen, 2001).

- The partial own-price elasticities vary from –1.29 to –2.42. These values show that the demand for electricity during both peak and off-peak periods is responsive to changes in price. A 1% increase in the peak price of electricity will result in about a 1.3% decline in the per household consumption of peak electricity, while a 1% increase in the off-peak price will result in about a 2.4% decline in the per household consumption of off-peak-electricity (Massimo Filippini, 1995).

- The price elasticity is –0.183, indicating a 0.18% reduction in electricity use with a 1% increase in electricity price (Joseph C. Lam, 1998).
- The residential electricity consumption is inelastic with respect to both income and price. The price elasticity is –0.70, while the income elasticity is 0.34 (Piyush Tiwari, 2000).

G.2.3 Changes in the Socio-Economy

- Structural changes in the economies of the OECD countries also have a strong influence on electricity demand, through the effects of increased personal income and changes in lifestyle (Genevieve McInnes, et al, 1991).
- An increase in gross domestic product (GDP) implicates an increase in electrical energy consumption (Nasr G. E., et al, 2000).
- With the economy soaring in recent years, urbanization progresses fast and resident incomes are increasing rapidly in China. This makes urban household-electricity use the most active component of electricity consumption growth (Falong Yan, 1995).
- With rapid economic growth and improvements in living standards, there has been a substantial increase in energy consumption during the eighties (Joseph C. Lam, 1998).
- The measure of economic development is expected to increase the consumption of electricity. The reason is twofold. First, urbanization implies greater access to electricity, since households can be more easily connected to the grid. Second, those consumers that already had access to electricity before moving are likely to increase their consumption once they arrive in an urban setting (Pernille Holtedahl, et al, 2000).

G.2.4 Income Level

- The annual income elasticity is 0.533, and a 1% increase in income will result in 0.53% increase in the annual electricity use (Joseph C. Lam, 1998).
- The income of households is the single most important determinant of residential electricity consumption. This variable captures, besides a number of behavioural

effects related to variations in income, the number and size of appliances that a household possess (Piyush Tiwari, 2000).

- Income measured at a constant price rose by an average 1.6% a year measured along a linear trend. This means that income has a significant effect on electricity consumption. This would, therefore, point to increased electricity consumption per household in a period due to an increase in household income (Bente Halvorsen, Bodil M. Larsen, 2001).
- The income variable also represents some unobservables like the size and the characteristics of appliances. For example, it is expected that families with higher income may choose a larger freezer (Rudolf K. H. Dennerlein, 1987).

G.2.5 Characteristics of Electric Appliances

- The electricity consumption rises with the stock of electric appliances and this stock of appliances has a relatively large impact on electricity consumption. For many types of appliances, technological advances have occurred over time, which make the appliance more energy efficient. The purchase of new appliances, therefore, influences electricity consumption both through a change in the stock of appliances and through more energy efficient appliances (Bente Halvorsen, Bodil M. Larsen, 2001).
- Based on the presumption that, with the development of more efficient machinery and appliances in the related sectors, the real energy demand would be reduced for the same numbers of machinery and appliances (Tripathy S. C., 1997).
- The use of appliances and stock of appliances are major determinants of the demand for residential electricity (Piyush Tiwari, 2000).
- Some of the appliances that are popular in developed countries are often not so popular in developing countries. This is due to the lower standard of living and the high cost of electricity (Bilal A. Akash, Mousa S. Mohsen, 1999).
- The increase in demand will take place through increased use of existing appliances (the utilization rate), and through the purchase of new ones (increased stock of capital-using equipment) (Pernille Holtedahl, et al, 2000).

G.2.6 Climatic Variations

- For the cooling requirement, a 1% increase in cooling degree-days (CDD) will result in a 0.22% rise in the electricity consumption (Joseph C. Lam, 1998).
- The variations in ambient temperature cause virtually all of the variations in energy consumption (Alan Meier, 1995).

G.3 End-use Model Analyses

Like other models, the development of end-use models has been influenced by the nature of the available data and the finiteness of various resources. Improvements and extensions are always possible. One important limitation of the present version of the end-use model is the absence of price variables. For the electric appliances included in the end-use model, the driving variables for simulating electricity demand are the unit electricity consumption of an end-use for different household income levels. According to electricity consumption for households in each income level that are different, the effect of the price variables on electricity demand could be represented by the average number and usage hours of electric appliances owned by the different income levels.

The proportion of households in the low income level will gradually decrease and shift to the medium or high income levels. Therefore, electric appliance penetration rates could be generally varied across household income classes. New electric appliances could be purchased through the improvement of the number of electrified households. Moreover, the number of electric appliances will be increased by shifting the number of households in low income level to medium or high income for every year.

The end-use model is a function of the number of electrified households in each income level, average numbers of electric appliances, average usage hours, and average capacity of electric appliances. According to the lack of data, limited time, the scope of this study, and the end-use model, the household electricity demand projection for the residential sector in Phnom Penh could be considered the only four variables as the input parameters. For the efficient improvement, this study has also considered some of electric appliances, such as efficient lighting and efficient refrigerators to examine the energy efficient program in case the current use of these appliances are still occurring in Cambodia.

In the further study, the other modeling analyses, such as econometric analysis, time series analysis, correlation coefficient analysis, regression analysis, and so on, should be used to analyze the price of electricity and electric appliances related to electricity demand for all sectors in Cambodia.

In the further study, for the efficient program, the planner should consider the government's policy, the least cost, such as price of electricity and price of efficient appliances that could make people have willingness to use the efficient appliances.

To reach the accurate forecasting of electricity demand in the future study should have adequate data and information, which are suitable for the modeling analyses. The corporation of modeling analyses and the systematic analyses should be used to achieve good results and to determine the factors that have an impact on electricity demand for all sectors.