ECONOMIC EVALUATION OF SMALL WIND GENERATION OWNERSHIP UNDER DIFFERENT ELECTRICITY PRICING SCENARIOS

by

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Abstract

With the Smart Grid trend setting in, various techniques to make the existing grid smarter are being considered. The price of electricity is one of the major factors, which affects the electric utility as well as the numerous consumers connected to the grid. Therefore deciding the right price of electricity for the time of day would be an important decision to make. Consumers' response to this change in price will impact peak demand as well as their own annual energy bill. Owning a small wind generator under the Critical Peak Pricing (CPP) and Time of Use (TOU) price-based demand response programs could be a viable option. Economic evaluation of owning a small wind generator under the two pricing schemes, namely Critical Peak Pricing (CPP) and Time of Use (TOU), is the main focus of this research. Analysis shows that adopting either of the pricing schemes will not change the annual energy bill for the consumer. Taking into account the installed cost of the turbine, it may not be significantly economical for a residential homeowner to own a small wind turbine with either of the pricing schemes in effect under the conditions assumed.

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Acronyms

TOU	Time of Use
RTP	Real-time Pricing
CPP	Critical Peak Pricing
ISO	Independent System Operator
RTO	Regional Transmission Organization
DR	Demand Response
NPV	Net Present Value

CHAPTER 1 - Introduction

With the increase in global population, the demand for energy has also been on the rise. Over a course of time, this rise in demand for energy would completely deplete our energy resources. Our main source of energy currently is fossil fuels that include coal, oil and gas. This brings in the need to tap other sources of energy like wind, solar, geothermal and many other renewable sources of energy. Another main reason for switching to renewable sources of energy would be the effect of burning fossil fuels on global warming. Presently, global warming and climate change have become a matter of major concern. This research will further focus only on wind energy and also determine if owning a wind generator would be feasible for a residential homeowner under certain assumed conditions.

Wind Generation

What is wind energy? The sun's radiation heats different parts of the earth at different rates during the day. Different surfaces (land and water) absorb or reflect this heat at different rates. This causes portions of the atmosphere to heat up differently. Hot air rises reducing the atmospheric pressure at the earth's surface and cooler air is drawn to replace it. This phenomenon results in 'wind', which can be used to drive wind machines to generate electricity [1]. Tapping this form of clean energy reduces greenhouse gas emissions. With wind energy the question of reliability would arise, but reliability remains an issue even with conventional sources of energy where significant generation reserves are required to accommodate unexpected changes in electricity supply and demand. Wind is variable and intermittent in nature. It is also non-dispatchable, implying that its output can be controlled only to a limited extent. Therefore wind power should be combined with other utility generation to make electrical service more reliable [2]. The wind energy capacity installed worldwide has increased rapidly over the years. Common people are thinking of moving towards more cleaner and greener energy sources. Therefore, the question of owning a wind or solar generator and its affordability arises. This is the main focus of this research. Another rising trend is the implementation of a smarter and more reliable grid. The electric industry is trying to make the transformation from a centralized, producer-controlled network to a one that is less centralized and more consumer-interactive. Adoption of the Smart Grid would enhance all parts of the electric delivery system that includes generation, transmission, distribution and consumption. Smart Grid will energize the utility initiatives that encourage consumers to modify patterns of electric usage, including the timing and level of electricity demand. It also increases the possibilities of distributed generation, bringing generation closer to its consumers. The shorter the distance from generation to consumption, the more efficient, economical and green it would be. Therefore, the Smart Grid will empower consumers to become active participants in their energy choices to a degree never possible before [3].

Demand Response

Enabling or encouraging customers to modify their electric usage patterns can be done through Demand Response. Demand Response allows retail customers to participate in electricity markets by giving them the ability to respond to prices as they change over time, either daily or hourly in most instances. Methods to engage customers in demand response include offering a retail electricity rate that reflects the time-varying nature of electricity costs or programs that provide incentives to reduce load at critical times [4]. In general Demand Response can be defined as: changes in electric usage by end-use consumers from their normal consumption patterns in response to changes in the price of electricity with time of day (or) in response to incentive payments at times of high wholesale market prices or when the system is unable to meet the load demand [5]. The modern methods of pricing can be broadly classified into two types, static and dynamic pricing. In static pricing, prices vary across peak and off-peak hours and sometimes also across seasons. The rates and pricing periods are fixed ahead of time. An example of static pricing is Time of Use pricing (TOU). In the case of dynamic pricing the prices rise substantially by known amounts during critical peak hours. They are communicated to customers on a day-ahead basis through phone, e-mail or other media. An example for dynamic pricing is the Critical Peak Pricing (CPP) [6]. The CPP and TOU pricing schemes will be explained in detail in later sections. With these pricing schemes in effect residential customers may have to turn up the set-point on their central air conditioner or reschedule their kitchen and laundry activities to avoid running their appliances during high priced hours without making any drastic changes in their lifestyle. The higher priced peak hours are accompanied by lower priced off-peak hours, providing customers with an opportunity to reduce their electricity bill through these actions. The effect of these pricing schemes on the customer's annual energy bill could directly affect customer satisfaction. Advanced Metering Infrastructure (AMI) will enable real-time pricing. AMI includes communication networks and database systems that will help modernize the existing grid providing benefits to both the utility and the consumer. It involves a two-way communication between the electric companies and the consumers through smart meters and other energy management devices. This makes it simple and quicker for the electric company to respond to problems in the system and also communicate the real-time electricity prices. On the whole, this implementation would improve reliability of the system.

Table 1.1 Distribution of energy consumption by common household appliances [7]

Appliances	Energy Consumption (in percentage)
Heating and Cooling	45
Water Heater	11
Clothes Washer & Dryer	10
Lighting	7
Refrigerator	6
Dishwasher	2
Computer & Monitor	2
TV, VCR,DVD	2
Other	15

Table 1.1 gives an idea of some of the common home appliances and their percentage of overall energy consumption. The 'Other' category included in the pie-chart applies to stoves, microwaves, ovens and small appliances. Most of the devices like TV, VCR or DVD players account for no more than 2% of a household's energy bill. Heating and cooling are the major contributors to energy consumption. The deferrable loads include dishwasher, clothes washer and dryer. Usage of these loads can be moved to the time of day when the price of electricity is low or in other words when the off-peak rate prevails. The Demand Response process flow would resemble Figure 1.2.

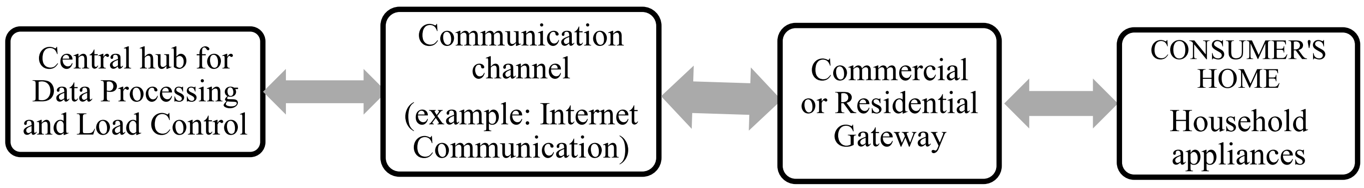

Figure 1.1 Residential Architecture for Demand Response [8]

All the appliances of the house are connected to a Smart Metering device that is installed at the home. This device helps to monitor energy consumption at regular intervals and also enables remote communication to the Data Processing or Load Control Unit of the utility. It is a two-way communication system between the consumer and the utility. Smart Meters enable the implementation of Demand Response by communicating the price of electricity to the consumer on a day-ahead basis depending on the demand response program.

Small Wind Turbines

The United States is the main market for small wind turbines in the world, with more than 100,000 small turbines in operation in the 90W to 100kW size range, totaling more than 80MW. Small wind turbines that fall under the category of micro turbines have their rated output power between 1kW and 7kW. Depending on the size of the system, the small wind turbines are used for wind home systems, hybrid systems and wind-diesel systems. A market with great potential for small wind turbines is in grid connected applications for residential, industrial or urban environments. In response to the increase in energy prices and increase in demand for on-site generation, distributed wind application assures rapid market growth [9]. The decision to own a small wind generator would depend on, the wind profile of the location under consideration, if tall towers are permitted in and around the location or not, open space without obstruction, how much electricity is needed or in other words how much should be produced and finally if it would be economical. Wind energy systems can be one of the most cost-effective home-based renewable energy systems in locations with good wind or if the location is very remote and far away from the grid.

Turbines used in residential applications can range in size from 400W to 100kW. An energy budget would help determine the turbine size. Usually, energy efficiency is less expensive than energy production therefore making the house more energy efficient would be more cost-effective and it will also reduce the size of the turbine needed.

Installation cost of the turbine can vary greatly depending on the local zoning, permitting and utility interconnection costs. A general rule of thumb followed for estimating the cost of an industrial-scale turbine is $1000 to $5000 per KW. Wind energy becomes more cost-effective as the turbine's rotor size increases. Although small turbines cost less in an initial outlay, they are proportionally more expensive. An installed residential wind energy system with an 80-foot tower, batteries and inverter can typically range from $15,000 to $50,000 for a 3 to 10KW wind turbine.

The length of the payback period, which is the time before the savings resulting from the wind-energy system equals the cost of the system, completely depends on the system chosen, wind-resource at the site, electricity costs in the area and finally on how the system is used. Generally the turbine needs to be located upwind of buildings, obstacles or trees and it needs to be 30 feet above anything that is within 300 feet.

Small wind energy systems can be connected to the electric distribution system and are called grid-connected systems. A grid connected turbine can reduce consumption of utility supplied electricity for lighting, appliances and electric heat. If the turbine cannot deliver the amount of energy needed, the utility makes up for the difference. When the wind system produces more electricity than the household requires, the excess is stored or sold to the utility. The concept of net-metering allows customers to use their generation to offset their consumption over the entire billing period. This would help customers with on-site generation to receive the retail price for excess electricity they generate. Net metering varies by state and by the utility company depending whether legislated or directed by the Public Utility Commission [10].

Motivation

With the growing importance and need for renewable sources of energy, common man is thinking of owning a wind generator in his backyard or a solar panel on the roof of his house. Making the right decision depends on a number of factors including resource assessment, location, investment, and rebates available in the state being considered. The future would see more of the Smart Grid being implemented. This would involve demand response, smart meters and plug-in electric hybrid vehicles. Therefore the price of electricity per kWh as well as consumer load modification in response to the change in price would have to be taken into consideration. This research focuses on determining if owning a small wind generator would be economically feasible under the electricity pricing schemes. Effects of applying Critical Peak Pricing (CPP) and Time of Use (TOU) pricing to the annual electricity bill of a single household that owns a small wind generator is studied. Given the load data, renewable resource data and a power curve for the generation system to be considered any type of small-scale renewable energy system could be simulated for any desired period of time [11].The above stated approach was used to determine the annual energy bill savings for the consumer where the load profile, wind profile and the output of the turbine is known or pre-determined. A Monte-Carlo Simulation was used to determine a range of annual savings in order to determine the Net Present Value (NPV) for performing a cost-benefit analysis for the investment.

CHAPTER 2 - Demand Response

The energy crisis of 1973 resulted in the hike of oil prices over the years that has gradually lead to electricity rate increase and transformed the way electricity was consumed. To improve energy security, better ways of pricing electricity needed to be considered. Pricing innovation slowed down as utilities turned their attention to improving energy efficiency through demand-side management programs and government formulated codes and standard for new buildings and appliances. Experiments with electricity pricing have picked up pace presently and electric utilities are conducting experiments with various demand response mechanisms to improve the link between the retail and wholesale markets. An experiment was conducted in the state of California in the year 2003 with about 2500 residential and small commercial customers to test the various tariff designs [12]. Other states have started following similar experiments with great interest. However, barriers in bringing efficient pricing into effect, such as acceptance by customers, still exist. The purpose of the experiments was to measure the overall expected peak reduction and change in consumption patterns by customers. The results show that it is possible to develop dynamic pricing for all customer classes: residential, commercial and industrial to benefit both the customers and the utilities. The dynamic rates were developed in such a way as to revenue-neutralize the existing rates of electricity, which in other words means that the utility's revenue would be unaffected by the new rates in the absence of any change in customer consumption behavior [12] [13] [14].

Recognizing the importance of demand response, FERC has provided support for it as an important part of utility operation [15]. From the perspective of an electric system, demand response is the reduction in energy usage during critical time periods. These critical time periods are typically few hours per year when electricity market prices are at their highest or when energy reserves are low due to generator outages, downed transmission lines or severe weather conditions. From a customer point of view, demand response is a retail electricity rate or a program that attempts to induce customers to change their energy consumption behavior by providing incentives to reduce load at critical times. This results in the efficient use of the electric system and also promotes economic growth [5]. Therefore for ease of implementation the demand response initiatives should be both customer-driven and customer-friendly. It can be customer-driven by giving the customers the option of whether to participate in the program or not. It can be customer-friendly on the other hand by making the initiatives straightforward, in other words giving the customers easy-to-understand information [15]. Currently insufficient levels of demand response exist in the United States electric power system. Presently most consumers face retail electricity rates that are fixed for months or years at a time. The consumers do not see the underlying cost of supplying electricity and therefore do not have an incentive to adjust their demand to supply side conditions.

Since at any given time the power plant capacity must equal or exceed consumer's demand, one of the benefits of demand response is the avoided need to build new power plants to serve the increase in demand that occur only for a few hours per year. Many regions are facing significant energy price pressure, demand for grid infrastructure modernization and excessive reliance on natural gas for electric generation. Demand response is a possible solution to the above stated problems. The main drivers of demand response programs that could help motivate the customers to reduce energy consumption during periods of peak demand are as follows [16]:

- The differentiated rates for electricity in order to give consumers an incentive to manage their hourly energy usage efficiently
- The method of sending critical peak pricing signals to the consumers during specific times when excess power generation is required, or in other words when power shortages exist. This also serves as the consumer's motivation to conserve energy
- Effective and regular communication with consumers on their energy usage patterns to induce change in their traditional consumption behavior

The implementation of viable and cost-effective demand response programs requires the best and most suitable metering technology. It has been concluded that a two-way communication metering system with the capability of collecting and storing interval data would be the most cost-effective choice giving utilities the flexibility to adapt to the changes in the energy market [16].

Classification of Demand Response Programs

The two major classes of demand response programs are:

1) Price-based demand response
2) Incentive-based demand response

This research concentrates on the price-based demand response programs. The incentive-based demand response programs will also be explained briefly.

Price-based demand response programs

Time-of-Use (TOU)

Varying electricity rates for different blocks of time are usually defined for a 24-hour day. TOU rates generally reflect the average cost of generating and delivering power during those time periods. TOU rates often vary with time of day and by season which are typically pre-determined for a period of several months or years. This type of pricing requires meters that register cumulative usage during different time blocks.

Real-time pricing (RTP)

The electricity rate fluctuates hourly, reflecting changes in the wholesale price of electricity. RTP prices are generally known to customers on a day-ahead or hour-ahead basis.

Critical Peak Pricing (CPP)

This type of pricing includes a pre-specified high rate for usage, designated by the utility to be a critical period. The CPP events are generally triggered by system contingencies or high prices faced by the utility in procuring power in the wholesale market, depending on the program design. CPP rates may be super-imposed on either a TOU or time-invariant rate and are called on relatively short notice for a limited number of days or hours per year. CPP customers typically receive a price discount during non-CPP periods. CPP rates are not yet common, but have been tested in pilots for large and small customers in several states including Florida, California and North and South Carolina.

Incentive-based demand response programs

The Direct Load Control (DLC) and Interruptible/ Curtailable Service programs fall under the classical incentive-based programs where the customer receives payments for participation usually in the form of a bill credit or discount rate.

Direct load control

In this program the utility or system operator remotely shuts down or cycles a customer's electrical equipment like the air conditioner or water heater on short notice usually to address system or local reliability issues. Customers participating often receive a payment usually in the form an electricity bill credit. Some programs give the option for customers to opt-out of the control action. Direct load control programs are primarily offered to residential and small commercial customers.

Interruptible/Curtailable Service

This program is integrated with the customer tariff that provides a rate of discount or bill credit for agreeing to reduce load, typically to a pre-specified firm service level during system contingencies. Customers that do not reduce load typically pay penalties in the form of very high electricity prices that come into effect during contingency events, or they may be removed from the program. This program is traditionally offered to large industrial or commercial customers.

The Demand Bidding, Emergency Demand Response, Capacity Market and Ancillary Service Market programs can be categorized under the market-based demand response programs where the participants are rewarded with money for their performance depending on the amount of load reduction during critical conditions.

Demand Bidding or Buyback programs

This program encourages large customers to bid into a wholesale electricity market and offer to provide load reductions at a price at which they are willing to be curtailed. It also encourages customers to identify how much load they would be willing to curtail at a utility-posted price. Customers whose load-reduction offers are accepted must reduce load as contracted or would have to face a penalty.

Emergency Demand Response Programs

This program provides incentive payments to customers for measured load reductions during reliability–triggered events. This program may not be subject to penalties when enrolled customers do not respond.

Capacity Market Programs

These programs are typically offered to customers that can commit to providing pre-specified load reductions when system contingencies arise. Customers are typically informed or given notice of such event days. Incentives for this program usually consist of upfront reservation payments, determined by capacity market prices, and additional energy payments for reductions during events. This program is subject to significant penalties for customers that do not respond when called.

Ancillary Services Market Programs

These programs allow customers to bid load curtailments in Independent System Operator (ISO) or Regional Transmission Organization (RTO) markets as operating reserves. If their bids are accepted, they are paid the market price for committing to be on standby. If their load curtailments are needed they are called by the ISO or RTO, and may be paid the spot energy price.

Customer Participation in Demand Response

Customer participation in demand response involves two important decisions. The first decision is whether to sign up for a voluntary program or tariff, and the second is whether or not to respond to program events or adjust usage in response to prices as they occur. Uncertainties in the costs and benefits of the program participation seem as risks to customers that may be significant barriers to their signing up.

Customer Load Response

The three possible responses from customers are as follows:

Foregoing

This involves reducing energy usage at times of high prices or demand response program events without making it up later. For example, when a residential customer might turn off lights or turn up the thermostat on an air conditioner during an event, temporary loss of amenity or comfort results [17][5].

Shifting

This involves rescheduling energy usage away from times of high prices or demand response program events to other times. For example when a residential customer might put off running a dishwasher until later in the day, lost amenity is made up either prior to the event or at a subsequent time.

Onsite generation

Some customers may respond to the demand response program events by turning on an onsite or backup emergency generator to supply some or all of their electricity needs. Although customers may have little or no interruption to their electrical usage, their net load requirement on the power system is reduced.

Benefits of Demand Response

- The financial benefits of demand response include: cost savings on the customers' annual electricity bills from using less energy when prices are high or from shifting energy usage to lower-priced hours as well as other financial payments or incentives the customer receives for agreeing to or actually curtailing usage in a demand response program.
- The reliability benefits for the customer would include the reduced risk of being exposed to forced outages or electricity interruption. On the other hand the operator would have more options and resources to maintain system reliability [11]. The customer may also derive satisfaction from helping to avoid widespread contingencies. These benefits serve as motivation to some customers.
- The environmental benefit of demand response programs is the reduction in the emissions from generation plants during peak demand periods. Overall conservation effects result either directly from demand response load reductions or indirectly from increased customer awareness of their energy usage and costs.

Possible Problems with Dynamic Pricing [18]

There are a few possible issues that can cause significant stability problems when the number of participants in a dynamic pricing program is very high. Some of the problems that could arise are as follows:

The Rebound Effect

When consumers reduce their consumption during peak pricing periods a significant portion of the load gets shifted to subsequent hours. For example the thermostats of air conditioners are set back in order to reduce energy consumption during demand response events. Once the event period ends the thermostats are returned to their original set point, but the ambient temperature is above the set point, resulting in an increase in load following the demand response event. The same applies when a dishwasher or dryer is delayed to avoid usage during the demand response event. There would be a subsequent increase in demand following the Demand Response period. For lower participation levels the rebound effect is more likely to be small and have a positive impact on the system by leveling the overall load curve. However as participation increases, utilities may have to update their load forecasts to account for the rebound effect so that the generation dispatch can be adjusted to serve the additional load that may be seen in the hours subsequent to the Demand Response periods. Rebound effect may result in generation shortage or an additional peak in the expected load profile.

Coincident Load Shifting

The simultaneous implementation of pricing events for a fixed period of time may result in coincident load reductions at the start of the pricing event or coincident load restoration or pick-up at the end of the pricing events. This could create disturbances on the grid leading to both financial and physical instability.

CHAPTER 3 - Methodology

This chapter focuses on the method followed to evaluate the economics of owning a wind generator under the two pricing schemes, namely Critical Peak Pricing (CPP) and Time of Use Pricing (TOU). The assumptions made for this evaluation will also be explained.

Load Forecasting

Load forecasting can be either short-term or long-term. Short-term load forecasting involves various factors such as time, weather and customer classes that include residential, commercial and industrial. Long-term load forecasting on the other hand involves factors like historical load and weather data, number of customers, type of appliances used and demographic data. Load varies with the time of the year, day of the week and hour of the day. There is a difference in the load profile between a weekday and a weekend. Load can behave differently on holidays depending on the consumers' lifestyle, making load predictions difficult due to their infrequent occurrence. Weather conditions greatly influence the load. Weather variables, namely temperature and humidity, are commonly used for load forecasting. Typically a utility would use short-term forecast for a day to determine whether it should be a CPP day. Since such information was not available, for this research maximum temperature of the day is chosen as the major factor for load forecasting and for declaring CPP days.

Temperature of day

Historical temperature and load data is used to estimate the load for a particular day. The two pricing schemes considered here will be applied only to the summer months (June, July, August and September). All summer days for the 11 year period (1999-2009) were classified based on the maximum temperature of the day. The locations chosen for the analysis were Topeka and Manhattan in the state of Kansas, United States. It was seen that most of the high temperature days were concentrated in the months of July and August. Temperature varied with the year, with some years having extremely hot summer days whereas some other years had milder summers. Of the two pricing schemes CPP and TOU, CPP requires a cut-off temperature to declare the CPP days. This required classification of days into different temperature ranges.

Temperature ranges

All summer days were classified into six temperature ranges. The temperature here refers to the maximum temperature of the day. The distribution of weekdays and weekends in each of the temperature ranges for the city of Manhattan are as shown in the tabulations below.

Table 3.1 Distribution of summer weekdays in June for Manhattan, KS

JUNE	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	0	0	0	0	0	0	0	0	0	0	0
99-101°F	0	0	0	1	0	0	1	2	0	0	0
96-98°F	0	0	0	1	0	0	1	5	0	0	3
93-95°F	0	5	2	7	1	3	3	4	0	1	4
90-92°F	4	3	3	2	2	2	4	2	1	2	2
< 90°F	18	14	16	8	18	19	13	9	20	18	13

Table 3.2 Distribution of summer weekends in June for Manhattan, KS

JUNE	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	0	0	0	0	0	0	0	0	0	0	0
99-101°F	0	0	0	0	0	0	0	0	0	0	0
96-98°F	0	0	0	1	0	0	1	0	0	0	0
93-95°F	0	1	1	5	0	1	1	0	0	0	2
90-92°F	1	0	3	2	0	1	0	0	1	1	1
< 90°F	7	7	5	2	8	6	6	8	8	8	5

Table 3.3 Distribution of summer weekdays in July for Manhattan, KS

JULY	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	4	1	4	4	2	0	0	4	0	0	0
99-101°F	2	2	3	3	2	1	4	2	0	1	0
96-98°F	5	6	4	3	7	3	0	5	3	1	0
93-95°F	4	3	5	7	4	2	1	1	2	6	2
90-92°F	2	3	3	2	4	1	7	3	4	6	2
< 90°F	5	6	3	4	4	15	9	6	3	9	19

Table 3.4 Distribution of summer weekends in July for Manhattan, KS

JULY	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	2	2	2	2	1	0	1	3	0	0	0
99-101°F	0	1	1	1	2	0	1	2	0	1	0
96-98°F	0	1	0	2	0	0	3	1	0	1	0
93-95°F	3	2	0	0	3	1	3	0	5	1	0
90-92°F	2	0	2	2	0	2	1	2	1	2	1
< 90°F	2	4	3	1	2	6	1	2	3	3	7

Table 3.5 Distribution of summer weekdays in August for Manhattan, KS

AUGUST	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	0	12	2	0	5	0	3	3	5	1	0
99-101°F	1	4	4	1	2	0	3	3	1	0	0
96-98°F	3	3	3	1	3	2	2	1	8	0	0
93-95°F	3	0	2	2	1	1	1	2	3	3	2
90-92°F	7	2	5	6	4	3	1	3	1	1	3
< 90°F	8	2	7	12	6	16	13	11	5	16	16

Table 3.6 Distribution of summer weekends in August for Manhattan, KS

AUGUST	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	0	6	0	0	4	0	6	3	1	2	0
99-101°F	0	0	2	2	0	0	0	1	0	0	0
96-98°F	1	1	0	0	1	0	1	0	2	0	2
93-95°F	3	0	1	1	2	1	0	0	1	0	0
90-92°F	1	1	0	3	1	0	1	0	3	1	0
< 90°F	4	0	5	3	2	8	0	4	1	7	8

Table 3.7 Distribution of summer weekdays in September for Manhattan, KS

SEPTEMBER	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	0	1	0	0	0	0	0	0	0	0	0
99-101°F	0	3	0	1	0	0	0	0	0	0	0
96-98°F	1	1	0	3	0	0	1	0	1	0	0
93-95°F	2	1	0	0	0	2	0	0	0	0	0
90-92°F	2	3	2	3	0	0	3	0	4	1	0
< 90°F	17	11	16	14	22	20	18	21	15	21	22

Table 3.8 Distribution of summer weekends in September for Manhattan, KS

SEPTEMBER	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
> 101°F	0	3	0	0	0	0	0	0	0	0	0
99-101°F	0	0	0	0	0	0	0	0	0	0	0
96-98°F	0	2	0	1	0	0	0	0	0	0	0
93-95°F	0	0	0	3	0	1	0	1	0	0	0
90-92°F	0	1	1	0	0	4	2	0	1	0	0
< 90°F	8	3	8	5	8	4	6	8	9	8	8

Electricity Pricing

The two pricing schemes considered here and their characteristics are as follows:

1) Critical Peak Pricing (CPP)
2) Time of Use (TOU)

Critical Peak Pricing

This pricing applies only during the summer season that includes the months June through September. All other months of the year see the fixed-rate of electricity of $0.095/kWh throughout the day. Only up to 15 CPP days, which should be weekdays, can be declared over the summer months. A cut-off temperature of 99°F was chosen to declare a CPP day in June and 96°F was chosen to declare a CPP day in July, August and September. The difference in cut-off temperatures for the months was to try to include most of the high temperature days which were found to be concentrated in the months of July and August. Also, very high temperature days occurred sporadically in June with very little heat build-up. A few of the characteristics of the Critical Peak Pricing scheme are:

- There is a 15:1 ratio between the peak-rate and the off-peak rate
- The peak-rate of $0.895/kWh applies to the 5 afternoon hours (1pm to 6pm) of the day
- For all days other than CPP days, an off-peak rate of $0.056/kWh is applied throughout the day. This off-peak rate is also applied to the weekends.

The peak-rate and off-peak rates in comparison to the fixed-rate are as shown in Figure 3.1.

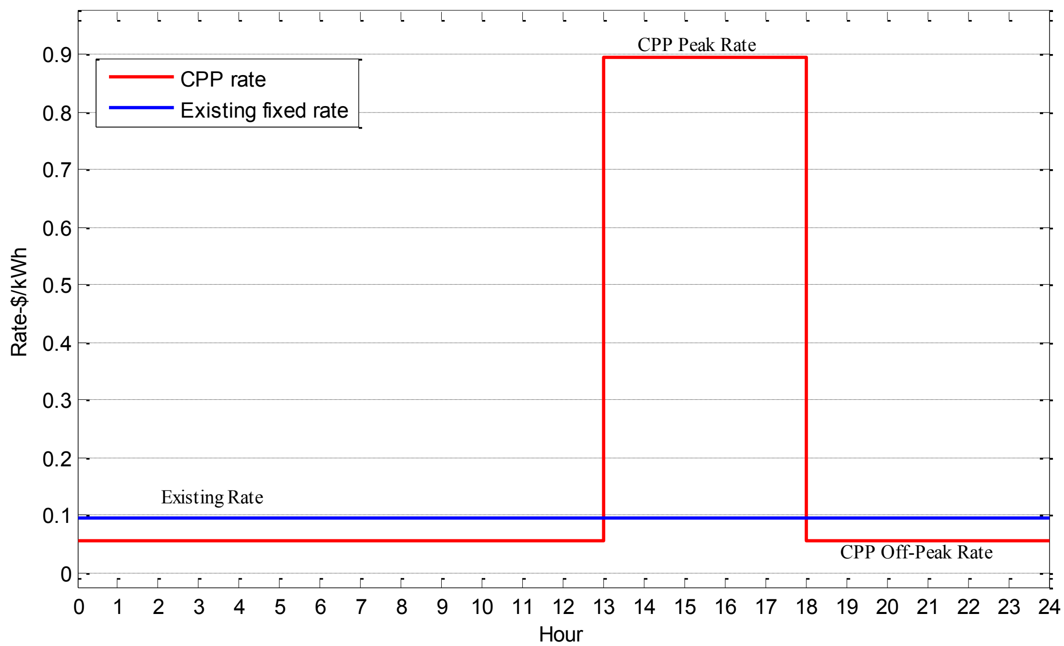

Figure 3.1 Critical Peak Pricing [19]

Of the 122 days in the four summer months, there would be 85 weekdays and 37 weekends on an average. Based on the historical data, given in Table 3.1 to Table 3.8, the average number of weekdays in the different temperature ranges for Manhattan, KS is shown in Table 3.9.

Table 3.9 Average number of summer weekdays in various temperature ranges - Manhattan

Month	>101 F	99-101F	96-98F	93-95F	90-92F	<90F
June	0	0	1	3	2	15
July	**2**	**2**	**3**	3	3	8
August	**3**	**2**	**2**	2	3	10
September	0	0	0	0	2	18

Excluding the days in the month of June that fall in the 96-98°F temperature range, we could expect an average of 14 CPP days per year for Manhattan, Kansas. Similar temperature data was tabulated for Topeka and are summarized in Table 3.10. This shows that excluding the days in the month of June that fall in the 96-98°F temperature range, we could expect an average of 12 CPP days per year for Topeka, Kansas.

Table 3.10 Average number of summer weekdays in various temperature ranges –Topeka

Month	>101 F	99-101F	96-98F	93-95F	90-92F	<90F
June	0	0	0	2	3	16
July	**1**	**2**	**4**	3	4	9
August	**1**	**1**	**3**	2	4	10
September	0	0	0	1	1	18

Time of Use Pricing

This pricing applies only during the summer season including months June through September. All other months of the year see the fixed-rate of electricity, here $0.095/kWh throughout the day. A few of the characteristics of the Time of Use pricing scheme are:

- There is a 4:1 ratio between the peak-rate and the off-peak rate
- The peak-rate of $0.234/kWh applies to the 5 afternoon hours (1pm to 6pm) of the day
- This rate is applied to every weekday
- The off-peak rate of $ 0.061/kWh is applied to the weekends

The peak-rate and off-peak rates in comparison to the fixed-rate are as shown in Figure3.2.

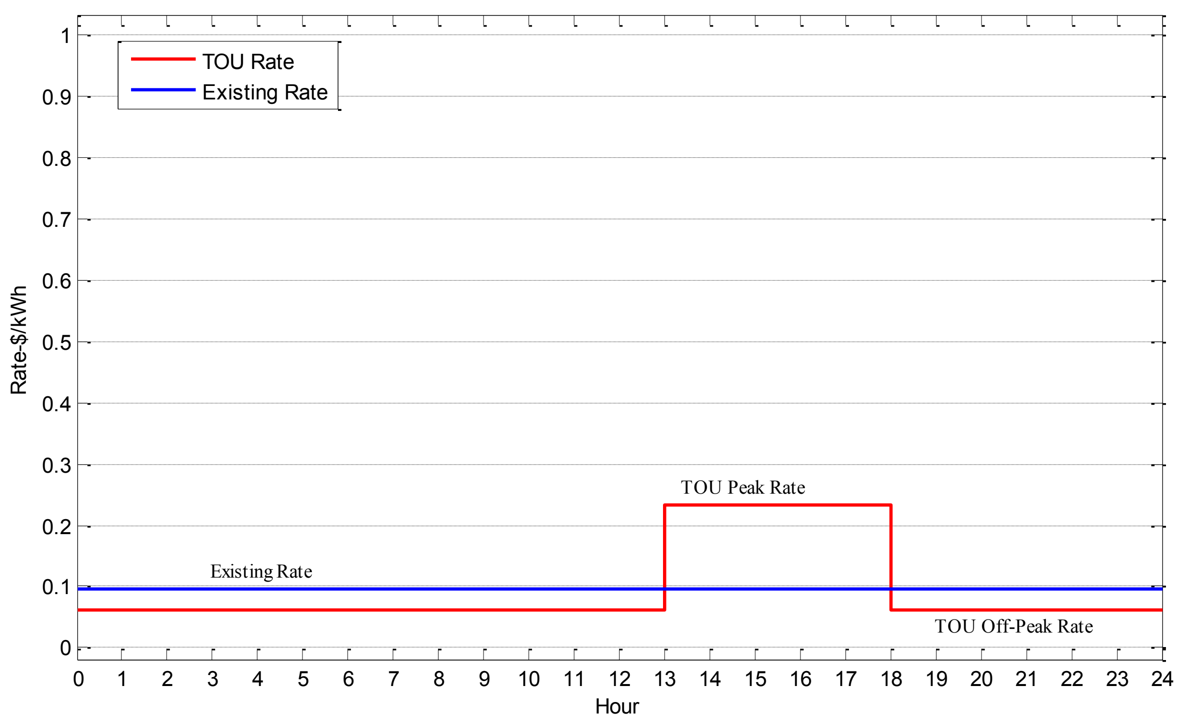

Figure 3.2 Time of Use Pricing [19]

Load Profile

The hourly load data for a single household in Manhattan, Kansas for a three year period from 2007 to 2009 was obtained. This data was classified based on the days with temperature maxima falling in each of the six temperature ranges. Therefore, an average load profile for each temperature range is obtained.

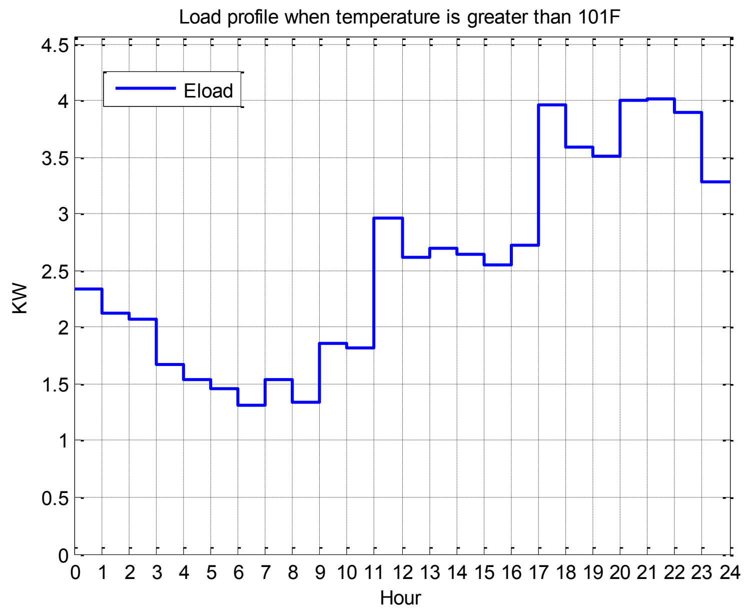

Figure 3.3 Average load profile when maximum temperature is greater than 101°F

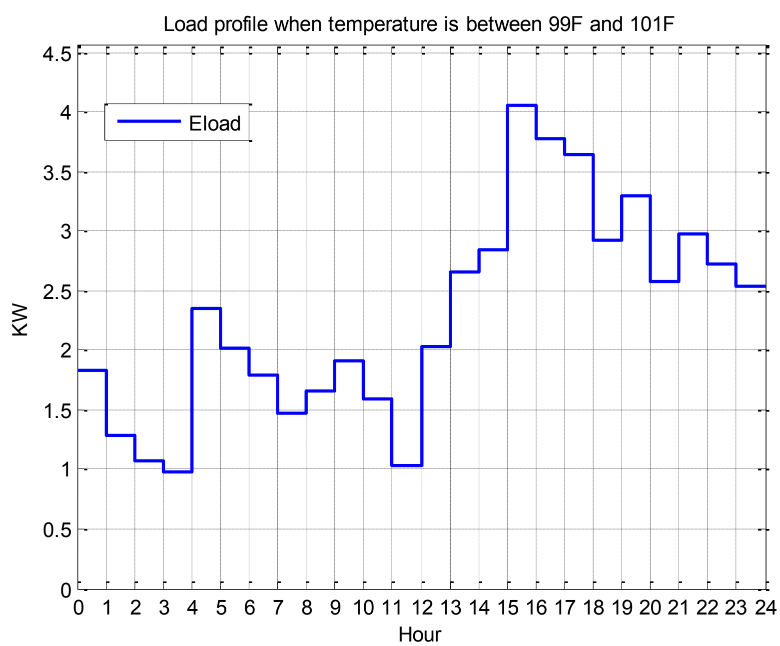

Figure 3.4 Average load profile when maximum temperature is between 99°F and 101°F

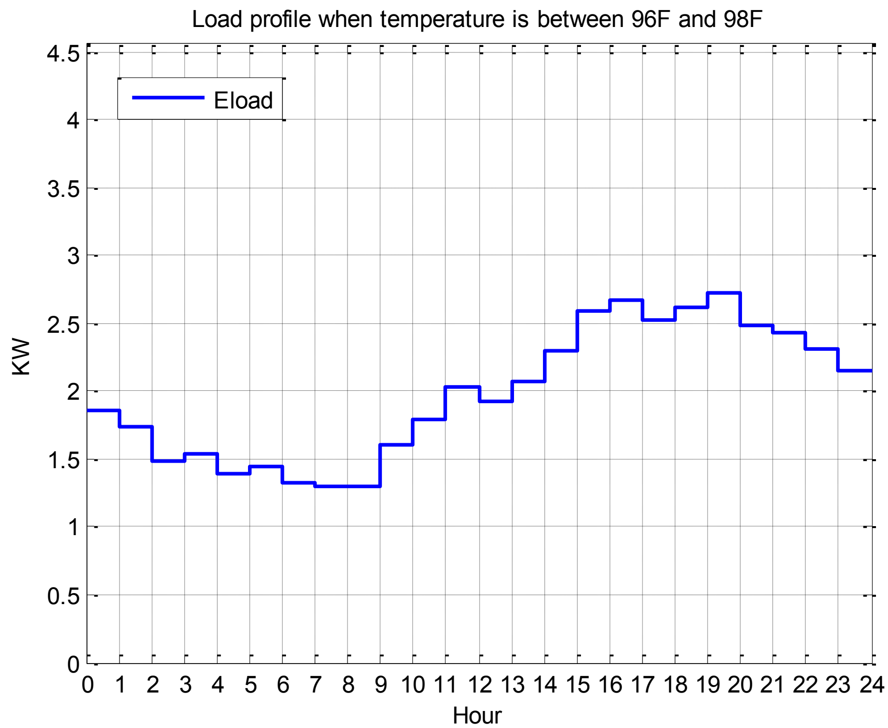

Figure 3.5 Average load profile when maximum temperature is between 96°F and 98°F

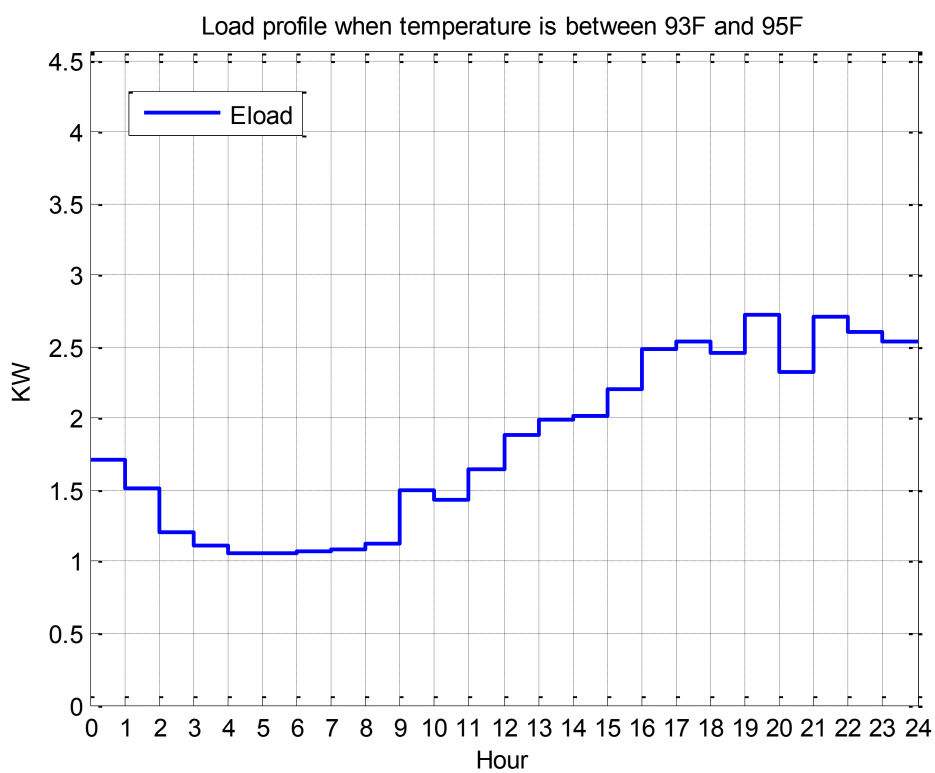

Figure 3.6 Average load profile when maximum temperature is between 93°F and 95°F

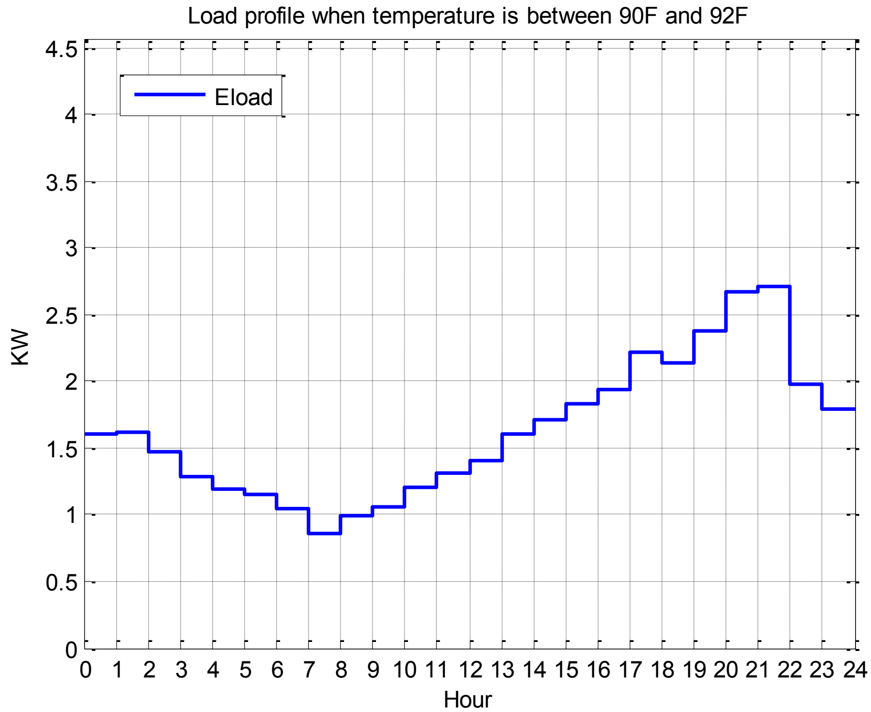

Figure 3.7 Average load profile when maximum temperature is between 90ºF and 92ºF

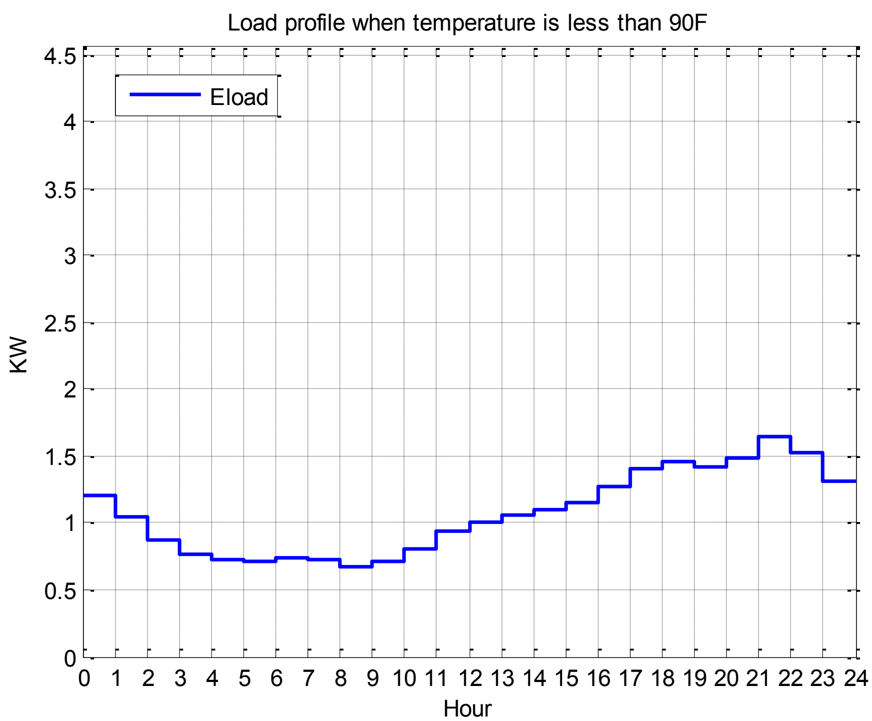

Figure 3.8 Average load profile when maximum temperature is less than 90°F

With the pricing schemes in effect the customers would modify their energy consumption by shifting certain loads from high price periods to lower price periods to reduce the impact on their electricity bill. A load modification was assumed when the CPP and TOU pricing schemes were in effect.

Based on the information about weather, existing rates and new rates, the PRSIM-KS software was used by The Brattle Group [19] to generate the demand response curves. The results of the demand response curves showed that, for the Residential group of customers under a peak-rate of greater than $0.80/kWh we could expect a peak reduction of 20% to 25%. Based on this result the following load modification assumptions were made for this research.

Load Modification for the CPP scheme: A 20% load reduction was assumed for the peak hours (1pm to 6pm) and a 3% increase in load three hours before and after the peak period.

Load Modification for the TOU scheme: A 5% load reduction was assumed for the peak hours (1pm to 6pm) and a 1% increase in load three hours before and after the peak period.

Wind Profile

An average wind profile was obtained for each of the six temperature ranges from the weather data of the years 2007 through 2009.

Wind data location: Manhattan Municipal Airport, KS-USA [20]

County: Riley, KS

Wind class: Class 1 (average wind speed is less than 5.6m/s at 50m)

Manhattan-Kansas proper would fall into Class 2 with mean wind speed between 5.6m/s and 6.4m/s. This difference in wind speeds is due to the location of the Manhattan Municipal Airport. The anemometer at the airport is atop a tower that is approximately 30-foot tall [21]. To account for this difference in wind class the wind profile for each of the six temperature ranges was scaled to match the wind data obtained from the Skystream3.7 located at Kansas State University, Manhattan-Kansas.

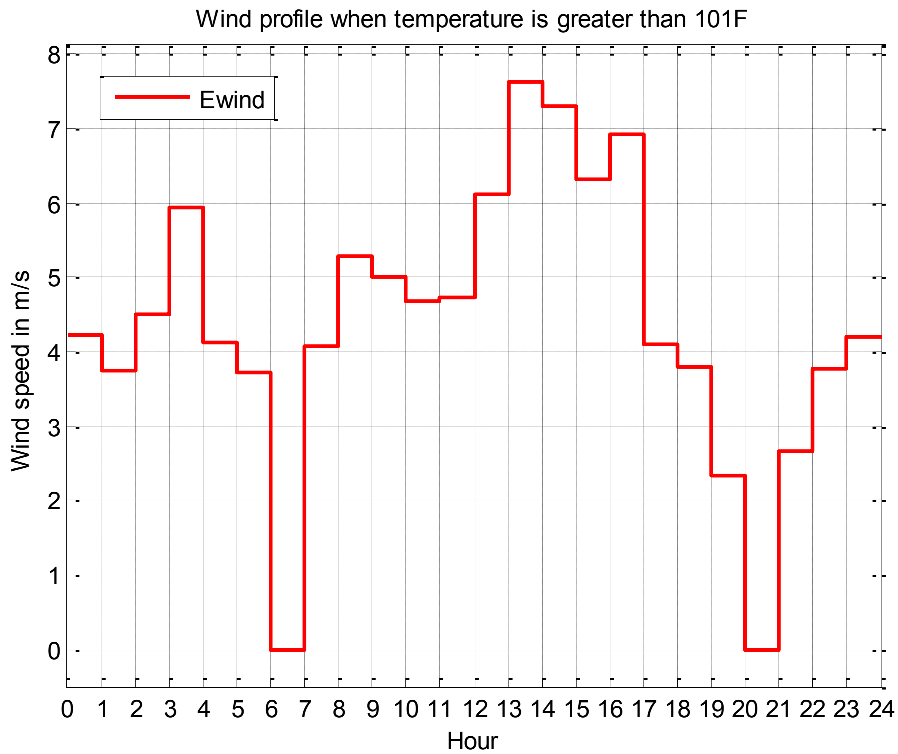

Figure 3.9 Average wind profile when maximum temperature is greater than 101°F

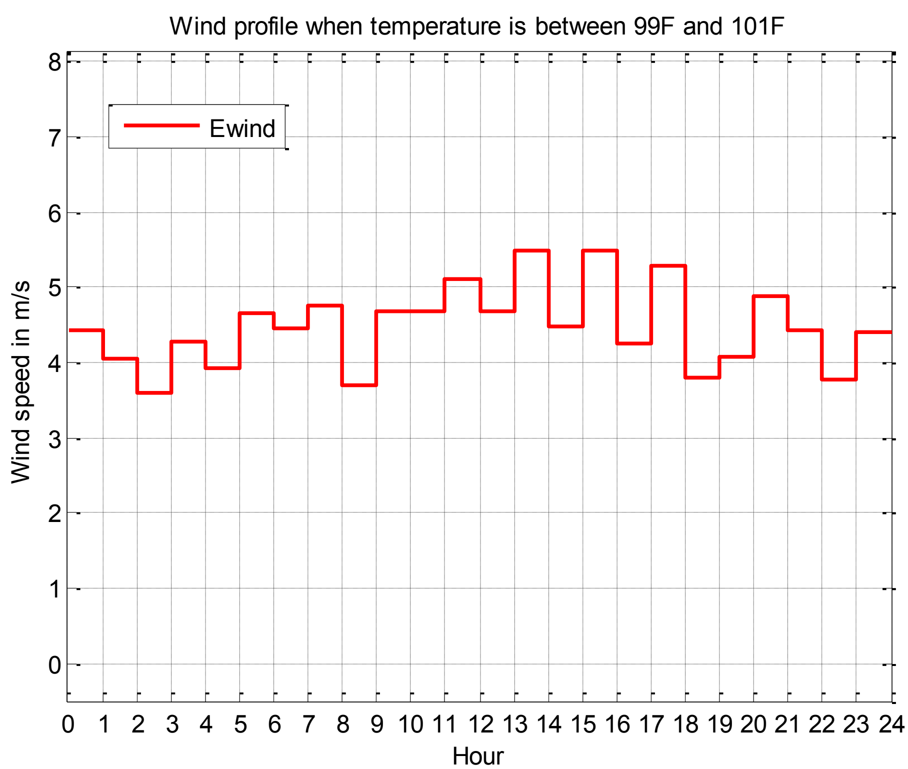

Figure 3.10 Average wind profile when maximum temperature is between 99°F and 101°F

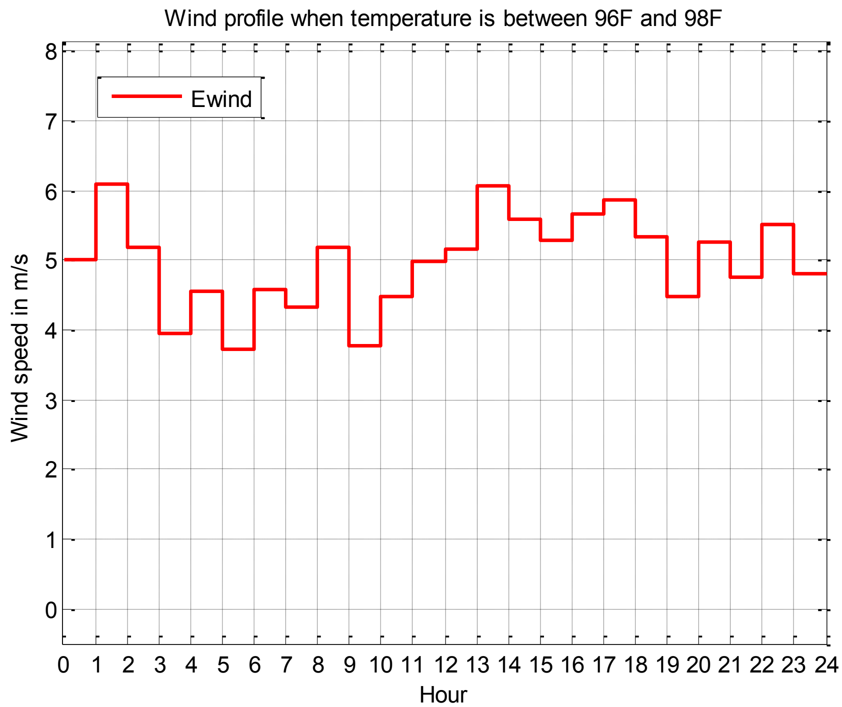

Figure 3.11 Average wind profile when maximum temperature is between 96°F and 98°F

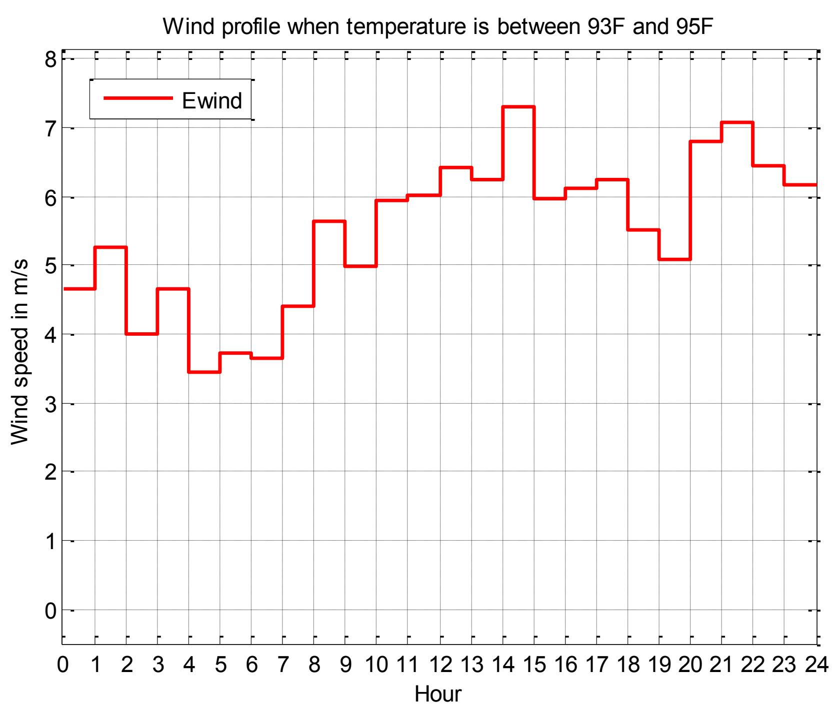

Figure 3.12 Average wind profile when temperature is between 93°F and 95°F

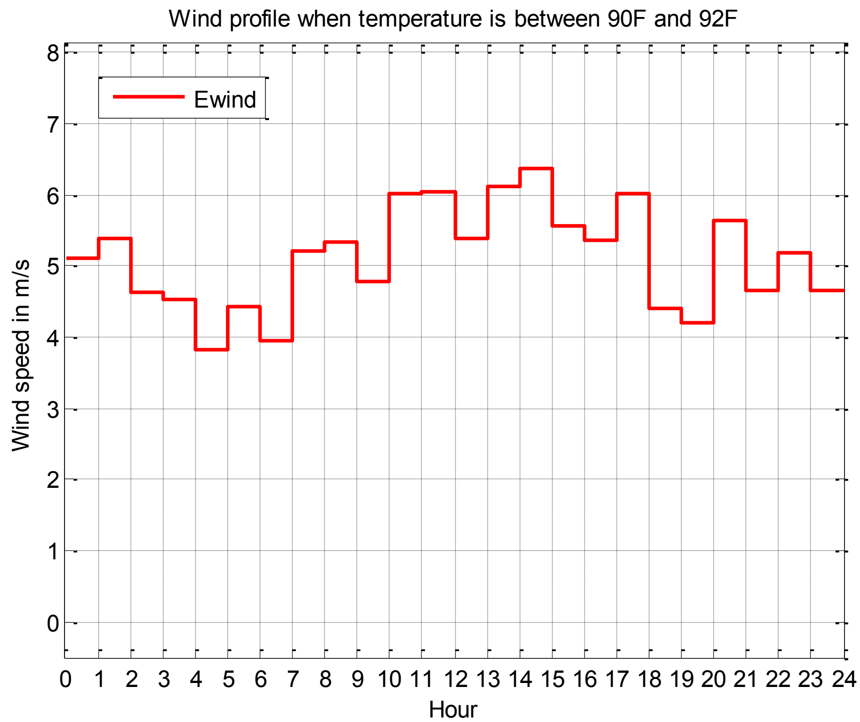

Figure 3.13 Average wind profile when temperature is between 90°F and 92°F

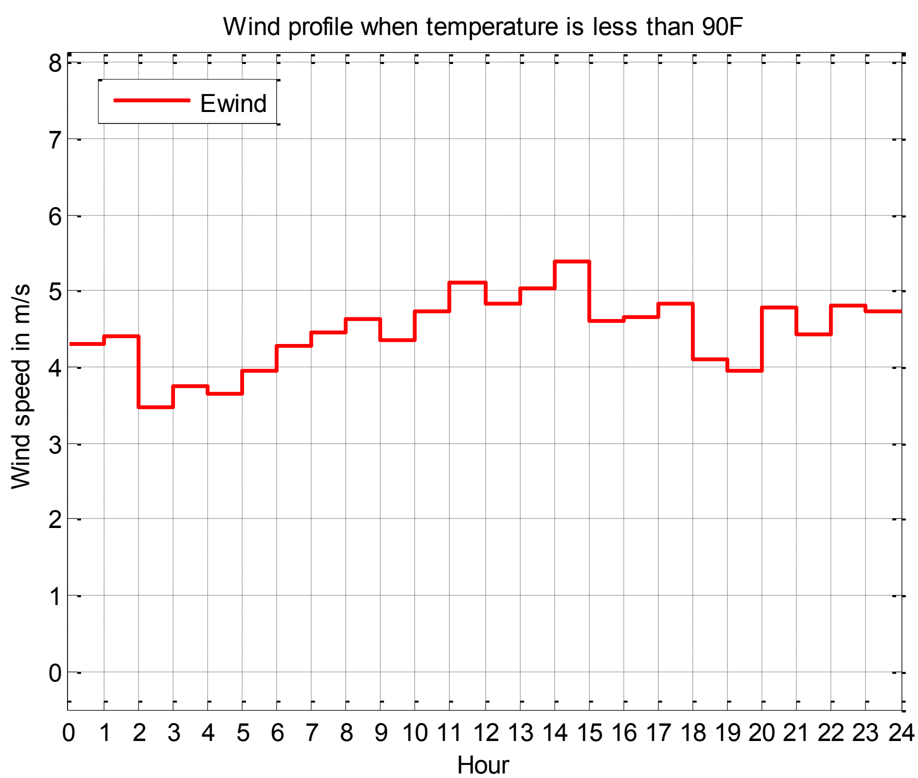

Figure 3.14 Average wind profile when temperature is less than 90°F

Choosing a wind generator involves various factors that include overall cost of the investment, average wind speed of the location, savings on the energy bill, ease of interconnection to the grid and various other factors. Since this research was to concentrate on small wind generation ownership for a residential home we found the Skystream3.7 to be the most suitable. It is the first small wind generator specifically designed for utility-connected residential and commercial use with built-in controls and an inverter. The Skystream3.7 begins producing power at 3.5m/s (8mph) and produces its full output at 13m/s (29mph). In certain states the consumer can take advantage of 'net-metering' by selling excess energy generated back to the utility [22]. Approximate values for the power output at various wind speeds were obtained through HOMER Version2.68 (July 24, 2009) [23].

Table 3.11 Power output at various wind speeds

Wind speed (m/s)	Power Output (KW)
3.5	0.07
4	0.14
4.5	0.22
5	0.31
5.5	0.397
6	0.51
6.5	0.628
7	0.769
7.5	0.944
8	1.084
8.5	1.235
9	1.424
9.5	1.562
10	1.667
10.5	1.744
11	1.804
11.5	1.82
12	1.82
12.5	1.82
13	1.82
13.5	1.82
14	1.82
14.5	1.82
15	1.82
15.5	1.82
16	1.82
16.5	1.82
17	1.82
17.5	1.762
18	1.666
18.5	1.633
19	1.601
19.5	1.568
20	1.553
20.5	1.541
21	1.528
21.5	1.516
22	1.503
22.5	1.491
23	1.478
23.5	1.466
24	1.453
24.5	1.441
25	1.428

Annual Electricity Bill

Knowing the load profile for each temperature range, the power output from the wind turbine, the rates for electricity, and the average number of days that fall in each of the temperature ranges, the annual energy bill is calculated to compare the savings of owning a wind generator under the various pricing schemes. For the summer months June through August the CPP, TOU or CPP-TOU rate is applied based on the criteria assumed. The electricity bill for all other months of the year is calculated based on the average load profile and the average power output for each month. The calculation in Table 3.12 shows the annual energy bill for the selected household in Manhattan, KS. The option of selling back power during excess generation is enabled under the condition that the selling price is equivalent to the purchasing price of electricity.

Table 3.12 Annual electricity bill under the pricing schemes-Manhattan,KS

Case under study	Fixed-rate	CPP-rate	TOU-rate	CPP-TOU rate
Annual energy bill (no wind generation)	$888.42	$872.873	$875.32	$977.86
Annual energy bill (wind generation)	$591.292	$583.45	$578.39	$661.64
SAVINGS	**$297.13**	**$289.42**	**$296.93**	**$316.22**

For a comparison, a similar analysis was performed with the load data from the city of Topeka. However, the wind profile for Manhattan was used to calculate the annual energy bill of the customer as shown in Table 3.13. Note that the wind speed in Topeka vicinity is lower than in Manhattan. Therefore, savings would have been lower if Topeka's wind data were used. Both houses showed similar results with almost equal savings.

Table 3.13 Annual electricity bill under the pricing schemes- Topeka,KS

Case under study	Fixed-rate	CPP-rate	TOU-rate	CPP-TOU
Annual energy bill (no wind generation)	$823.16	$816.54	$817.48	$852.75
Annual energy bill (wind generation)	$522.01	$525.10	$515.82	$534.52
SAVINGS	**$301.15**	**$291.44**	**$301.66**	**$318.23**

Summarizing the results in Table3.12 and Table 3.13, a consumer under the combinational rate (CPP-TOU) would receive a higher energy bill with or without a wind generator. On the other hand the annual savings is greater under the CPP-TOU pricing scheme in the presence of a wind generator. The annual savings is $316.22 for Manhattan and $318.23 for Topeka under this scheme. In comparison, when the other rates namely fixed-rate, CPP-rate and the TOU-rate are applied the change in the annual energy bill is not significant for Manhattan as well as Topeka. The difference in savings in the presence of a wind generator for these pricing schemes is also not significant.

CHAPTER 4 - Monte-Carlo Simulation

Results given in the previous chapter were based on average values. To obtain a range of savings under more realistic scenarios a Monte-Carlo simulation was performed. Monte-Carlo simulation is a class of computational algorithm that uses repeated random sampling. The underlying probability of occurrences is either known or pre-determined.

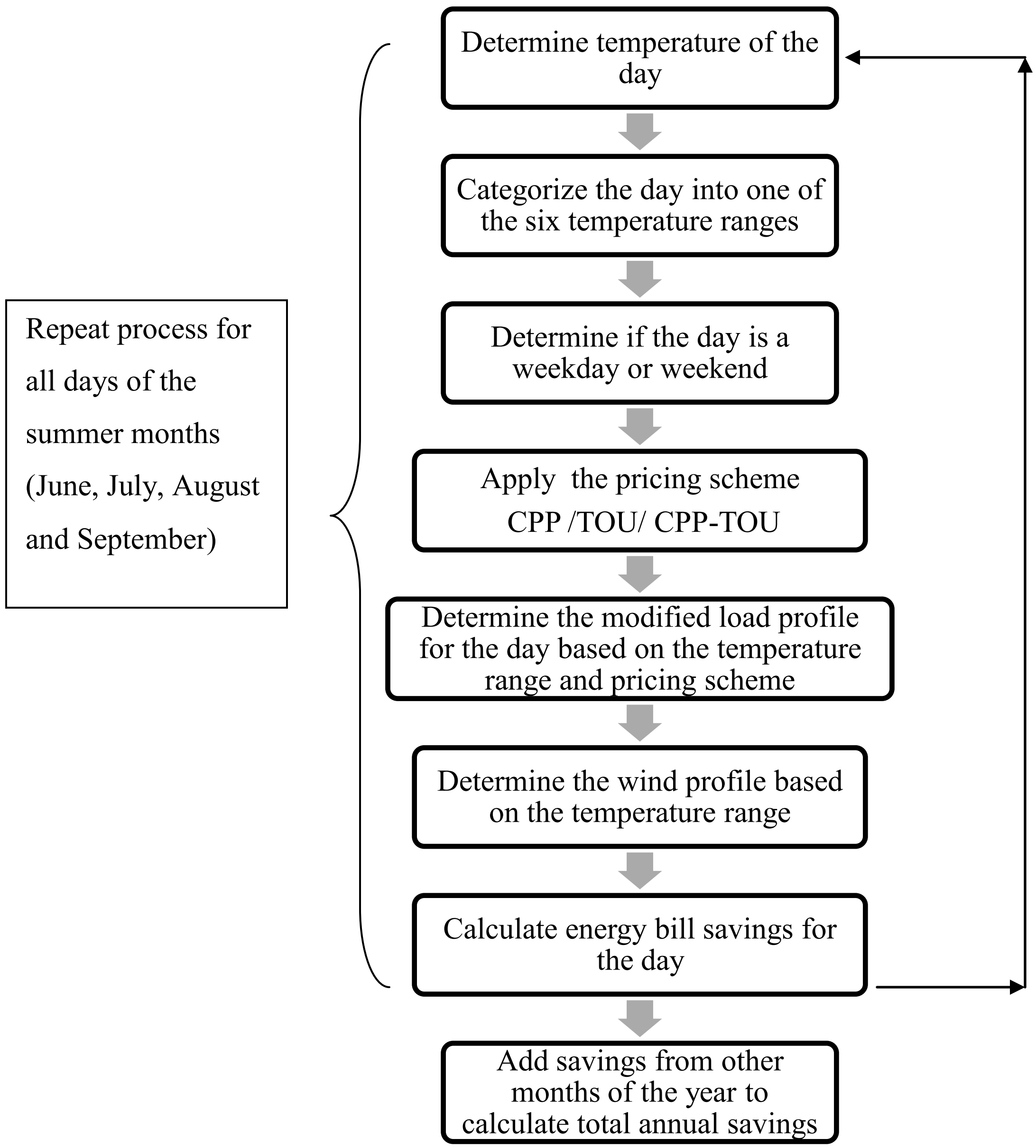

Figure 4.1 General flow of the Monte Carlo Simulation for one iteration for the given problem

This simulation is generally used to estimate or forecast a decision for a problem with significant uncertainty. The method of application of the pricing scheme is varied based on the assumed conditions. The Monte Carlo simulation for this problem is implemented by using steps 1 to 6 for all the days in the months of June, July, August and September as shown in the flowchart in Figure 4.1. The runs are repeated 1000 times.

Step #1: A uniformly distributed random number generator was used to generate temperature of the day. The temperature for each day was classified into the six temperature ranges based on the distribution shown in Table 4.1. The probabilities for days in each of the temperature ranges were obtained from the 11 year historical temperature data.

Table 4.1 Distribution of days in each temperature range for Manhattan, KS

Temperature range	Probability-June	Probability-July	Probability-August	Probability-September
> 101ºF	0	0.093841642	0.15542522	0.012121212
99-101ºF	0.012121212	0.085043988	0.070381232	0.012121212
96-98ºF	0.033333333	0.131964809	0.099706745	0.03030303
93-95ºF	0.124242424	0.161290323	0.085043988	0.03030303
90-92ºF	0.112121212	0.152492669	0.137829912	0.081818182
< 90ºF	0.718181818	0.375366569	0.451612903	0.833333333

Step #2: A second uniformly distributed random number generator was used to classify the days into weekdays and weekends based on the probability that there could be 22 weekdays and 8 or 9 weekend days depending on the summer month considered. Each day of the summer months was classified similarly into weekdays and weekends.

Step #3: Apply the pricing scheme CPP if weekday and the maximum temperature for the day is greater than the CPP cut-off temperature (or) TOU scheme if weekday (or) CPP-TOU, depending on which one is to be applied.

Step #4: The load profile for the particular temperature range is subjected to the assumed modification. It is assumed that the consumer would respond to the pricing scheme by shifting certain loads to later than or prior to the peak period.

Step #5: Use the average wind profile of days in the specific temperature range to find the hourly power output of the wind generator using the HOMER software.

Step #6: The difference between the load at each hour and the power output of the wind generator at each hour gives the net power the consumer draws from the electricity grid. The electricity rate at each hour is then applied to this difference, to calculate the energy bill of the consumer for that day.

Step #7: The pricing schemes discussed are to be applied only for the summer months. For all other months of the year a general load profile and wind profile is obtained. The power output for each hour is calculated as discussed before and the fixed-rate of electricity is applied to the net power that is drawn from the grid to calculate the energy bill of the consumer for these months.

Step #8: The savings in dollars obtained is compared for the different pricing schemes.

All the assumptions including the cut-off temperature and load modification were maintained throughout the simulation. Once the limit of 15 CPP days is reached, additional days with higher temperature are not considered as CPP days. The difference in the load profile between a weekday and a weekend has also been considered. The load profile of a single household in Manhattan, KS and the wind profile obtained for Manhattan, KS were used to generate the histograms for the different pricing schemes. A range of values obtained as annual savings was plotted against the number of occurrences for 1000 iterations.

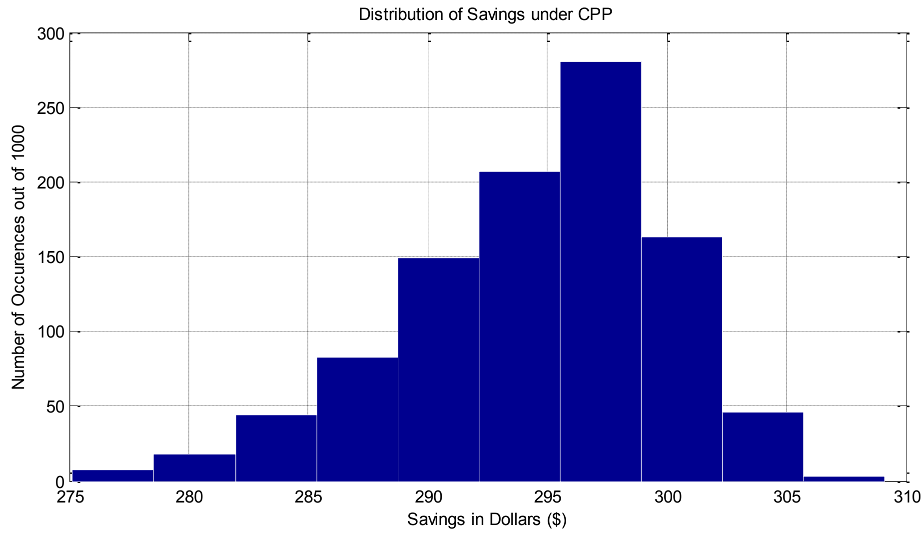

Figure 4.2 Distribution of Savings under CPP scheme for 1000 iterations

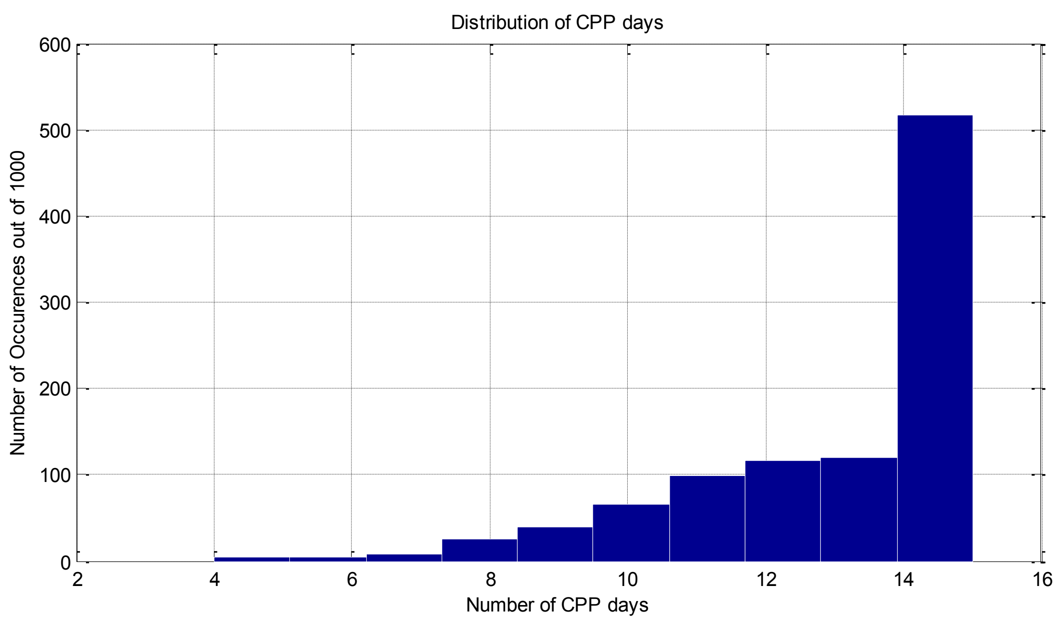

Figure 4.3 Distribution of CPP days for the summer months (1000 iterations)

Under the CPP pricing scheme, the consumer would save on an average $294.3834 annually with a standard deviation of $5.7976 by owning a wind generator. An average of 13 CPP days per year can be expected to be declared.

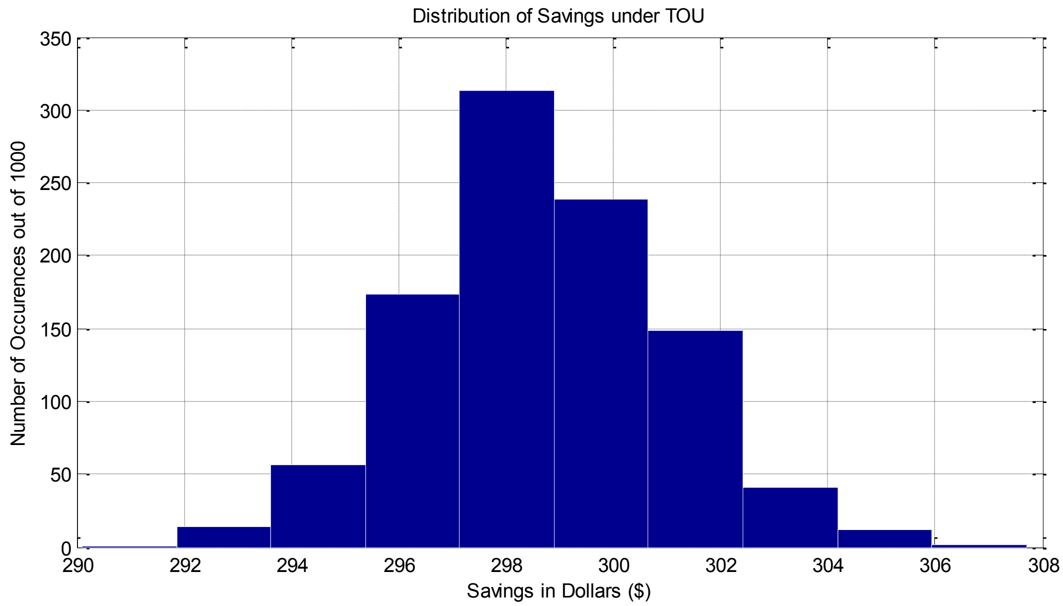

Figure 4.4 Distribution of Savings under TOU scheme for 1000 iterations

Under the TOU pricing scheme also the consumer would save on an average of $298.6983 annually with a standard deviation of $ 2.3794 by owning a wind generator.

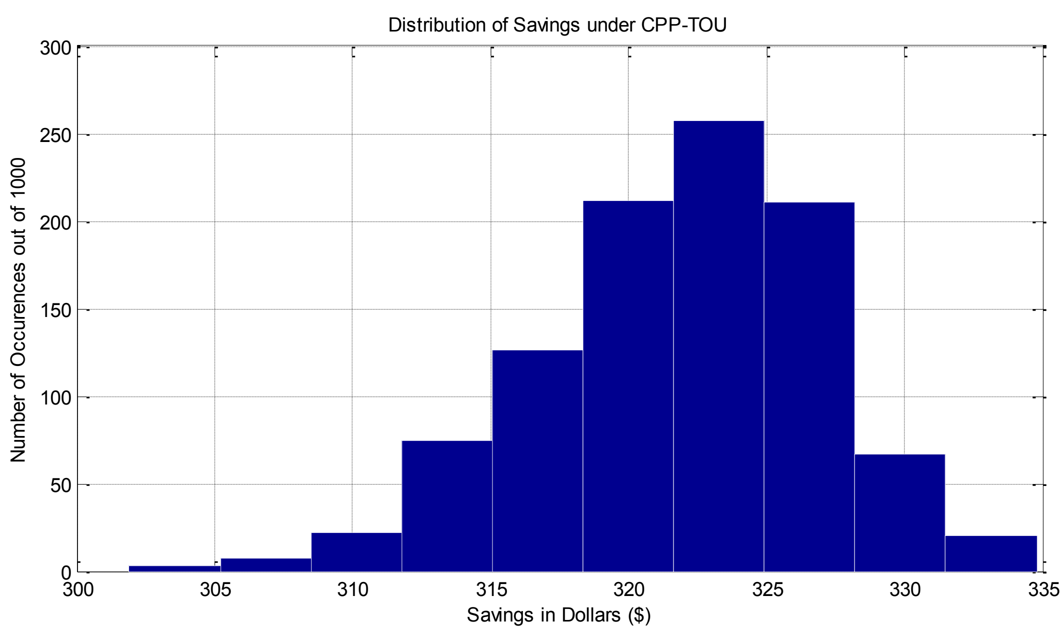

Figure 4.5 Distribution of Savings under the CPP-TOU pricing scheme for 1000 iterations

Under the combination CPP-TOU pricing scheme the consumer would save an average of $321.8822 with a standard deviation of $5.3101 by owning a wind generator.

The mean and standard deviation obtained for each histogram are as in Table 4.2.

Table 4.2 Mean Savings obtained by Monte-Carlo Simulation

Pricing Scheme	Mean of Savings (in dollars)	Standard deviation (in dollars)
CPP	$294.3834	$5.7976
TOU	$298.6983	$ 2.3794
CPP-TOU	$321.8822	$5.3101

Comparing the pricing schemes, a consumer could save approximately $300 annually by owning a wind generator under the CPP or TOU pricing scheme. A combination of the two schemes when applied gave slightly higher savings of approximately $320 annually. These values match with those obtained in the previous chapter. There is a 16.4% probability that a consumer would save greater than $300 annually with the CPP scheme, 30.5% probability under the TOU scheme and 100% probability under the combination of the two schemes referred to as the CPP-TOU scheme.

Net Present Value (NPV)

The Net Present Value (NPV) is the indicator of the value added by the project being considered and helps decide if the project is worth being considered. The Net Present Value is calculated based on the savings over 20 years with the initial purchase and installation cost of the wind turbine being considered.

Cost of Skystream3.7 - $ 15,000

Federal tax credit allowed- $5000 (one-third of the cost of the turbine)

Discount rate- 8%

Table 4.3 Net Present Value under the various pricing schemes

Pricing Scheme	NPV
Critical Peak Pricing Scheme (CPP)	-$7111.412
Time of Use (TOU)	-$7069.073
CPP_TOU	-$6841.585

The negative NPV shows that owning a Skystream3.7 under the pricing schemes may not be economically feasible under the assumed conditions of location and the pricing of electricity considered. Increasing the CPP peak rate to about $22.375/kWh for the peak hours from 1pm to 6pm would help breakeven the initial investment over a 20 year period. Similarly, a rate of $4.68/kWh for the peak period under the TOU scheme would breakeven the initial investment. This was determined based on the expression for the calculation of the 20-year net present value (NPV) mentioned in Appendix B. The annual benefit to bring the NPV to zero was calculated for the CPP and TOU pricing schemes assuming the same discount rate of 8%. The Monte-Carlo simulation was then used to determine the price of electricity for the peak period (1pm to 6pm) by trial and error to arrive at this calculated annual benefit. Although these rates are unrealistic to implement, the pricing rates may vary with utilities and could result in varying energy bill savings based on the location and the wind turbine being considered.

To make a comparison on the variation of annual savings, Spearville, KS was chosen as a location. Based on the mean wind speed distribution for Kansas, Spearville, KS had a mean wind speed of 7m/s in comparison to a 5m/s mean wind speed for Manhattan, KS [24]. The wind output was scaled and the annual savings were calculated for a house in Spearville, KS assuming the load profile was the same as that of the house in Manhattan, KS. A Monte-Carlo simulation of 1000 iterations was run to determine the mean annual savings. The distribution of savings is as shown in Fig 4.6. This consumer in Spearville, KS would save about $455.38 annually on the energy bill. This amount in savings is still insufficient to breakeven the initial investment over a 20 year period.

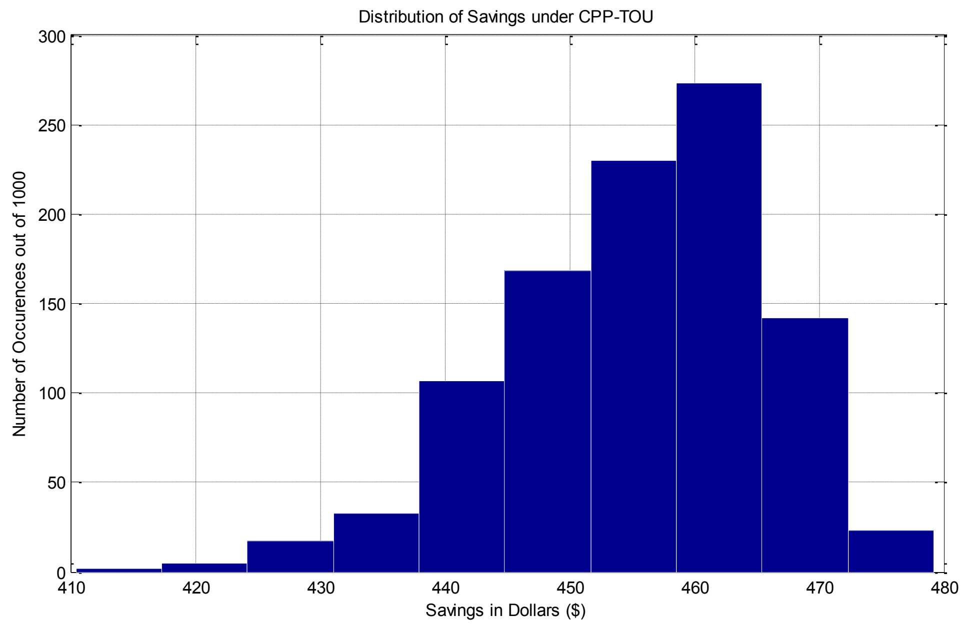

Figure 4.6 Distribution of savings under the CPP-TOU scheme for Spearville, KS

Chapter 5- Conclusion

The aim of this research was to economically evaluate the factors involved in owning a small wind generator under the different pricing schemes. The pricing schemes considered here are the Critical Peak Pricing (CPP), Time of Use (TOU) pricing and a combination of the two, CPP-TOU. Maximum temperature of a day was used as the major factor to forecast load and CPP days. Days of the summer months (June through September) were classified into six different temperature ranges. Load profiles for each of these temperature ranges were obtained for both a location in Manhattan-KS and a location in Topeka-KS. The wind profile for a day in each temperature range was obtained for Manhattan, KS. The wind turbine chosen was the Skystream3.7 rated at 2.4KW which was ideally designed for residential use. The power output was obtained using the data available in HOMER for the chosen turbine. The annual savings on the consumer's annual energy bill was calculated.

Under the pricing schemes discussed and the assumptions made for this research, the CPP and TOU schemes caused no significant change in the consumer's annual energy bill in comparison to the fixed-rate of electricity. However, a combination of the CPP and TOU pricing schemes resulted in slightly higher savings than when the individual schemes were applied. This implies that adopting either of the pricing schemes would not affect the consumer financially but on the other hand by opting for either of the pricing schemes the consumer is helping the utility manage peak load demand during the peak hours of the day. This as mentioned can avoid the construction of newer power plants which in turn reduces environmental pollution and overall reduces the interruptions in providing energy to consumers.

The results from the economic evaluation of owning a small wind generator show that the energy consumer or the owner of a Skystream3.7 under the discussed pricing schemes would not make significant savings under the conditions assumed. The consumer would save approximately $300 annually. The 20 year Net Present Value (NPV) shows that owning a wind generator under the different pricing schemes considered is not an economically viable option. A different location with higher wind profile than Manhattan, KS was considered, which gave higher savings but not enough to make owning a small wind generator economical. Also, higher rates of electricity for CPP and TOU rates were considered and it was found that the rates which would provide zero NPV over a period of 20 years are too high and unrealistic to implement. Thus, the cost of small wind generators has to reduce significantly to make them economical for homeowners to own them. Presently, they are viable for locations far away from the grid or under some special condition such as desire of the owner to promote green technology.

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Appendix A - Load and Wind Profile based on Temperature Ranges

Average hourly load (KW) in each temperature range:

Hour	>101° F	99°F-101°F	96°F-98°F	93°F-95°F	90°F-92°F	<90°F
1	2.342167	1.836	1.856875	1.712	1.603	1.212364
2	2.1215	1.2905	1.743	1.5115652	1.6211154	1.039359
3	2.0765	1.0675	1.48675	1.2001304	1.4744615	0.872152
4	1.670667	0.9735	1.53975	1.1117826	1.2802308	0.760386
5	1.543167	2.347	1.3926875	1.0543478	1.1937308	0.72537
6	1.458	2.0215	1.4435625	1.0618696	1.1480385	0.718451
7	1.306667	1.7875	1.3295625	1.076087	1.0470769	0.745125
8	1.533833	1.474	1.3026875	1.0910435	0.8639231	0.729489
9	1.338833	1.659	1.2995	1.1322174	0.9929615	0.670087
10	1.86	1.908	1.608625	1.498	1.0558077	0.715973
11	1.8165	1.5875	1.791375	1.4274348	1.2068462	0.808293
12	2.965833	1.035	2.0373125	1.6388261	1.3159231	0.93512
13	2.618833	2.029	1.92475	1.8788261	1.4082308	1.004989
14	2.696333	2.66	2.06975	1.9945652	1.6039231	1.061848
15	2.6435	2.8395	2.299125	2.0173478	1.7113077	1.100092
16	2.554833	4.0565	2.5953125	2.2039565	1.8348462	1.149859
17	2.719167	3.7705	2.6705625	2.484087	1.9417308	1.268446
18	3.967833	3.6475	2.523	2.5406087	2.2158846	1.400321
19	3.592167	2.92	2.6174375	2.4641304	2.136	1.457038
20	3.5045	3.2925	2.7229375	2.7283913	2.3830385	1.423549
21	4.007333	2.5725	2.4889375	2.3256957	2.6680385	1.485196
22	4.017833	2.9835	2.4286875	2.7094348	2.7163846	1.639299
23	3.895167	2.725	2.3175	2.6111739	1.978	1.526582
24	3.285	2.5355	2.1556875	2.5356087	1.7872692	1.307514

Average hourly wind speed (m/s) in each temperature range:

Hour	>101° F	99°F-101°F	96°F-98°F	93°F-95°F	90°F-92°F	< 90°F
1	4.217013889	4.421840277	5.0112	4.6628125	5.1206597	4.301354
2	3.741176472	4.052941178	6.0981176	5.2750588	5.3872941	4.414588
3	4.499526068	3.599620854	5.174455	4.0045782	4.6345119	3.475884
4	5.936651585	4.274389141	3.95381	4.6543348	4.5237285	3.751964
5	4.118048781	3.918029269	4.5651512	3.4356293	3.8356683	3.65918
6	3.71862069	4.648275863	3.7186207	3.7186207	4.4251586	3.954133
7	0	4.450397468	4.584043	3.6485241	3.9425443	4.276658
8	4.075609755	4.754878048	4.3201463	4.4016585	5.2031951	4.456
9	5.280751172	3.69652582	5.1751361	5.6372019	5.3335587	4.633859
10	5.01328125	4.6790625	3.7655313	4.991	4.7793281	4.355984
11	4.67061144	4.67061144	4.4721105	5.9550296	6.0134122	4.728994
12	4.725581396	5.115441861	4.9973023	6.0251163	6.0369302	5.103628
13	6.131784384	4.68245353	5.1729963	6.4105019	5.3848216	4.838535
14	7.625090909	5.478334545	6.0766109	6.2525745	6.1118036	5.044291
15	7.313402064	4.473364262	5.5825636	7.3134021	6.3748488	5.38754
16	6.332854578	5.488473968	5.2773788	5.9634381	5.572912	4.612429
17	6.914918628	4.25533454	5.6702333	6.1276817	5.3510832	4.659591
18	4.104607843	5.277352941	5.8637255	6.2507314	6.0279098	4.843437
19	3.7926	3.7926	5.331312	5.52636	4.410252	4.106844
20	2.324778762	4.068362834	4.4751991	5.0912655	4.2078496	3.963748
21	0	4.8742875	5.2695	6.8064375	5.6354375	4.771825
22	2.6543379	4.419472604	4.7512648	7.0738105	4.6450913	4.432744
23	3.763975155	3.763975155	5.5204969	6.4363975	5.1942857	4.817888
24	4.204615384	4.408839559	4.8052747	6.174778	4.6611165	4.721182

Appendix B - 20 Year Net Present Value Calculation

The following method was used to calculate the 20 year Net Present Value under the Critical Peak Pricing (CPP), Time of Use (TOU) and the CPP-TOU pricing scheme.

Discount rate = r % = 8 % =0.08

Present Worth factor = $\frac{(1+r)^{N}-1}{r(1+r)^{N}}$

Where N = 20

Net Present Value = **NPV** = (Present Worth factor *Annual Benefits) – Cost