

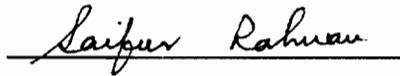
# **A Methodology to Study Photovoltaics and Storage System Interactions**

by

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(ABSTRACT)

A methodology is developed to study the interrelations between photovoltaics (PV) and storage systems in the context of demand side management. This study concentrates on the most prominent types of storage systems and photovoltaic technologies, which are lead acid batteries and single crystalline silicon cells and amorphous silicon cells, respectively. The methodology concentrates on the daily operating cost of the system. Only from a detailed comparison of alternatives, can we develop a system that maximizes the benefits of photovoltaics and storage systems, while remaining cost competitive. This methodology consists of several steps that include; simulation runs to determine yearly energy production and consumption, life cycle costing, and analysis of daily cost graphs. During the analysis several items including photovoltaic and storage system technologies, different demand limits and demand charges, and different amounts of load control and purchased electricity as well as different PV and electricity costs are discussed, and the following conclusions are reached.

The type of photovoltaics used plays an important role in the system design. The amorphous cells seem to have a lower performance degradation in cloudy or hazy conditions, but single crystalline cells have a lower operating cost especially when there

is high sunlight. The cost of photovoltaics also has a great effect on the daily operating cost. By keeping the cost of photovoltaics low (around \$2.00/watt), the overall daily operating cost decreases while increasing the photovoltaic array size. This shows that photovoltaics can have a positive economic benefit. The effect of battery cost and on the daily operating cost is minimal. This is because its cost per day is a small part of the total daily operating cost. On the other hand, the demand limit and demand charge greatly effect the magnitude of the daily operating cost. The main component of the daily operating cost is purchased electricity. The daily operating cost increases as the cost of purchased electricity increases.

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# 1.0 INTRODUCTION

Photovoltaic (PV) modules convert sunlight into electricity. They transform a free and inexhaustible supply of energy into electricity. Once they are installed, they produce energy for their entire life, whenever the sun is shining. Like all energy sources though, they have advantages and disadvantages. Since they are modular, they can be installed relatively easily. They also have a long life span and require very little maintenance. There are, however, two drawbacks to the use of photovoltaics. One is that their power output fluctuates with the weather and the time of day. This causes their output to be intermittent. Second is that they have a high initial cost. However, due to their low operation and maintenance costs, they may remain cost competitive in a life cycle cost comparison to other energy sources. PV energy is also environmentally attractive because it does not pollute the atmosphere and there is no fear of harmful radiation leaks. One way to solve the output fluctuation of photovoltaic power is to install a buffer between the PV array and the load. This can be done by connecting the system to a utility grid or a storage device, typically a battery. This combination of PV with a backup energy source creates reliable and efficient energy source.

Since a photovoltaics-energy storage system produces clean and efficient energy, it can be a useful tool in load management. The energy from photovoltaics can be used to reduce instantaneous loads while stored energy can provide additional power for reducing peak loads, thereby improving the daily load curve. The PV-Storage system can not only help utilities improve load curves, but it can also help energy consumers in the form of demand side management (DSM).

Demand side management can be thought of as a combination of various customer actions and incentives that improve system load patterns. Thus load management can be

thought of as a form of DSM. DSM can be helpful to both the utility and the consumer since this practice reduces costs for both parties. For example, most commercial buildings in various parts of the country are required to pay a demand (capacity) charge in addition to the standard energy charge. This extra charge is for the utility to be prepared to supply the expected demand. These demand charges are relatively high; for Virginia Power this is about \$15.00 per kW per month. The typical power demand for a 100,000 square foot commercial building is 1000 kW or more, assuming non-electrical space heating. Thus, such a building will have to pay \$15,000/month just for the permission to draw up to 1000 kW peak load. Thus if a PV-Storage system is implemented, it can reduce the building's capacity charge as well as provide energy savings. This results in a reduced capacity need for the utility during peak demand hours, and for consumers there is a lower cost since the energy they purchase is lower during peak hours when rates are higher. For photovoltaic-DSM systems to work properly, the utility must offer incentives for consumers to build the PV array or lease roof space for their own as reported by Farber [20] and Sim [47]. To develop the most cost effective DSM and photovoltaic systems, different types of storage systems must be considered.

There are several types of energy storage systems that need to be examined to determine which is best for use with a particular load type and the available photovoltaic system. The most common type of energy storage is a battery system which usually consists of several modules of rechargeable units. Since batteries are modular and can respond quickly to load changes, they are very attractive for use in load management. Another type of energy storage is pumped hydro. Here water is pumped to an elevated reservoir during off-peak hours. This water is allowed to fall into a lower reservoir while spinning turbines to produce energy during peak load hours. This form of energy storage has been used for years, but it has slow reaction times to load changes and needs places for the water reservoirs. A third type of energy storage is compressed air energy storage or

CAES. This system pumps air into a large underground cavern during off-peak hours and then releases the air, through a turbine, to produce electricity during peak demand times. Other types of storage include superconducting magnetic energy storage (SMES) and flywheels. These energy storage systems are further examined in a later chapter.

Storage systems can reduce operating costs by allowing a utility or building to store inexpensive off peak energy and use it when the demand is high. One advantage to storage systems is that they can start up quickly and respond rapidly to load fluctuations. They can also be used for frequency regulation, and voltage and power factor corrections. This lets the energy system that is on line to run at its most cost effective rating. The main problem with storage systems is their costs. Storage systems in the form of battery, pumped hydro, compressed air, or SMES have a large initial cost but usually have lower operational and maintenance costs than fossil fuel plants. They also run much cleaner than fossil fuel plants.

The development of a methodology that determines the daily operating cost at a particular site can be very useful. This study looks at this problem by considering several areas of photovoltaic and energy storage device performances. This includes a discussion of the characteristics of different storage technologies and different photovoltaic module technologies. Other factors that will be examined include amounts of demand side energy control, building load shapes, and demand charges.

This study concentrates on the most prominent types of storage systems and photovoltaic technologies. The most popular type of energy storage is lead acid batteries. The most popular types of photovoltaics are single crystalline silicon cells and amorphous silicon cells. These technologies along with others are discussed in later chapters. Since this study uses technology that is readily available, it will be of considerable usefulness for utilities and consumers. For utilities, this study will show how much capacity a utility can expect to save by implementing a photovoltaic - storage - DSM system. For consumers

this study will give an idea of the economic benefits of purchasing and using such a system. By developing a way to optimize the benefits of photovoltaic with DSM and storage systems, it can be shown that the system is economically attractive.

The remainder of this study is given in the following chapters. Chapter 2 will cover background information on PV - DSM - Battery systems. Chapter 3 will give a problem statement for this study. Chapter 4 gives an overview of current photovoltaic and storage technologies. Chapter 5 shows the design of the simulation model. Chapter 6 gives the results of the study and discusses them. Chapter 7 gives the conclusions of the study and makes recommendations. Chapter 8 contains the bibliography. Appendix A gives the operating characteristics of the two types of photovoltaic modules used in the study. Finally, Appendix B gives the complete results of the simulations in table form.

## 2.0 Background Information

In the area of photovoltaics a lot of research is being done on the development of new cells that have high efficiencies. These cells implement different technologies such as using concentrators, placing the cells in tandem as discussed by Gale, McClelland, Dingle, and Gormley [21] , and cell corrugation reported by Uematsu, Kanda, Kokunai, Warabisako, Iida, and Saitoh [53], to get high efficiencies. There is also development in using materials other than silicon, like gallium arsenide, for higher efficiency cells as discussed in Gale, McClelland, Dingle, and Gormley [21] and Green [25].

Significant research has also been conducted in monitoring photovoltaic power stations and their effects on utility grid electricity. Several test facilities have been constructed to examine the performance of crystalline and amorphous silicon cells. These include a performance discussion on a 15 kW amorphous cell system in Florida by Atmaram [1] and the Carrisa Plans facility by Wenger [54]. A report on the VISTA and VTSES facilities in Virginia by Rahman [42] and [44], also examines the performance of crystalline and amorphous cell facilities. Other papers have discussed the performances of large numbers of array facilities such as Conover [12] and Schaefer[45]. These test facilities have found that photovoltaics can be a reliable source of energy. With the use of photovoltaics on the utility grid systems, there were many concerns about the quality of electricity and security of the system. Several studies have been done on the effect photovoltaic stations have on security by Chowdhury [11], distribution feeders by New England Power Service Company [32] and Shugar[46], islanding problems by Sims [48], and grid connections by Kobayshi [27]. The implementation of a large scale photovoltaic test project was conducted in Garner, MA. Here the New England Electric System Company installed photovoltaic arrays on thirty houses. This system is monitored and

evaluated to study various topics. These including; steady state and slow transients, harmonics, and performance of the distribution system. These studies were done by the New England Power Service Company [32] and Bzura [9]. The integration of photovoltaics with utilities has been discussed by several people and groups including Herig [26], Perez [33], Rahman [40], and Electric Power Research Institute (EPRI) [49]. These papers show that photovoltaics can be effectively combined with present electrical utility systems.

The use of storage systems to help improve energy management has been developed for many years. In recent years with the technological development of practical and efficient energy storage system, more uses for storage systems have been implemented. The advancement of reliable and efficient solar technologies has also led to their application to energy management. Therefore, a literature search in the areas of storage systems, photovoltaic systems, energy management, and their interrelationships was conducted.

Currently there is a lot of motivation for utilizing storage systems. According to an EPRI report [15], "The electric utility industry needs to maximize the use of capital-intensive baseload plants, reduce their dependence on foreign oil, minimize the environmental effects of energy use, and continue to provide highly reliable service". One way of achieving these goals is through the use of energy storage. In their study, EPRI found that by the year 2000, the market for energy storage could be more than 10,000 MW. While pumped hydro plays an important role now, concentration will be on compressed air energy storage (CAES) and battery systems to serve to new capacity. These systems have been examined by several research groups as discussed in the following.

In the area of battery storage, a study was done by the Public Service Electric and Gas Company [37], in New Jersey, for EPRI on the development of a 500-kW peak

shaving lead acid battery storage system. In the study it was found that lead acid batteries could deliver power with 75% efficiency and 86% availability. Not only can the batteries be used to increase the peak capacity of the utility, but they can also enhance system reliability illustrated by Eckroad and Radimer [17] and Power Technologies Inc. [35]. They can also provide a dynamic spinning reserve shown by the Zaininger Engineering Company [55], and help regulate the electrical system demonstrated by EPRI [52]. There is also considerable research in the development of new types of advanced batteries that are more efficient, smaller, and less costly than lead-acid batteries. Some examples are zinc-chloride and sodium sulfur batteries as reported by Genta [22]. These advanced batteries are discussed in later chapters.

In the area of compressed air energy storage, a new pilot plant is being tested in Alabama. These systems have been in existence for over 10 years in Germany with very promising results as reported by Boutacoff [8]. The CAES, like batteries, has a very good response time to demand changes. This makes the system attractive for load management.

In the area of energy management there are papers that have evaluated both supply side and demand side management. Supply side management refers to how a utility company manages the energy production, transmission and distribution of power. Supply side management takes into account the baseload capacity, intermittent energy generation and wheeled power. Demand side management on the other hand, is the management of energy on the consumer side of the meter. The consumer can take actions like installing high efficiency appliances or allowing the utility to cut off certain electrical appliances when demand is high. In the paper by McCarthy [29], an evaluation of different supply side and demand side management programs was done. It was found that demand side management offered a viable and effective way of energy management.

The most important reason for energy management is the fact that the daily load curve can be altered. This is to achieve a better match between the customers' demands and

the utilities' current and planned resources as discussed by Rabel [38, 39]. This is done by using various means to shave the peak demand and fill the low demand valleys of the daily load curve. EPRI [5, 18] has done several studies that examine the ways utilities can meet increasing electricity demand and they have found that implementing DSM can help reduce the need for building expensive power generating units.

There are also a few papers in the area of interaction between photovoltaics, storage, and DSM. These have looked at using photovoltaics as a DSM tool or a load-leveling device. Currently there is a good deal of research being done on how photovoltaics can reduce peak loads and thus contribute to a better load curve. This is being addressed by Perez [33] and Bailey [2]. Perez addresses the issues of interaction between photovoltaics and summer-peaking utilities and the evaluation of existing solar resources to meet the demands. One problem with just using a PV system for load leveling is that the peak loads must coincide with the maximum output of the photovoltaic arrays, which does not happen frequently. The relationship between photovoltaic power and battery storage on a utility scale has been discussed by Rahman and Chowdhury [41]. They explore the impact of photovoltaic power generation on the electric utility's load shape under supply-side peak load management conditions. They show that some utilities employing battery storage for peak load shaving might benefit from the use of photovoltaic power. This paper looks at the benefits gained by including a storage device with the photovoltaic array. Further investigation of photovoltaic-storage systems and their applications to supply side and demand side energy management are pursued in this study.

### **3.0 Problem Statement**

Demand side management is becoming a more important issue as utilities are forced to find ways to meet new demand without building large scale power generation plants. Through demand side management, consumers can save money while reducing the utility's responsibility to cover some capacity. One of the most promising ideas in DSM is the use of photovoltaics as a supplementary generation source since they can supply clean efficient energy and capacity during high demand periods, such as summer air conditioning loads. Since photovoltaic energy can be intermittent, the addition of an energy storage system can make the PV-DSM system more reliable.

A methodology is needed to study the interrelations between photovoltaics and storage systems in the context of demand side management. This methodology needs to discuss several items including; storage requirements for different solar cell technologies, different (building) load sizes, and different amounts of load control. The methodology should also concentrate on the total system cost as well as the daily operating cost. Only from a detailed comparison of alternatives, can we develop a system that maximizes the benefits of photovoltaics and storage systems, while remaining cost competitive.

## **4.0 Photovoltaic and Storage Technologies**

### **4.1 Photovoltaic Technologies**

Photovoltaic power systems have several characteristics that make them an attractive energy source. They require no fuel for operation, and therefore produce no harmful emissions. They are low maintenance, especially in non-tracking systems, this is explained in more detail in section 4.2. They also offer a modular design which allows for growth with increasing capacity as examined by EPRI [49]. The major disadvantages for photovoltaic energy is their intermittent energy production and their cost. Although not a lot can be done to change photovoltaics power production, several types of solar cells have been developed to reduce the cost of production. A discussion of these cell technologies follows.

#### **4.1.1 Single Crystalline Silicon Cells**

This is the most common type of cell. One reason it is so popular is that there is a lot of information on the properties of crystalline silicon from research in semiconductors and space experience. These cells also have a high efficiency, around 12%, and their performance does not degrade over time. The one drawback of single crystalline technology is its cost. One popular way to construct single crystal cells is by the Czochralski method, where a long single crystal is grown and then sliced into wafers (3 to 5 inches in diameter). Then the silicon wafer is made into solar cells by additions of dopant and the connection of electrical contacts. Then the cells are wired together and placed into a module with a substrate (usually MYLAR) and super substrate (tempered glass) for protection. This multi-step process is complex and expensive. EPRI has shown that

photovoltaic modules constructed from single crystalline silicon cells currently cost between \$5 and \$10/Wp [49].

#### **4.1.2 Amorphous Silicon Cells**

Amorphous silicon solar cells have an important advantage over single crystalline cells, they are less expensive to produce. Amorphous cells are made by depositing thin layers of doped silicon on glass substrates. This can be done easily on a large scale or continuous process. Although these cells can be produced easily, their efficiencies are low, around 3 or 4%. Therefore it takes more amorphous modules to produce the same amount of energy as from a single crystalline modules. Currently there are many research projects trying to improve amorphous cell efficiency by using multi-junction approaches. These cells have expected efficiencies of 15 to 18%. EPRI has shown that this would make them more cost competitive than single crystalline cells [49]. Another problem associated with amorphous cells is that their performance degrades with sunlight exposure. This is called the Staebler-Wronski effect. By examining cell performance Schaefer [45] it has been shown that these cells degrade around 10-30% in their first few months of operation, then level out to a stable performance.

Recently, research has been conducted on the relative benefits of amorphous and single crystalline cell technologies. It has been shown by Rahman [42] that single crystalline cells perform better under clear sky conditions, while amorphous cells outperform single crystalline cells under diffuse light or improper angle tilts. This fact can be of some uses when considering that climate conditions that the cells will be used.

### **4.1.3 Other Photovoltaic Technologies**

Currently research is being done on developing new thin-film photovoltaic cells that have high efficiencies. Researchers are looking at materials other than silicon to reach these high efficiencies. One of these materials is Gallium Arsenide (GaAs). As explained by Green [25], these cells have much higher theoretical efficiencies than silicon cells because of the size of their band gaps. Currently available GaAs cell efficiencies are around 22%. The problem with these cells is that they are made from more expensive materials. These cells have given good performance in laboratory tests and space applications, but their price still remains out of reach for most utility applications.

Another improvement in photovoltaic efficiencies is with the use of concentrators. This process uses mirrors or lenses to increase the amount of sunlight that a cell receives. These usually raise the efficiencies a few percent. The mirror design has led to some problems in the Carrisa Plains Photovoltaic station as reported by Schaefer [45]. A problem called "brown cell" where the color of the cell turns from blue to brown, has caused a deterioration of power output. This is because the high cell temperature, caused by the intensified sunlight, oxidized a polymer that is encapsulated between the cells and the front glass plate. Therefore it has been shown that mirrors should only be used if high temperature cell designs are implemented.

## **4.2 Array Orientation Schemes**

### **4.2.1 Tracking Mechanisms**

There are several ways in which photovoltaic modules can be oriented to gather sunlight. First is a stationary position. In this position the array faces due south. This

allows for the most sunlight to reach the panels during the day. Second is a fixed array that is facing some degree to the east or west of due south. This is a change in the azimuth angle. This allows for more sunlight to reach the panels during the morning or afternoon hours. Farber [20] discusses how a fixed azimuth angle set to the east or west of due south can be useful in covering morning or afternoon peak loads. The third way to track the sun is with a continuous azimuth tracking system such as is found in two-axis tracking. This allows for the maximum amount of sunlight to be utilized. The continuous tracking system uses a small amount of power and may not be easy to maintain. It has been shown by Rahman [40] in his discussion of the Virginia Integrated Solar Test Arrays, that in Virginia 2-axis tracking arrays are not cost effective.

#### **4.2.2 Tilting Mechanisms**

There are also three ways to view the tilting mechanisms of photovoltaic arrays. first is the fixed tilt. Here the tilt of arrays is left at an optimal angle for the entire year. This is usually equal to the latitude of the site. Next is a fixed tilt that is changed during the year. For example, a tilt that is changed twice a year, usually in the spring and fall to increase energy production. In the summer the tilt should be smaller since the sun is higher in the sky, and in the winter the tilt should be larger since the sun is lower in the sky. This type of angle movement should be reversed for use in the southern hemisphere. The third type of tilting would be a continues change. This type is found in two-axis tracking. Here the array keeps a path normal to the sun's radiation, and therefore produces the maximum energy output.

## 4.3 Storage Technologies

There are many different storage technologies, each with its own operating characteristics. A thorough examination of all alternatives must be made before selecting a storage medium. A detailed discussion of storage devices follows.

### 4.3.1 Battery Storage

Batteries are the most common type of energy storage system used with photovoltaics. They have the characteristics of being flexible, reliable, and responsive. They are also quiet and nonpolluting. This allows them to be installed near load centers and in existing suburban substations. Batteries are also modular and can be therefore be accurately matched to the load growth of the system. One of the strongest points of batteries is that they have a fast response time, typically responding to load changes in about 20 milliseconds, this is discussed in Boutacoff [7]. A battery is constructed with one or more cells that stores two or more chemicals. There are two types of batteries; primary and secondary. The primary battery cannot be recharged. A typical example would be a dry cell used in flashlights. The secondary type of battery is used in energy storage. This type of battery can be recharged. The most common example would be the lead-acid battery found in cars. The battery stores energy by converting DC electrical energy to chemical energy during charging and the reverses this reaction upon discharge. Since there are no mechanical components, the response time is fast shown by Cultu [13]. Currently, much research is going on in the development of new battery types to replace the lead-acid type. A discussion of the type of batteries currently available including their performance measures is give in the next section.

#### 4.3.1.1 Lead-Acid Batteries

The lead-(sulfuric)acid battery is the most common type of energy storage battery. This type of battery contains a solid electrode (lead) and a liquid electrolyte (sulfuric acid). Usually special deep discharge batteries are used in photovoltaic applications. These batteries are used because of their long life (up to 15 years) and the ability to be discharged to deep levels without affecting their performance. This attribute is critical in PV systems. One problem with lead-acid batteries is that their performance degrades with decreasing temperature. Since photovoltaic performance increases with the decrease of temperature, one must be careful not to overcharge the batteries. This shortens the battery life span and is discussed by Komp [28].

#### 4.3.1.2 Nickel-Cadmium Batteries

Nickel-Cadmium (Ni-Cad) batteries use two plates for the electrode. One is a nickel plate the other a cadmium plate. The electrolyte for this battery is a potassium hydroxide solution. These batteries are more expensive than lead-acid but have better performance with temperature changes. Komp [28] also reports that there is also one problem with Ni-Cad batteries. This is the fact that they have a memory effect. This means that if they are repeatedly discharged to a certain level, then the battery behaves as if its full capacity is up to that certain level. So the voltage drops when that level is surpassed. Usually since these batteries are so expensive, they are only used for small applications.

#### 4.3.1.3 Sodium Sulfur Batteries

In the sodium sulfur battery, the sodium atoms loose electrons during discharge, this results in ions passing through the sulfur solution to form sodium polysulfide in the cathode. The sodium sulfur battery uses inexpensive and readily available materials.

However, the materials require expensive purifying techniques reported by Cultu [13]. These also have long life spans typically 15 to 30 years. One drawback discussed by Komp [28] to these batteries is that they need to be kept between 300 and 350°C to operate. EPRI [34] reports that the successful development of these batteries depends on the commercialization strategy to make them economically feasible.

#### 4.3.1.4 Zinc Chlorine Batteries

A fourth type of battery is the zinc-chloride type. The zinc chloride battery has an energy density between the sodium sulfur battery and the lead acid type. As discussed by Cultu [13], the cost of the materials in this battery is relatively low, but one of its disadvantages is that since chlorine is a gas at room temperature, refrigeration is needed to store the chlorine as a hydrate. These batteries also are reported by Komp [28] to have at least a 15 year life. An experimental 100-kW facility has been built and tested by EPRI [19]. However it only operated at 66% DC efficiency. But this project was discontinued because of lack of funding.

#### 4.3.1.5 Lithium Metal Sulfide Batteries

This battery, like the sodium sulfur battery, needs to operate at high temperatures, around 400-500°C. One of the main advantages of lithium metal sulfide batteries is their small dimensions. It is reported by Cultu [13] that they take up one twelfth of the square footage and weigh one fourth less than a similar lead-acid unit. These batteries have already been designed for use in electric vehicles (EV) and have outperformed lead-acid batteries in tests by EPRI [24]. EV batteries are designed for quick response, large discharge, and frequent recharging. These characteristics make them attractive for use in photovoltaic applications.

### 4.3.2 Pumped Hydro Storage

This form of storage has been around for more than fifty years. In these plants, off-peak energy is used to pump water back into an elevated reservoir. This water can then be used during the peak load periods to turn turbines in the same fashion as a regular hydroelectric plant. Pumped storage plants need to be in the range of 200-2000 MW to be economically feasible. The availability and reliability of pumped hydro plants can be found easily since there is a large number of actual working plants. A paper by Cultu finds that the average availability is around 87% and the forced outage rate around 4% [13]. Pumped hydro also has the ability to store energy for long periods of time if the reservoir size permits. Some other advantages to pumped hydro are that they have a long life, usually over 50 years, and that they have a low maintenance cost. The main problem with pumped storage is finding a suitable site. Pumped storage requires a large area that can hold two reservoirs at different elevations. A new idea of developing an underground pumped hydro plant is discussed by Boutacoff [7] and may hold some promise for the future. A second disadvantage with pumped hydro is the turn-around time from storing to discharging. This is because the pumps must overcome hydraulic inertia. Typical turnaround times as reported by Cultu [13] are:

From pumping to full load generation	2-20 minutes
From generation to pumping	5-40 minutes
From shutdown to full load generation	1-5 minutes
From shutdown to pumping	3-30 minutes

Another disadvantage discussed by Castro [10] is that once a pumped hydro plant is complete, it is difficult to increase capacity since reservoirs must be expanded and plant capacity increased.

### **4.3.3 Compressed Air Energy Storage (CAES)**

Compressed air energy storage (CAES) plants use off peak electricity to compress air into an underground reservoir. When electricity is needed the air is withdrawn, heated with gas or oil, and run through expansion turbines to drive a generator. These plants burn about one-third the fuel of a conventional combustion turbine and thus produce one-third of the pollutants. A paper by Boutacoff [7] discusses ways to store compressed air in several types of underground structures, including caverns in salt or rock formations, aquifers, and depleted natural gas fields.

The first working CAES plant has been in operation in Hunfort, Germany for 10 years. It has demonstrated strong availability 90% and reliability 99%. Currently there is an pilot plant in McIntosh, Alabama. It can produce 110 MW for 26 hours as reported by Boutacoff [8].

### **4.3.4 Superconducting Magnetic Energy Storage (SMES)**

Superconducting magnetic energy storage (SMES) is a prospective form of energy storage. In a description of a SMES device by Boutacoff [7], off-peak power is converted to direct current that is fed into a donut-shaped electromagnetic coil of superconducting wire. The coil, some 1000 meters in diameter, would be installed in a trench and kept at super conductive temperature by a refrigeration system. It is reported by Cultu [14] that a SMES unit could store and discharge power at AC-AC efficiencies of 90% or more and switch between charging and discharging within 20 milliseconds. SMES have a significant positive effect on electric power transmission because they can also be used as continues VAR controller or load frequency stabilizer as discussed by Banerjee [3, 4]. Tam [51] reports that by implementing SMES technology, transmission line loading during heavy periods can be reduced and transmission losses can be decreased. Tam [50] also discusses

another attribute that make SMES attractive, that is that large SMES can link together separate power systems through a DC asynchronous connection. This allows for the interchange of power between the two systems. Although these systems are only in the research phase, they may prove valuable in the future.

#### **4.3.5 Flywheels**

A flywheel as described by Genta [23] consists of a wheel, a casing which provide a containment structure, bearings, and a vacuum and seal system. It stores inertial energy in the rotating mass of the flywheel. The most important feature of the flywheel is its high power density. They can be charged at very high rates and can deliver very high powers. Flywheels do not pollute the air and have very high efficiencies. The disadvantages to the use of the flywheel is that since it stored energy in a mechanical form, it losses energy in conversion back to electricity. It also has to be well secured otherwise it can rip itself apart. A study of flywheel use with photovoltaics was done by Miller [31]. It showed that the flywheel can be an good device for storing energy if it can be made at a commercially attractive price.

### **4.4 Conclusions**

Table 4.1 gives the expected technical and cost characteristics of the discussed energy storage systems. This table was developed by EPRI in 1976, while most of the cost have increased, the plant sizes, efficiencies, and construction times have remained approximately the same. Here power related costs are associated with the power output of the device. The storage related costs are determined by the specific costs of the energy storage capacity and the time for which the storage system can deliver energy at rated

output power. In the efficiency rating, CAES is not rated because fuel is burned during the discharge portion of the cycle. Since this is not a pure energy storage system the comparison between efficiencies would not be meaningful.

**Table 4.1**

**Expected Technical and Cost Characteristics of  
Selected Energy Storage Systems [36]**

Characteristics	Lead Acid Batteries	Advanced Batteries	Pumped Storage	CAES	SMES	Flywheel
Economic Plant Size (MW or MWh)	20-50	20-50	200-2000	200-2000	10,000+	10-50
Power Related Costs( \$/kW)	70-80	60-70	90-160	100-210	50-60	65-75
Storage Related Costs ( \$/kWh)	65-110	20-60	2-12	4-30	30-140	100-300
Expected Life (Years)	15	10-20	50	20-25	20-30	20-25
Efficiency %	60-75	70-80	70-75	(na)	70-85	70-85
Construction Lead Time (Years)	2-3	2-3	8-12	3-12	8-12	2-3

## **5.0 Design of Simulation Model**

### **5.1 Introduction**

A simulation model is necessary to study the interaction between photovoltaics, storage systems, demand side management controls, and the building load. This model can be used to test different design specifications and characteristics. Conclusions can then be drawn on the system interactions from the results of model testing. This section describes the process of developing a model for photovoltaic, storage system, and DSM control interaction.

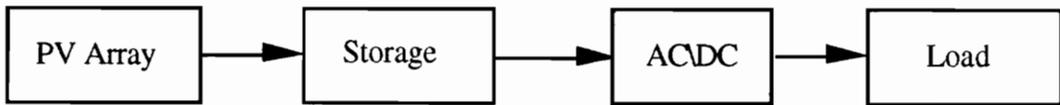
### **5.2 Photovoltaic - Storage System Configurations**

There are two basic configurations for a combined photovoltaic - storage system. These are stand-alone and grid-connected systems. In the stand-alone configuration, the photovoltaic array and the storage system are the only energy sources available to cover the load. This system usually has to be oversized to protect against energy shortages that may come from bad weather. There are two ways that the stand-alone system can be designed. These are shown in Figures 5.1 and 5.2. In Figure 5.1 the photovoltaic array is connected to the storage system, and the stored energy covers the load. This configuration allows the DC energy from the array to be stored directly. This system has one drawback in that the storage system must be large enough to cover the load. In Figure 5.2 the photovoltaic system covers the building load and the storage system just acts as a backup. This allows for the storage of excess PV energy. Then that energy is used during night or cloudy

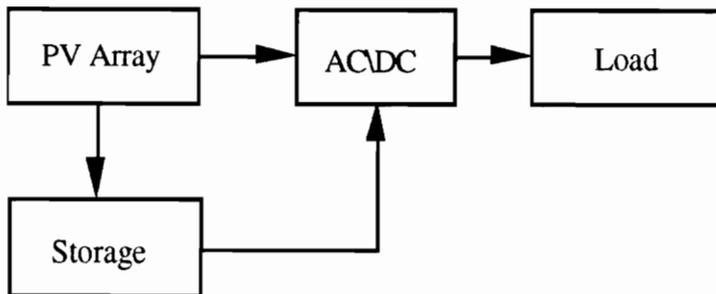
periods. This array must be carefully sized to be able to cover loads during long periods of cloudy days.

There are several ways that a grid-connected system can be implemented. These are shown in Figures 5.3 through 5.7. Figure 5.3 shows the simplest configuration where the utility acts as a backup to the photovoltaic array. The utility not only covers the load that the array cannot cover, but it also buys back extra energy generated by the photovoltaic array. The rest of the diagrams show the addition of an energy storage system.

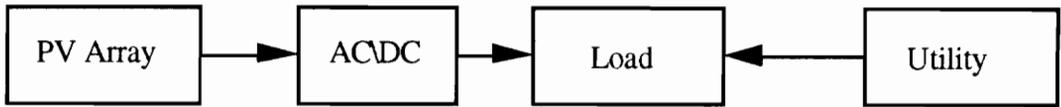
The design of a PV-storage system is very site specific and a lot of preparation should be done to develop an efficient system. This study will concentrate on the system layout shown in Figure 5.7 (Configuration 7). This configuration incorporates all possible connections between the photovoltaic array, the storage system and the utility. In PV-Storage System Configuration 7, the PV and the utility can be used to cover the load as well as replenish the storage system. This configuration works well with the concept of demand side management. The photovoltaic and stored energy are used to cover peak demand periods, while the utility energy covers the base load and replenishes the storage during off-peak demand times. If the array generates energy during off-peak demand times, its energy is also stored. This way the building uses less utility power during peak demand times, when electricity is more expensive. Figure 5.8 shows the implications of a PV - storage system used as a DSM program on the daily load curve of a building. The peak load is reduced during the day by the energy from array and stored energy, while the nighttime load is increased due to the recharging of the storage system.



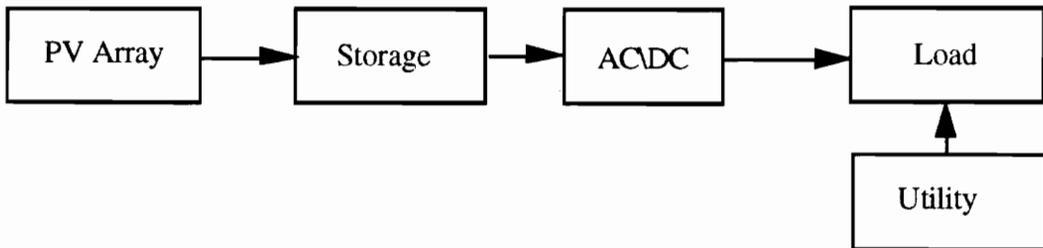
**Figure 5.1 Stand Alone PV-Storage Configuration 1.**



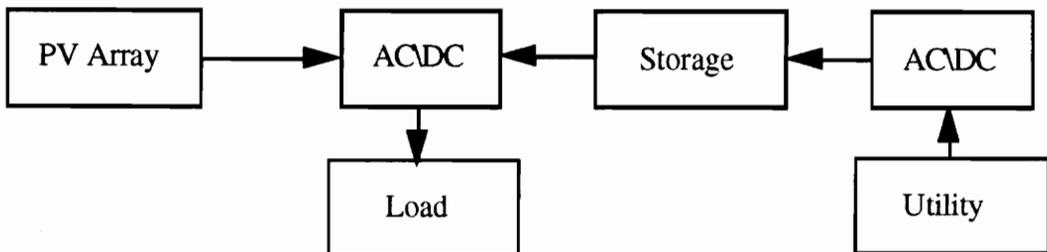
**Figure 5.2 Stand Alone PV-Storage Configuration 2.**



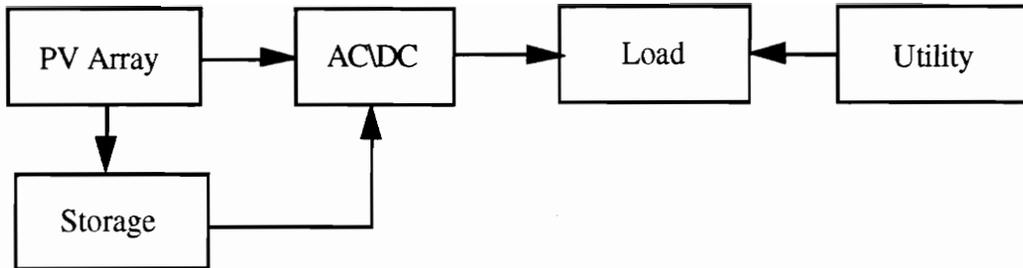
**Figure 5.3 Grid Connected PV System Configuration 3.**



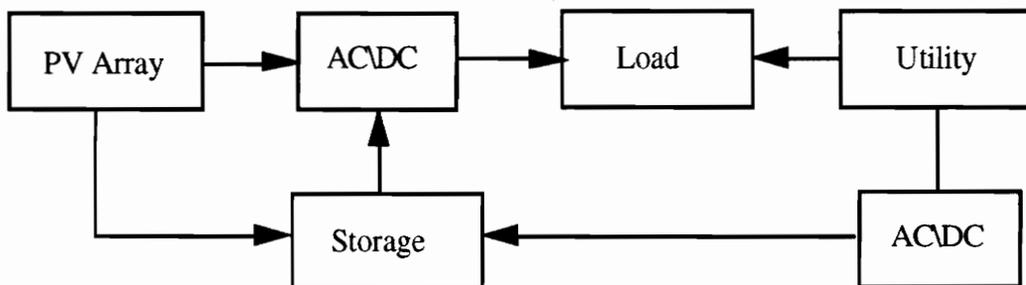
**Figure 5.4 Grid Connected PV-Storage System Configuration 4.**



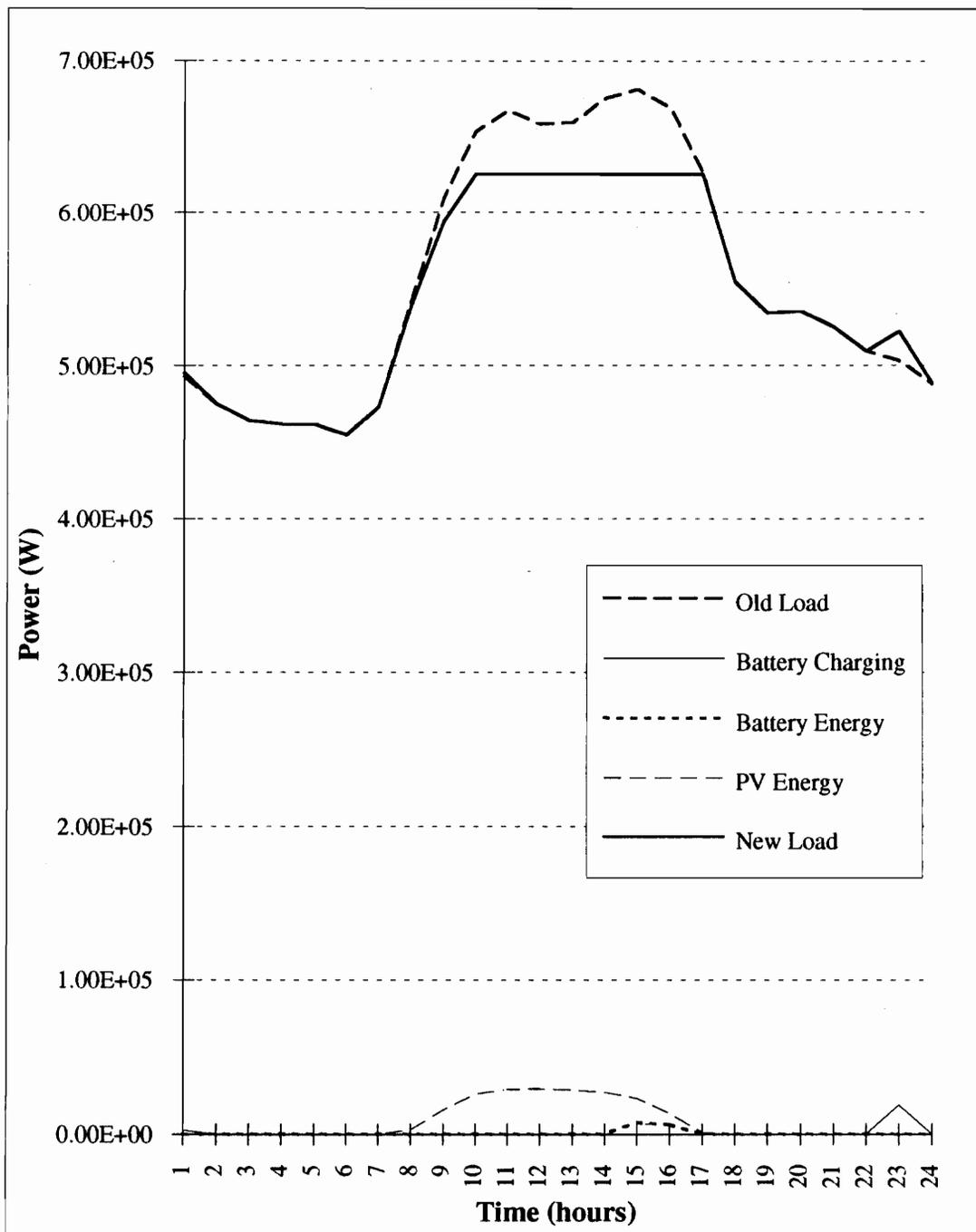
**Figure 5.5 Grid Connected PV-Storage System Configuration 5.**



**Figure 5.6** Grid Connected PV-Storage System Configuration 6.



**Figure 5.7** Grid Connected PV-Storage System Configuration 7.



**Figure 5.8 Effect of a PV - Storage System acting as a DSM program on Daily Load Curve**

### 5.3 Building Load

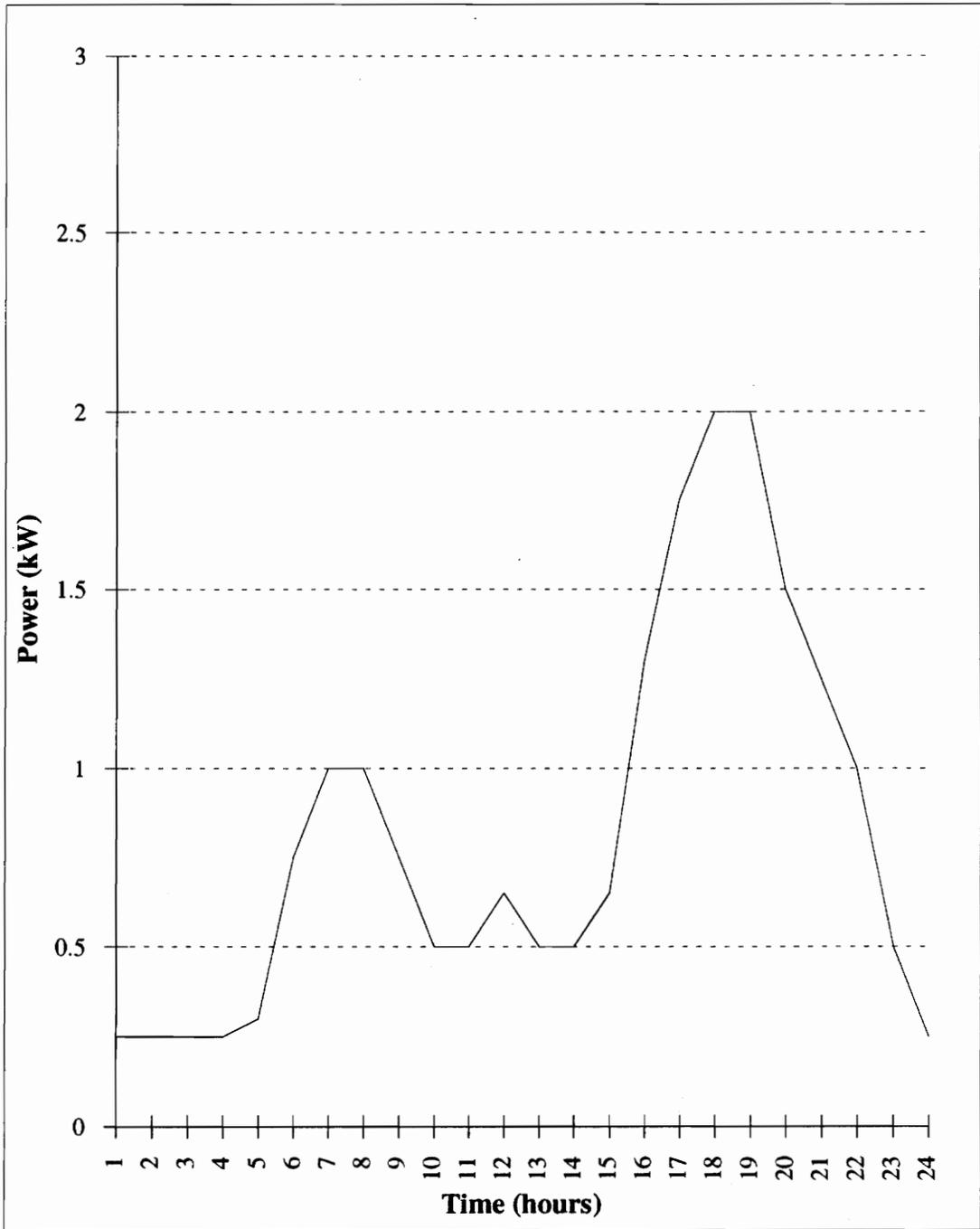
This study is specifically aimed at controlling the electrical load of a single building. Although this study can be applicable to managing a town's load, or the entire utility's load, with small modifications to the load profiles and sizes of the photovoltaic array and battery storage system. In order to properly size the photovoltaic - energy storage system, the building load at which the system is to be implemented must be considered. The type of building load plays an important role when designing photovoltaic and energy storage systems. There are three basic types of loads that can have different effects on system design. These are residential, industrial, and commercial. Their typical load shapes are presented in figures 5.9 -5.11. The residential load (see Figure 5.9) has two peaks, one in the morning usually before 8 a.m., and another around 6 p.m. This load usually does not match well with photovoltaic output, but if energy storage is implemented, the load can be matched. The industrial load (see Figure 5.10), maintains a consistent load pattern since the building is in use around the clock. The third type of load is commercial load (see Figure 5.11). In commercial building loads, the demand follows the work schedule in that it starts to rise around 8 a.m., then it peaks from 10 to 4, with a slight dip at noon. The commercial load then falls around 6 p.m. and returns to a level nighttime demand. This type of load matches very well with photovoltaic output. This type of load will be examined during the remainder of the study.

The kind of day also plays an important role in the building load. Weekday loads are usually different from those on weekends and holidays. In commercial buildings, weekends and holidays usually have flat load curves. This is important when sizing the storage system, because the storage systems will usually have a chance to fully recharge

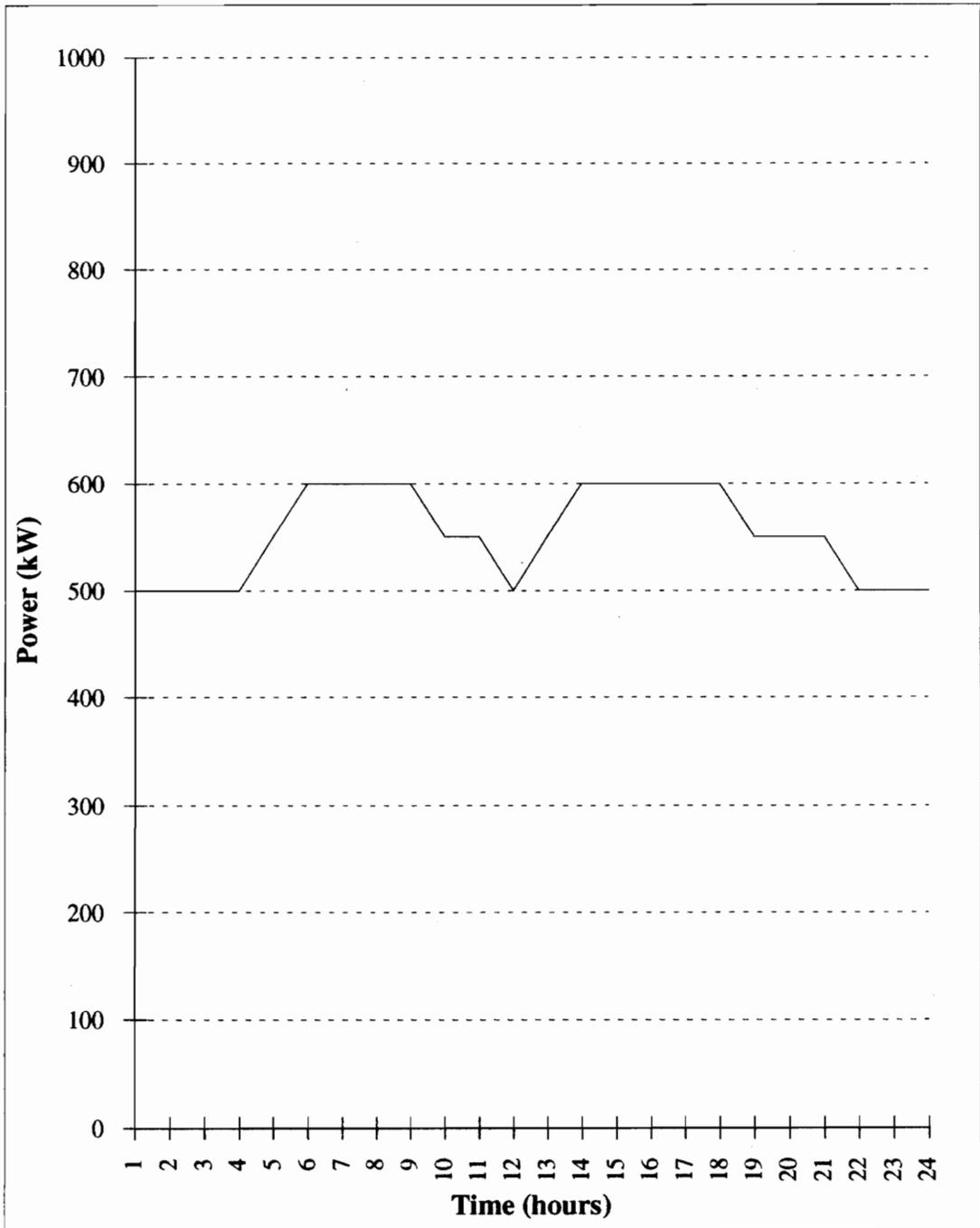
over a weekend. Other factors that influence the building load include weather and climate of the site.

## **5.4 Solar Effects**

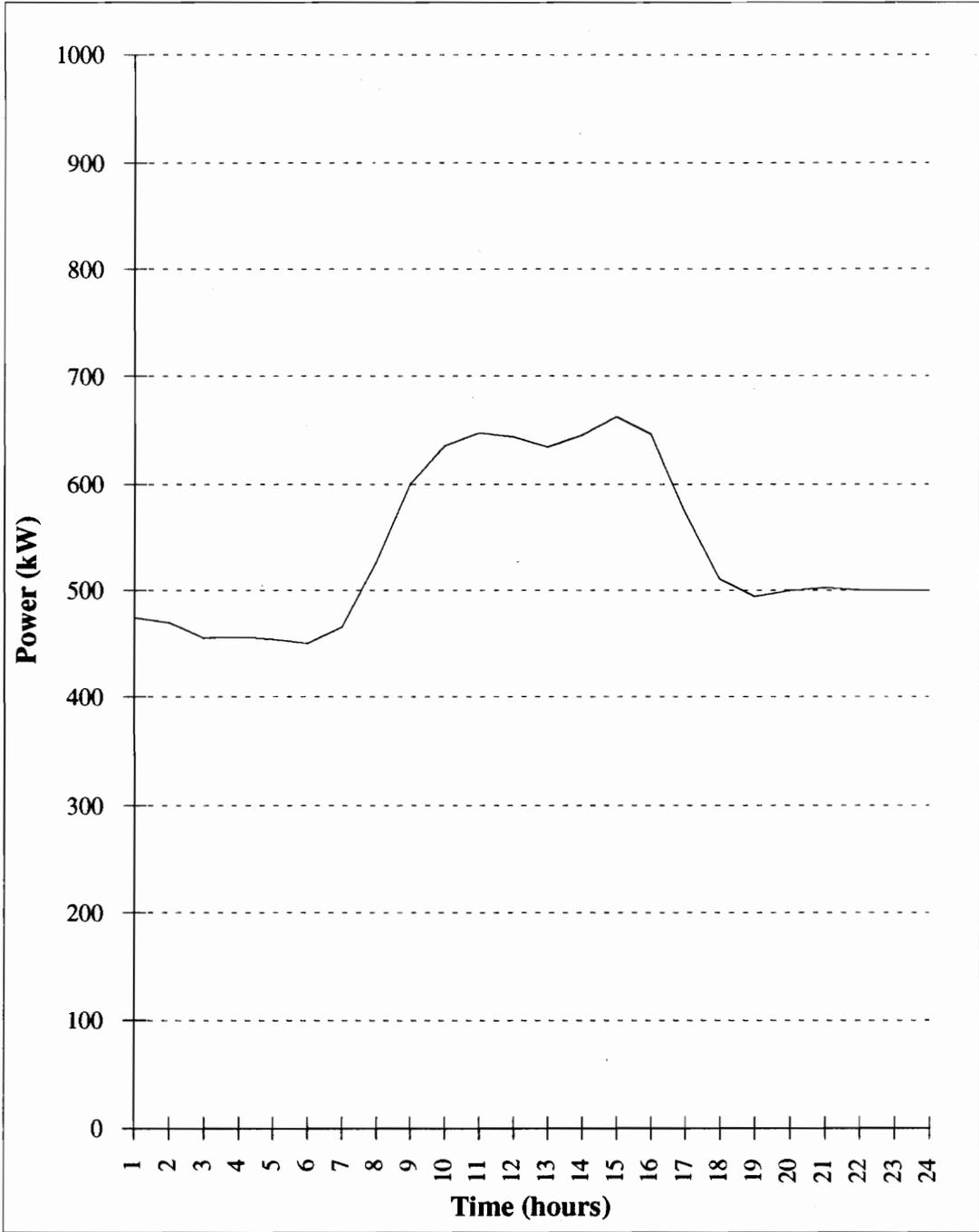
There are several factors that effect the design and size of the solar array. These include the climate, the change in seasons, and the type of solar day. The climate in the region, and the amount of solar radiation, affect the amount of energy that a photovoltaic array can produce. The photovoltaic array energy also varies with the season. The arrays produce more energy during the summer when there is more sunlight. This may or may not match up well with the yearly load curve of the area. For example, a high air conditioning load during the summer would match well with photovoltaic energy production, while a high winter heating load would not. Finally the type of solar day has an obvious effect on the energy outputs of both the photovoltaic array and the energy storage system. On low solar days, the PV output is low and the storage systems output must increase to compensate.



**Figure 5.9 Residential Load Curve**



**Figure 5.10 Industrial Load Curve**



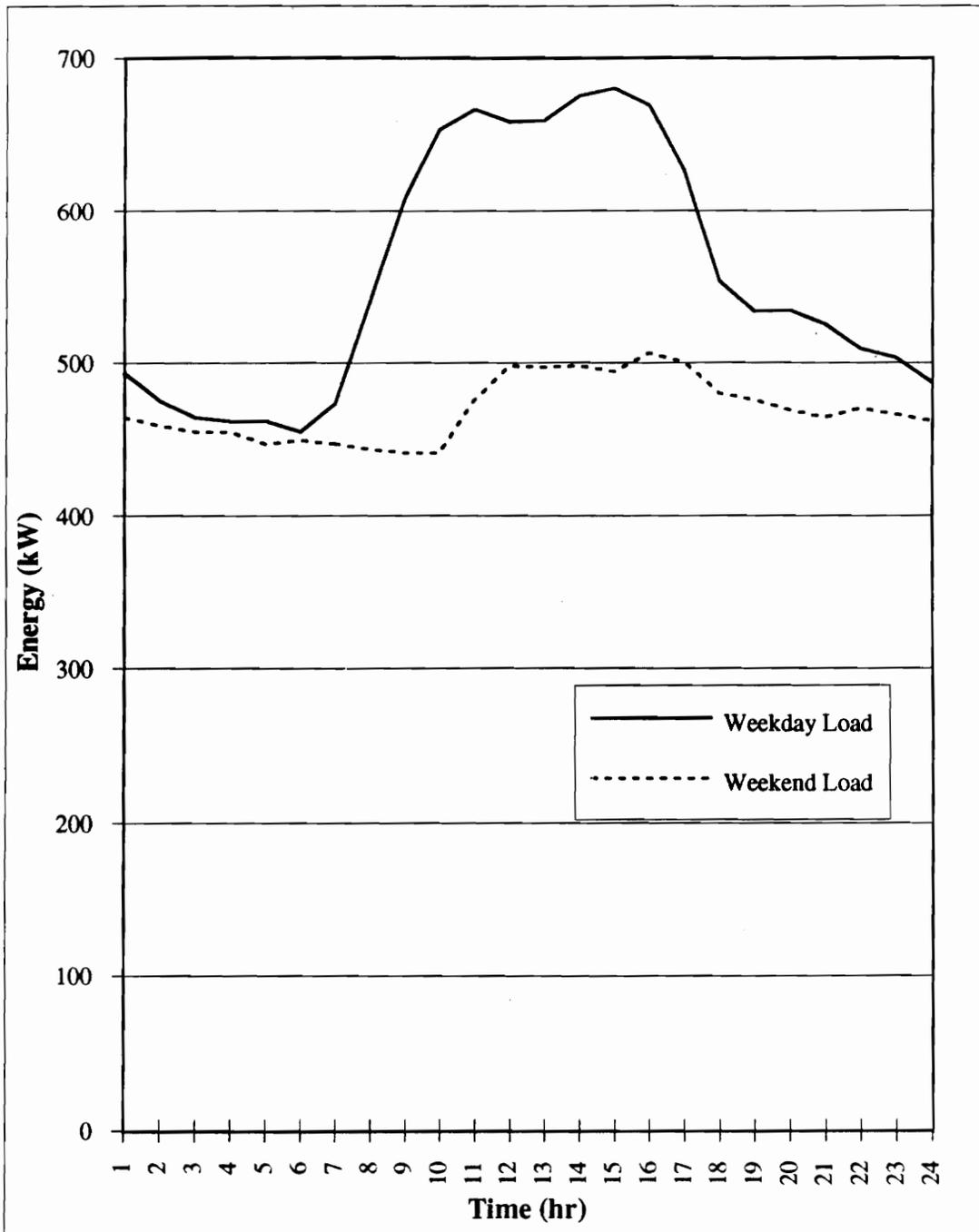
**Figure 5.11 Commercial Load Curve**

## 5.5 Data Development

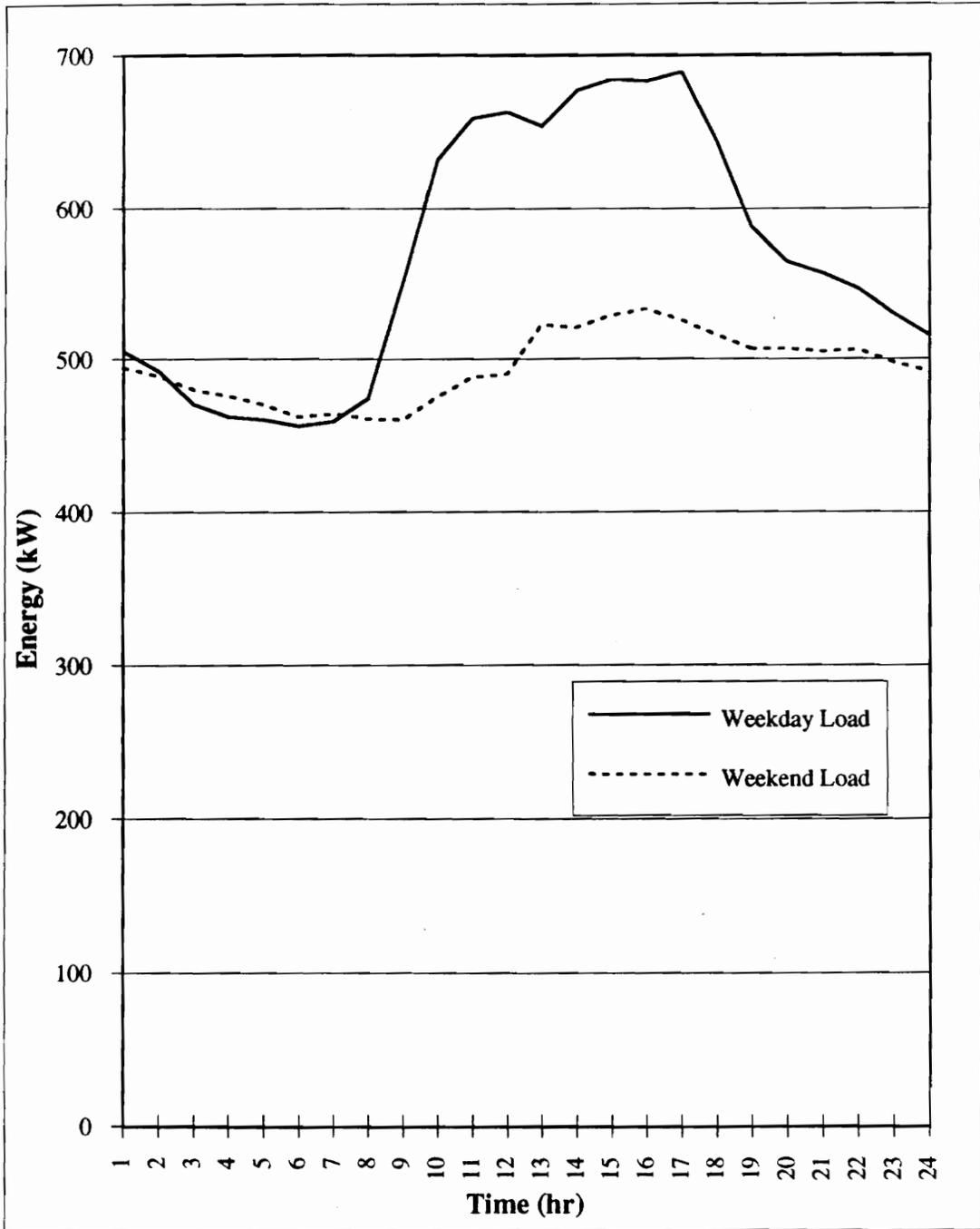
A data file of photovoltaic performance on high and low solar days over four seasons is needed for the simulation. For this model actual data from the Virginia Tech Solar Experimental Station was used. This station provided photovoltaic output data from the M55 and G4000 arrays. Other photovoltaic data can be used such as that created by photovoltaic simulation programs like PVFORM [30].

A building load data file is also needed for the simulation. This file consists of the building load in kilowatt-hour for four different seasons of the year. This study used the load data from Whittemore Hall in Blacksburg, Virginia. Whittemore Hall is an academic building on the Virginia Tech campus. It has a peak demand of 690 kW during the weekdays. Graphs of the typical building load for all seasons are given in figures 5.12 through 5.15. From the graphs of Whittemore's load demand, several observations can be made. First the peak loads occurs in Spring and Winter. This is because the building follows an academic calendar, therefore there are more people in the building using more electricity during these periods. Also the weather in Blacksburg is usually colder in the winter and spring and the building uses more energy to heat the building. In the summer and fall the energy demand is lower because the air conditioning for the building is run by a chilled water facility that is not connected to the electrical load of the building. Another important observation about the building load data is the difference between the weekday and weekend load. The weekday load has a definite demand rise and fall that parallels the activity of the day. This is a good place to implement load management to try and reduce the great demand rise. The demand also closely matches the output of a photovoltaic array. This correlation means that a photovoltaic array might be beneficial for load management.

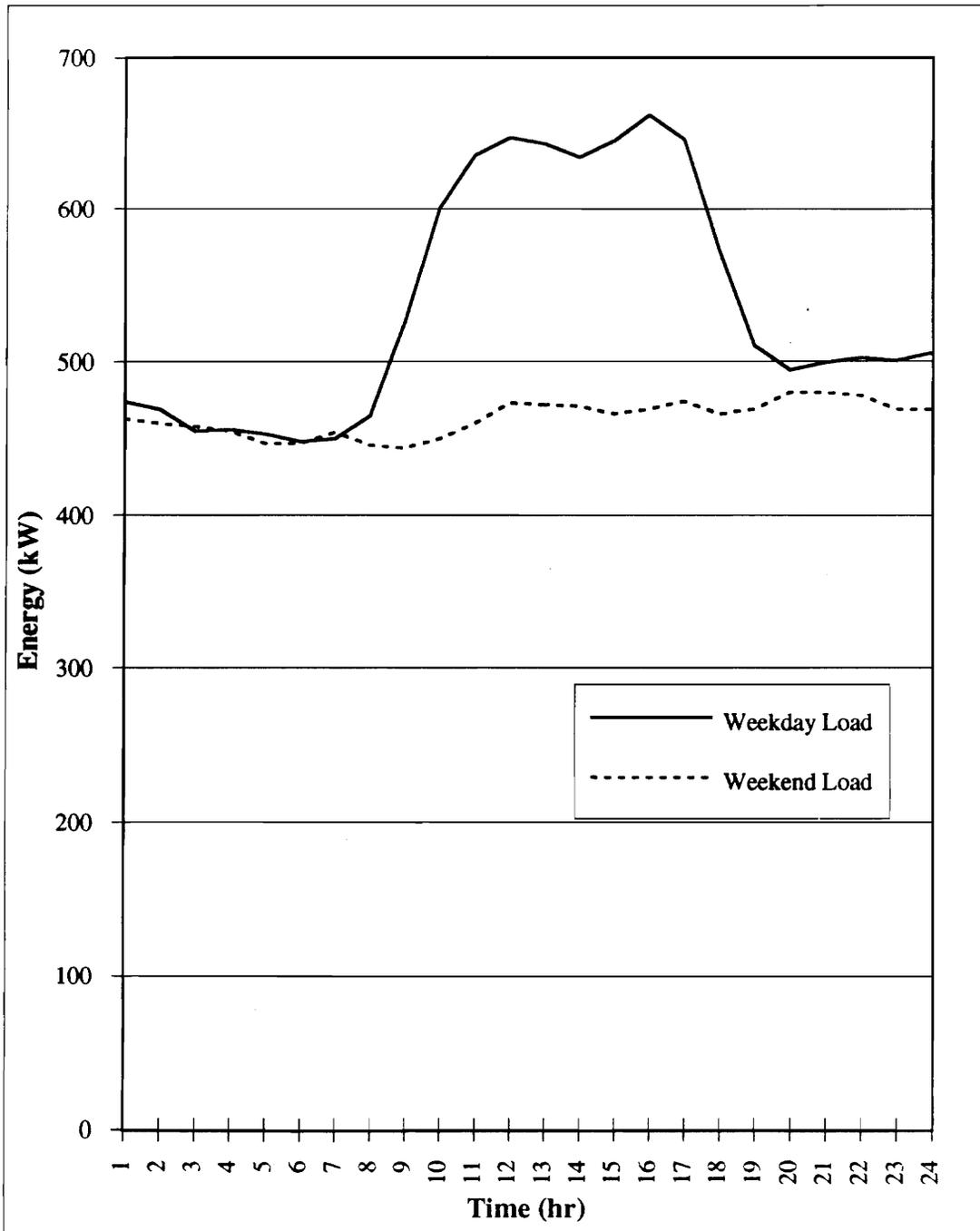
But on the weekends, the load curve is very flat. If the load was always flat, load management would not be cost effective.



**Figure 5.12 Typical Building Load for Whittemore Hall in Winter**



**Figure 5.13 Typical Building Load for Whittemore Hall in Spring**



**Figure 5.14 Typical Building Load for Whittemore Hall in Summer**

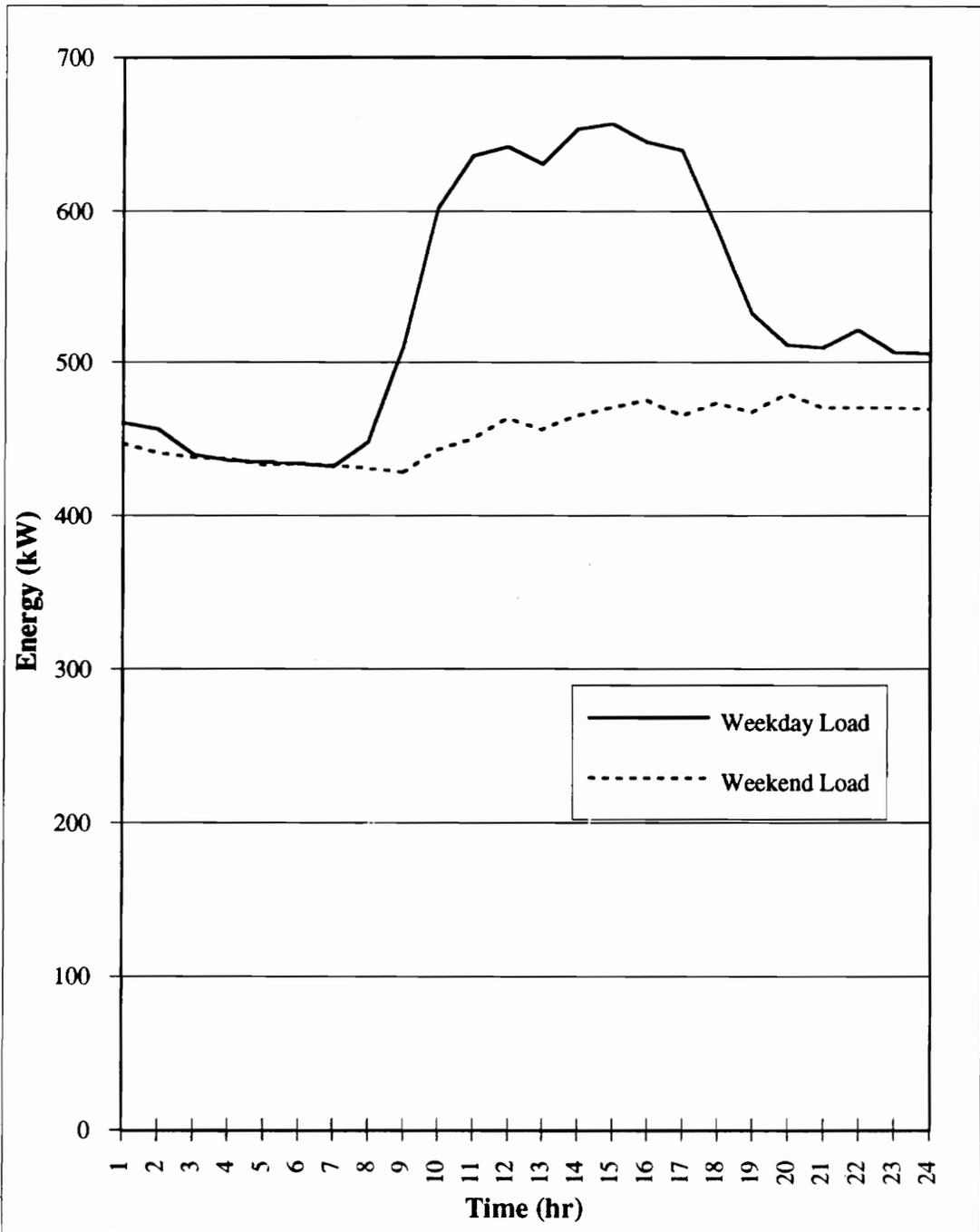


Figure 5.15 Typical Building Load for Whittemore Hall in Fall

## **5.6 Discussion of Variables**

In this study, the simulations are divided into seven different groups. The different groups represent different variations of Configuration 7, which contains a PV array , battery backup system, and grid connection. Table 5.1 gives the cost variables for each of the groups. These five variables are used to see how the cost graphs change. A discussion of the five variables follows.

### **5.6.1 Photovoltaics**

There are two types of photovoltaic modules used in this study. These are the single crystal ARCO Solar M55 modules and the amorphous silicon ARCO Solar G4000 modules (ARCO Solar is now Seimans Solar). All of the groups except Group G use M55 modules in their photovoltaic array. These modules made from single crystalline silicon cells and have an efficiency of around 12%. Group 2 uses G4000 cells, these are amorphous cells and have an efficiency of 4%. The specifications for each of these modules are given in Appendix A. The cost of the photovoltaic cells is also a variable, and ranges from \$2/watt to \$6/watt for this study. Presently the cost of photovoltaics is around \$7/watt.

### **5.6.2 Demand Limit**

Another variable that is changed is the demand limit. The demand limit is varied from 550 kW to 610 kW. This is a limit that is imposed by the utility company for setting the demand charge. The demand charge is a charge levied by the utility on a building just for the right to draw electricity. For this study, the demand charge varied from \$20/kW/month to \$30/kW/month. At the present time in Virginia the demand charge is

around \$15/kW/month. The building is required to stay under this demand limit, but if the building exceeds this limit then they must pay an additional charge of \$15/kW/month for at least one year. Lowering the demand limit, not only saves money by reducing the demand charge, but the building also saves money from not having to pay for that electricity (energy).

### **5.6.3 Batteries**

The cost of batteries is a main concern with the total cost of the load management system discussed in this paper. Since batteries are very expensive they make up a large part of the total cost of the system. The total cost of a battery system was varied between \$100 and \$175 /kWh.

### **5.6.4 DSM Controls**

The amount of DSM controls is kept constant at 80 kW for this study. This amount is used because it corresponds to 11% of the peak load. This is a reasonable amount to control excess light, air-conditioning, or heating elements. The cost for DSM was also fixed at \$500/kW.

### **5.6.5 Purchased Electricity**

The cost of purchased electricity is the amount of electricity that is needed to cover the base load and charge the batteries. The price of electricity varied from \$0.12/\$0.06 to \$0.08/\$0.04 per kWh. The first number represents the cost of electricity during on-peak hours; which are from 7 am to 10 pm. The second number represents the cost of electricity during off-peak hours.

**Table 5.1**  
**Variables in Simulations**

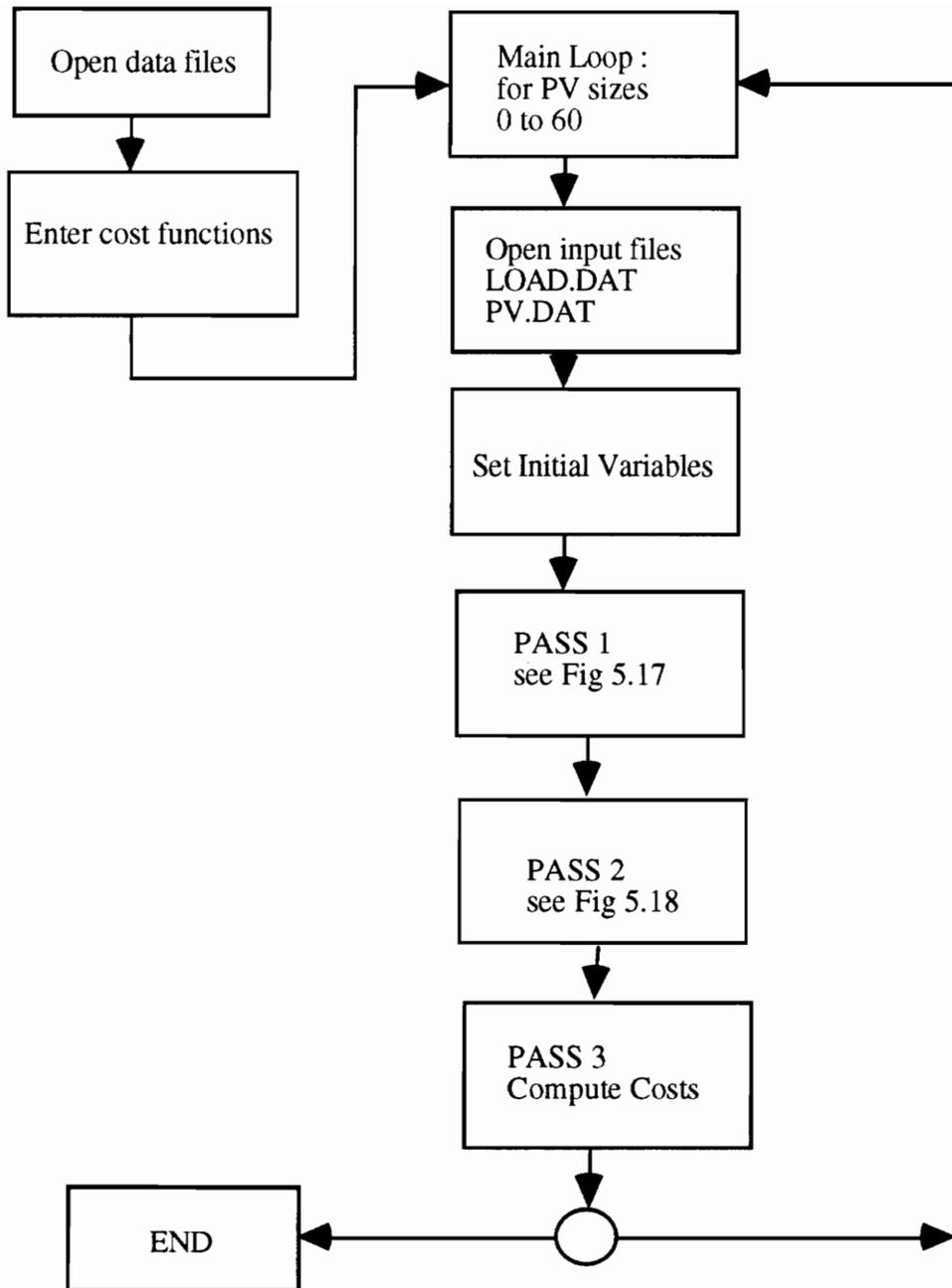
Group	PV Type	PV Cost (\$/watt)	Demand Limit (kW)	Demand Cost (\$/kW/mo)	Battery Cost (\$/kWh)	Cost of Electricity (\$/kW)
						high/low
A	M55	4.00	590	20.00	140.00	.10/.05
B	M55	2.00	550	30.00	100.00	.12/.06
C	M55	6.00	610	25.00	175.00	.08/.04
D	M55	4.00	590	20.00	140.00	.10/.05
E	M55	2.00	550	30.00	100.00	.12/.06
F	M55	6.00	610	25.00	175.00	.08/.04
G	G4000	4.00	590	20.00	140.00	.10/.05

## 5.7 Model Simulation

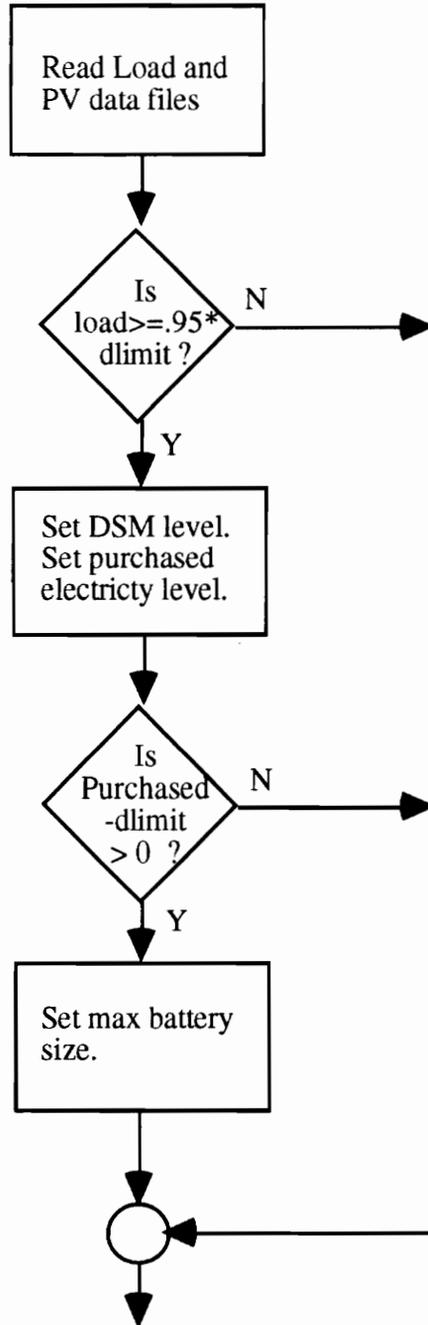
A computer model was created that simulated the PV-Battery-DSM system of Configuration 7, which contains a PV array, battery backup system, and grid connection. The flow chart for the model is given in Figure 5.16. The computer model reads two sets of data; a building load data set and a photovoltaic output data set.

In the operation of the program, it first finds the maximum battery size for each season. This is shown in Figure 5.17 and is called Pass 1 of the program. The building load and photovoltaic data sets are read for a low solar day. Then the program sets the DSM controls and PV levels. Then the program finds out how much energy is needed to cover the load. This gives the amount of battery energy needed for that day. The process is repeated for each season.

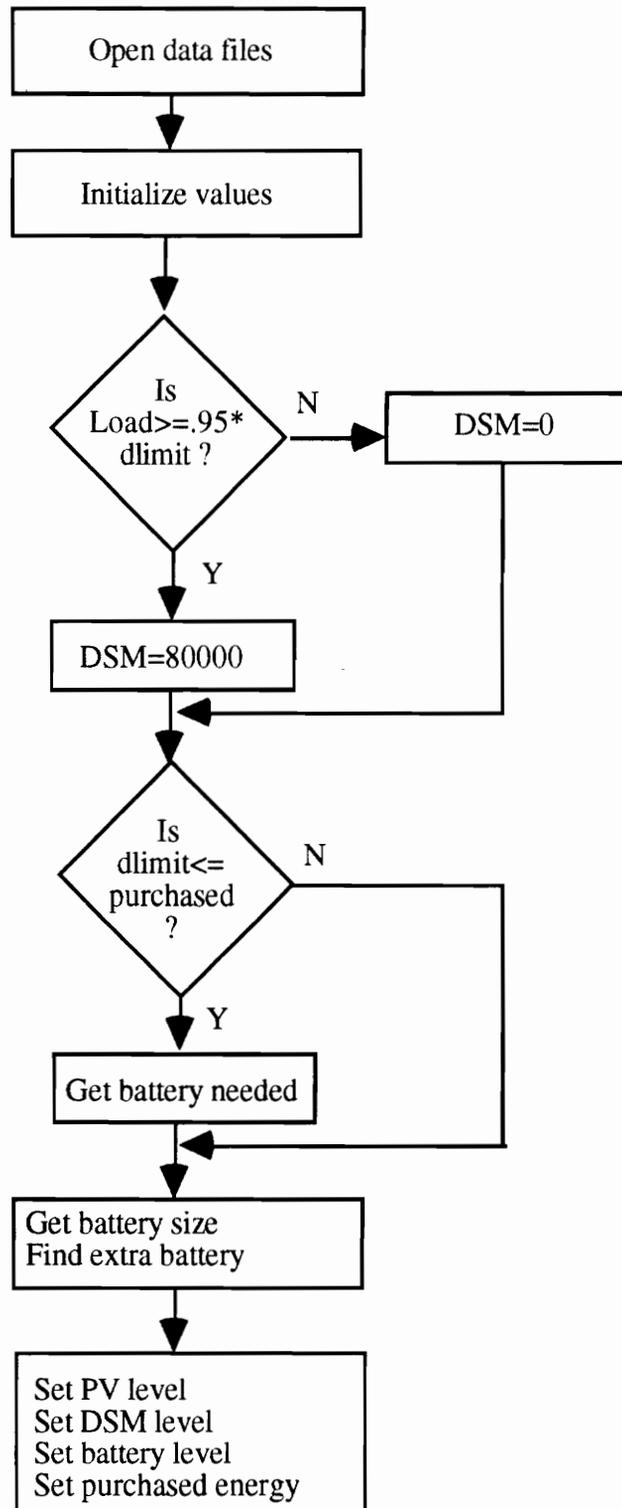
The next procedure executed by the program is called Pass 2. This is illustrated in Figure 5.18. Here the program assigns the values for building load and PV energy from the data files. Then the program sets the DSM level and the amount of battery needed to cover the load. The DSM controls are activated if the building load is greater than 95% of the demand limit. This allows for a smoother energy curve. The battery level for each day is found. If the amount of battery energy is needed is less than the battery level that was found in Pass 1, the remaining battery charge is extra energy and is spread equally though out the high demand part of the day so that all the battery energy is used up. The battery has a 30% depth of discharge. This means that the battery will never fall below 30% of its rated capacity. The battery also has an 80 % round trip efficiency. This means that it loses 20% of its energy in charging and discharging. Finally all of the values for load, photovoltaic output, DSM controls, battery output, and purchased energy are set.



**Figure 5.16 Complete Program Flowchart**



**Figure 5.17** Flowchart of Pass 1



**Figure 5.18 Flowchart of Pass 2**

The next part of the program is Pass 3. Here the values from Pass 2 are used to find the total daily operating cost for a certain day. The costs are then printed out. The battery's recharge cycle is also figured out in this section. The battery is only recharged from 12 am to 6 am or from 11 pm to 12 am. This coincides with the lower cost for electricity.

## 5.8 Daily Cost Development

The costs for each variable are found separately within the program. The initial cost for the variable are given by the user in the beginning of the program. These are entered as the following:

Battery cost in \$/kWh. (10 year life)

PV cost in \$/watt. (20 year life)

DSM cost in \$/watt. (20 year life)

Demand charge in \$/kW/month.

Cost of utility generated electricity from 7 am to 10 pm (On-Peak electricity).

Cost of utility generated electricity from 12 am to 6 am or 11 pm to 12 am (Off-Peak).

The daily cost for each variable are computed and then a total cost for daily operation is given. The daily cost for PV, DSM, and Batteries are computed using a life cycle costing program called LIFECC2 [16]. The life cycle cost of the photovoltaic array and demand side management controls are based on a twenty year life, while the batteries are assumed to have a ten year life. All of the life cycle costing was done at an interest rate of 10%. To get a daily cost from the demand charge, the amount was divided by 30 days per month. The purchased electricity was computed throughout the day. An example of how the daily cost was derived is shown in Figure 5.19.

Life cycle cost of ((Size of PV array) x (Cost / m2)) = PV COST  
 Life cycle cost of ((Size of Battery) x (Cost / kWhr) = BATTERY COST  
 Life cycle cost of ((DSM controls) = DSM COST  
 Demand Charge = DEMAND CHARGE  
 Purchaced electricity = ELECTRICTY COST

**Daily Operating Cost = PV COST + BATTERY COST + DSM COST**  
**DEMAND CHARGE + ELECTRICITY COST**

**Figure 5.19 Example of computing daily costs.**

## 6.0 Results and Discussion

The PV-Storage-DSM system will prove beneficial to a consumer if the savings by not purchasing energy from the utility outweighs the cost of the implementing and upkeeping the system. The system will prove beneficial to a utility if it reduces the capacity that the utility needs to provide, this is assuming that the utility is considering obtaining more generating capacity or needs to reduce operating capacity. The result contained in this section will show that if carefully selected, the PV-Storage-DSM system will have a positive value, not only in energy efficiency but in also cost.

From each case of the simulation, four graphs are produced. Each graph shows daily operating cost versus photovoltaic array size. The photovoltaic data for each run is actual normalized PV data from the Virginia Tech Solar Experimental Station, located atop Whittemore Hall in Blacksburg, Virginia. The first graph shows the daily operating cost vs. photovoltaic array size in summer on a low solar day for four demand limits. The second graph shows the daily operating cost vs. PV array size in summer on a high solar day for four demand limits. The third graph shows the daily operating cost vs. PV array size for a certain demand limit over the four seasons on a low solar day. The fourth graph shows the daily operating cost vs. PV array size for a certain demand limit on a high solar day. These graphs help show the effect of different variables on the daily operating cost of the facility. The complete set of graphs is given at the end of Chapter 6 after the discussion. The array size is varied from 0 to 60 kW to show the effect of photovoltaics on the daily operating cost. Increasing the amount of photovoltaic energy helps reduce the amount of purchased electricity as well as reducing the actual demand limit and battery size. However, the higher cost of PV (\$4.00/watt in Case A) offsets any such savings. In some specific cases such as Case B, it is shown that large PV arrays are economically attractive

for low PV costs. Each group of simulations also produces a table of battery sizes and actual demand limits. These are discussed in Chapter 6 and complete tables are found in Appendix C. Throughout this discussion, Case A will be considered the reference case.

## 6.1 Photovoltaic Technologies

First there is a comparison between the two photovoltaic technologies that were studied will be done. These two types were the single crystalline silicon cells of the M55 array and the amorphous silicon of the G4000 array. Both of these arrays are produced by ARCO Solar (now Siemens Solar) and their operating characteristics are given in Appendix B. This section will examine the differences between Case A and Case G (refer to Table 5.1). Figure 6.1 shows the effect of different demand limits on daily operating cost on a low solar day. The costs rise at a constant rate as the size of the photovoltaic array increases. The daily operating cost increases from \$1440 to \$1505 for a nominal demand limit of 610 kW. This is because the cost of the array is greater than the savings in purchased electricity, demand charge, and battery size. In Figure 6.2 one can see the benefit of a high solar day. Here the costs increase from \$1400 to \$1464 for a nominal demand limit of 610 kW. This shows that on a high solar day the photovoltaics have a larger impact on reducing the daily operating cost, but it is still not enough to offset the initial cost of purchasing them.

Figures 6.3 and 6.4 show the seasonal effects on daily operating cost. Spring has the highest cost because it has the largest building load of the four seasons (see Figure 5.13). In Figure 6.3, the summer low solar day produces more energy than the fall low solar day. That is why the summer line crosses over the fall line. In spring and winter, the photovoltaic output on a low solar day is approximately equal and therefore the cost line

remain parallel. Figure 6.4 demonstrates the effect of a high solar day during each season. Because the high solar day photovoltaic output is greater in the summer than the fall, those lines become parallel.

Figures 6.29 and 6.30 show the effect of using different types of photovoltaic modules. The only difference between Case A and Case G is the fact that Case A used ARCO Solar M55 single crystalline silicon modules, while Case G uses ARCO Solar G4000 amorphous silicon modules. Figure 6.29 shows that on a low solar day, the costs for Case A are almost identical to Case G, but in Figure 6.30, the costs for the G4000 cells is higher. This shows that the single crystalline cells perform better under clear sky conditions. Here in spring, the single crystalline cells produce a large amount of energy and reduce the cost accordingly on a high solar day. In the summer the cost for the single crystalline and amorphous are almost equal. This is because the high solar day in Blacksburg in the summer is very hazy and the single crystalline cells do not work as well. Another observation is the single crystalline cells perform better as the array area increases, while the amorphous cells perform worse as the array increases.

Next the study will discuss the effect of initial photovoltaic costs on the daily operating cost. In Case A the initial cost for photovoltaics is \$4 per watt. This means a 20 kW facility costs \$80,000. This cost is varied from \$2 per watt in Case B to \$6 per watt in Case C. A good example of what the lower photovoltaic price will do to the daily operating cost is seen in Figure 6.8. Here the lower photovoltaic cost actually causes the daily operating cost to decline in all the seasons as the size of the photovoltaic array is increased. The opposite happens in Figure 6.12 where the initial photovoltaic cost is increased to \$6 per watt.

## 6.2 Batteries

Two different ways of sizing the battery system were implemented in these simulations. The first way was to size the battery for the low solar day for each season. This was done in Cases A, B, and C. The second way was to size the battery for the low solar day of the year. This was done in Cases D, E, and F. The batteries used in these simulations were lead-acid batteries. They were allowed to discharge up to 70% of their rated capacity and had an overall charge/discharge efficiency of 80%. For the most part, having the battery size for the entire year leads to an increase in daily cost. This is because the increased cost in purchasing the battery.

The battery size for each run is determined by finding the exact size to keep the load under a certain demand limit on a low solar day with demand side management controls running. This method always produces the optimal battery size that can cover the load. The battery is always used to 70% of its rated capacity, and recharged overnight when the electricity rates are lower. The tables in Appendix B contain the actual battery size used for each simulation run.

The effects of changing the initial cost of the battery system can be seen by looking at figure 6.31. Here the initial battery cost varies between \$100/kWh to \$175/kWh. This figure shows that the initial cost of the battery is only a small portion of the total daily cost. The figure also shows that as the initial battery cost increases, the daily operating costs increase, but only by a small amount. This should be expected since the initial battery cost is converted into a daily cost using life cycle costing.

### **6.3 Demand limit**

Demand limits for the simulations are varied from 610 kW to 550 kW, which represent the maximum amount of purchased electricity. These limits are set initially at the beginning of each simulation, but can be lowered by increasing the photovoltaic output, demand side management control, or battery output. A complete listing of the demand limits for each simulation is given in the tables in Appendix B.

At a demand limit of 610 kW no battery or PV is needed to cover the load on a low solar day. This was set as the maximum demand limit. As the demand limit is lowered, the total demand charge is reduced, but an increased battery size is needed to cover the load. For each test run, there is a certain lowest acceptable demand limit. This means that there should be an optimal demand limit for each run. For most of the cases the lower the demand limit, the more economical the system was.

The effect of demand charge is also seen in Figure 6.32. The demand charge is raised from \$20/kW/month to \$30/kW/month. By increasing the demand charge, the daily operating cost goes up. Unlike the initial battery cost, the demand charge greatly effects the total daily operating cost. From this fact, one can see that using photovoltaics and stored energy to bring the peak energy limits can be beneficial.

### **6.4 Purchased electricity**

The price of purchased electricity is the largest factor in the daily operating cost. In the simulation models it was assumed that the utility priced electricity on a split schedule, that is the it charge one rate for on-peak electricity and another for off-peak electricity. In

the simulation runs the on-peak cost varied from a low of \$0.08/kWh to a high of \$0.12/kWh and the off-peak cost varied from \$0.04/kWh to \$0.06/kWh. The effect of changing the purchased electricity can be seen in comparing Cases A, B, and C. In Case B (see Figure 6.7), the daily operating cost is goes from \$1835 at 0 kW PV to \$1872 at 60 kW PV in spring. The main portion of this cost is purchased electricity. In Case A (see Figure 6.3), the same cost drops to \$1490 at 0 kW PV and \$1562 at 60 kW PV, and in Case C (see Figure 6.11), the cost drops to \$1390 at 0 PV and \$1503 at 60 kW PV. This corresponds to a decrease in electricity rates.

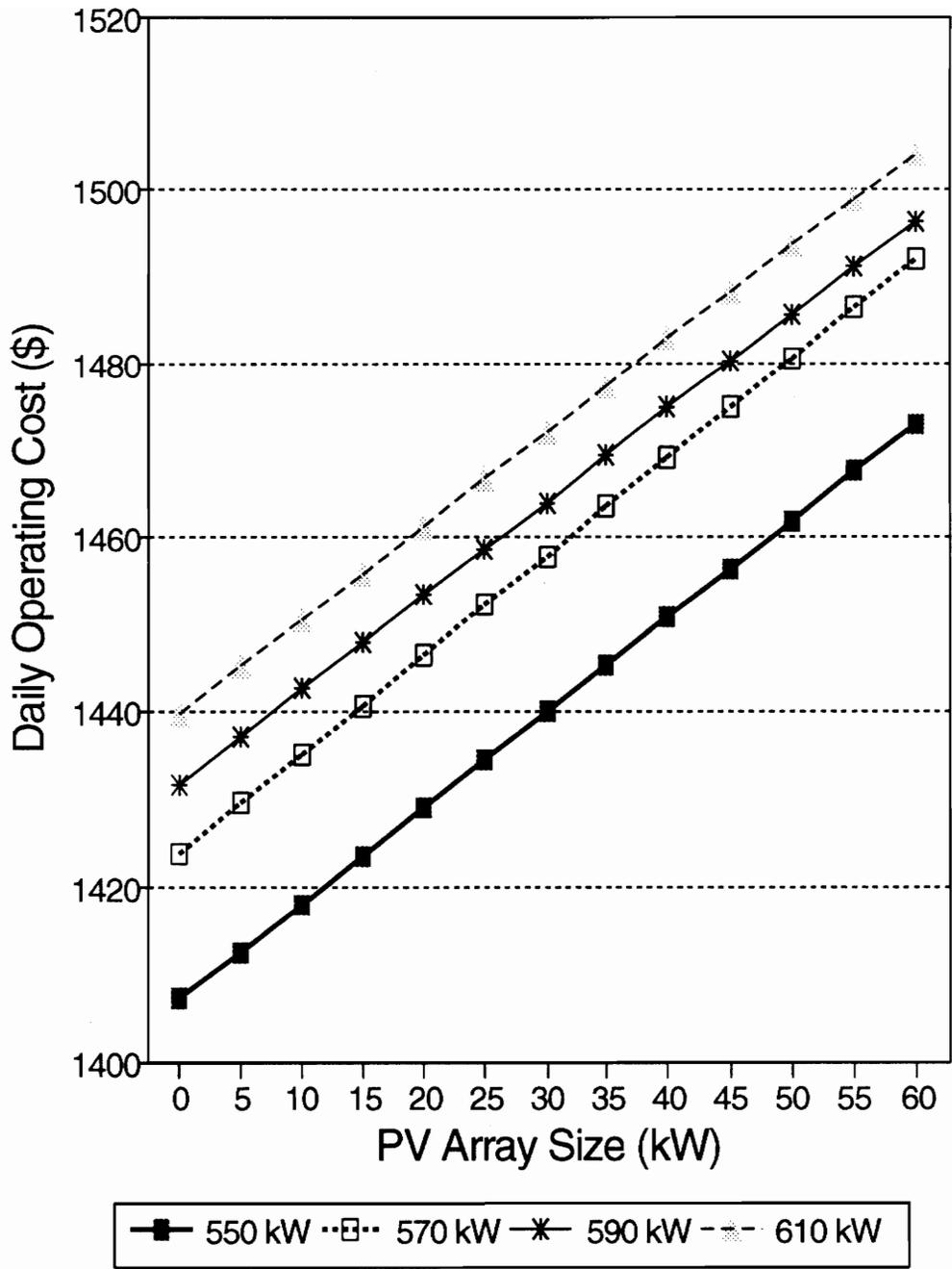


Figure 6.1 Daily Operating Cost vs. PV Array Size on a Low Solar Summer Day - CASE A (electricity cost \$.10/\$.05).

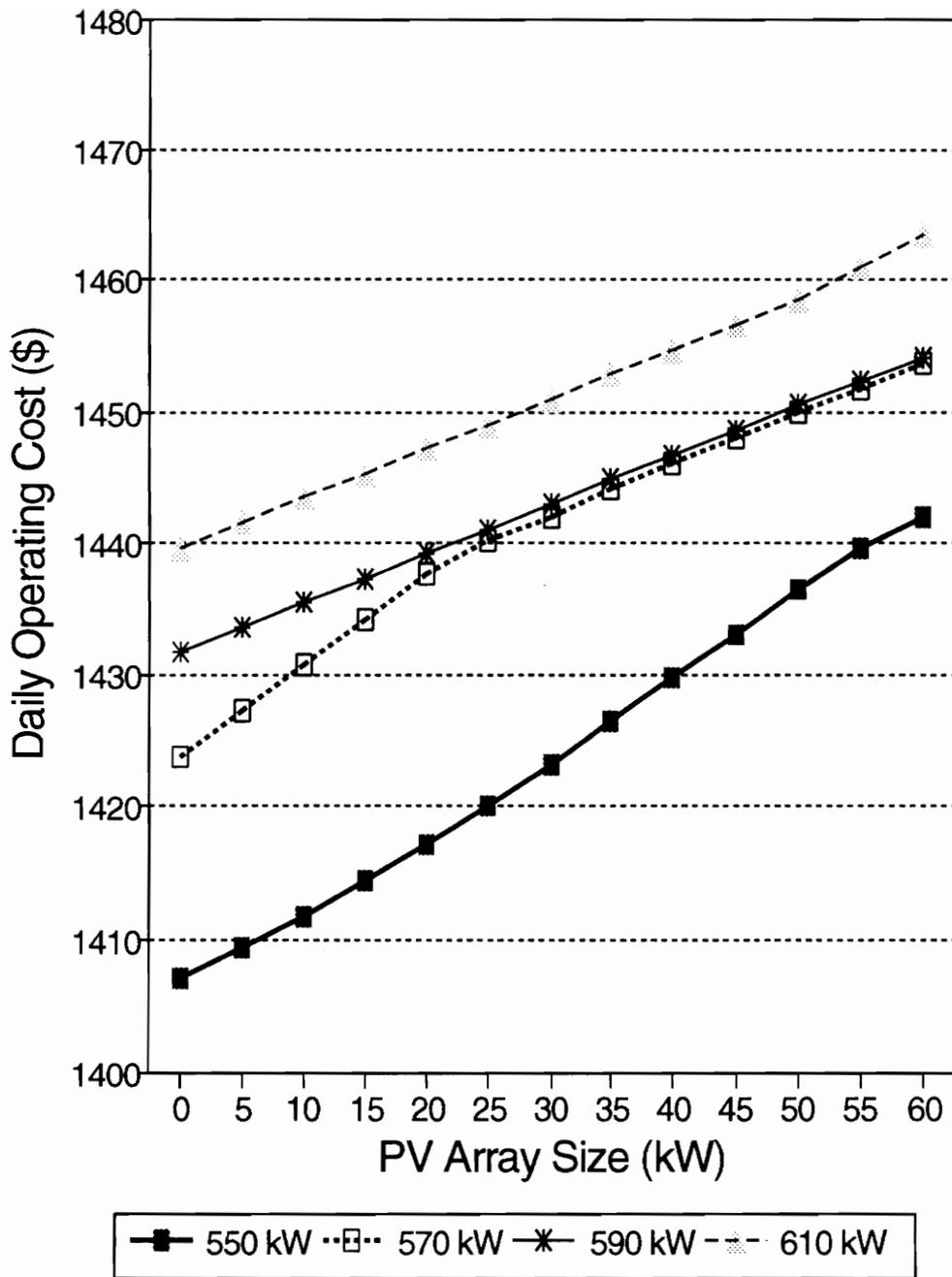
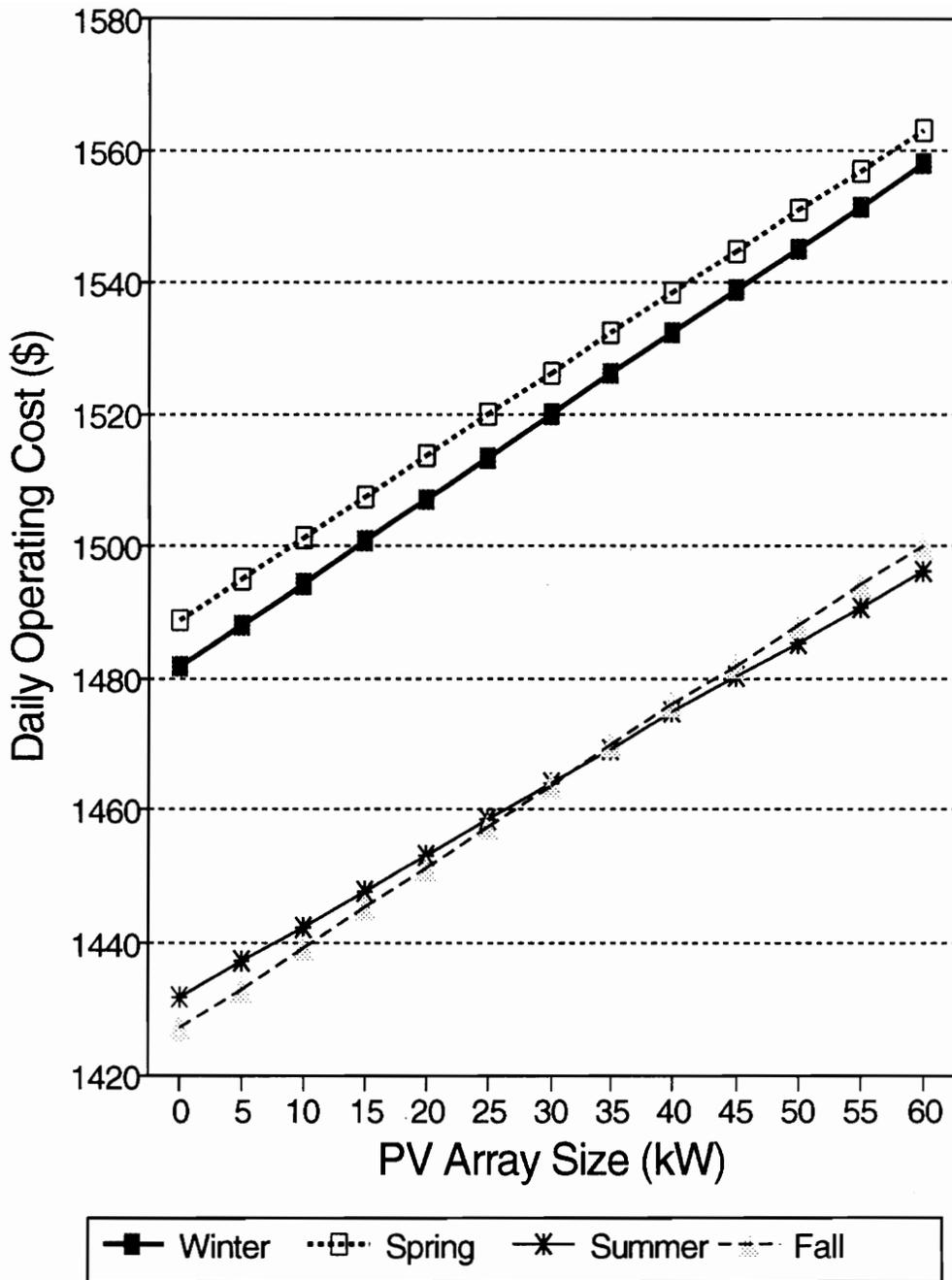


Figure 6.2 Daily Operating Cost vs. PV Array Size on a High Solar Summer Day - CASE A (electricity cost \$.10/\$.05).



**Figure 6.3 Daily Operating Cost vs. PV Array Size at a Demand Limit of 590 kW on a Low Solar Day - CASE A (electricity cost \$.10/\$.05).**

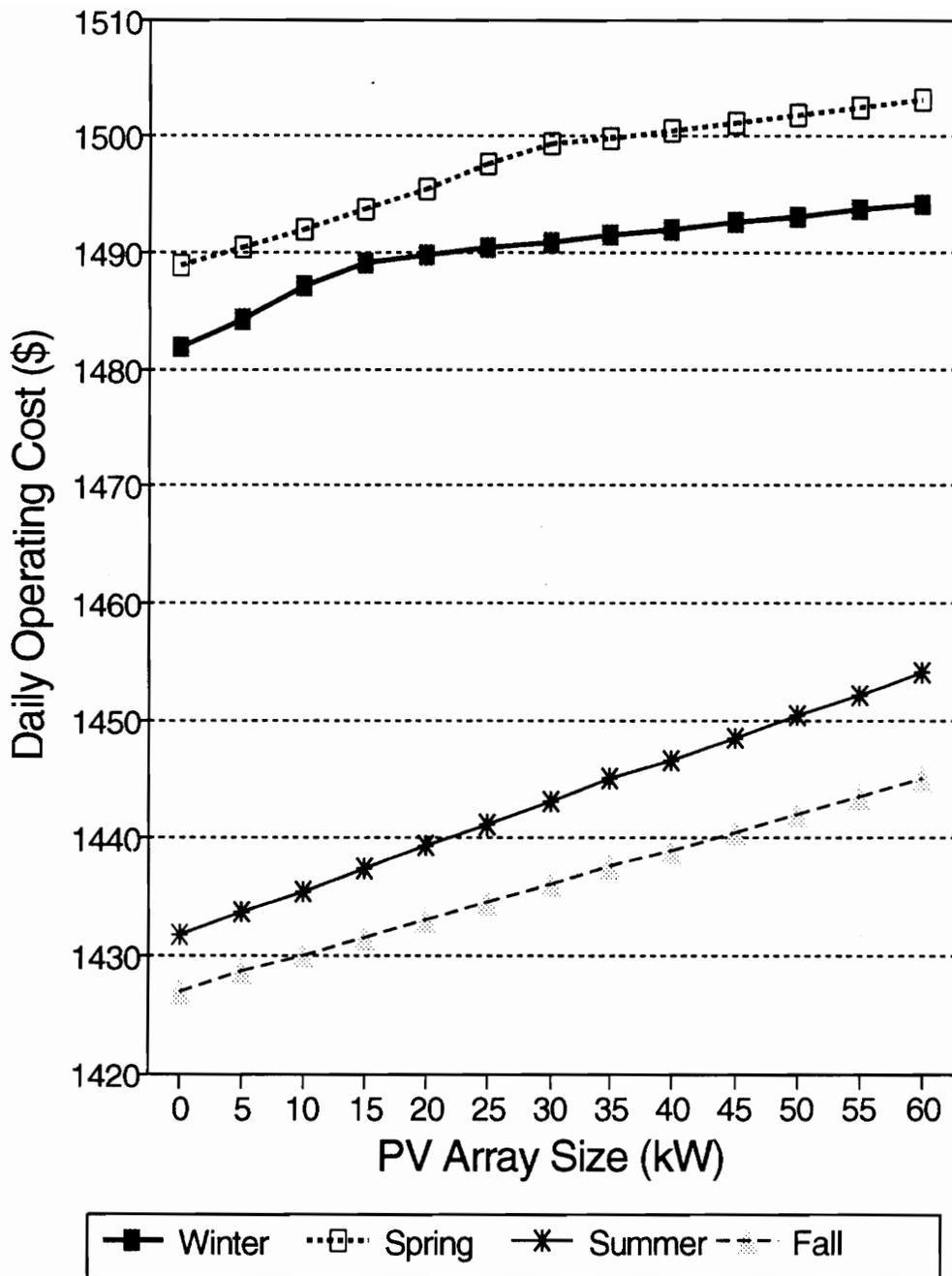


Figure 6.4 Daily Operating Cost vs. PV Array Size at a Demand Limit of 590 kW on a High Solar Day - CASE A (electricity cost \$.10/\$.05).

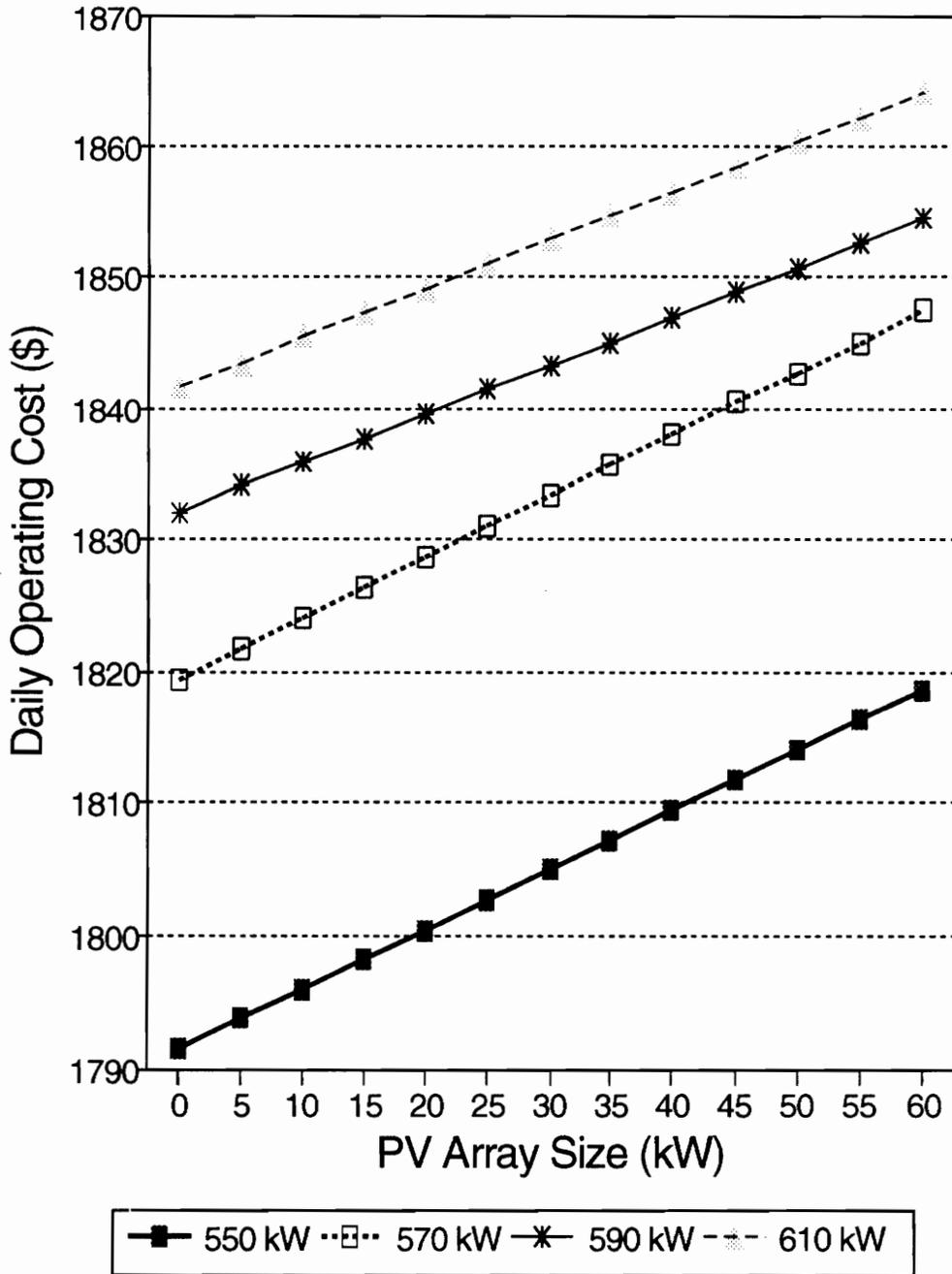
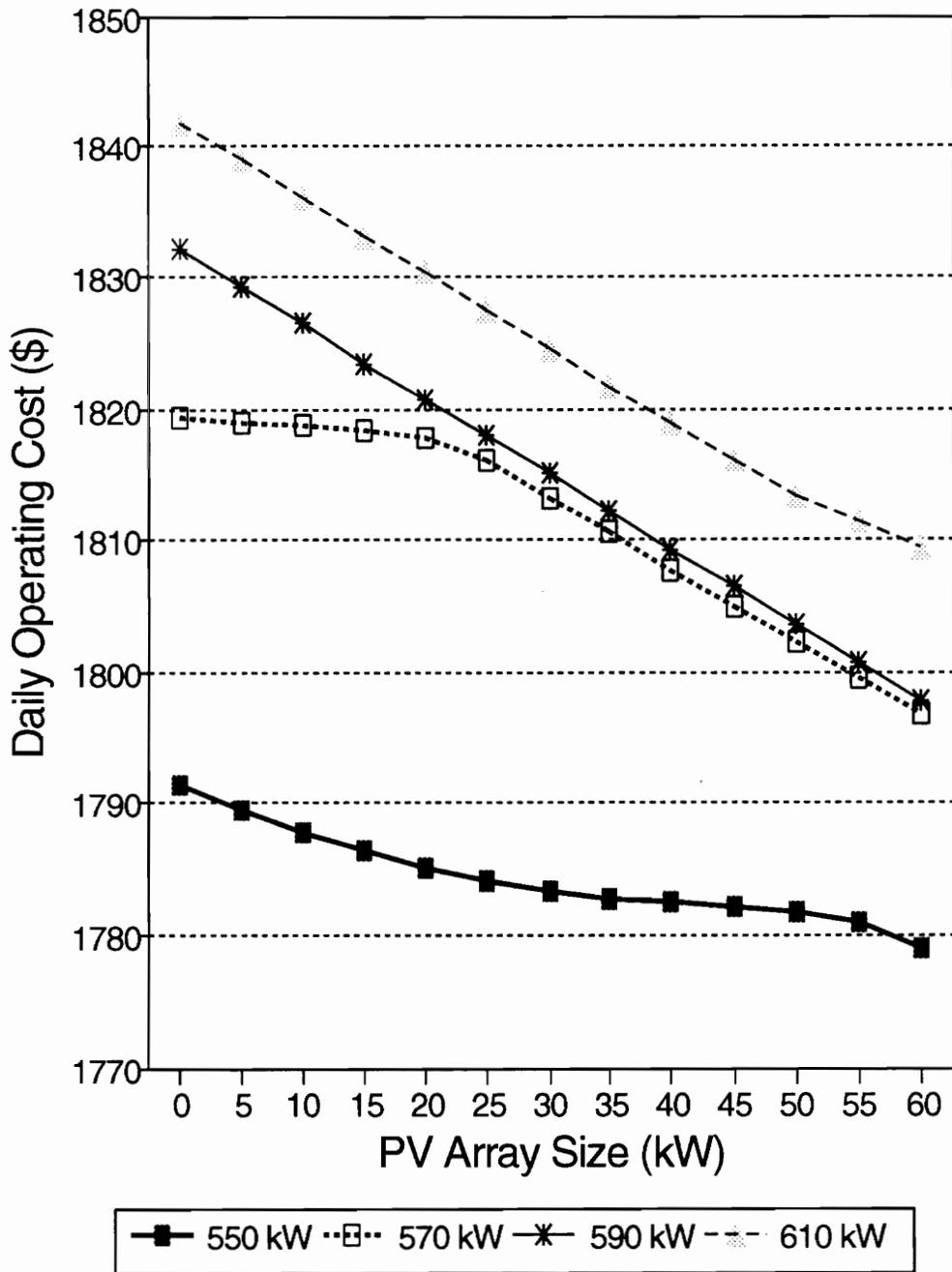


Figure 6.5 Daily Operating Cost vs. PV Array Size on a Low Solar Summer Day - CASE B (electricity cost \$.12/\$.06).



**Figure 6.6 Daily Operating Cost vs. PV Array Size on a High Solar Summer Day - CASE B (electricity cost \$.12/\$.06).**

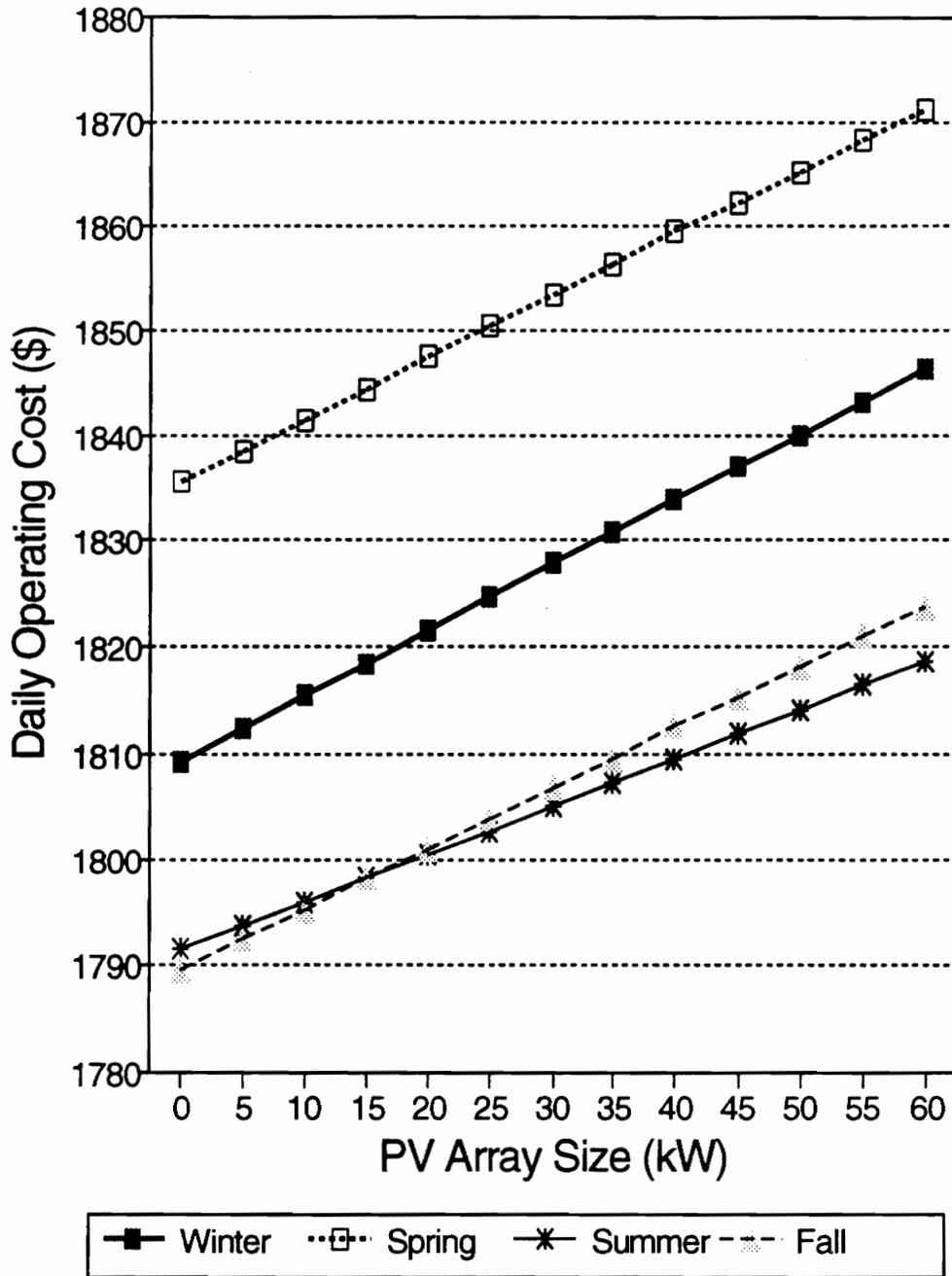


Figure 6.7 Daily Operating Cost vs. PV Array Size at a Demand Limit of 550 kW on a Low Solar Day - CASE B (electricity cost \$.12/\$.06).

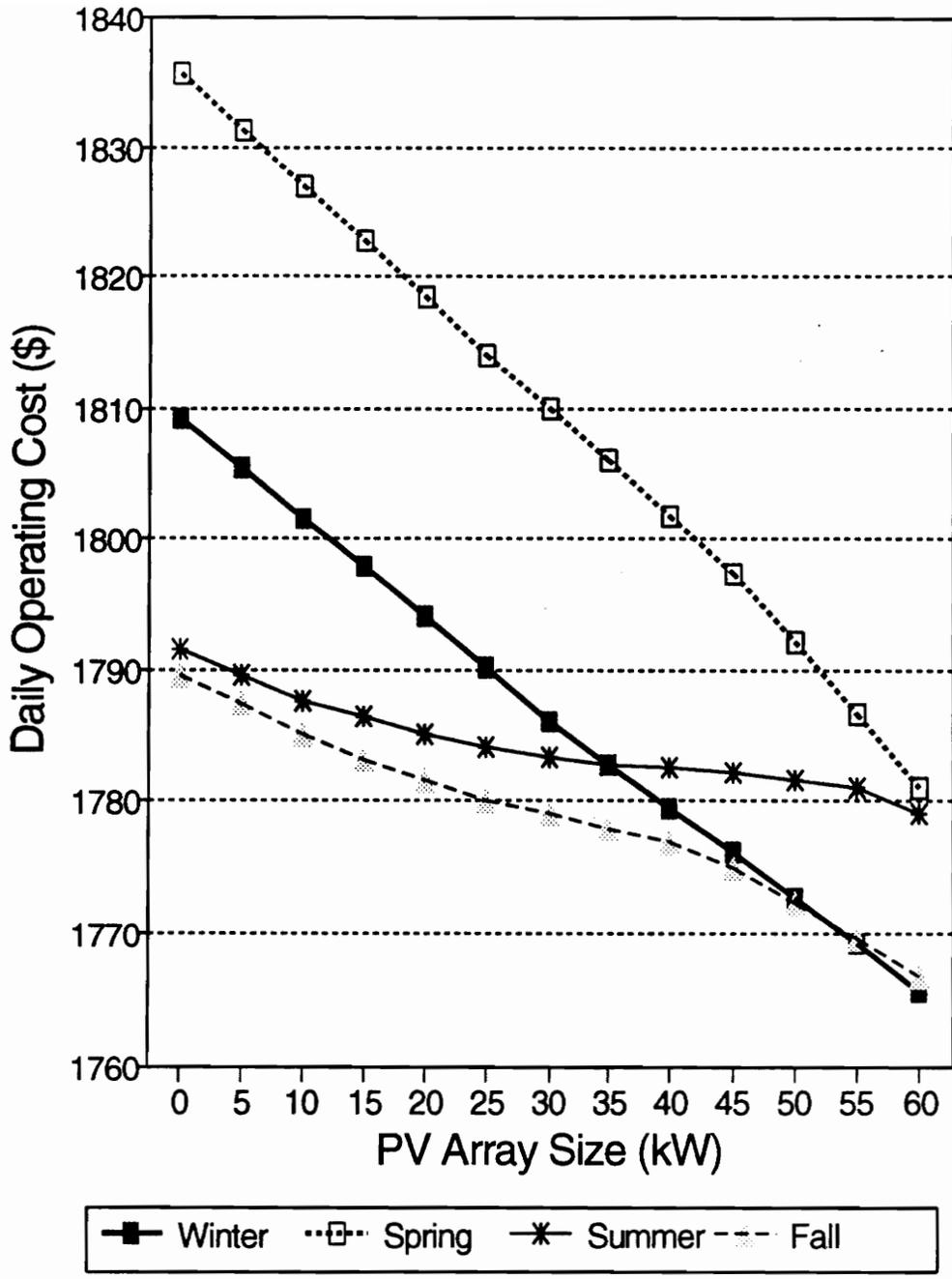


Figure 6.8 Daily Operating Cost vs. PV Array Size at a Demand Limit of 550 kW on a High Solar Day - CASE B (electricity cost \$.12/\$.06).

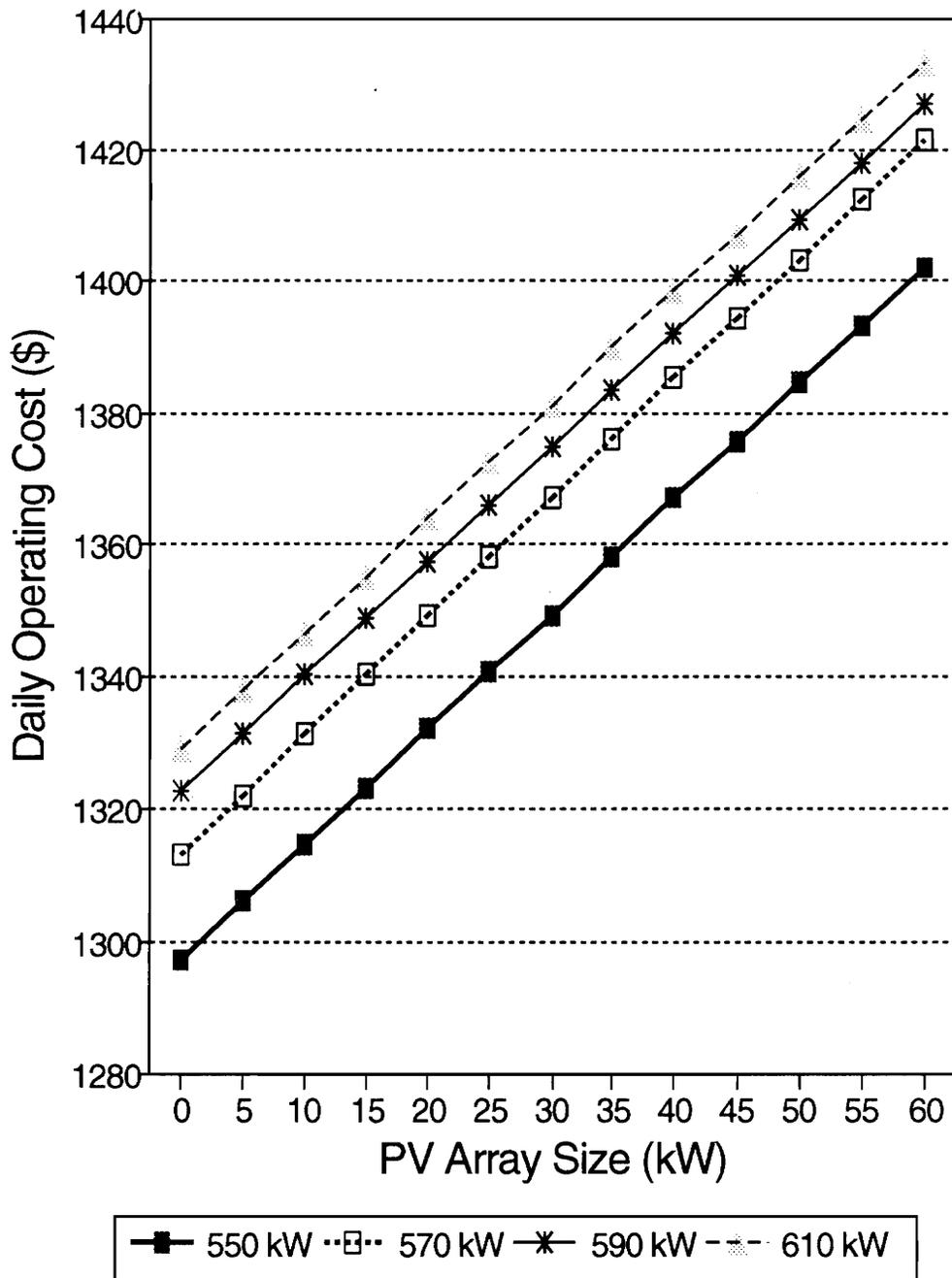


Figure 6.9 Daily Operating Cost vs. PV Array Size on a Low Solar Summer Day - CASE C (electricity cost \$.08/\$.04).

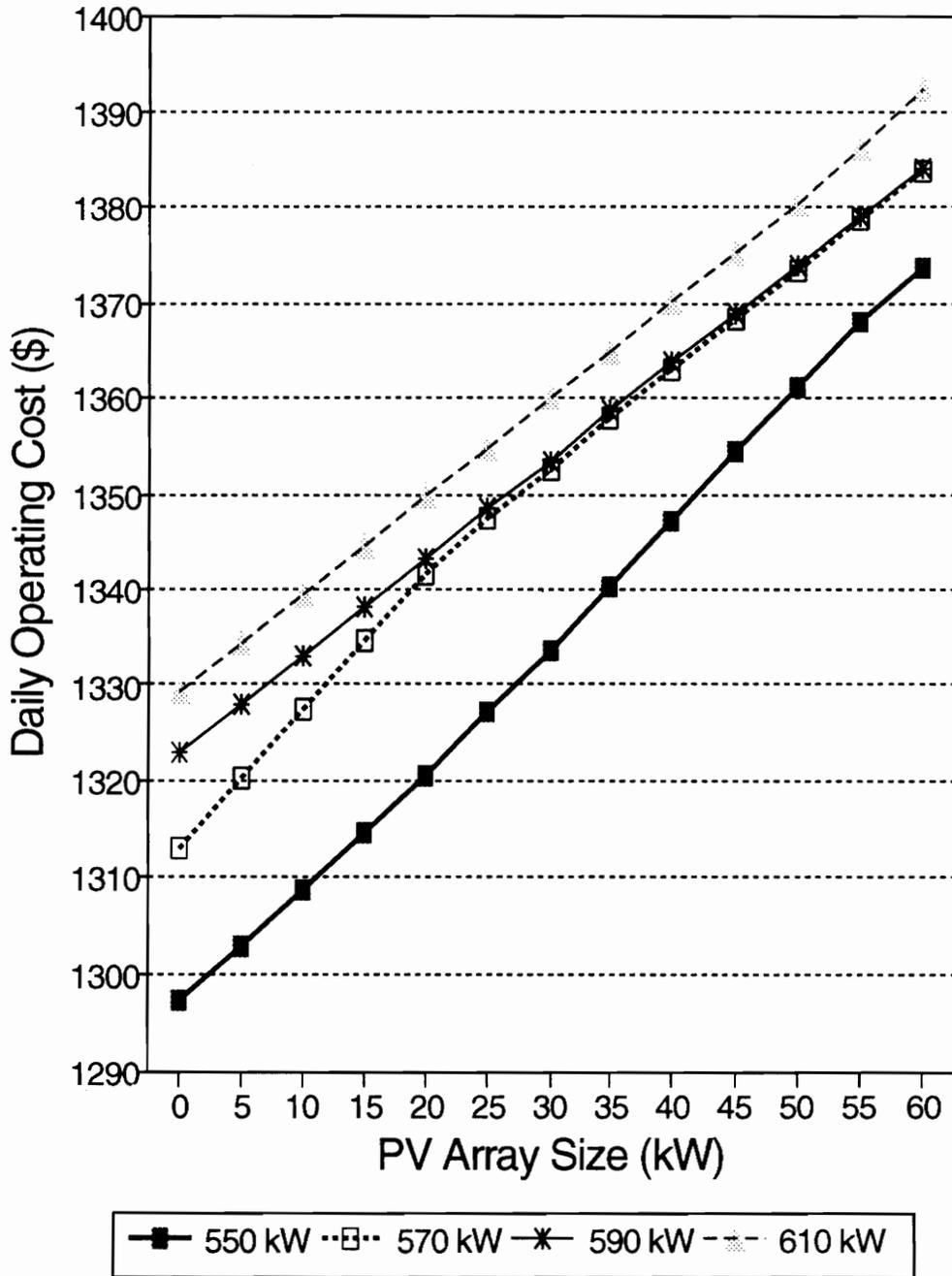


Figure 6.10 Daily Operating Cost vs. PV Array Size on a High Solar Summer Day - CASE C (electricity cost \$.08/\$.04).

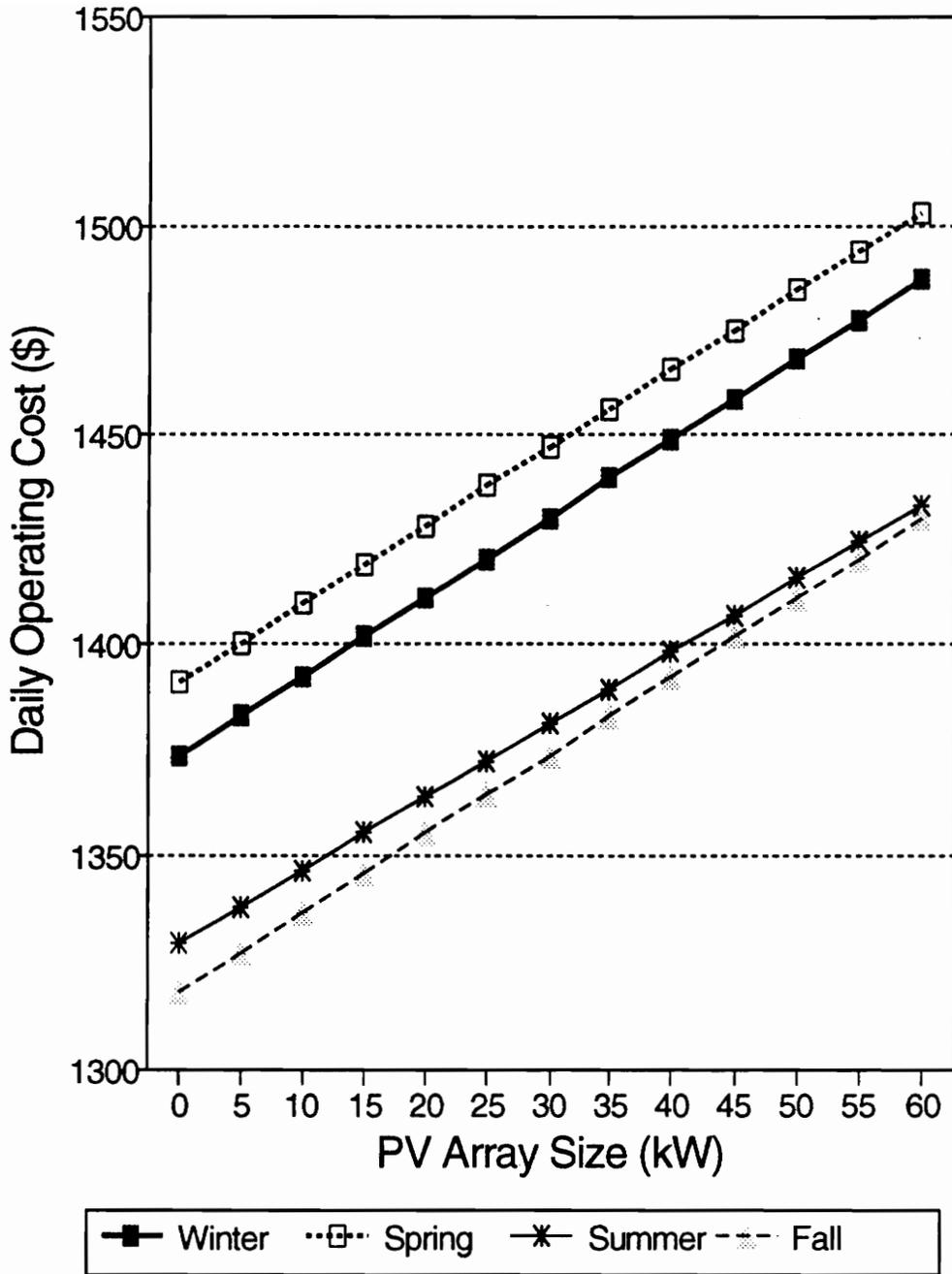


Figure 6.11 Daily Operating Cost vs. PV Array Size at a Demand Limit of 610 kW on a Low Solar Day - CASE C (electricity cost \$.08/\$.04).

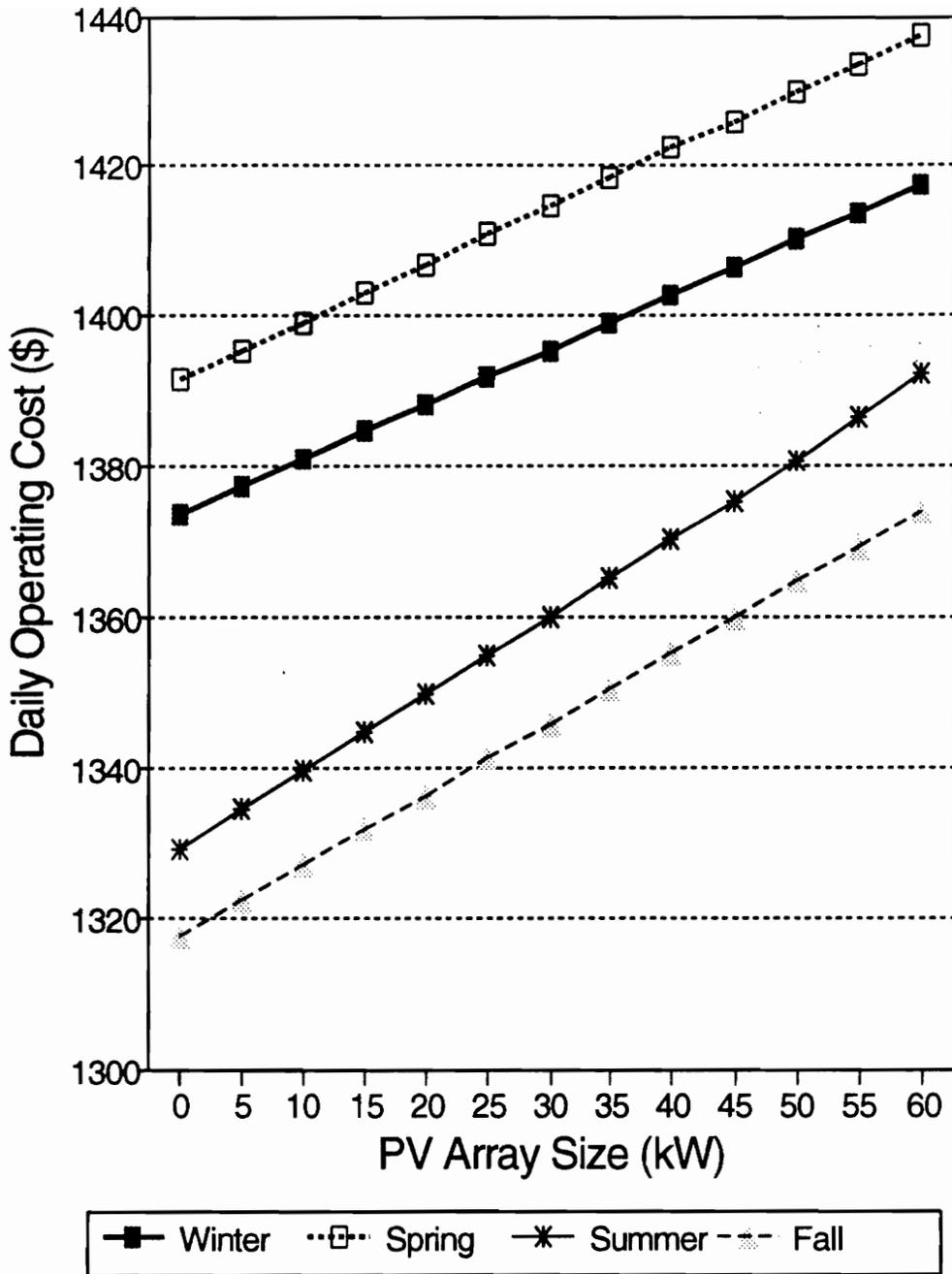


Figure 6.12 Daily Operating Cost vs. PV Array Size at a Demand Limit of 610 kW on a High Solar Day - CASE C (electricity cost \$.08/\$.04).

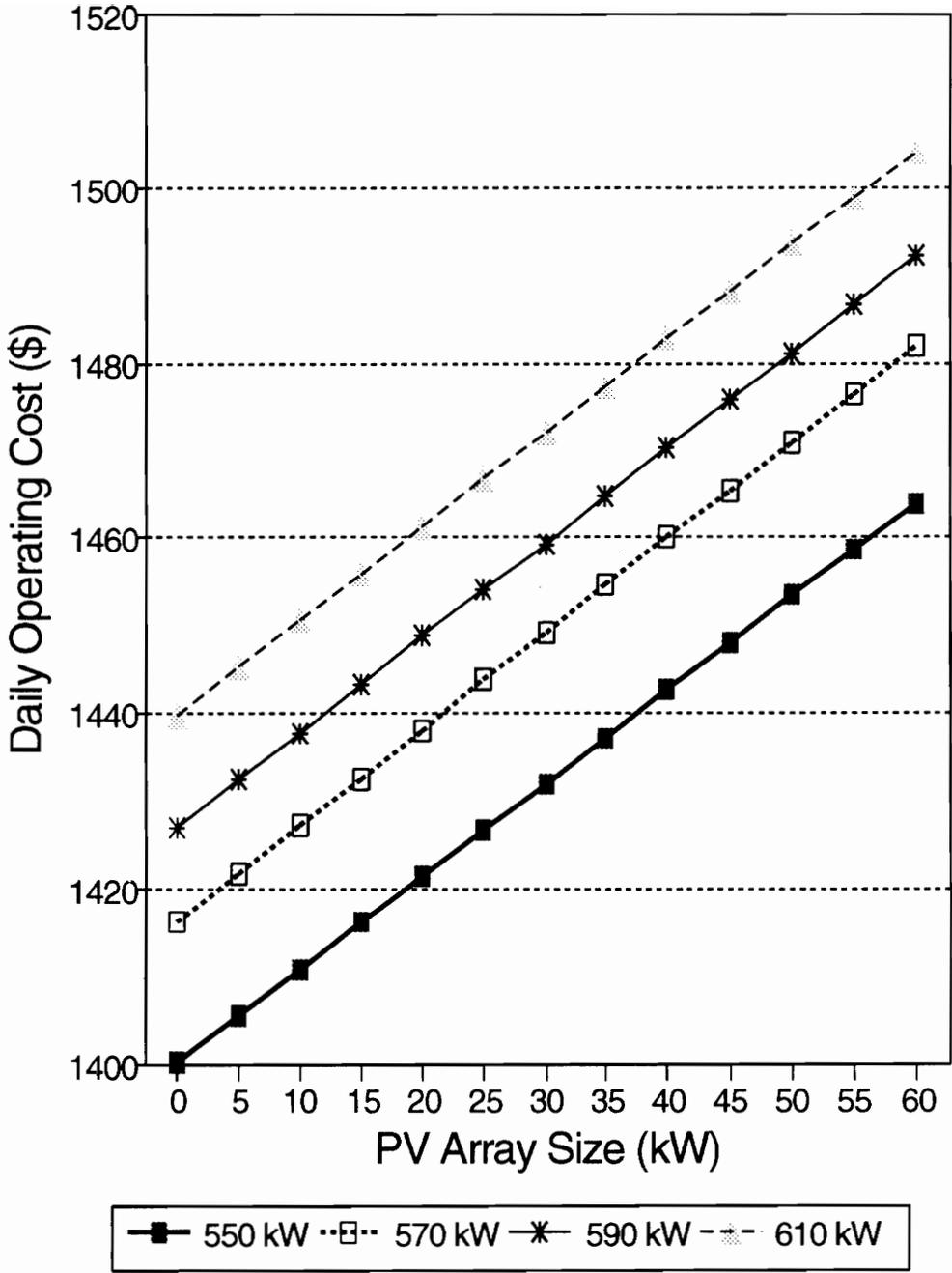


Figure 6.13 Daily Operating Cost vs. PV Array Size on a Low Solar Summer Day - CASE D (electricity cost \$.10/\$.05).

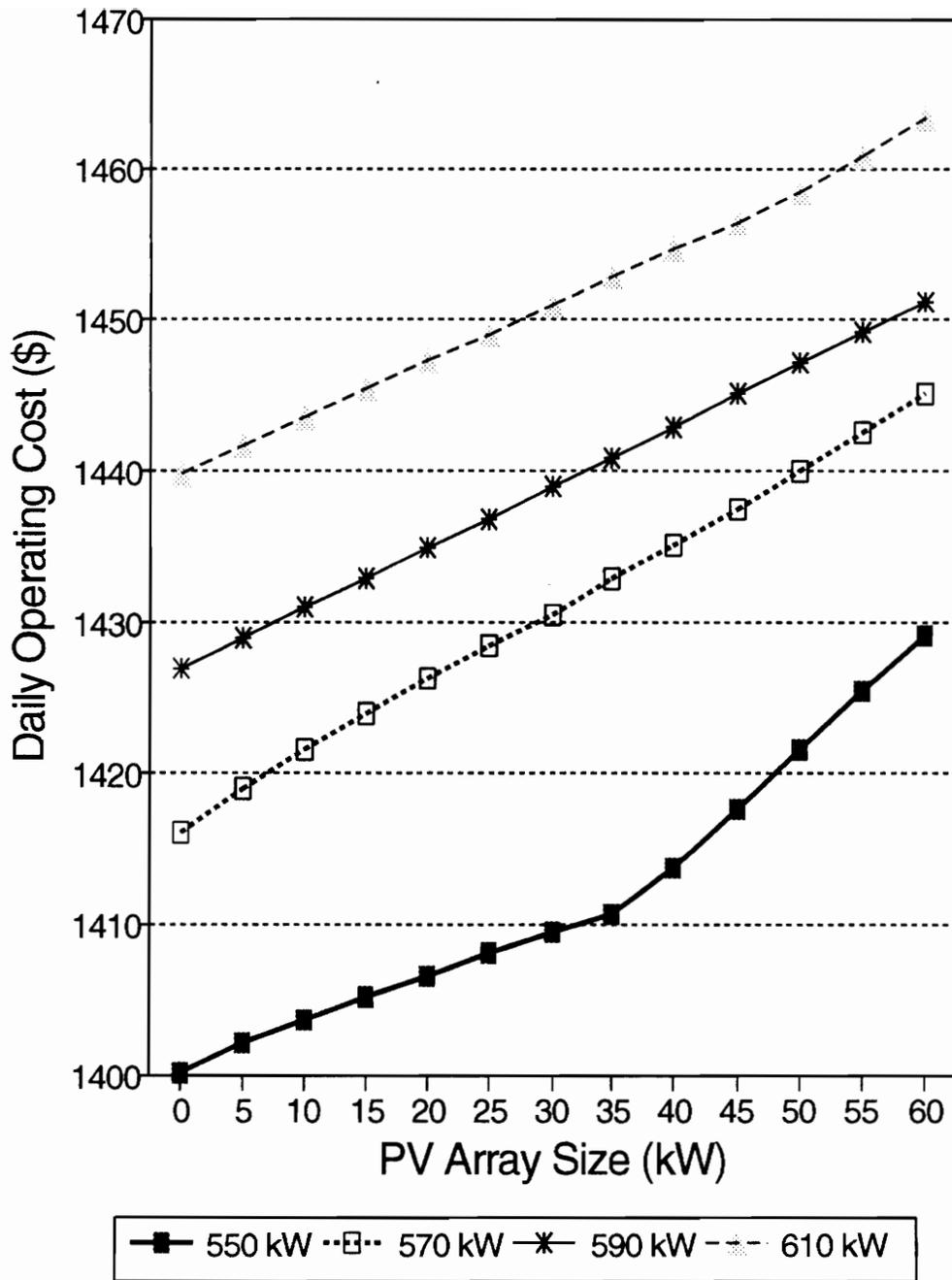


Figure 6.14 Daily Operating Cost vs. PV Array Size on a High Solar Summer Day - CASE D (electricity cost \$.10/\$.05).

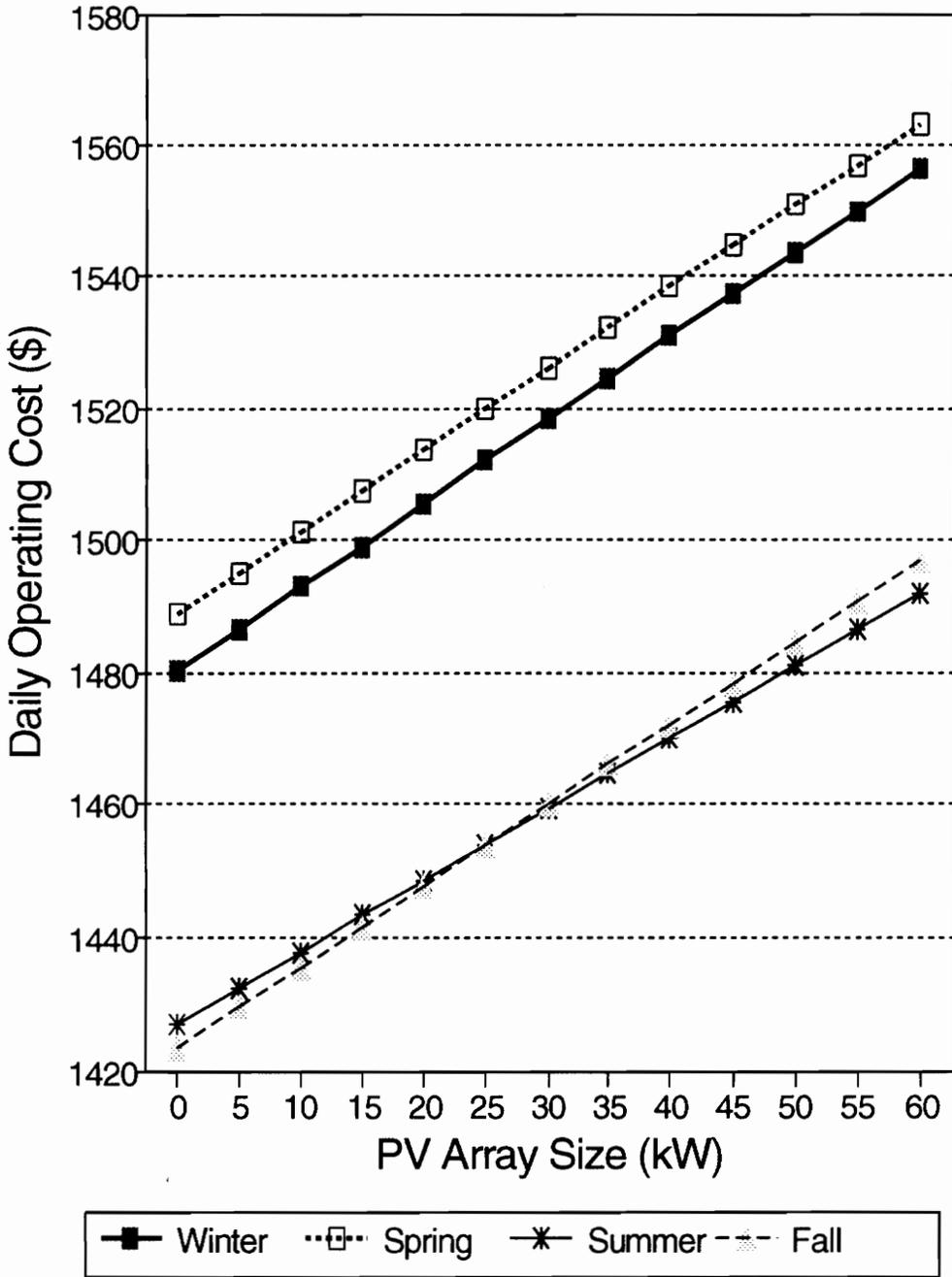
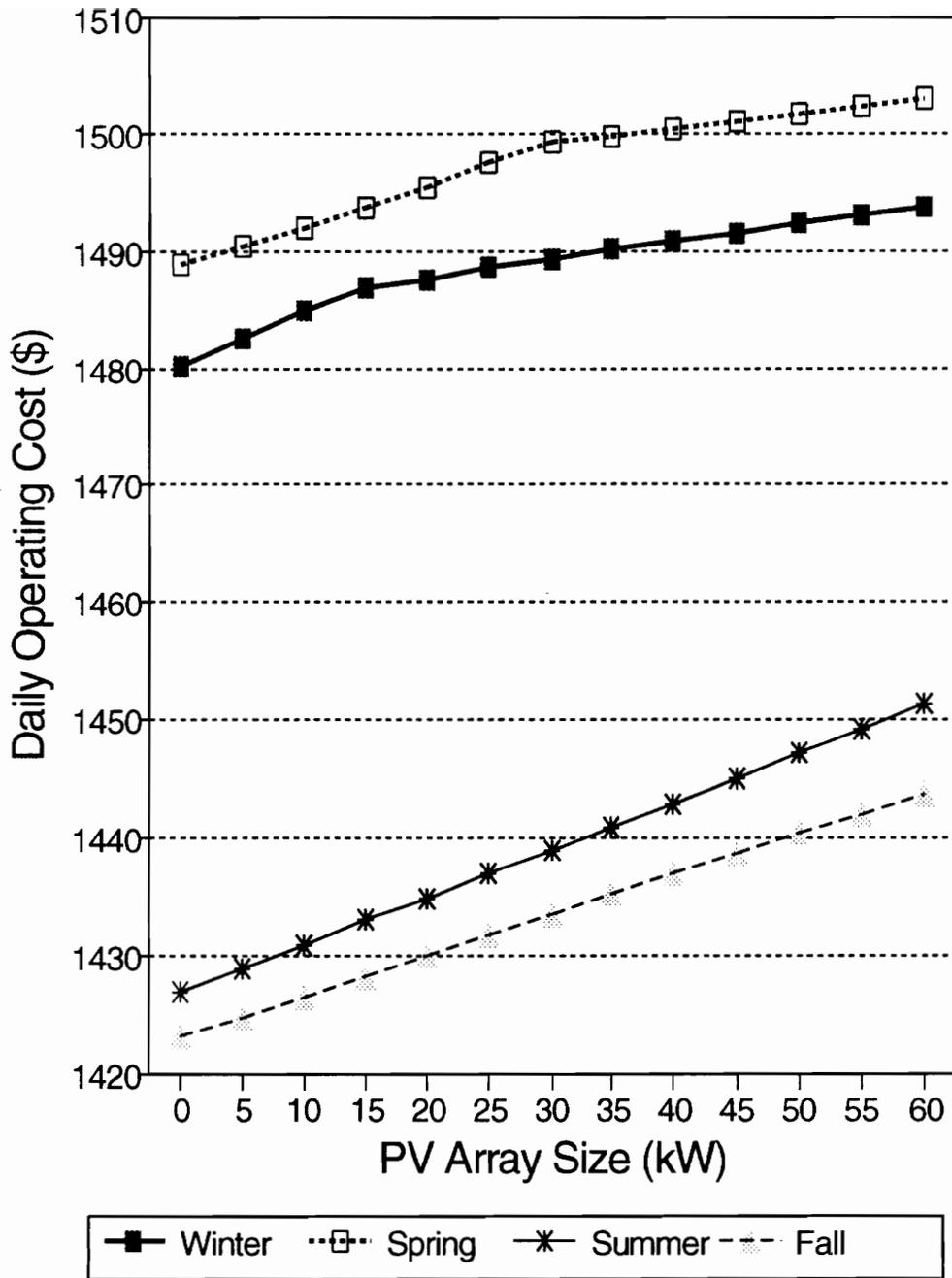


Figure 6.15 Daily Operating Cost vs. PV Array Size at a Demand Limit of 590 kW on a Low Solar Day - CASE D (electricity cost \$.10/\$.05).



**Figure 6.16 Daily Operating Cost vs. PV Array Size at a Demand Limit of 590 kW on a High Solar Day - CASE D (electricity cost \$.10/\$.05).**

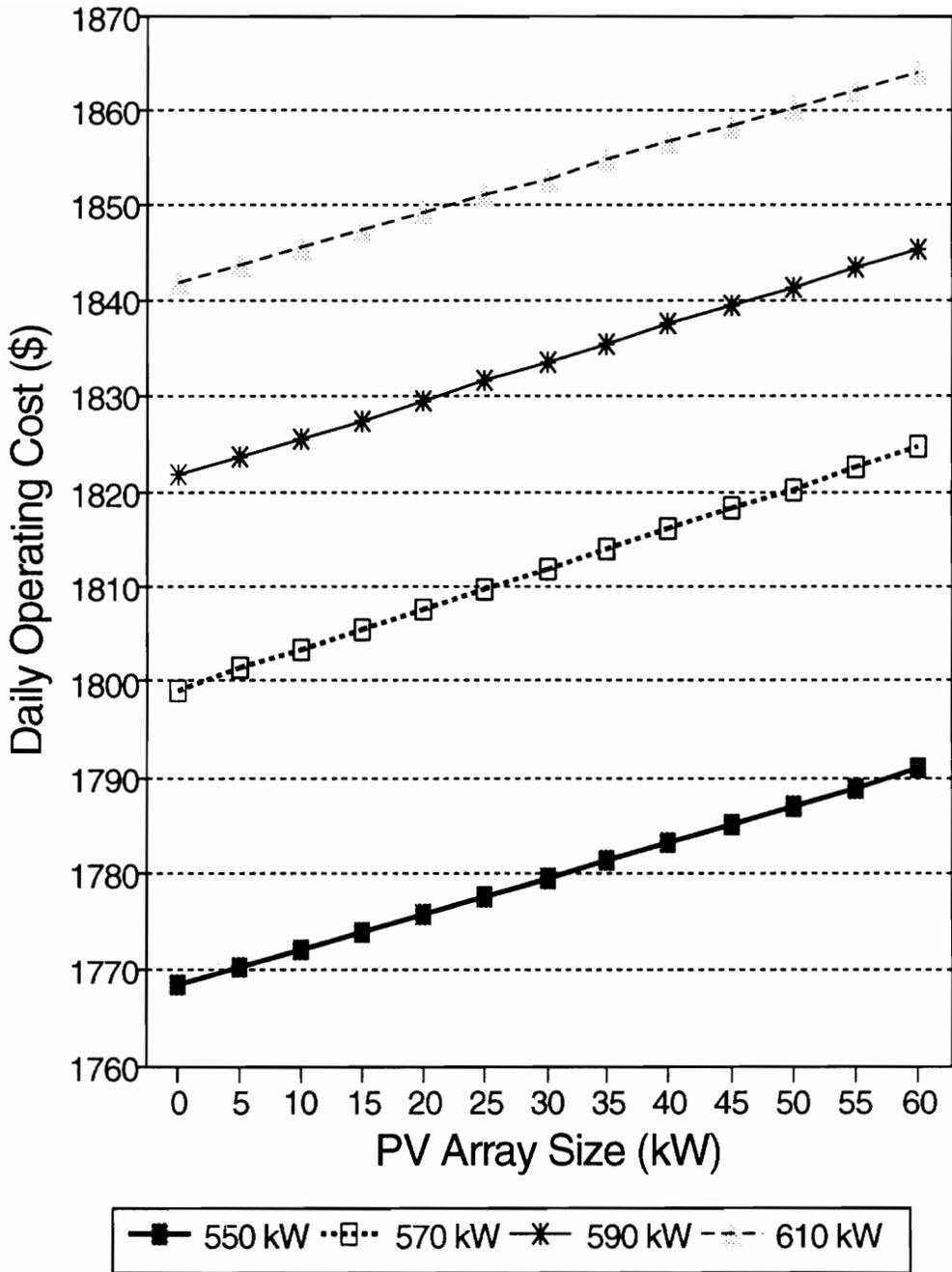
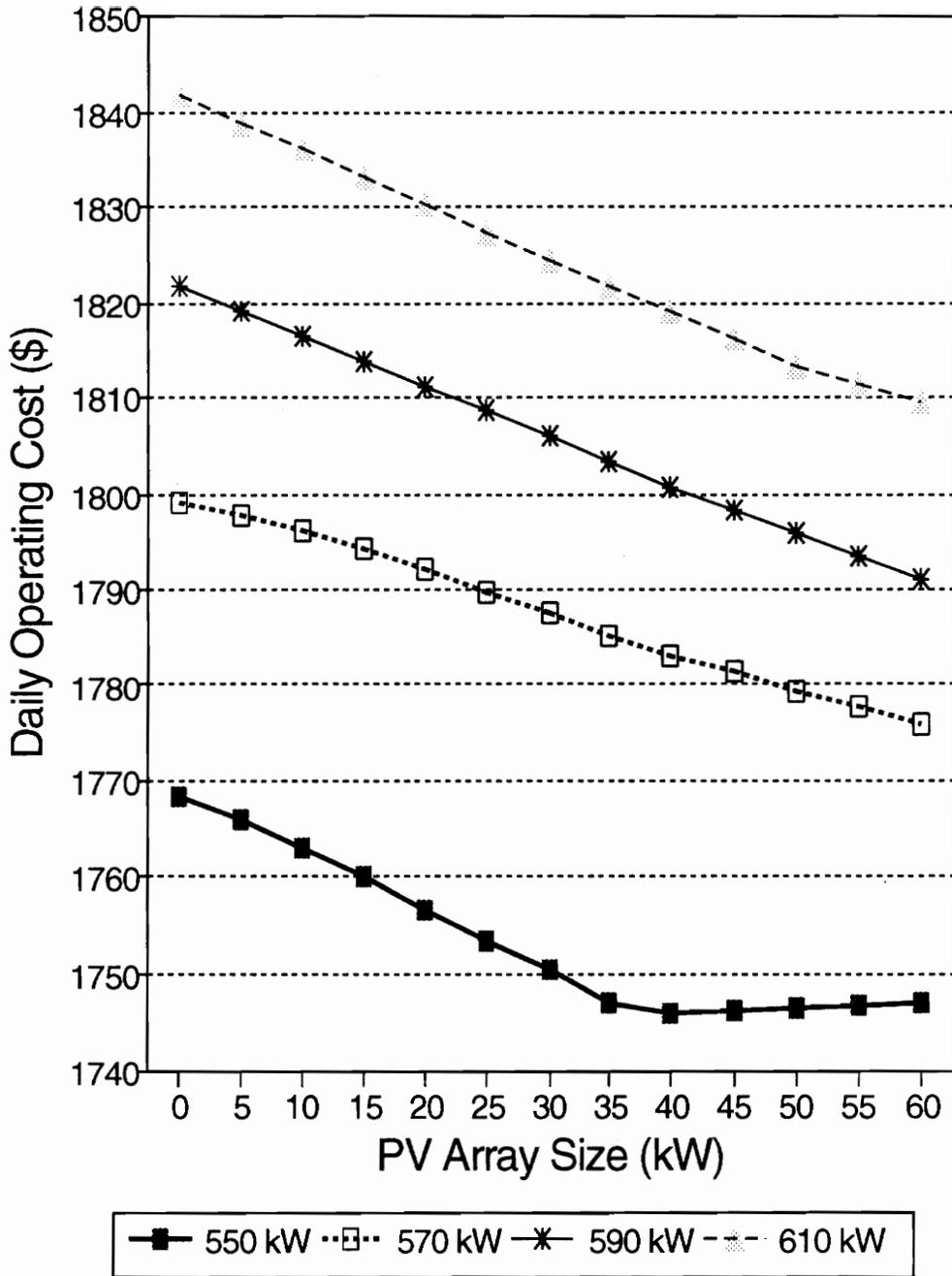
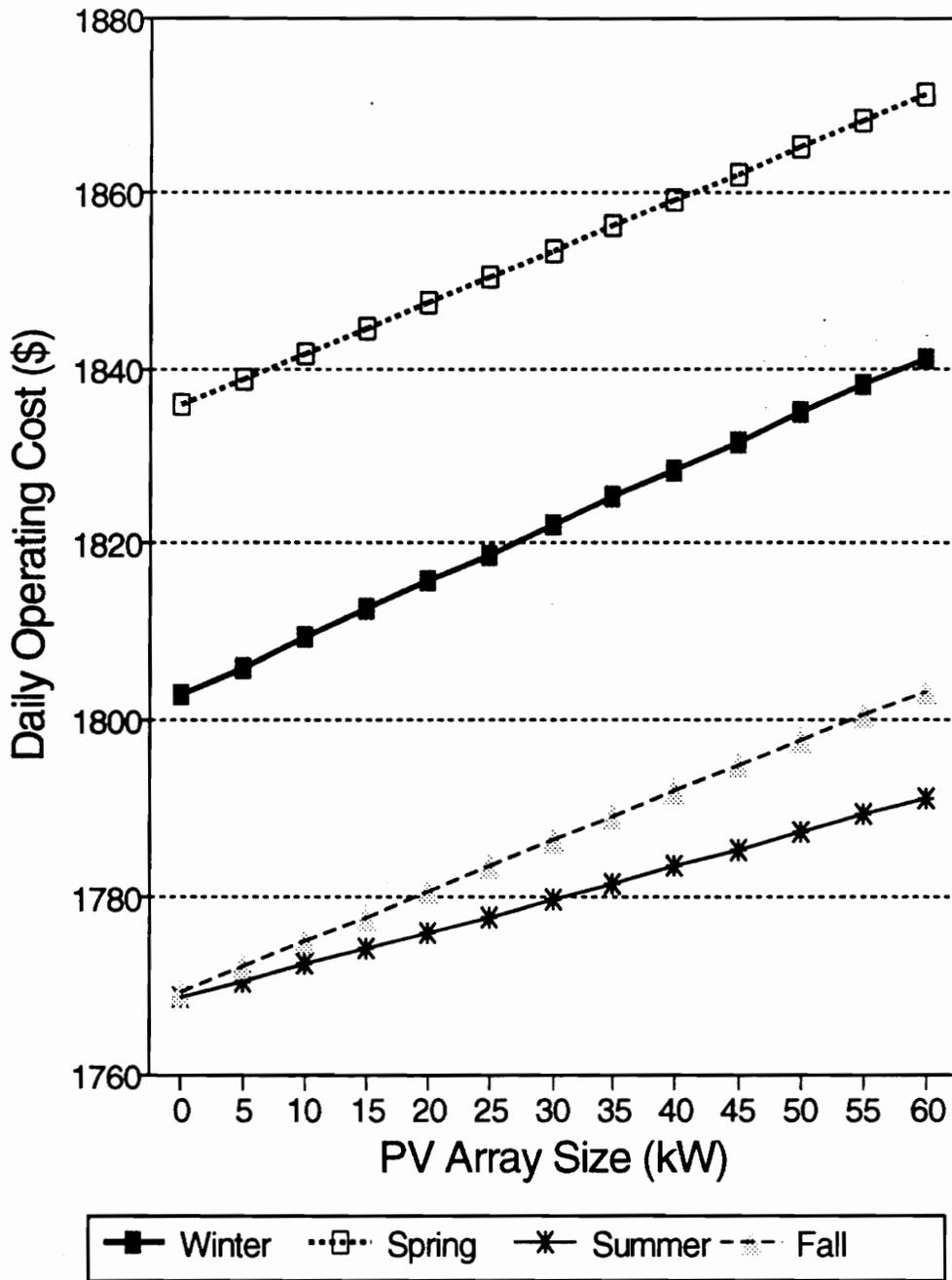


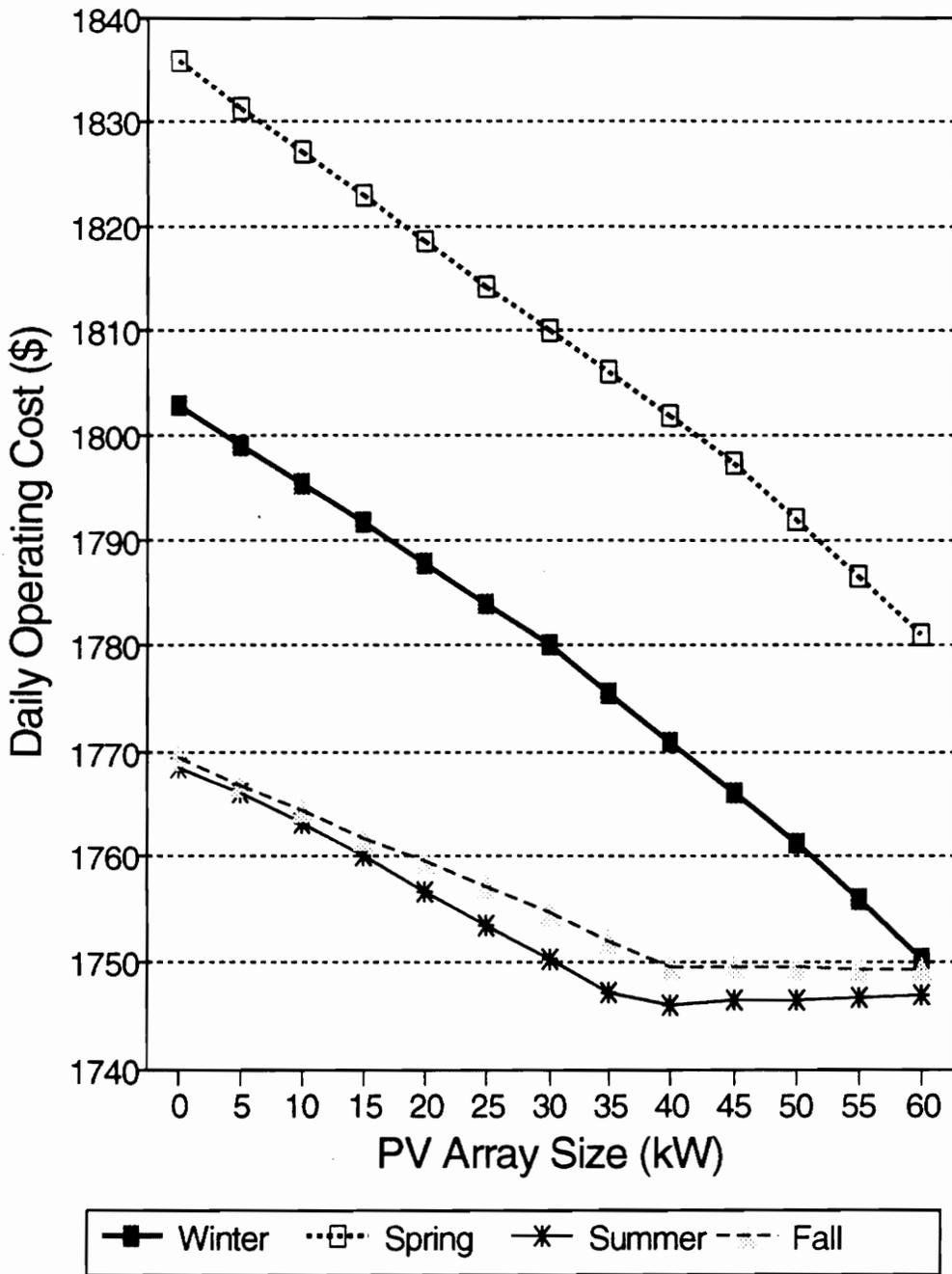
Figure 6.17 Daily Operating Cost vs. PV Array Size on a Low Solar Summer Day - CASE E (electricity cost \$.12/\$.06).



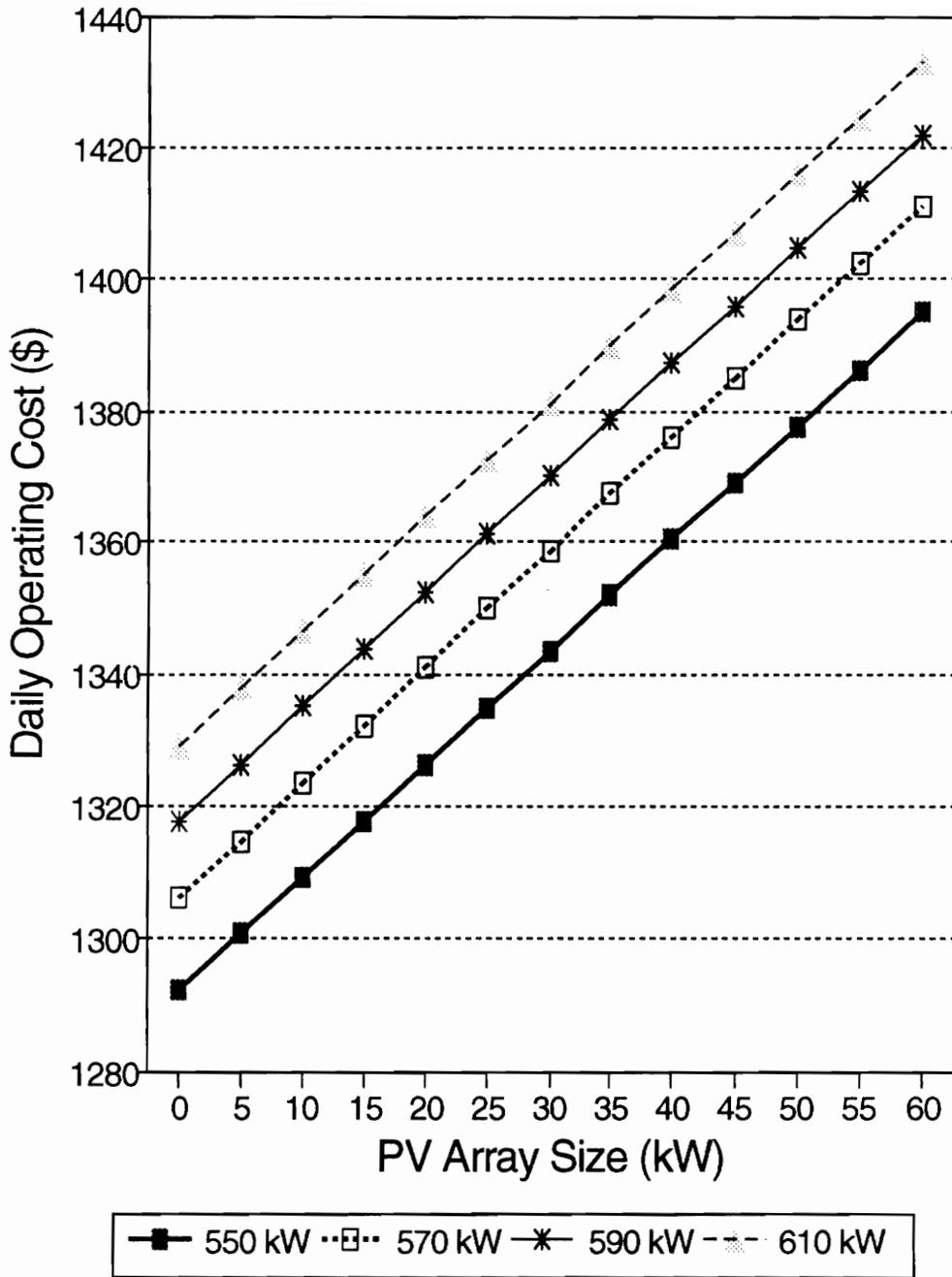
**Figure 6.18 Daily Operating Cost vs. PV Array Size on a High Solar Summer Day - CASE E (electricity cost \$.12/\$.06).**



**Figure 6.19 Daily Operating Cost vs. PV Array Size at a Demand Limit of 550 kW on a Low Solar Day - CASE E (electricity cost \$.12/\$.06).**



**Figure 6.20 Daily Operating Cost vs. PV Array Size at a Demand Limit of 550 kW on a High Solar Day - CASE E (electricity cost \$.12/\$.06).**



**Figure 6.21 Daily Operating Cost vs. PV Array Size on a Low Solar Summer Day - CASE F (electricity cost \$.08/\$.04).**

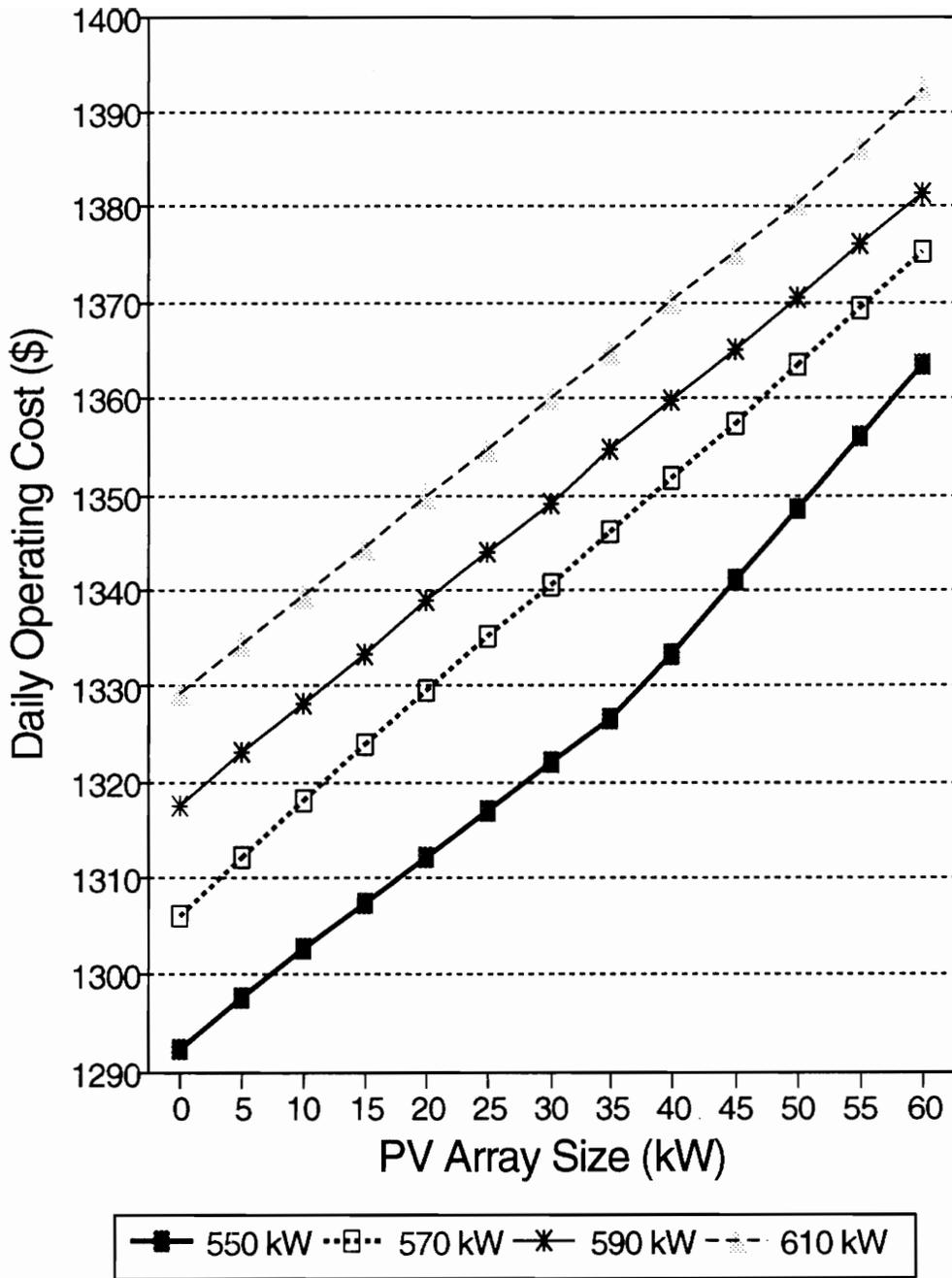


Figure 6.22 Daily Operating Cost vs. PV Array Size on a High Solar Summer Day - CASE F (electricity cost \$.08/\$.04).

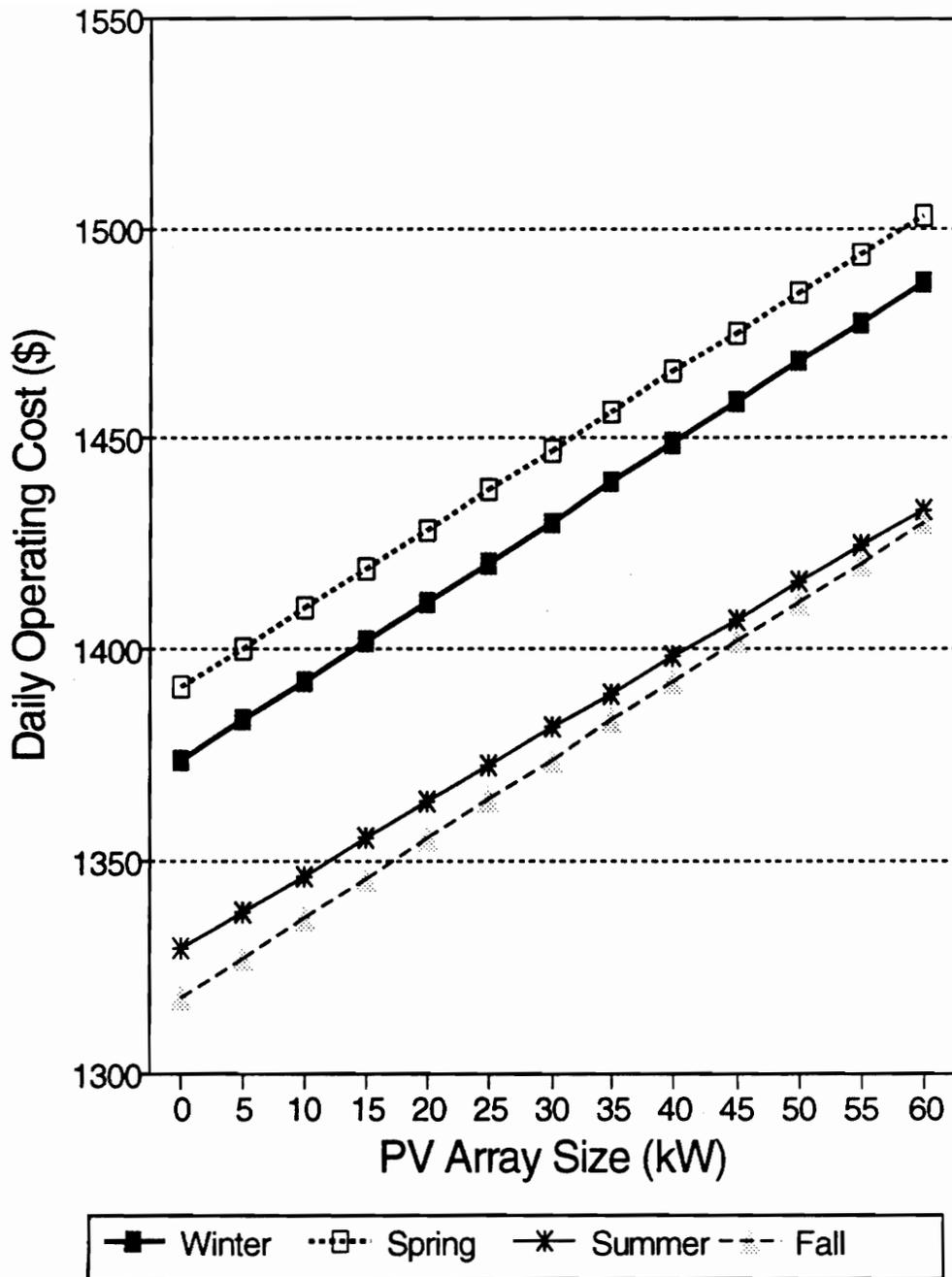


Figure 6.23 Daily Operating Cost vs. PV Array Size at a Demand Limit of 610 kW on a Low Solar Day - CASE F (electricity cost \$.08/\$.04).

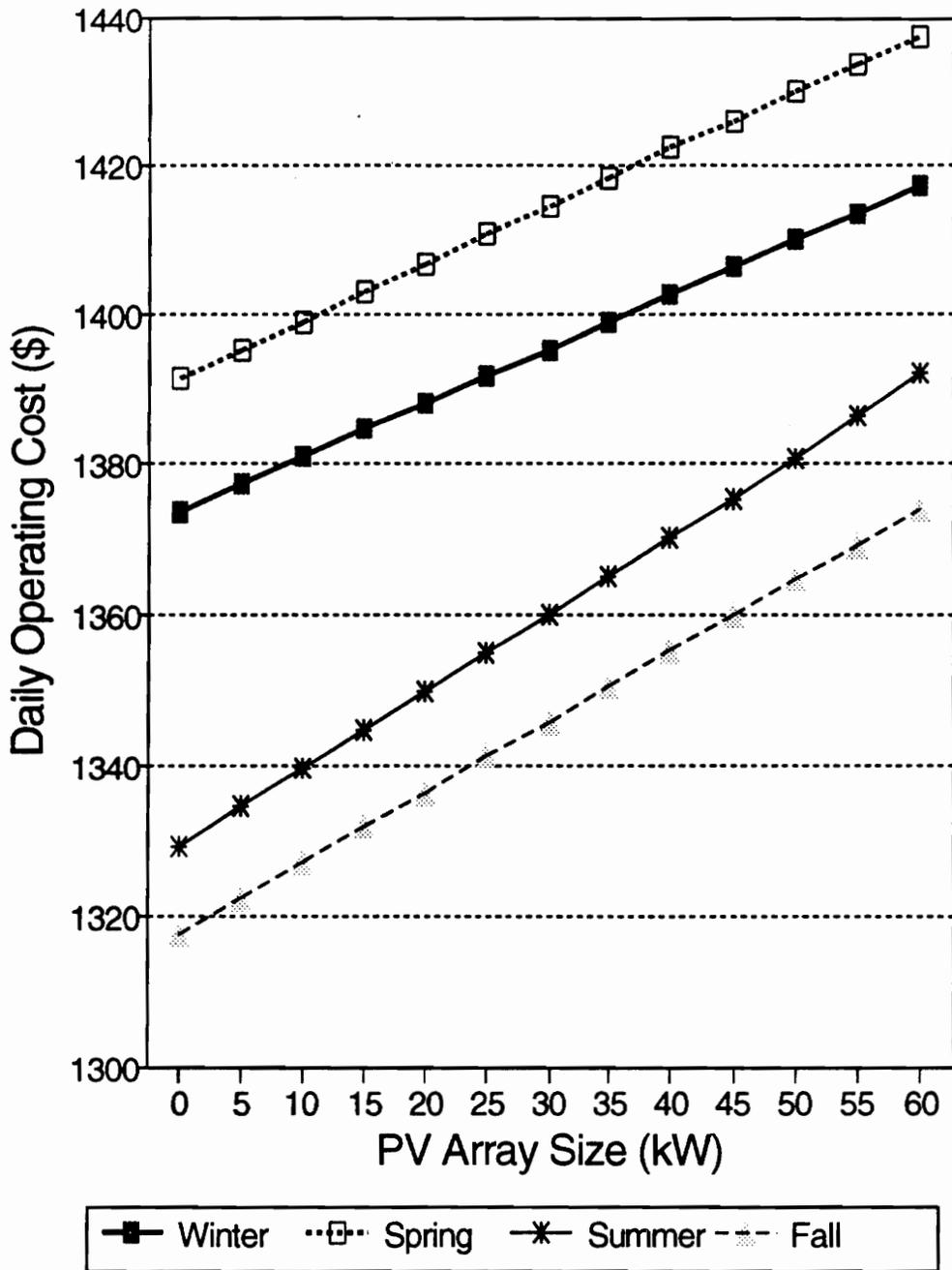


Figure 6.24 Daily Operating Cost vs. PV Array Size at a Demand Limit of 610 kW on a High Solar Day - CASE F (electricity cost \$.08/\$.04).

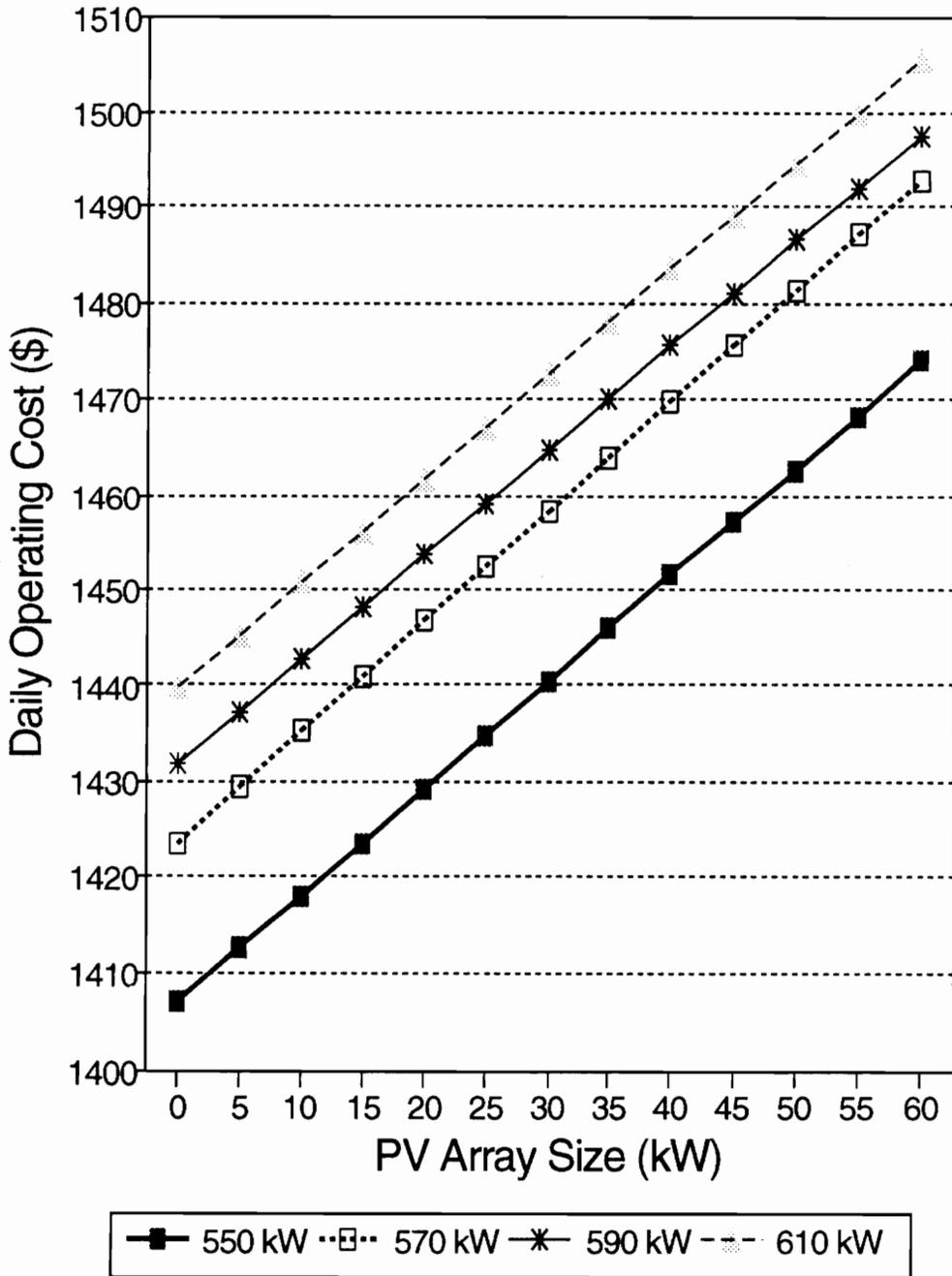


Figure 6.25 Daily Operating Cost vs. PV Array Size on a Low Solar Summer Day - CASE G (electricity cost \$.10/\$.05).

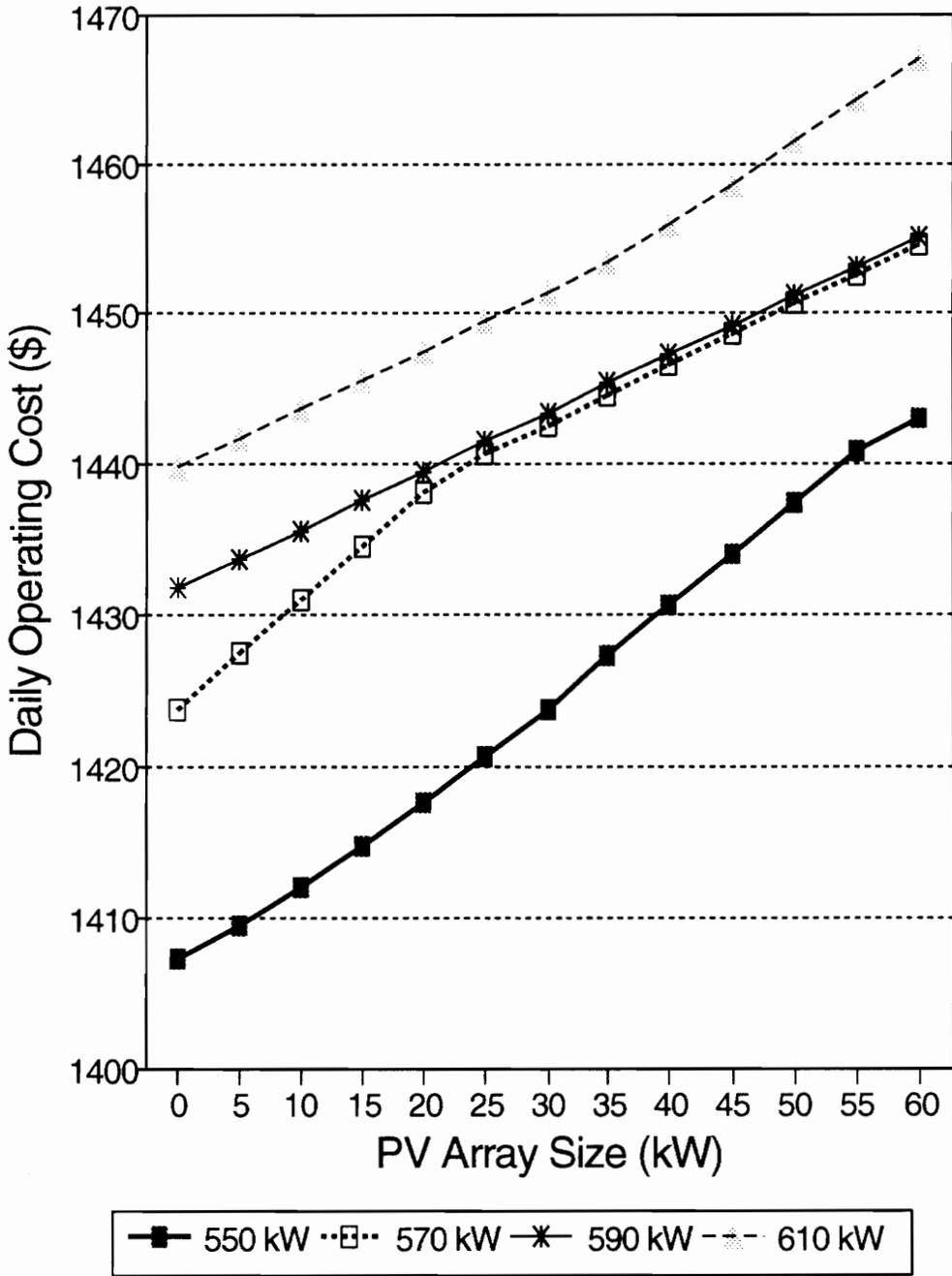
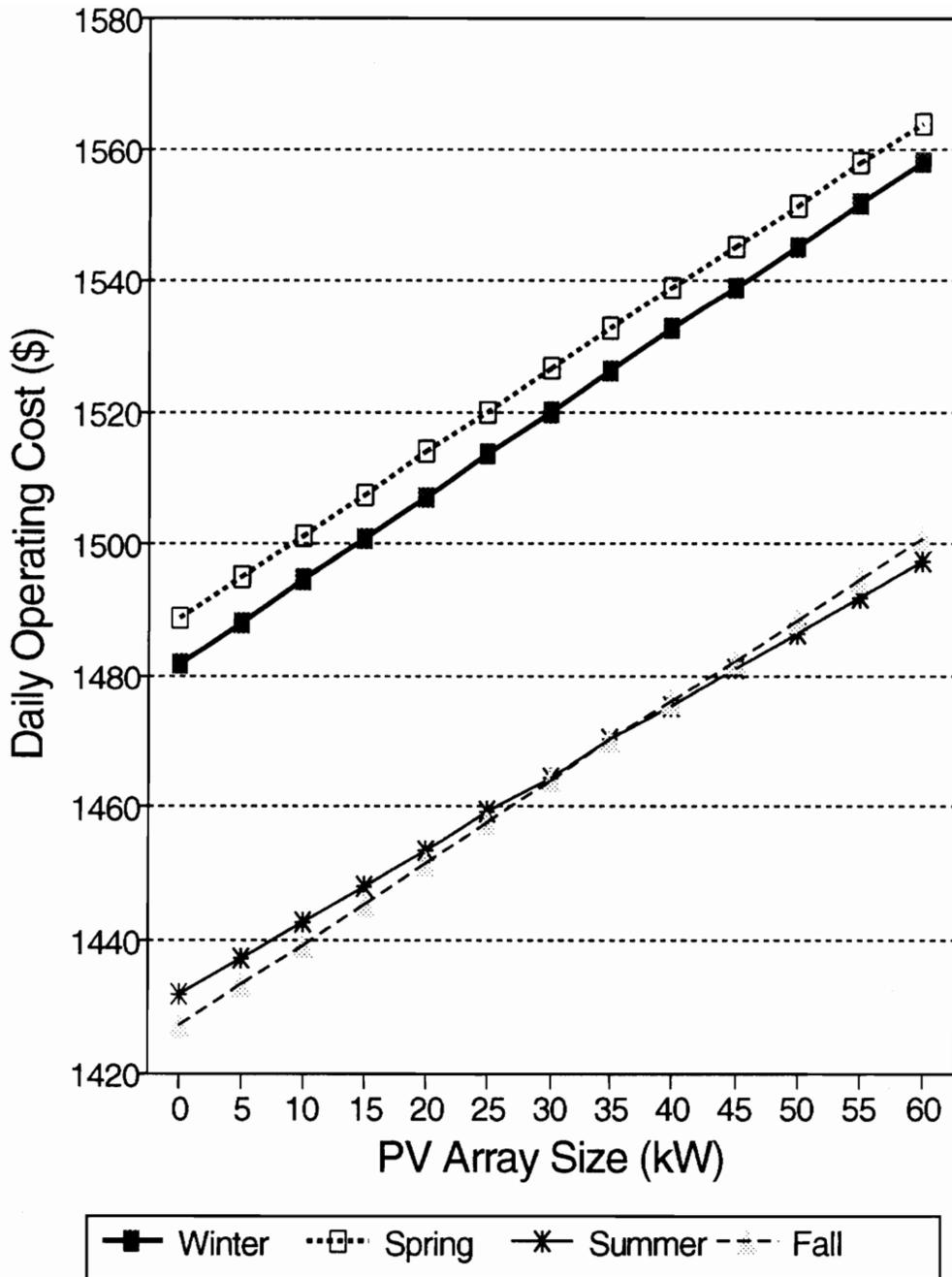


Figure 6.26 Daily Operating Cost vs. PV Array Size on a High Solar Summer Day - CASE G (electricity cost \$.10/\$.05).



**Figure 6.27 Daily Operating Cost vs. PV Array Size at a Demand Limit of 590 kW on a Low Solar Day - CASE G (electricity cost \$.10/\$.05).**

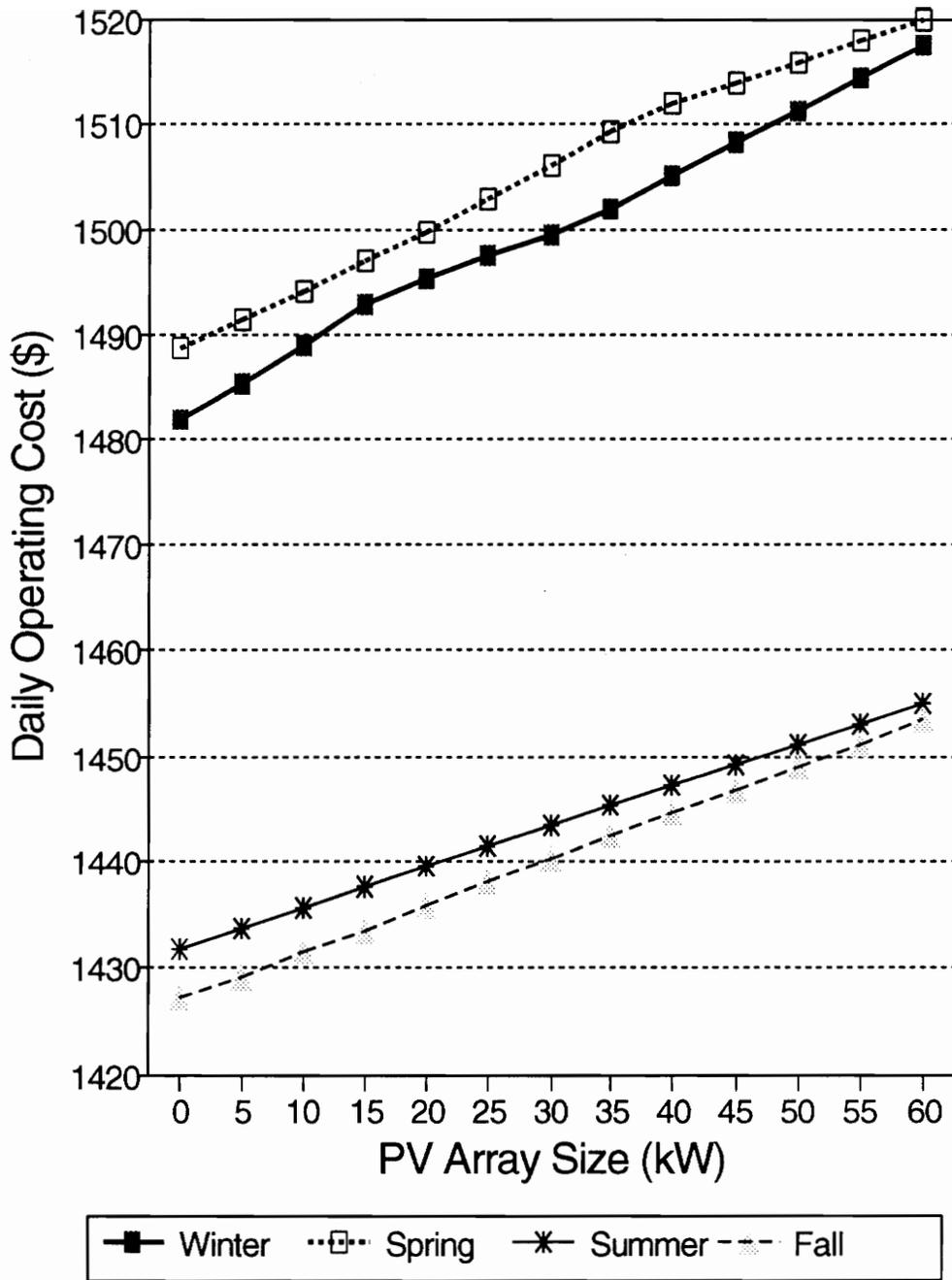
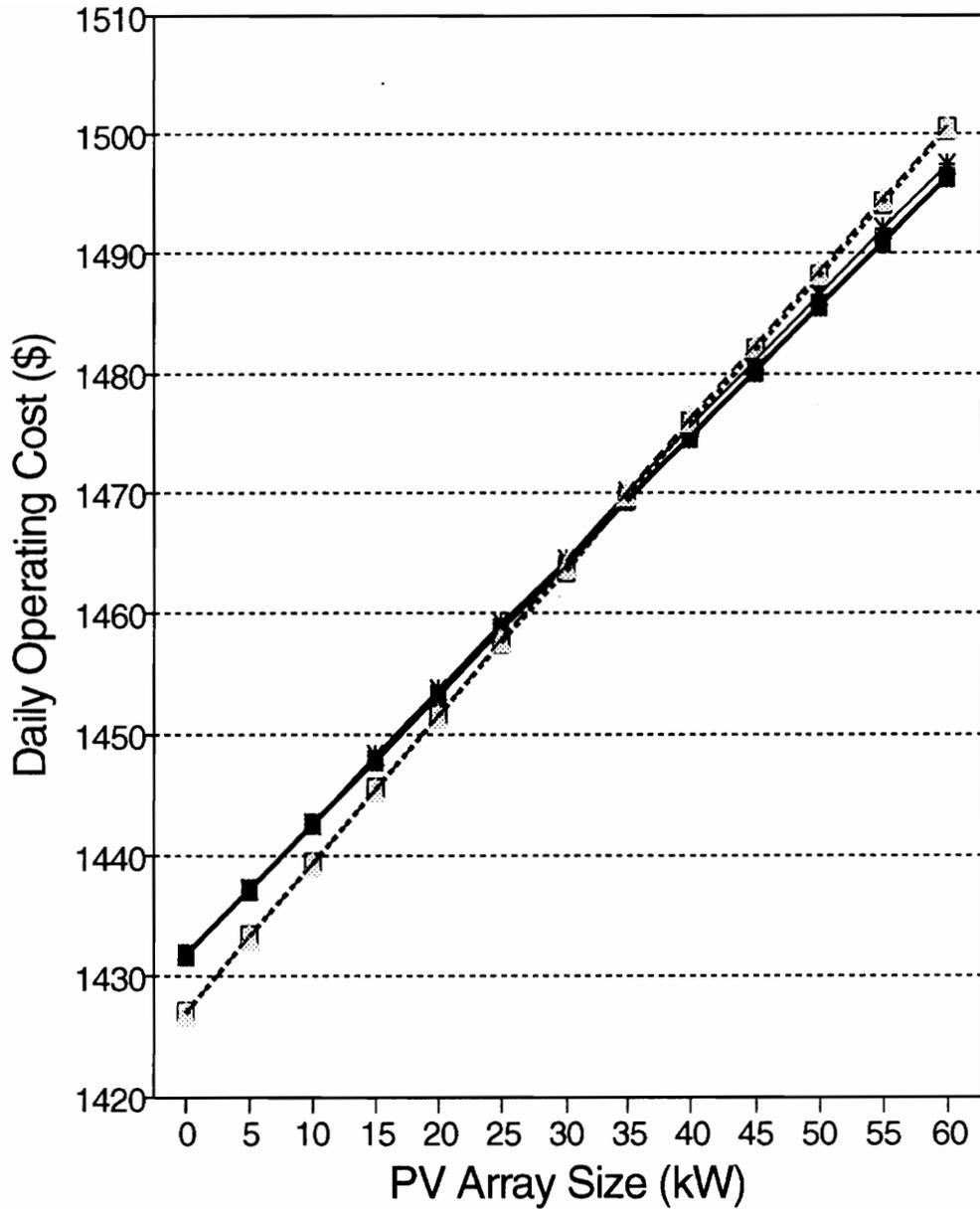
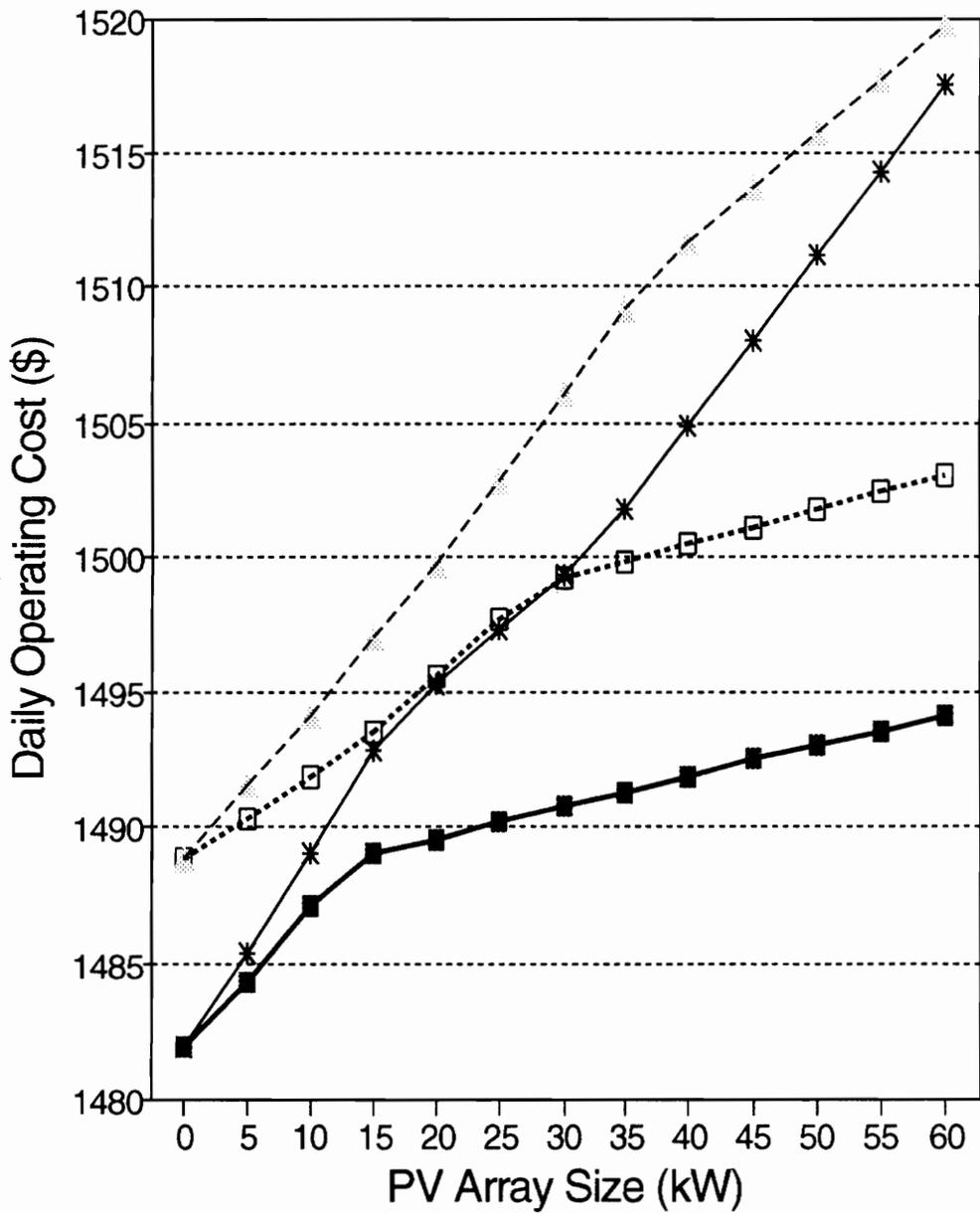


Figure 6.28 Daily Operating Cost vs. PV Array Size at a Demand Limit of 590 kW on a High Solar Day - CASE G (electricity cost \$.10/\$.05).



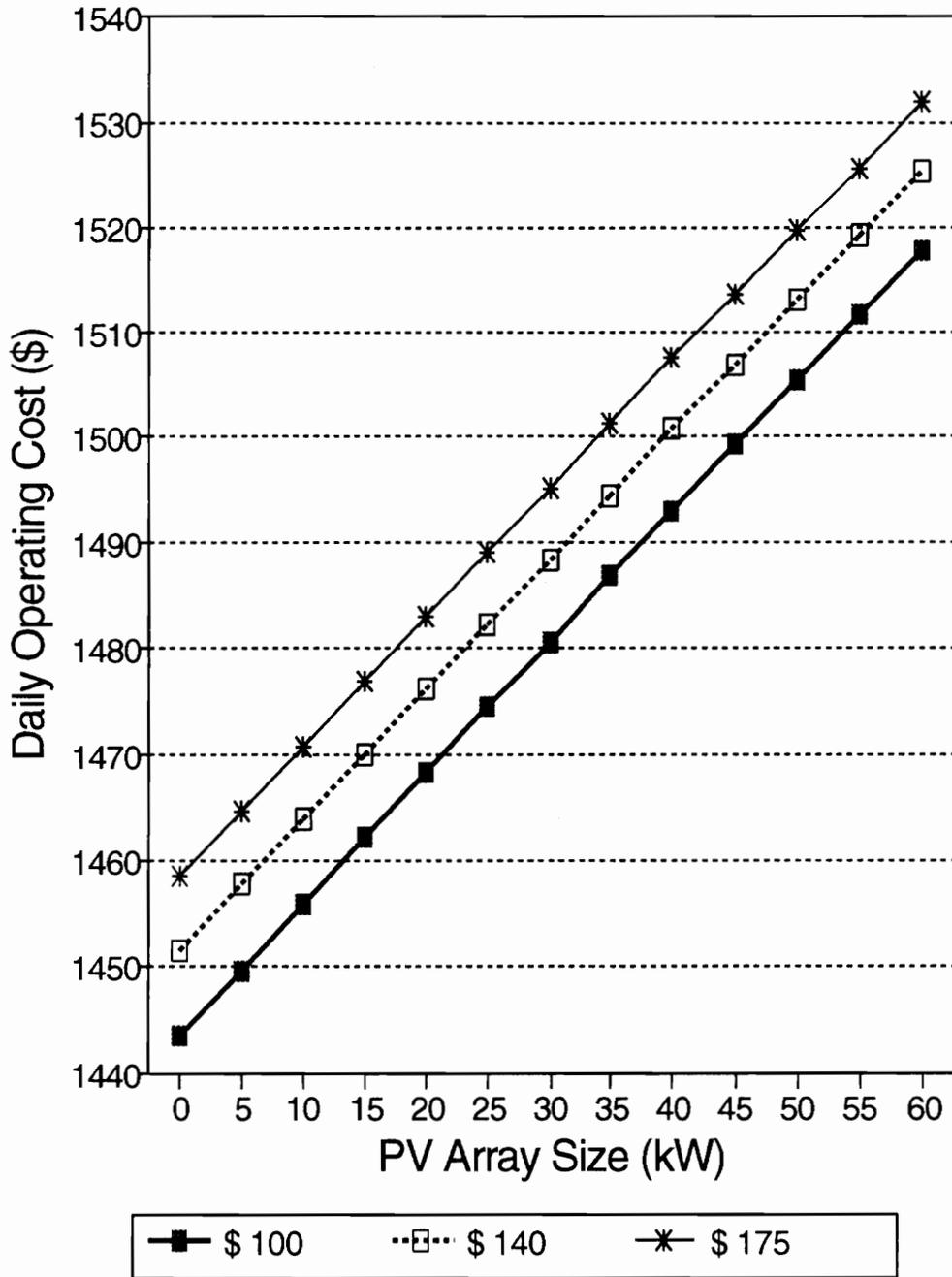
M55(Sum)  
 M55(Fal)  
 G4000(Sum)  
 G4000(Fal)

**Figure 6.29 Daily Operating Cost vs. PV Array Size on a Low Solar Day (M55 vs G4000) (Demand Limit 590 kW).**



M55(Win)  
 M55(Spr)  
 G4000(Win)  
 G4000(Spr)

**Figure 6.30 Daily Operating Cost vs. PV Array Size on a High Solar Day (M55 vs G4000) (Demand Limit 590 kW).**



**Figure 6.31 Daily Operating Cost vs. PV Array Size at a Demand Limit of 550 kW on a Low Solar Day - Battery Cost (electricity cost \$.10/\$.05).**

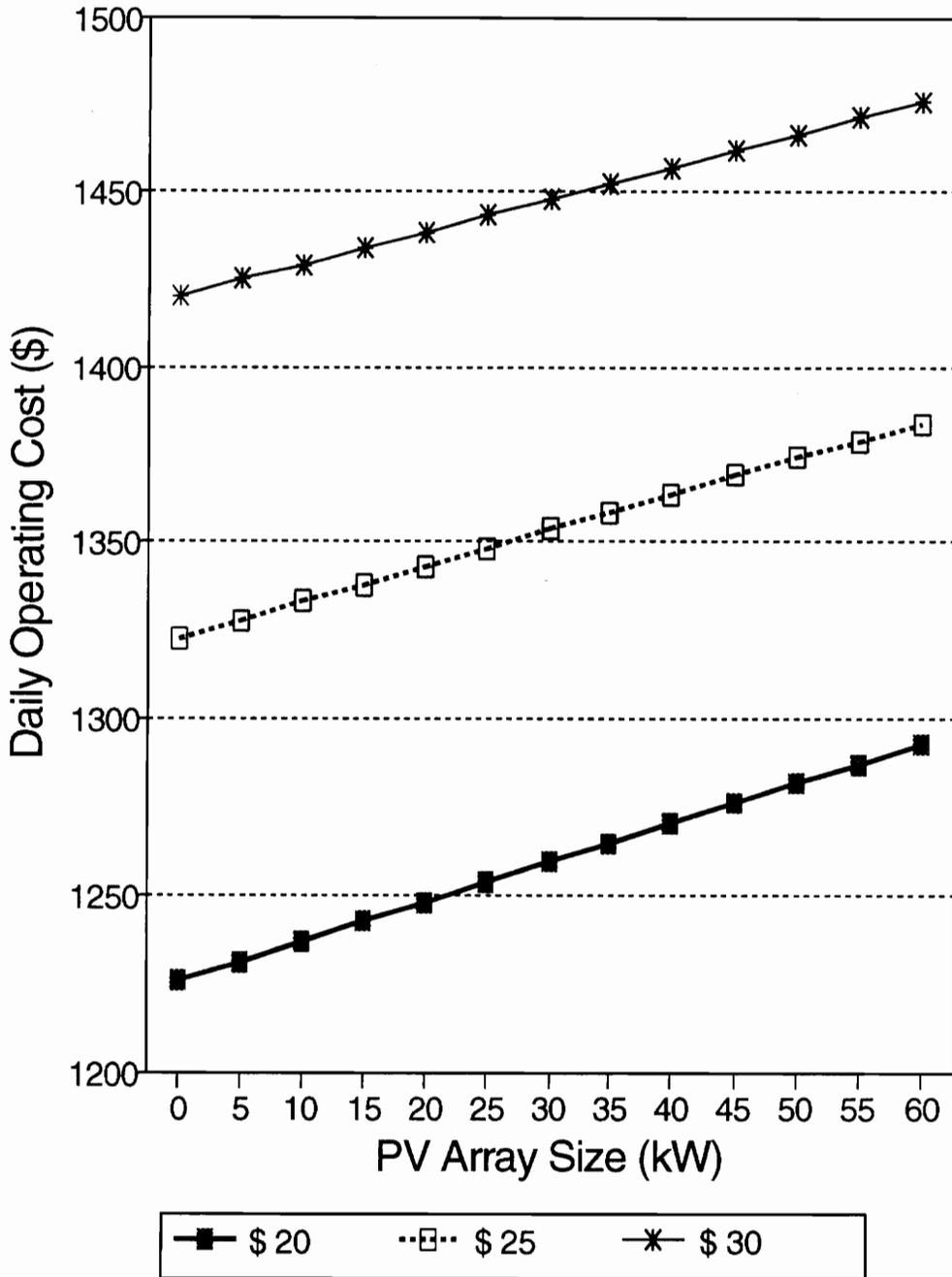


Figure 6.32 Daily Operating Cost vs. PV Array Size on a High Solar Day - (Demand Limit) (electricity cost \$.10/\$.05).

## **7.0 Conclusions and Recommendations**

This study shows that there exists a good match between photovoltaic output and some building loads. This fact is important in using photovoltaics and energy storage systems for demand side management. In this study a methodology was developed to evaluate the use of photovoltaics and energy storage systems as a demand side management tool. The methodology examines variables that affect a PV-DSM-Battery storage system and quantifies them. This study then looks at how factors such as demand limits, battery size, battery cost, PV cost, demand charge, energy cost, and seasonal differences affect the cost of supplying electricity to a building. From this information the methodology develops boundary conditions for when PV becomes economically attractive, and what are attractive array sizes and battery sizes for certain building load levels. This could be of use for utilities that give incentives for photovoltaic array construction.

This study showed that by carefully analyzing a set of alternatives, it is possible to find an economically attractive photovoltaic - DSM - storage system. A load management system can be optimized for certain cost parameters and operating conditions. This study can be extended in several ways. First, more cases can be run on the system. This will provide a way to narrow the minimum cost to an exact number. There may also be other variables that effect the minimum operating cost. These may need to be explored to find a true minimum operating cost. The final step in developing this methodology would be to construct a computer program that follows all of the steps in this methodology and arrives at an optimal configuration for the load management system.

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## 9.0 Appendix A

Appendix A contains the operating characteristics for the M55 single crystalline modules and G4000 amorphous silicon modules.

### Module Specifications for M55

Peak Power	53 W
Voltage at Peak Power	17.4 V
Current at Peak Power	3.05 A
Short Circuit Current	3.37 A
Open Circuit Voltage	21.8 V

### Module Specifications for G4000

Peak Power	30 W
Voltage at Peak Power	16.5 V
Current at Peak Power	1.8 A
Short Circuit Current	2.2 A
Open Circuit Voltage	23 V

## 10.0 Appendix B

**Table 10.1 Case A - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1427.18 360 550	\$1451.57 456 550	\$1407.09 150 550	\$1405.34 141 550
5	\$1433.48 359 550	\$1457.71 453 550	\$1412.55 143 550	\$1411.38 138 550
10	\$1439.78 358 550	\$1463.85 450 550	\$1418.00 136 550	\$1417.43 135 550
15	\$1446.08 357 550	\$1469.99 448 550	\$1423.46 129 550	\$1423.51 132 550
20	\$1452.38 355 550	\$1476.13 445 550	\$1428.91 122 550	\$1429.58 130 550
25	\$1458.68 354 550	\$1482.27 442 550	\$1434.37 115 550	\$1435.66 127 550
30	\$1464.97 353 550	\$1488.41 440 550	\$1439.83 108 550	\$1441.73 125 550
35	\$1471.27 352 550	\$1494.55 437 550	\$1445.33 102 550	\$1447.81 122 550
40	\$1477.57 351 550	\$1500.69 434 550	\$1450.83 97 550	\$1453.88 120 550
45	\$1483.87 350 550	\$1506.83 432 550	\$1456.34 91 550	\$1459.95 117 550
50	\$1490.17 348 550	\$1512.97 429 550	\$1461.86 86 550	\$1466.03 115 550
55	\$1496.47 347 550	\$1519.11 426 550	\$1467.46 83 550	\$1472.10 112 550
60	\$1502.77 346 550	\$1525.25 424 550	\$1473.06 80 550	\$1478.18 109 550

**Table 10.2 Case A - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1427.18 360 550	\$1451.57 456 550	\$1407.09 150 550	\$1405.34 141 550
5	\$1428.30 359 547	\$1452.13 453 547	\$1409.39 143 548	\$1407.51 138 548
10	\$1429.40 358 544	\$1452.80 450 544	\$1411.76 136 546	\$1409.71 135 546
15	\$1430.48 357 540	\$1453.45 448 540	\$1414.46 129 545	\$1412.04 132 544
20	\$1431.54 355 537	\$1454.07 445 537	\$1417.12 122 544	\$1414.60 130 542
25	\$1432.56 354 534	\$1454.66 442 534	\$1420.05 115 543	\$1417.38 127 541
30	\$1433.57 353 531	\$1455.45 440 531	\$1423.17 108 542	\$1420.26 125 540
35	\$1434.94 352 528	\$1456.28 437 528	\$1426.43 102 541	\$1423.21 122 539
40	\$1436.33 351 525	\$1457.03 434 525	\$1429.83 97 541	\$1426.21 120 538
45	\$1437.68 350 522	\$1457.43 432 522	\$1433.22 91 541	\$1428.61 117 536
50	\$1439.04 348 519	\$1457.18 429 519	\$1436.54 86 540	\$1430.47 115 534
55	\$1440.39 347 516	\$1456.90 426 516	\$1439.73 83 539	\$1432.30 112 531
60	\$1441.54 346 513	\$1456.41 424 513	\$1442.10 80 537	\$1434.10 109 528

**Table 10.3 Case A - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1465.43 160 570	\$1465.01 233 570	\$1423.77 19 570	\$1422.27 17 570
5	\$1471.73 159 570	\$1471.16 231 570	\$1429.45 18 570	\$1428.41 17 570
10	\$1478.03 158 570	\$1477.32 228 570	\$1435.12 17 570	\$1434.55 16 570
15	\$1484.33 157 570	\$1483.47 226 570	\$1440.80 16 570	\$1440.69 15 570
20	\$1490.62 155 570	\$1489.62 224 570	\$1446.48 16 570	\$1446.84 15 570
25	\$1496.92 154 570	\$1495.78 221 570	\$1452.16 15 570	\$1452.98 14 570
30	\$1503.22 153 570	\$1501.93 219 570	\$1457.84 14 570	\$1459.12 13 570
35	\$1509.52 152 570	\$1508.09 217 570	\$1463.52 14 570	\$1465.26 13 570
40	\$1515.82 151 570	\$1514.24 215 570	\$1469.20 13 570	\$1471.41 12 570
45	\$1522.12 150 570	\$1520.40 212 570	\$1474.88 12 570	\$1477.55 12 570
50	\$1528.42 148 570	\$1526.55 210 570	\$1480.56 12 570	\$1483.69 11 570
55	\$1534.72 147 570	\$1532.71 208 570	\$1486.23 11 570	\$1489.83 10 570
60	\$1541.02 146 570	\$1538.86 206 570	\$1491.91 10 570	\$1495.99 10 570

**Table 10.4 Case A - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1465.43 160 570	\$1465.01 233 570	\$1423.77 19 570	\$1422.27 17 570
5	\$1466.67 159 567	\$1465.78 231 567	\$1427.31 18 570	\$1425.26 17 569
10	\$1468.20 158 564	\$1466.78 228 564	\$1430.82 17 569	\$1428.53 16 568
15	\$1470.17 157 563	\$1467.71 226 562	\$1434.30 16 569	\$1430.81 15 566
20	\$1472.07 155 561	\$1469.02 224 559	\$1437.72 16 568	\$1432.37 15 563
25	\$1474.10 154 559	\$1470.26 221 557	\$1440.23 15 566	\$1433.93 14 560
30	\$1476.27 153 557	\$1471.45 219 555	\$1442.15 14 563	\$1435.49 13 557
35	\$1478.66 152 556	\$1472.74 217 553	\$1444.07 14 560	\$1437.04 13 554
40	\$1480.22 151 553	\$1473.93 215 550	\$1445.99 13 558	\$1438.58 12 550
45	\$1481.23 150 550	\$1475.34 212 548	\$1447.92 12 555	\$1440.12 12 547
50	\$1482.22 148 547	\$1476.59 210 546	\$1449.85 12 552	\$1441.66 11 544
55	\$1483.16 147 543	\$1477.54 208 543	\$1451.78 11 549	\$1443.19 10 541
60	\$1484.06 146 540	\$1478.32 206 540	\$1453.70 10 546	\$1444.71 10 538

**Table 10.5 Case A - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1481.90 23 590	\$1488.93 80 590	\$1431.78 0 583	\$1426.99 0 578
5	\$1488.23 22 590	\$1495.12 79 590	\$1437.15 0 583	\$1433.10 0 578
10	\$1494.55 22 590	\$1501.31 77 590	\$1442.53 0 582	\$1439.21 0 578
15	\$1500.88 22 590	\$1507.49 76 590	\$1447.90 0 582	\$1445.32 0 578
20	\$1507.20 21 590	\$1513.69 75 590	\$1453.28 0 581	\$1451.43 0 578
25	\$1513.53 21 590	\$1519.88 74 590	\$1458.65 0 581	\$1457.54 0 578
30	\$1519.85 20 590	\$1526.06 72 590	\$1464.03 0 580	\$1463.65 0 578
35	\$1526.18 20 590	\$1532.25 71 590	\$1469.40 0 580	\$1469.76 0 577
40	\$1532.51 19 590	\$1538.44 70 590	\$1474.78 0 579	\$1475.87 0 577
45	\$1538.83 19 590	\$1544.63 68 590	\$1480.15 0 579	\$1481.98 0 577
50	\$1545.16 19 590	\$1550.82 67 590	\$1485.53 0 578	\$1488.09 0 577
55	\$1551.48 18 590	\$1557.01 66 590	\$1490.90 0 578	\$1494.20 0 577
60	\$1557.81 18 590	\$1563.20 65 590	\$1496.28 0 577	\$1500.31 0 577

**Table 10.6 Case A - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1481.90 23 590	\$1488.93 80 590	\$1431.78 0 583	\$1426.99 0 578
5	\$1484.34 22 589	\$1490.39 79 588	\$1433.64 0 580	\$1428.49 0 575
10	\$1487.09 22 588	\$1491.94 77 586	\$1435.51 0 577	\$1429.98 0 571
15	\$1489.05 22 586	\$1493.56 76 584	\$1437.37 0 574	\$1431.47 0 568
20	\$1489.63 21 582	\$1495.53 75 583	\$1439.23 0 571	\$1432.96 0 565
25	\$1490.22 21 578	\$1497.67 74 582	\$1441.10 0 568	\$1434.46 0 562
30	\$1490.80 20 574	\$1499.23 72 580	\$1442.96 0 565	\$1435.95 0 558
35	\$1491.37 20 570	\$1499.87 71 577	\$1444.82 0 562	\$1437.44 0 555
40	\$1491.94 19 566	\$1500.51 70 574	\$1446.69 0 559	\$1438.94 0 552
45	\$1492.50 19 562	\$1501.15 68 570	\$1448.55 0 556	\$1440.43 0 548
50	\$1493.05 19 558	\$1501.78 67 567	\$1450.42 0 553	\$1441.92 0 545
55	\$1493.60 18 554	\$1502.41 66 564	\$1452.28 0 551	\$1443.42 0 542
60	\$1494.14 18 550	\$1503.07 65 561	\$1454.15 0 548	\$1444.91 0 538

**Table 10.7 Case A - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1488.43 0 601	\$1507.43 0 610	\$1439.78 0 583	\$1426.99 0 578
5	\$1494.66 0 601	\$1513.49 0 610	\$1445.15 0 583	\$1433.10 0 578
10	\$1500.89 0 601	\$1519.55 0 609	\$1450.53 0 582	\$1439.21 0 578
15	\$1507.12 0 601	\$1525.61 0 609	\$1455.90 0 582	\$1445.32 0 578
20	\$1513.35 0 600	\$1531.68 0 609	\$1461.28 0 581	\$1451.43 0 578
25	\$1519.59 0 600	\$1537.74 0 609	\$1466.65 0 581	\$1457.54 0 578
30	\$1525.82 0 600	\$1543.80 0 608	\$1472.03 0 580	\$1463.65 0 578
35	\$1532.05 0 600	\$1549.86 0 608	\$1477.40 0 580	\$1469.76 0 577
40	\$1538.28 0 600	\$1555.92 0 608	\$1482.78 0 579	\$1475.87 0 577
45	\$1544.51 0 600	\$1561.99 0 608	\$1488.15 0 579	\$1481.98 0 577
50	\$1550.75 0 599	\$1568.05 0 607	\$1493.53 0 578	\$1488.09 0 577
55	\$1556.98 0 599	\$1574.11 0 607	\$1498.90 0 578	\$1494.20 0 577
60	\$1563.21 0 599	\$1580.17 0 607	\$1504.28 0 577	\$1500.31 0 577

**Table 10.8 Case A - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1488.43 0 601	\$1507.43 0 610	\$1439.78 0 583	\$1426.99 0 578
5	\$1488.92 0 597	\$1507.92 0 606	\$1441.64 0 580	\$1428.49 0 575
10	\$1489.41 0 593	\$1508.42 0 603	\$1443.51 0 577	\$1429.98 0 571
15	\$1489.90 0 588	\$1508.91 0 599	\$1445.37 0 574	\$1431.47 0 568
20	\$1490.40 0 584	\$1509.40 0 596	\$1447.23 0 571	\$1432.96 0 565
25	\$1490.89 0 580	\$1509.90 0 592	\$1449.10 0 568	\$1434.46 0 562
30	\$1491.38 0 576	\$1510.39 0 589	\$1450.96 0 565	\$1435.95 0 558
35	\$1491.87 0 572	\$1510.88 0 585	\$1452.82 0 562	\$1437.44 0 555
40	\$1492.36 0 568	\$1511.38 0 582	\$1454.69 0 559	\$1438.94 0 552
45	\$1492.85 0 563	\$1511.87 0 578	\$1456.55 0 556	\$1440.43 0 548
50	\$1493.35 0 559	\$1512.36 0 575	\$1458.47 0 554	\$1441.92 0 545
55	\$1493.84 0 555	\$1512.86 0 571	\$1460.94 0 551	\$1443.42 0 542
60	\$1494.33 0 551	\$1513.35 0 568	\$1463.41 0 549	\$1444.91 0 538

**Table 10.9 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1809.26 360 550	\$1835.66 456 550	\$1791.44 150 550	\$1789.59 141 550
5	\$1812.35 359 550	\$1838.61 453 550	\$1793.70 143 550	\$1792.45 138 550
10	\$1815.45 358 550	\$1841.56 450 550	\$1795.96 136 550	\$1795.31 135 550
15	\$1818.54 357 550	\$1844.50 448 550	\$1798.21 129 550	\$1798.17 132 550
20	\$1821.64 355 550	\$1847.45 445 550	\$1800.47 122 550	\$1801.04 130 550
25	\$1824.73 354 550	\$1850.40 442 550	\$1802.73 115 550	\$1803.91 127 550
30	\$1827.82 353 550	\$1853.35 440 550	\$1804.99 108 550	\$1806.77 125 550
35	\$1830.92 352 550	\$1856.30 437 550	\$1807.26 102 550	\$1809.64 122 550
40	\$1834.01 351 550	\$1859.25 434 550	\$1809.53 97 550	\$1812.50 120 550
45	\$1837.11 350 550	\$1862.19 432 550	\$1811.80 91 550	\$1815.37 117 550
50	\$1840.20 348 550	\$1865.14 429 550	\$1814.09 86 550	\$1818.23 115 550
55	\$1843.30 347 550	\$1868.09 426 550	\$1816.39 83 550	\$1821.10 112 550
60	\$1846.39 346 550	\$1871.04 424 550	\$1818.70 80 550	\$1823.96 109 550

**Table 10.10 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1809.26 360 550	\$1835.66 456 550	\$1791.44 150 550	\$1789.59 141 550
5	\$1805.51 359 547	\$1831.26 453 547	\$1789.53 143 548	\$1787.39 138 548
10	\$1801.72 358 544	\$1827.02 450 544	\$1787.72 136 546	\$1785.21 135 546
15	\$1797.91 357 540	\$1822.74 448 540	\$1786.39 129 545	\$1783.20 132 544
20	\$1794.06 355 537	\$1818.43 445 537	\$1785.02 122 544	\$1781.54 130 542
25	\$1790.17 354 534	\$1814.06 442 534	\$1784.05 115 543	\$1780.20 127 541
30	\$1786.24 353 531	\$1810.00 440 531	\$1783.35 108 542	\$1779.02 125 540
35	\$1782.85 352 528	\$1805.99 437 528	\$1782.83 102 541	\$1777.93 122 539
40	\$1779.52 351 525	\$1801.87 434 525	\$1782.51 97 541	\$1776.94 120 538
45	\$1776.10 350 522	\$1797.36 432 522	\$1782.17 91 541	\$1775.03 117 536
50	\$1772.71 348 519	\$1792.04 429 519	\$1781.71 86 540	\$1772.31 115 534
55	\$1769.29 347 516	\$1786.70 426 516	\$1780.97 83 539	\$1769.55 112 531
60	\$1765.58 346 513	\$1781.06 424 513	\$1779.01 80 537	\$1766.75 109 528

**Table 10.11 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1865.15 160 570	\$1862.46 233 570	\$1819.39 19 570	\$1817.64 17 570
5	\$1868.24 159 570	\$1865.42 231 570	\$1821.73 18 570	\$1820.53 17 570
10	\$1871.34 158 570	\$1868.37 228 570	\$1824.06 17 570	\$1823.41 16 570
15	\$1874.43 157 570	\$1871.32 226 570	\$1826.40 16 570	\$1826.30 15 570
20	\$1877.53 155 570	\$1874.28 224 570	\$1828.74 16 570	\$1829.19 15 570
25	\$1880.62 154 570	\$1877.23 221 570	\$1831.07 15 570	\$1832.08 14 570
30	\$1883.71 153 570	\$1880.18 219 570	\$1833.41 14 570	\$1834.97 13 570
35	\$1886.81 152 570	\$1883.14 217 570	\$1835.74 14 570	\$1837.86 13 570
40	\$1889.90 151 570	\$1886.09 215 570	\$1838.08 13 570	\$1840.75 12 570
45	\$1893.00 150 570	\$1889.04 212 570	\$1840.41 12 570	\$1843.64 12 570
50	\$1896.09 148 570	\$1891.99 210 570	\$1842.75 12 570	\$1846.53 11 570
55	\$1899.19 147 570	\$1894.95 208 570	\$1845.09 11 570	\$1849.42 10 570
60	\$1902.28 146 570	\$1897.90 206 570	\$1847.42 10 570	\$1852.32 10 570

**Table 10.12 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1865.15 160 570	\$1862.46 233 570	\$1819.39 19 570	\$1817.64 17 570
5	\$1861.58 159 567	\$1858.36 231 567	\$1819.09 18 570	\$1816.54 17 569
10	\$1858.44 158 564	\$1854.59 228 564	\$1818.73 17 569	\$1815.87 16 568
15	\$1855.96 157 563	\$1850.73 226 562	\$1818.32 16 569	\$1813.71 15 566
20	\$1853.37 155 561	\$1847.43 224 559	\$1817.84 16 568	\$1810.46 15 563
25	\$1850.99 154 559	\$1844.03 221 557	\$1815.98 15 566	\$1807.22 14 560
30	\$1848.81 153 557	\$1840.56 219 555	\$1813.23 14 563	\$1803.97 13 557
35	\$1846.95 152 556	\$1837.22 217 553	\$1810.49 14 560	\$1800.71 13 554
40	\$1843.86 151 553	\$1833.75 215 550	\$1807.75 13 558	\$1797.45 12 550
45	\$1839.94 150 550	\$1830.60 212 548	\$1805.02 12 555	\$1794.18 12 547
50	\$1835.99 148 547	\$1827.21 210 546	\$1802.30 12 552	\$1790.90 11 544
55	\$1831.97 147 543	\$1823.36 208 543	\$1799.57 11 549	\$1787.61 10 541
60	\$1827.89 146 540	\$1819.28 206 540	\$1796.83 10 546	\$1784.30 10 538

**Table 10.13 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1893.03 23 590	\$1899.74 80 590	\$1832.16 0 583	\$1825.42 0 578
5	\$1896.13 22 590	\$1902.71 79 590	\$1834.01 0 583	\$1828.24 0 578
10	\$1899.23 22 590	\$1905.68 77 590	\$1835.86 0 582	\$1831.05 0 578
15	\$1902.34 22 590	\$1908.64 76 590	\$1837.71 0 582	\$1833.87 0 578
20	\$1905.44 21 590	\$1911.61 75 590	\$1839.57 0 581	\$1836.68 0 578
25	\$1908.54 21 590	\$1914.57 74 590	\$1841.42 0 581	\$1839.50 0 578
30	\$1911.65 20 590	\$1917.54 72 590	\$1843.27 0 580	\$1842.31 0 578
35	\$1914.75 20 590	\$1920.51 71 590	\$1845.12 0 580	\$1845.13 0 577
40	\$1917.85 19 590	\$1923.47 70 590	\$1846.97 0 579	\$1847.94 0 577
45	\$1920.96 19 590	\$1926.44 68 590	\$1848.82 0 579	\$1850.76 0 577
50	\$1924.06 19 590	\$1929.40 67 590	\$1850.68 0 578	\$1853.58 0 577
55	\$1927.16 18 590	\$1932.37 66 590	\$1852.53 0 578	\$1856.39 0 577
60	\$1930.27 18 590	\$1935.33 65 590	\$1854.38 0 577	\$1859.21 0 577

**Table 10.14 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1893.03 23 590	\$1899.74 80 590	\$1832.16 0 583	\$1825.42 0 578
5	\$1891.23 22 589	\$1896.63 79 588	\$1829.31 0 580	\$1822.05 0 575
10	\$1889.88 22 588	\$1893.65 77 586	\$1826.45 0 577	\$1818.68 0 571
15	\$1887.36 22 586	\$1890.79 76 584	\$1823.60 0 574	\$1815.32 0 568
20	\$1882.77 21 582	\$1888.44 75 583	\$1820.74 0 571	\$1811.95 0 565
25	\$1878.18 21 578	\$1886.34 74 582	\$1817.89 0 568	\$1808.58 0 562
30	\$1873.58 20 574	\$1883.38 72 580	\$1815.04 0 565	\$1805.21 0 558
35	\$1868.98 20 570	\$1879.04 71 577	\$1812.18 0 562	\$1801.84 0 555
40	\$1864.36 19 566	\$1874.70 70 574	\$1809.33 0 559	\$1798.47 0 552
45	\$1859.74 19 562	\$1870.35 68 570	\$1806.47 0 556	\$1795.11 0 548
50	\$1855.11 19 558	\$1865.99 67 567	\$1803.62 0 553	\$1791.74 0 545
55	\$1850.47 18 554	\$1861.64 66 564	\$1800.77 0 551	\$1788.37 0 542
60	\$1845.82 18 550	\$1857.32 65 561	\$1797.91 0 548	\$1785.00 0 538

**Table 10.15 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1903.74 0 601	\$1928.34 0 610	\$1841.76 0 583	\$1825.42 0 578
5	\$1906.69 0 601	\$1931.06 0 610	\$1843.61 0 583	\$1828.24 0 578
10	\$1909.63 0 601	\$1933.79 0 609	\$1845.46 0 582	\$1831.05 0 578
15	\$1912.58 0 601	\$1936.51 0 609	\$1847.31 0 582	\$1833.87 0 578
20	\$1915.52 0 600	\$1939.23 0 609	\$1849.17 0 581	\$1836.68 0 578
25	\$1918.47 0 600	\$1941.95 0 609	\$1851.02 0 581	\$1839.50 0 578
30	\$1921.41 0 600	\$1944.68 0 608	\$1852.87 0 580	\$1842.31 0 578
35	\$1924.36 0 600	\$1947.40 0 608	\$1854.72 0 580	\$1845.13 0 577
40	\$1927.31 0 600	\$1950.12 0 608	\$1856.57 0 579	\$1847.94 0 577
45	\$1930.25 0 600	\$1952.84 0 608	\$1858.42 0 579	\$1850.76 0 577
50	\$1933.20 0 599	\$1955.57 0 607	\$1860.28 0 578	\$1853.58 0 577
55	\$1936.14 0 599	\$1958.29 0 607	\$1862.13 0 578	\$1856.39 0 577
60	\$1939.09 0 599	\$1961.01 0 607	\$1863.98 0 577	\$1859.21 0 577

**Table 10.16 Case B - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1903.74 0 601	\$1928.34 0 610	\$1841.76 0 583	\$1825.42 0 578
5	\$1899.00 0 597	\$1923.73 0 606	\$1838.91 0 580	\$1822.05 0 575
10	\$1894.25 0 593	\$1919.11 0 603	\$1836.05 0 577	\$1818.68 0 571
15	\$1889.51 0 588	\$1914.50 0 599	\$1833.20 0 574	\$1815.32 0 568
20	\$1884.77 0 584	\$1909.88 0 596	\$1830.34 0 571	\$1811.95 0 565
25	\$1880.02 0 580	\$1905.27 0 592	\$1827.49 0 568	\$1808.58 0 562
30	\$1875.28 0 576	\$1900.65 0 589	\$1824.64 0 565	\$1805.21 0 558
35	\$1870.53 0 572	\$1896.04 0 585	\$1821.78 0 562	\$1801.84 0 555
40	\$1865.79 0 568	\$1891.43 0 582	\$1818.93 0 559	\$1798.47 0 552
45	\$1861.05 0 563	\$1886.81 0 578	\$1816.07 0 556	\$1795.11 0 548
50	\$1856.30 0 559	\$1882.20 0 575	\$1813.30 0 554	\$1791.74 0 545
55	\$1851.56 0 555	\$1877.58 0 571	\$1811.35 0 551	\$1788.37 0 542
60	\$1846.81 0 551	\$1872.97 0 568	\$1809.41 0 549	\$1785.00 0 538

**Table 10.17 Case C - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1319.30 360 550	\$1341.47 456 550	\$1297.41 150 550	\$1295.77 141 550
5	\$1328.81 359 550	\$1350.81 453 550	\$1306.08 143 550	\$1305.00 138 550
10	\$1338.32 358 550	\$1360.15 450 550	\$1314.75 136 550	\$1314.26 135 550
15	\$1347.83 357 550	\$1369.49 448 550	\$1323.42 129 550	\$1323.55 132 550
20	\$1357.33 355 550	\$1378.82 445 550	\$1332.09 122 550	\$1332.84 130 550
25	\$1366.84 354 550	\$1388.16 442 550	\$1340.76 115 550	\$1342.13 127 550
30	\$1376.35 353 550	\$1397.50 440 550	\$1349.44 108 550	\$1351.42 125 550
35	\$1385.85 352 550	\$1406.84 437 550	\$1358.18 102 550	\$1360.71 122 550
40	\$1395.36 351 550	\$1416.18 434 550	\$1366.92 97 550	\$1369.99 120 550
45	\$1404.87 350 550	\$1425.52 432 550	\$1375.67 91 550	\$1379.28 117 550
50	\$1414.38 348 550	\$1434.85 429 550	\$1384.45 86 550	\$1388.57 115 550
55	\$1423.88 347 550	\$1444.19 426 550	\$1393.34 83 550	\$1397.86 112 550
60	\$1433.39 346 550	\$1453.53 424 550	\$1402.24 80 550	\$1407.15 109 550

**Table 10.18 Case C - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1319.30 360 550	\$1341.47 456 550	\$1297.41 150 550	\$1295.77 141 550
5	\$1323.72 359 547	\$1345.36 453 547	\$1302.97 143 548	\$1301.28 138 548
10	\$1328.11 358 544	\$1349.39 450 544	\$1308.63 136 546	\$1306.84 135 546
15	\$1332.47 357 540	\$1353.38 448 540	\$1314.69 129 545	\$1312.56 132 544
20	\$1336.81 355 537	\$1357.34 445 537	\$1320.71 122 544	\$1318.57 130 542
25	\$1341.11 354 534	\$1361.27 442 534	\$1327.06 115 543	\$1324.85 127 541
30	\$1345.38 353 531	\$1365.44 440 531	\$1333.66 108 542	\$1331.26 125 540
35	\$1350.10 352 528	\$1369.66 437 528	\$1340.44 102 541	\$1337.75 122 539
40	\$1354.86 351 525	\$1373.78 434 525	\$1347.40 97 541	\$1344.31 120 538
45	\$1359.55 350 522	\$1377.66 432 522	\$1354.34 91 541	\$1350.12 117 536
50	\$1364.27 348 519	\$1381.00 429 519	\$1361.22 86 540	\$1355.25 115 534
55	\$1368.96 347 516	\$1384.32 426 516	\$1367.94 83 539	\$1360.34 112 531
60	\$1373.41 346 513	\$1387.40 424 513	\$1373.65 80 537	\$1365.40 109 528

**Table 10.19 Case C - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1350.35 160 570	\$1352.04 233 570	\$1313.10 19 570	\$1311.86 17 570
5	\$1359.86 159 570	\$1361.40 231 570	\$1322.12 18 570	\$1321.26 17 570
10	\$1369.37 158 570	\$1370.76 228 570	\$1331.15 17 570	\$1330.66 16 570
15	\$1378.88 157 570	\$1380.12 226 570	\$1340.17 16 570	\$1340.05 15 570
20	\$1388.38 155 570	\$1389.48 224 570	\$1349.20 16 570	\$1349.45 15 570
25	\$1397.89 154 570	\$1398.84 221 570	\$1358.22 15 570	\$1358.84 14 570
30	\$1407.40 153 570	\$1408.20 219 570	\$1367.24 14 570	\$1368.24 13 570
35	\$1416.91 152 570	\$1417.56 217 570	\$1376.27 14 570	\$1377.64 13 570
40	\$1426.41 151 570	\$1426.92 215 570	\$1385.29 13 570	\$1387.04 12 570
45	\$1435.92 150 570	\$1436.28 212 570	\$1394.31 12 570	\$1396.43 12 570
50	\$1445.43 148 570	\$1445.64 210 570	\$1403.34 12 570	\$1405.83 11 570
55	\$1454.93 147 570	\$1455.00 208 570	\$1412.36 11 570	\$1415.22 10 570
60	\$1464.44 146 570	\$1464.36 206 570	\$1421.38 10 570	\$1424.64 10 570

**Table 10.20 Case C - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1350.35 160 570	\$1352.04 233 570	\$1313.10 19 570	\$1311.86 17 570
5	\$1354.93 159 567	\$1356.19 231 567	\$1320.30 18 570	\$1318.43 17 569
10	\$1359.85 158 564	\$1360.64 228 564	\$1327.45 17 569	\$1325.36 16 568
15	\$1365.33 157 563	\$1365.00 226 562	\$1334.56 16 569	\$1331.04 15 566
20	\$1370.71 155 561	\$1369.82 224 559	\$1341.61 16 568	\$1335.81 15 563
25	\$1376.27 154 559	\$1374.56 221 557	\$1347.52 15 566	\$1340.60 14 560
30	\$1381.99 153 557	\$1379.24 219 555	\$1352.68 14 563	\$1345.37 13 557
35	\$1387.99 152 556	\$1384.04 217 553	\$1357.84 14 560	\$1350.14 13 554
40	\$1392.96 151 553	\$1388.72 215 550	\$1363.01 13 558	\$1354.90 12 550
45	\$1397.23 150 550	\$1393.67 212 548	\$1368.19 12 555	\$1359.66 12 547
50	\$1401.48 148 547	\$1398.42 210 546	\$1373.37 12 552	\$1364.41 11 544
55	\$1405.67 147 543	\$1402.80 208 543	\$1378.55 11 549	\$1369.16 10 541
60	\$1409.81 146 540	\$1406.96 206 540	\$1383.72 10 546	\$1373.89 10 538

**Table 10.21 Case C - Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1365.73 23 590	\$1372.93 80 590	\$1322.89 0 583	\$1317.57 0 578
5	\$1375.28 22 590	\$1382.35 79 590	\$1331.55 0 583	\$1326.93 0 578
10	\$1384.82 22 590	\$1391.77 77 590	\$1340.20 0 582	\$1336.29 0 578
15	\$1394.37 22 590	\$1401.18 76 590	\$1348.85 0 582	\$1345.66 0 578
20	\$1403.92 21 590	\$1410.60 75 590	\$1357.50 0 581	\$1355.02 0 578
25	\$1413.47 21 590	\$1420.01 74 590	\$1366.15 0 581	\$1364.38 0 578
30	\$1423.02 20 590	\$1429.43 72 590	\$1374.81 0 580	\$1373.75 0 578
35	\$1432.57 20 590	\$1438.85 71 590	\$1383.46 0 580	\$1383.11 0 577
40	\$1442.11 19 590	\$1448.26 70 590	\$1392.11 0 579	\$1392.47 0 577
45	\$1451.66 19 590	\$1457.68 68 590	\$1400.76 0 579	\$1401.84 0 577
50	\$1461.21 19 590	\$1467.09 67 590	\$1409.42 0 578	\$1411.20 0 577
55	\$1470.76 18 590	\$1476.51 66 590	\$1418.07 0 578	\$1420.56 0 577
60	\$1480.31 18 590	\$1485.93 65 590	\$1426.72 0 577	\$1429.93 0 577

**Table 10.22 Case C - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1365.73 23 590	\$1372.93 80 590	\$1322.89 0 583	\$1317.57 0 578
5	\$1371.80 22 589	\$1377.96 79 588	\$1328.00 0 580	\$1322.27 0 575
10	\$1378.26 22 588	\$1383.10 77 586	\$1333.10 0 577	\$1326.98 0 571
15	\$1383.73 22 586	\$1388.33 76 584	\$1338.21 0 574	\$1331.68 0 568
20	\$1387.48 21 582	\$1394.00 75 583	\$1343.31 0 571	\$1336.39 0 565
25	\$1391.23 21 578	\$1399.87 74 582	\$1348.42 0 568	\$1341.09 0 562
30	\$1394.98 20 574	\$1405.02 72 580	\$1353.52 0 565	\$1345.80 0 558
35	\$1398.72 20 570	\$1409.03 71 577	\$1358.63 0 562	\$1350.50 0 555
40	\$1402.45 19 566	\$1413.03 70 574	\$1363.73 0 559	\$1355.20 0 552
45	\$1406.17 19 562	\$1417.03 68 570	\$1368.84 0 556	\$1359.91 0 548
50	\$1409.89 19 558	\$1421.02 67 567	\$1373.94 0 553	\$1364.61 0 545
55	\$1413.60 18 554	\$1425.02 66 564	\$1379.05 0 551	\$1369.32 0 542
60	\$1417.30 18 550	\$1429.04 65 561	\$1384.15 0 548	\$1374.03 0 538

**Table 10.23 Case C - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1373.61 0 601	\$1391.51 0 610	\$1329.29 0 583	\$1317.57 0 578
5	\$1383.05 0 601	\$1400.79 0 610	\$1337.94 0 583	\$1326.93 0 578
10	\$1392.49 0 601	\$1410.06 0 609	\$1346.60 0 582	\$1336.29 0 578
15	\$1401.92 0 601	\$1419.33 0 609	\$1355.25 0 582	\$1345.66 0 578
20	\$1411.36 0 600	\$1428.60 0 609	\$1363.90 0 581	\$1355.02 0 578
25	\$1420.80 0 600	\$1437.87 0 609	\$1372.55 0 581	\$1364.38 0 578
30	\$1430.23 0 600	\$1447.15 0 608	\$1381.21 0 580	\$1373.75 0 578
35	\$1439.67 0 600	\$1456.42 0 608	\$1389.86 0 580	\$1383.11 0 577
40	\$1449.11 0 600	\$1465.69 0 608	\$1398.51 0 579	\$1392.47 0 577
45	\$1458.54 0 600	\$1474.96 0 608	\$1407.16 0 579	\$1401.84 0 577
50	\$1467.98 0 599	\$1484.23 0 607	\$1415.81 0 578	\$1411.20 0 577
55	\$1477.42 0 599	\$1493.51 0 607	\$1424.47 0 578	\$1420.56 0 577
60	\$1486.85 0 599	\$1502.78 0 607	\$1433.12 0 577	\$1429.93 0 577

**Table 10.24 Case C - Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1373.61 0 601	\$1391.51 0 610	\$1329.29 0 583	\$1317.57 0 578
5	\$1377.26 0 597	\$1395.35 0 606	\$1334.40 0 580	\$1322.27 0 575
10	\$1380.90 0 593	\$1399.18 0 603	\$1339.50 0 577	\$1326.98 0 571
15	\$1384.54 0 588	\$1403.02 0 599	\$1344.61 0 574	\$1331.68 0 568
20	\$1388.18 0 584	\$1406.85 0 596	\$1349.71 0 571	\$1336.39 0 565
25	\$1391.82 0 580	\$1410.69 0 592	\$1354.82 0 568	\$1341.09 0 562
30	\$1395.47 0 576	\$1414.52 0 589	\$1359.92 0 565	\$1345.80 0 558
35	\$1399.11 0 572	\$1418.36 0 585	\$1365.03 0 562	\$1350.50 0 555
40	\$1402.75 0 568	\$1422.19 0 582	\$1370.13 0 559	\$1355.20 0 552
45	\$1406.39 0 563	\$1426.03 0 578	\$1375.24 0 556	\$1359.91 0 548
50	\$1410.04 0 559	\$1429.86 0 575	\$1380.41 0 554	\$1364.61 0 545
55	\$1413.68 0 555	\$1433.69 0 571	\$1386.27 0 551	\$1369.32 0 542
60	\$1417.32 0 551	\$1437.53 0 568	\$1392.13 0 549	\$1374.03 0 538

**Table 10.25 Case D Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1425.49 456 542	\$1451.57 456 550	\$1400.04 456 523	\$1400.33 456 526
5	\$1431.82 453 543	\$1457.71 453 550	\$1405.35 453 523	\$1406.36 453 526
10	\$1438.14 450 543	\$1463.85 450 550	\$1410.66 450 522	\$1412.39 450 526
15	\$1444.47 448 543	\$1469.99 448 550	\$1415.96 448 522	\$1418.44 448 526
20	\$1450.79 445 543	\$1476.13 445 550	\$1421.26 445 521	\$1424.49 445 526
25	\$1457.12 442 543	\$1482.27 442 550	\$1426.56 442 521	\$1430.54 442 526
30	\$1463.44 440 543	\$1488.41 440 550	\$1431.87 440 520	\$1436.59 440 526
35	\$1469.77 437 543	\$1494.55 437 550	\$1437.20 437 520	\$1442.63 437 526
40	\$1476.10 434 543	\$1500.69 434 550	\$1442.53 434 520	\$1448.68 434 525
45	\$1482.42 432 543	\$1506.83 432 550	\$1447.86 432 519	\$1454.73 432 525
50	\$1488.75 429 544	\$1512.97 429 550	\$1453.20 429 519	\$1460.78 429 525
55	\$1495.07 426 544	\$1519.11 426 550	\$1458.59 426 518	\$1466.83 426 525
60	\$1501.40 424 544	\$1525.25 424 550	\$1463.98 424 518	\$1472.88 424 525

**Table 10.26 Case D Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1425.49 456 542	\$1451.57 456 550	\$1400.04 456 523	\$1400.33 456 526
5	\$1426.61 453 539	\$1452.13 453 547	\$1402.15 453 521	\$1402.31 453 523
10	\$1427.72 450 536	\$1452.80 450 544	\$1403.74 450 518	\$1404.28 450 521
15	\$1428.80 448 533	\$1453.45 448 540	\$1405.20 448 516	\$1406.29 448 519
20	\$1429.85 445 530	\$1454.07 445 537	\$1406.57 445 514	\$1408.36 445 516
25	\$1430.89 442 527	\$1454.66 442 534	\$1408.01 442 511	\$1410.46 442 514
30	\$1431.89 440 523	\$1455.45 440 531	\$1409.43 440 509	\$1412.50 440 512
35	\$1432.18 437 521	\$1456.28 437 528	\$1410.73 437 507	\$1414.43 437 509
40	\$1432.45 434 518	\$1457.03 434 525	\$1413.74 434 506	\$1416.48 434 507
45	\$1432.60 432 515	\$1457.43 432 522	\$1417.60 432 506	\$1420.18 432 507
50	\$1432.69 429 512	\$1457.18 429 519	\$1421.45 429 506	\$1423.78 429 507
55	\$1432.64 426 509	\$1456.90 426 516	\$1425.31 426 506	\$1427.37 426 507
60	\$1432.20 424 505	\$1456.41 424 513	\$1429.16 424 506	\$1430.97 424 507

**Table 10.27 Case D Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1464.36 233 565	\$1465.01 233 570	\$1416.08 233 547	\$1415.00 233 548
5	\$1470.67 231 565	\$1471.16 231 570	\$1421.58 231 547	\$1421.12 231 548
10	\$1476.99 228 565	\$1477.32 228 570	\$1427.08 228 547	\$1427.23 228 548
15	\$1483.30 226 565	\$1483.47 226 570	\$1432.58 226 547	\$1433.35 226 548
20	\$1489.62 224 565	\$1489.62 224 570	\$1438.07 224 546	\$1439.47 224 548
25	\$1495.94 221 565	\$1495.78 221 570	\$1443.56 221 546	\$1445.58 221 548
30	\$1502.25 219 565	\$1501.93 219 570	\$1449.05 219 546	\$1451.70 219 548
35	\$1508.57 217 565	\$1508.09 217 570	\$1454.53 217 546	\$1457.82 217 548
40	\$1514.88 215 565	\$1514.24 215 570	\$1460.00 215 545	\$1463.94 215 548
45	\$1521.20 212 565	\$1520.40 212 570	\$1465.47 212 545	\$1470.06 212 548
50	\$1527.51 210 565	\$1526.55 210 570	\$1470.94 210 545	\$1476.18 210 548
55	\$1533.83 208 565	\$1532.71 208 570	\$1476.45 208 545	\$1482.30 208 548
60	\$1540.14 206 566	\$1538.86 206 570	\$1481.95 206 545	\$1488.43 206 548

**Table 10.28 Case D Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1464.36 233 565	\$1465.01 233 570	\$1416.08 233 547	\$1415.00 233 548
5	\$1465.60 231 562	\$1465.78 231 567	\$1418.81 231 546	\$1417.29 231 546
10	\$1467.09 228 559	\$1466.78 228 564	\$1421.43 228 544	\$1419.63 228 544
15	\$1468.98 226 557	\$1467.71 226 562	\$1423.90 226 542	\$1421.71 226 541
20	\$1470.78 224 555	\$1469.02 224 559	\$1426.20 224 540	\$1423.86 224 539
25	\$1472.69 221 553	\$1470.26 221 557	\$1428.36 221 537	\$1426.13 221 537
30	\$1474.70 219 551	\$1471.45 219 555	\$1430.53 219 535	\$1428.34 219 535
35	\$1476.87 217 550	\$1472.74 217 553	\$1432.77 217 533	\$1430.49 217 533
40	\$1478.46 215 547	\$1473.93 215 550	\$1435.07 215 531	\$1432.65 215 531
45	\$1479.70 212 544	\$1475.34 212 548	\$1437.50 212 529	\$1434.76 212 529
50	\$1480.92 210 541	\$1476.59 210 546	\$1440.04 210 527	\$1436.83 210 526
55	\$1482.06 208 538	\$1477.54 208 543	\$1442.58 208 525	\$1438.85 208 524
60	\$1483.14 206 535	\$1478.32 206 540	\$1445.08 206 523	\$1440.83 206 521

**Table 10.29 Case D Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1480.22 80 584	\$1488.93 80 590	\$1426.96 80 572	\$1423.19 80 568
5	\$1486.56 79 585	\$1495.12 79 590	\$1432.37 79 571	\$1429.32 79 568
10	\$1492.91 77 585	\$1501.31 77 590	\$1437.78 77 571	\$1435.46 77 568
15	\$1499.25 76 585	\$1507.49 76 590	\$1443.20 76 570	\$1441.59 76 568
20	\$1505.60 75 585	\$1513.69 75 590	\$1448.61 75 570	\$1447.73 75 568
25	\$1511.94 74 585	\$1519.88 74 590	\$1454.03 74 570	\$1453.87 74 568
30	\$1518.29 72 585	\$1526.06 72 590	\$1459.45 72 569	\$1460.01 72 568
35	\$1524.64 71 585	\$1532.25 71 590	\$1464.87 71 569	\$1466.15 71 568
40	\$1530.98 70 585	\$1538.44 70 590	\$1470.29 70 569	\$1472.29 70 568
45	\$1537.33 68 585	\$1544.63 68 590	\$1475.70 68 568	\$1478.43 68 568
50	\$1543.68 67 585	\$1550.82 67 590	\$1481.13 67 568	\$1484.57 67 568
55	\$1550.02 66 585	\$1557.01 66 590	\$1486.55 66 568	\$1490.71 66 568
60	\$1556.37 65 585	\$1563.20 65 590	\$1491.97 65 567	\$1496.86 65 568

**Table 10.30 Case D Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1480.22 80 584	\$1488.93 80 590	\$1426.96 80 572	\$1423.19 80 568
5	\$1482.49 79 583	\$1490.39 79 588	\$1428.94 79 569	\$1424.85 79 565
10	\$1485.01 77 582	\$1491.94 77 586	\$1430.93 77 566	\$1426.52 77 562
15	\$1486.89 76 580	\$1493.56 76 584	\$1432.91 76 563	\$1428.19 76 559
20	\$1487.69 75 576	\$1495.53 75 583	\$1434.89 75 561	\$1429.92 75 556
25	\$1488.51 74 573	\$1497.67 74 582	\$1436.87 74 558	\$1431.69 74 553
30	\$1489.31 72 569	\$1499.23 72 580	\$1438.86 72 555	\$1433.44 72 551
35	\$1490.08 71 565	\$1499.87 71 577	\$1440.88 71 553	\$1435.17 71 548
40	\$1490.83 70 562	\$1500.51 70 574	\$1442.91 70 550	\$1436.89 70 545
45	\$1491.56 68 558	\$1501.15 68 570	\$1444.99 68 547	\$1438.60 68 542
50	\$1492.28 67 554	\$1501.78 67 567	\$1447.10 67 545	\$1440.29 67 539
55	\$1492.97 66 550	\$1502.41 66 564	\$1449.20 66 542	\$1441.97 66 536
60	\$1493.65 65 546	\$1503.07 65 561	\$1451.30 65 540	\$1443.63 65 533

**Table 10.31 Case D Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1488.43 0 601	\$1507.43 0 610	\$1439.78 0 583	\$1426.99 0 578
5	\$1494.66 0 601	\$1513.49 0 610	\$1445.15 0 583	\$1433.10 0 578
10	\$1500.89 0 601	\$1519.55 0 609	\$1450.53 0 582	\$1439.21 0 578
15	\$1507.12 0 601	\$1525.61 0 609	\$1455.90 0 582	\$1445.32 0 578
20	\$1513.35 0 600	\$1531.68 0 609	\$1461.28 0 581	\$1451.43 0 578
25	\$1519.59 0 600	\$1537.74 0 609	\$1466.65 0 581	\$1457.54 0 578
30	\$1525.82 0 600	\$1543.80 0 608	\$1472.03 0 580	\$1463.65 0 578
35	\$1532.05 0 600	\$1549.86 0 608	\$1477.40 0 580	\$1469.76 0 577
40	\$1538.28 0 600	\$1555.92 0 608	\$1482.78 0 579	\$1475.87 0 577
45	\$1544.51 0 600	\$1561.99 0 608	\$1488.15 0 579	\$1481.98 0 577
50	\$1550.75 0 599	\$1568.05 0 607	\$1493.53 0 578	\$1488.09 0 577
55	\$1556.98 0 599	\$1574.11 0 607	\$1498.90 0 578	\$1494.20 0 577
60	\$1563.21 0 599	\$1580.17 0 607	\$1504.28 0 577	\$1500.31 0 577

**Table 10.32 Case D Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1488.43 0 601	\$1507.43 0 610	\$1439.78 0 583	\$1426.99 0 578
5	\$1488.92 0 597	\$1507.92 0 606	\$1441.64 0 580	\$1428.49 0 575
10	\$1489.41 0 593	\$1508.42 0 603	\$1443.51 0 577	\$1429.98 0 571
15	\$1489.90 0 588	\$1508.91 0 599	\$1445.37 0 574	\$1431.47 0 568
20	\$1490.40 0 584	\$1509.40 0 596	\$1447.23 0 571	\$1432.96 0 565
25	\$1490.89 0 580	\$1509.90 0 592	\$1449.10 0 568	\$1434.46 0 562
30	\$1491.38 0 576	\$1510.39 0 589	\$1450.96 0 565	\$1435.95 0 558
35	\$1491.87 0 572	\$1510.88 0 585	\$1452.82 0 562	\$1437.44 0 555
40	\$1492.36 0 568	\$1511.38 0 582	\$1454.69 0 559	\$1438.94 0 552
45	\$1492.85 0 563	\$1511.87 0 578	\$1456.55 0 556	\$1440.43 0 548
50	\$1493.35 0 559	\$1512.36 0 575	\$1458.47 0 554	\$1441.92 0 545
55	\$1493.84 0 555	\$1512.86 0 571	\$1460.94 0 551	\$1443.42 0 542
60	\$1494.33 0 551	\$1513.35 0 568	\$1463.41 0 549	\$1444.91 0 538

**Table 10.33 Case E Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1802.84 456 542	\$1835.66 456 550	\$1768.47 456 523	\$1769.34 456 526
5	\$1806.04 453 543	\$1838.61 453 550	\$1770.33 453 523	\$1772.13 453 526
10	\$1809.23 450 543	\$1841.56 450 550	\$1772.18 450 522	\$1774.94 450 526
15	\$1812.43 448 543	\$1844.50 448 550	\$1774.04 448 522	\$1777.77 448 526
20	\$1815.62 445 543	\$1847.45 445 550	\$1775.89 445 521	\$1780.61 445 526
25	\$1818.82 442 543	\$1850.40 442 550	\$1777.74 442 521	\$1783.44 442 526
30	\$1822.01 440 543	\$1853.35 440 550	\$1779.59 440 520	\$1786.27 440 526
35	\$1825.21 437 543	\$1856.30 437 550	\$1781.49 437 520	\$1789.10 437 526
40	\$1828.40 434 543	\$1859.25 434 550	\$1783.38 434 520	\$1791.93 434 525
45	\$1831.60 432 543	\$1862.19 432 550	\$1785.27 432 519	\$1794.77 432 525
50	\$1834.79 429 544	\$1865.14 429 550	\$1787.18 429 519	\$1797.60 429 525
55	\$1837.98 426 544	\$1868.09 426 550	\$1789.16 426 518	\$1800.43 426 525
60	\$1841.18 424 544	\$1871.04 424 550	\$1791.14 424 518	\$1803.26 424 525

**Table 10.34 Case E Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1802.84 456 542	\$1835.66 456 550	\$1768.47 456 523	\$1769.34 456 526
5	\$1799.16 453 539	\$1831.26 453 547	\$1766.08 453 521	\$1766.80 453 523
10	\$1795.44 450 536	\$1827.02 450 544	\$1763.08 450 518	\$1764.26 450 521
15	\$1791.68 448 533	\$1822.74 448 540	\$1759.97 448 516	\$1761.78 448 519
20	\$1787.89 445 530	\$1818.43 445 537	\$1756.73 445 514	\$1759.39 445 516
25	\$1784.07 442 527	\$1814.06 442 534	\$1753.59 442 511	\$1757.04 442 514
30	\$1780.21 440 523	\$1810.00 440 531	\$1750.41 440 509	\$1754.59 440 512
35	\$1775.56 437 521	\$1805.99 437 528	\$1747.08 437 507	\$1751.99 437 509
40	\$1770.90 434 518	\$1801.87 434 525	\$1746.11 434 506	\$1749.59 434 507
45	\$1766.06 432 515	\$1797.36 432 522	\$1746.31 432 506	\$1749.61 432 507
50	\$1761.16 429 512	\$1792.04 429 519	\$1746.52 429 506	\$1749.51 429 507
55	\$1756.05 426 509	\$1786.70 426 516	\$1746.73 426 506	\$1749.41 426 507
60	\$1750.40 424 505	\$1781.06 424 513	\$1746.93 424 506	\$1749.30 424 507

**Table 10.35 Case E Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1860.59 233 565	\$1862.46 233 570	\$1799.16 233 547	\$1797.99 233 548
5	\$1863.75 231 565	\$1865.42 231 570	\$1801.30 231 547	\$1800.90 231 548
10	\$1866.91 228 565	\$1868.37 228 570	\$1803.43 228 547	\$1803.82 228 548
15	\$1870.08 226 565	\$1871.32 226 570	\$1805.56 226 547	\$1806.74 226 548
20	\$1873.24 224 565	\$1874.28 224 570	\$1807.68 224 546	\$1809.65 224 548
25	\$1876.40 221 565	\$1877.23 221 570	\$1809.80 221 546	\$1812.57 221 548
30	\$1879.57 219 565	\$1880.18 219 570	\$1811.90 219 546	\$1815.49 219 548
35	\$1882.73 217 565	\$1883.14 217 570	\$1814.01 217 546	\$1818.41 217 548
40	\$1885.89 215 565	\$1886.09 215 570	\$1816.10 215 545	\$1821.33 215 548
45	\$1889.06 212 565	\$1889.04 212 570	\$1818.19 212 545	\$1824.25 212 548
50	\$1892.22 210 565	\$1891.99 210 570	\$1820.27 210 545	\$1827.17 210 548
55	\$1895.38 208 565	\$1894.95 208 570	\$1822.41 208 545	\$1830.09 208 548
60	\$1898.55 206 566	\$1897.90 206 570	\$1824.54 206 545	\$1833.04 206 548

**Table 10.36 Case E Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1860.59 233 565	\$1862.46 233 570	\$1799.16 233 547	\$1797.99 233 548
5	\$1857.06 231 562	\$1858.36 231 567	\$1797.71 231 546	\$1795.90 231 546
10	\$1853.91 228 559	\$1854.59 228 564	\$1796.08 228 544	\$1793.90 228 544
15	\$1851.35 226 557	\$1850.73 226 562	\$1794.23 226 542	\$1791.51 226 541
20	\$1848.67 224 555	\$1847.43 224 559	\$1792.11 224 540	\$1789.21 224 539
25	\$1846.14 221 553	\$1844.03 221 557	\$1789.80 221 537	\$1787.10 221 537
30	\$1843.77 219 551	\$1840.56 219 555	\$1787.50 219 535	\$1784.90 219 535
35	\$1841.63 217 550	\$1837.22 217 553	\$1785.29 217 533	\$1782.61 217 533
40	\$1838.63 215 547	\$1833.75 215 550	\$1783.19 215 531	\$1780.33 215 531
45	\$1835.10 212 544	\$1830.60 212 548	\$1781.28 212 529	\$1777.98 212 529
50	\$1831.53 210 541	\$1827.21 210 546	\$1779.52 210 527	\$1775.57 210 526
55	\$1827.86 208 538	\$1823.36 208 543	\$1777.78 208 525	\$1773.08 208 524
60	\$1824.09 206 535	\$1819.28 206 540	\$1775.98 206 523	\$1770.54 206 521

**Table 10.37 Case E Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1888.18 80 584	\$1899.74 80 590	\$1821.68 80 572	\$1816.46 80 568
5	\$1891.35 79 585	\$1902.71 79 590	\$1823.65 79 571	\$1819.37 79 568
10	\$1894.51 77 585	\$1905.68 77 590	\$1825.61 77 571	\$1822.28 77 568
15	\$1897.68 76 585	\$1908.64 76 590	\$1827.57 76 570	\$1825.18 76 568
20	\$1900.85 75 585	\$1911.61 75 590	\$1829.53 75 570	\$1828.09 75 568
25	\$1904.02 74 585	\$1914.57 74 590	\$1831.50 74 570	\$1831.00 74 568
30	\$1907.19 72 585	\$1917.54 72 590	\$1833.47 72 569	\$1833.91 72 568
35	\$1910.36 71 585	\$1920.51 71 590	\$1835.43 71 569	\$1836.82 71 568
40	\$1913.53 70 585	\$1923.47 70 590	\$1837.40 70 569	\$1839.73 70 568
45	\$1916.70 68 585	\$1926.44 68 590	\$1839.37 68 568	\$1842.65 68 568
50	\$1919.86 67 585	\$1929.40 67 590	\$1841.35 67 568	\$1845.56 67 568
55	\$1923.04 66 585	\$1932.37 66 590	\$1843.32 66 568	\$1848.48 66 568
60	\$1926.20 65 585	\$1935.33 65 590	\$1845.30 65 567	\$1851.40 65 568

**Table 10.38 Case E Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1888.18 80 584	\$1899.74 80 590	\$1821.68 80 572	\$1816.46 80 568
5	\$1886.16 79 583	\$1896.63 79 588	\$1819.06 79 569	\$1813.41 79 565
10	\$1884.51 77 582	\$1893.65 77 586	\$1816.44 77 566	\$1810.35 77 562
15	\$1881.90 76 580	\$1890.79 76 584	\$1813.81 76 563	\$1807.29 76 559
20	\$1877.68 75 576	\$1888.44 75 583	\$1811.19 75 561	\$1804.34 75 556
25	\$1873.46 74 573	\$1886.34 74 582	\$1808.56 74 558	\$1801.44 74 553
30	\$1869.23 72 569	\$1883.38 72 580	\$1805.95 72 555	\$1798.51 72 551
35	\$1864.97 71 565	\$1879.04 71 577	\$1803.38 71 553	\$1795.55 71 548
40	\$1860.66 70 562	\$1874.70 70 574	\$1800.83 70 550	\$1792.58 70 545
45	\$1856.33 68 558	\$1870.35 68 570	\$1798.35 68 547	\$1789.59 68 542
50	\$1851.98 67 554	\$1865.99 67 567	\$1795.91 67 545	\$1786.57 67 539
55	\$1847.59 66 550	\$1861.64 66 564	\$1793.48 66 542	\$1783.52 66 536
60	\$1843.16 65 546	\$1857.32 65 561	\$1791.02 65 540	\$1780.45 65 533

**Table 10.39 Case E Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1903.74	\$1928.34	\$1841.76	\$1825.42
	0	0	0	0
	601	610	583	578
5	\$1906.69	\$1931.06	\$1843.61	\$1828.24
	0	0	0	0
	601	610	583	578
10	\$1909.63	\$1933.79	\$1845.46	\$1831.05
	0	0	0	0
	601	609	582	578
15	\$1912.58	\$1936.51	\$1847.31	\$1833.87
	0	0	0	0
	601	609	582	578
20	\$1915.52	\$1939.23	\$1849.17	\$1836.68
	0	0	0	0
	600	609	581	578
25	\$1918.47	\$1941.95	\$1851.02	\$1839.50
	0	0	0	0
	600	609	581	578
30	\$1921.41	\$1944.68	\$1852.87	\$1842.31
	0	0	0	0
	600	608	580	578
35	\$1924.36	\$1947.40	\$1854.72	\$1845.13
	0	0	0	0
	600	608	580	577
40	\$1927.31	\$1950.12	\$1856.57	\$1847.94
	0	0	0	0
	600	608	579	577
45	\$1930.25	\$1952.84	\$1858.42	\$1850.76
	0	0	0	0
	600	608	579	577
50	\$1933.20	\$1955.57	\$1860.28	\$1853.58
	0	0	0	0
	599	607	578	577
55	\$1936.14	\$1958.29	\$1862.13	\$1856.39
	0	0	0	0
	599	607	578	577
60	\$1939.09	\$1961.01	\$1863.98	\$1859.21
	0	0	0	0
	599	607	577	577

**Table 10.40 Case E Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1903.74 0 601	\$1928.34 0 610	\$1841.76 0 583	\$1825.42 0 578
5	\$1899.00 0 597	\$1923.73 0 606	\$1838.91 0 580	\$1822.05 0 575
10	\$1894.25 0 593	\$1919.11 0 603	\$1836.05 0 577	\$1818.68 0 571
15	\$1889.51 0 588	\$1914.50 0 599	\$1833.20 0 574	\$1815.32 0 568
20	\$1884.77 0 584	\$1909.88 0 596	\$1830.34 0 571	\$1811.95 0 565
25	\$1880.02 0 580	\$1905.27 0 592	\$1827.49 0 568	\$1808.58 0 562
30	\$1875.28 0 576	\$1900.65 0 589	\$1824.64 0 565	\$1805.21 0 558
35	\$1870.53 0 572	\$1896.04 0 585	\$1821.78 0 562	\$1801.84 0 555
40	\$1865.79 0 568	\$1891.43 0 582	\$1818.93 0 559	\$1798.47 0 552
45	\$1861.05 0 563	\$1886.81 0 578	\$1816.07 0 556	\$1795.11 0 548
50	\$1856.30 0 559	\$1882.20 0 575	\$1813.30 0 554	\$1791.74 0 545
55	\$1851.56 0 555	\$1877.58 0 571	\$1811.35 0 551	\$1788.37 0 542
60	\$1846.81 0 551	\$1872.97 0 568	\$1809.41 0 549	\$1785.00 0 538

**Table 10.41 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1318.33 456 542	\$1341.47 456 550	\$1292.21 456 523	\$1293.23 456 526
5	\$1327.85 453 543	\$1350.81 453 550	\$1300.75 453 523	\$1302.45 453 526
10	\$1337.37 450 543	\$1360.15 450 550	\$1309.28 450 522	\$1311.69 450 526
15	\$1346.89 448 543	\$1369.49 448 550	\$1317.81 448 522	\$1320.94 448 526
20	\$1356.42 445 543	\$1378.82 445 550	\$1326.34 445 521	\$1330.20 445 526
25	\$1365.94 442 543	\$1388.16 442 550	\$1334.87 442 521	\$1339.45 442 526
30	\$1375.46 440 543	\$1397.50 440 550	\$1343.41 440 520	\$1348.71 440 526
35	\$1384.98 437 543	\$1406.84 437 550	\$1351.97 437 520	\$1357.96 437 526
40	\$1394.50 434 543	\$1416.18 434 550	\$1360.53 434 520	\$1367.22 434 525
45	\$1404.03 432 543	\$1425.52 432 550	\$1369.10 432 519	\$1376.47 432 525
50	\$1413.55 429 544	\$1434.85 429 550	\$1377.68 429 519	\$1385.72 429 525
55	\$1423.07 426 544	\$1444.19 426 550	\$1386.31 426 518	\$1394.98 426 525
60	\$1432.59 424 544	\$1453.53 424 550	\$1394.95 424 518	\$1404.23 424 525

**Table 10.42 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1318.33	\$1341.47	\$1292.21	\$1293.23
	456	456	456	456
	542	550	523	526
5	\$1322.73	\$1345.36	\$1297.58	\$1298.50
	453	453	453	453
	539	547	521	523
10	\$1327.10	\$1349.39	\$1302.55	\$1303.77
	450	450	450	450
	536	544	518	521
15	\$1331.44	\$1353.38	\$1307.47	\$1309.09
	448	448	448	448
	533	540	516	519
20	\$1335.76	\$1357.34	\$1312.30	\$1314.49
	445	445	445	445
	530	537	514	516
25	\$1340.05	\$1361.27	\$1317.20	\$1319.92
	442	442	442	442
	527	534	511	514
30	\$1344.31	\$1365.44	\$1322.07	\$1325.28
	440	440	440	440
	523	531	509	512
35	\$1348.10	\$1369.66	\$1326.82	\$1330.50
	437	437	437	437
	521	528	507	509
40	\$1351.90	\$1373.78	\$1333.42	\$1335.91
	434	434	434	434
	518	525	506	507
45	\$1355.56	\$1377.66	\$1340.93	\$1343.29
	432	432	432	432
	515	522	506	507
50	\$1359.16	\$1381.00	\$1348.44	\$1350.60
	429	429	429	429
	512	519	506	507
55	\$1362.60	\$1384.32	\$1355.95	\$1357.90
	426	426	426	426
	509	516	506	507
60	\$1365.62	\$1387.40	\$1363.46	\$1365.20
	424	424	424	424
	505	513	506	507

**Table 10.43 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1349.88 233 565	\$1352.04 233 570	\$1306.02 233 547	\$1305.33 233 548
5	\$1359.39 231 565	\$1361.40 231 570	\$1314.81 231 547	\$1314.67 231 548
10	\$1368.91 228 565	\$1370.76 228 570	\$1323.59 228 547	\$1324.02 228 548
15	\$1378.42 226 565	\$1380.12 226 570	\$1332.37 226 547	\$1333.36 226 548
20	\$1387.93 224 565	\$1389.48 224 570	\$1341.14 224 546	\$1342.71 224 548
25	\$1397.45 221 565	\$1398.84 221 570	\$1349.91 221 546	\$1352.05 221 548
30	\$1406.96 219 565	\$1408.20 219 570	\$1358.67 219 546	\$1361.40 219 548
35	\$1416.48 217 565	\$1417.56 217 570	\$1367.43 217 546	\$1370.74 217 548
40	\$1425.99 215 565	\$1426.92 215 570	\$1376.18 215 545	\$1380.09 215 548
45	\$1435.51 212 565	\$1436.28 212 570	\$1384.92 212 545	\$1389.44 212 548
50	\$1445.02 210 565	\$1445.64 210 570	\$1393.67 210 545	\$1398.79 210 548
55	\$1454.53 208 565	\$1455.00 208 570	\$1402.45 208 545	\$1408.13 208 548
60	\$1464.05 206 566	\$1464.36 206 570	\$1411.23 206 545	\$1417.50 206 548

**Table 10.44 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1349.88 233 565	\$1352.04 233 570	\$1306.02 233 547	\$1305.33 233 548
5	\$1354.43 231 562	\$1356.19 231 567	\$1312.19 231 546	\$1311.00 231 546
10	\$1359.30 228 559	\$1360.64 228 564	\$1318.21 228 544	\$1316.74 228 544
15	\$1364.66 226 557	\$1365.00 226 562	\$1324.05 226 542	\$1322.15 226 541
20	\$1369.91 224 555	\$1369.82 224 559	\$1329.67 224 540	\$1327.65 224 539
25	\$1375.30 221 553	\$1374.56 221 557	\$1335.12 221 537	\$1333.30 221 537
30	\$1380.81 219 551	\$1379.24 219 555	\$1340.58 219 535	\$1338.87 219 535
35	\$1386.52 217 550	\$1384.04 217 553	\$1346.12 217 533	\$1344.37 217 533
40	\$1391.51 215 547	\$1388.72 215 550	\$1351.75 215 531	\$1349.88 215 531
45	\$1396.06 212 544	\$1393.67 212 548	\$1357.54 212 529	\$1355.33 212 529
50	\$1400.58 210 541	\$1398.42 210 546	\$1363.45 210 527	\$1360.72 210 526
55	\$1405.01 208 538	\$1402.80 208 543	\$1369.38 208 525	\$1366.06 208 524
60	\$1409.36 206 535	\$1406.96 206 540	\$1375.26 206 523	\$1371.35 206 521

**Table 10.45 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1364.30 80 584	\$1372.93 80 590	\$1317.81 80 572	\$1313.75 80 568
5	\$1373.86 79 585	\$1382.35 79 590	\$1326.50 79 571	\$1323.13 79 568
10	\$1383.42 77 585	\$1391.77 77 590	\$1335.18 77 571	\$1332.51 77 568
15	\$1392.99 76 585	\$1401.18 76 590	\$1343.87 76 570	\$1341.89 76 568
20	\$1402.55 75 585	\$1410.60 75 590	\$1352.56 75 570	\$1351.28 75 568
25	\$1412.11 74 585	\$1420.01 74 590	\$1361.25 74 570	\$1360.66 74 568
30	\$1421.68 72 585	\$1429.43 72 590	\$1369.94 72 569	\$1370.04 72 568
35	\$1431.24 71 585	\$1438.85 71 590	\$1378.63 71 569	\$1379.43 71 568
40	\$1440.81 70 585	\$1448.26 70 590	\$1387.32 70 569	\$1388.81 70 568
45	\$1450.37 68 585	\$1457.68 68 590	\$1396.01 68 568	\$1398.20 68 568
50	\$1459.94 67 585	\$1467.09 67 590	\$1404.71 67 568	\$1407.59 67 568
55	\$1469.50 66 585	\$1476.51 66 590	\$1413.40 66 568	\$1416.98 66 568
60	\$1479.07 65 585	\$1485.93 65 590	\$1422.10 65 567	\$1426.37 65 568

**Table 10.46 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1364.30 80 584	\$1372.93 80 590	\$1317.81 80 572	\$1313.75 80 568
5	\$1370.15 79 583	\$1377.96 79 588	\$1323.06 79 569	\$1318.66 79 565
10	\$1376.31 77 582	\$1383.10 77 586	\$1328.29 77 566	\$1323.56 77 562
15	\$1381.68 76 580	\$1388.33 76 584	\$1333.53 76 563	\$1328.47 76 559
20	\$1385.69 75 576	\$1394.00 75 583	\$1338.77 75 561	\$1333.46 75 556
25	\$1389.72 74 573	\$1399.87 74 582	\$1344.00 74 558	\$1338.50 74 553
30	\$1393.73 72 569	\$1405.02 72 580	\$1349.25 72 555	\$1343.51 72 551
35	\$1397.71 71 565	\$1409.03 71 577	\$1354.53 71 553	\$1348.49 71 548
40	\$1401.66 70 562	\$1413.03 70 574	\$1359.84 70 550	\$1353.47 70 545
45	\$1405.59 68 558	\$1417.03 68 570	\$1365.19 68 547	\$1358.43 68 542
50	\$1409.50 67 554	\$1421.02 67 567	\$1370.59 67 545	\$1363.37 67 539
55	\$1413.38 66 550	\$1425.02 66 564	\$1375.98 66 542	\$1368.29 66 536
60	\$1417.23 65 546	\$1429.04 65 561	\$1381.36 65 540	\$1373.18 65 533

**Table 10.47 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1373.61 0 601	\$1391.51 0 610	\$1329.29 0 583	\$1317.57 0 578
5	\$1383.05 0 601	\$1400.79 0 610	\$1337.94 0 583	\$1326.93 0 578
10	\$1392.49 0 601	\$1410.06 0 609	\$1346.60 0 582	\$1336.29 0 578
15	\$1401.92 0 601	\$1419.33 0 609	\$1355.25 0 582	\$1345.66 0 578
20	\$1411.36 0 600	\$1428.60 0 609	\$1363.90 0 581	\$1355.02 0 578
25	\$1420.80 0 600	\$1437.87 0 609	\$1372.55 0 581	\$1364.38 0 578
30	\$1430.23 0 600	\$1447.15 0 608	\$1381.21 0 580	\$1373.75 0 578
35	\$1439.67 0 600	\$1456.42 0 608	\$1389.86 0 580	\$1383.11 0 577
40	\$1449.11 0 600	\$1465.69 0 608	\$1398.51 0 579	\$1392.47 0 577
45	\$1458.54 0 600	\$1474.96 0 608	\$1407.16 0 579	\$1401.84 0 577
50	\$1467.98 0 599	\$1484.23 0 607	\$1415.81 0 578	\$1411.20 0 577
55	\$1477.42 0 599	\$1493.51 0 607	\$1424.47 0 578	\$1420.56 0 577
60	\$1486.85 0 599	\$1502.78 0 607	\$1433.12 0 577	\$1429.93 0 577

**Table 10.48 Case F Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1373.61 0 601	\$1391.51 0 610	\$1329.29 0 583	\$1317.57 0 578
5	\$1377.26 0 597	\$1395.35 0 606	\$1334.40 0 580	\$1322.27 0 575
10	\$1380.90 0 593	\$1399.18 0 603	\$1339.50 0 577	\$1326.98 0 571
15	\$1384.54 0 588	\$1403.02 0 599	\$1344.61 0 574	\$1331.68 0 568
20	\$1388.18 0 584	\$1406.85 0 596	\$1349.71 0 571	\$1336.39 0 565
25	\$1391.82 0 580	\$1410.69 0 592	\$1354.82 0 568	\$1341.09 0 562
30	\$1395.47 0 576	\$1414.52 0 589	\$1359.92 0 565	\$1345.80 0 558
35	\$1399.11 0 572	\$1418.36 0 585	\$1365.03 0 562	\$1350.50 0 555
40	\$1402.75 0 568	\$1422.19 0 582	\$1370.13 0 559	\$1355.20 0 552
45	\$1406.39 0 563	\$1426.03 0 578	\$1375.24 0 556	\$1359.91 0 548
50	\$1410.04 0 559	\$1429.86 0 575	\$1380.41 0 554	\$1364.61 0 545
55	\$1413.68 0 555	\$1433.69 0 571	\$1386.27 0 551	\$1369.32 0 542
60	\$1417.32 0 551	\$1437.53 0 568	\$1392.13 0 549	\$1374.03 0 538

**Table 10.49 Case G Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1427.18 360 550	\$1451.57 456 550	\$1407.09 150 550	\$1405.34 141 550
5	\$1433.50 359 550	\$1457.78 454 550	\$1412.63 144 550	\$1411.43 138 550
10	\$1439.82 358 550	\$1463.99 452 550	\$1418.17 137 550	\$1417.53 136 550
15	\$1446.14 357 550	\$1470.21 450 550	\$1423.72 131 550	\$1423.66 133 550
20	\$1452.47 356 550	\$1476.42 448 550	\$1429.26 124 550	\$1429.78 131 550
25	\$1458.79 355 550	\$1482.64 446 550	\$1434.80 118 550	\$1435.91 129 550
30	\$1465.11 354 550	\$1488.85 444 550	\$1440.34 111 550	\$1442.03 127 550
35	\$1471.43 353 550	\$1495.06 442 550	\$1445.92 106 550	\$1448.15 125 550
40	\$1477.75 352 550	\$1501.28 440 550	\$1451.50 101 550	\$1454.28 122 550
45	\$1484.08 351 550	\$1507.49 438 550	\$1457.08 95 550	\$1460.40 120 550
50	\$1490.40 350 550	\$1513.70 436 550	\$1462.66 90 550	\$1466.53 118 550
55	\$1496.72 349 550	\$1519.92 434 550	\$1468.28 86 550	\$1472.65 116 550
60	\$1503.04 348 550	\$1526.13 432 550	\$1473.95 83 550	\$1478.77 114 550

**Table 10.50 Case G Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 550 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1427.18 360 550	\$1451.57 456 550	\$1407.09 150 550	\$1405.34 141 550
5	\$1429.74 359 548	\$1453.52 454 547	\$1409.50 144 548	\$1408.31 138 548
10	\$1432.30 358 545	\$1455.52 452 545	\$1411.96 137 546	\$1411.33 136 547
15	\$1434.85 357 543	\$1457.55 450 543	\$1414.75 131 545	\$1414.36 133 545
20	\$1437.40 356 541	\$1459.57 448 540	\$1417.51 124 543	\$1417.57 131 544
25	\$1439.93 355 538	\$1461.57 446 538	\$1420.60 118 542	\$1420.89 129 542
30	\$1442.45 354 536	\$1463.55 444 535	\$1423.81 111 542	\$1424.19 127 541
35	\$1444.96 353 533	\$1465.59 442 533	\$1427.17 106 541	\$1427.61 125 540
40	\$1447.57 352 531	\$1467.72 440 530	\$1430.56 101 541	\$1431.30 122 539
45	\$1450.41 351 529	\$1469.88 438 528	\$1434.03 95 540	\$1434.97 120 539
50	\$1453.21 350 527	\$1472.00 436 526	\$1437.47 90 540	\$1437.80 118 537
55	\$1455.98 349 525	\$1474.15 434 524	\$1440.83 86 539	\$1440.34 116 534
60	\$1458.76 348 523	\$1475.57 432 521	\$1443.12 83 537	\$1442.98 114 532

**Table 10.51 Case G Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1465.43 160 570	\$1465.01 233 570	\$1423.77 19 570	\$1422.27 17 570
5	\$1471.75 159 570	\$1471.23 231 570	\$1429.52 18 570	\$1428.45 17 570
10	\$1478.07 158 570	\$1477.46 229 570	\$1435.26 17 570	\$1434.63 16 570
15	\$1484.39 157 570	\$1483.68 228 570	\$1441.01 17 570	\$1440.81 15 570
20	\$1490.71 156 570	\$1489.91 226 570	\$1446.76 16 570	\$1446.99 15 570
25	\$1497.04 155 570	\$1496.13 224 570	\$1452.50 15 570	\$1453.18 14 570
30	\$1503.36 154 570	\$1502.35 223 570	\$1458.25 15 570	\$1459.36 14 570
35	\$1509.68 153 570	\$1508.58 221 570	\$1464.00 14 570	\$1465.54 13 570
40	\$1516.00 152 570	\$1514.80 219 570	\$1469.74 13 570	\$1471.72 13 570
45	\$1522.32 151 570	\$1521.03 218 570	\$1475.49 13 570	\$1477.90 12 570
50	\$1528.65 150 570	\$1527.25 216 570	\$1481.24 12 570	\$1484.08 11 570
55	\$1534.97 149 570	\$1533.48 214 570	\$1486.98 11 570	\$1490.27 11 570
60	\$1541.29 148 570	\$1539.70 213 570	\$1492.73 11 570	\$1496.45 10 570

**Table 10.52 Case G Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 570 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1465.43 160 570	\$1465.01 233 570	\$1423.77 19 570	\$1422.27 17 570
5	\$1468.08 159 568	\$1467.07 231 568	\$1427.41 18 570	\$1425.85 17 569
10	\$1470.81 158 566	\$1469.33 229 566	\$1431.01 17 569	\$1429.68 16 569
15	\$1473.92 157 564	\$1471.58 228 563	\$1434.58 17 569	\$1432.96 15 567
20	\$1477.13 156 563	\$1473.80 226 561	\$1438.11 16 568	\$1435.22 15 564
25	\$1480.31 155 561	\$1476.30 224 560	\$1440.60 15 566	\$1437.50 14 561
30	\$1483.52 154 560	\$1478.77 223 558	\$1442.58 15 563	\$1439.76 14 558
35	\$1486.88 153 559	\$1481.18 221 556	\$1444.58 14 560	\$1442.03 13 556
40	\$1490.36 152 558	\$1483.73 219 554	\$1446.57 13 557	\$1444.28 13 553
45	\$1493.79 151 557	\$1486.22 218 552	\$1448.57 13 554	\$1446.53 12 550
50	\$1497.32 150 556	\$1488.70 216 551	\$1450.58 12 552	\$1448.78 11 547
55	\$1500.86 149 555	\$1491.34 214 549	\$1452.57 11 549	\$1451.02 11 544
60	\$1504.34 148 554	\$1493.95 213 548	\$1454.57 11 546	\$1453.44 10 541

**Table 10.53 Case G Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a Low Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1481.90 23 590	\$1488.93 80 590	\$1431.78 0 583	\$1426.99 0 578
5	\$1488.25 22 590	\$1495.18 79 590	\$1437.25 0 583	\$1433.14 0 578
10	\$1494.59 22 590	\$1501.43 78 590	\$1442.72 0 582	\$1439.28 0 578
15	\$1500.94 22 590	\$1507.68 77 590	\$1448.19 0 582	\$1445.43 0 578
20	\$1507.28 21 590	\$1513.93 76 590	\$1453.66 0 581	\$1451.57 0 578
25	\$1513.62 21 590	\$1520.18 75 590	\$1459.12 0 581	\$1457.72 0 578
30	\$1519.97 21 590	\$1526.43 74 590	\$1464.59 0 580	\$1463.86 0 577
35	\$1526.31 20 590	\$1532.68 73 590	\$1470.06 0 580	\$1470.00 0 577
40	\$1532.66 20 590	\$1538.93 72 590	\$1475.53 0 579	\$1476.15 0 577
45	\$1539.00 20 590	\$1545.18 71 590	\$1481.00 0 579	\$1482.29 0 577
50	\$1545.34 19 590	\$1551.43 70 590	\$1486.47 0 578	\$1488.44 0 577
55	\$1551.69 19 590	\$1557.68 69 590	\$1491.94 0 578	\$1494.58 0 577
60	\$1558.03 19 590	\$1563.93 68 590	\$1497.41 0 578	\$1500.73 0 577

**Table 10.54 Case G Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a High Solar Day for 590 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1481.90 23 590	\$1488.93 80 590	\$1431.78 0 583	\$1426.99 0 578
5	\$1485.39 22 589	\$1491.55 79 588	\$1433.71 0 580	\$1429.20 0 575
10	\$1489.07 22 588	\$1494.16 78 587	\$1435.65 0 577	\$1431.40 0 572
15	\$1492.83 22 588	\$1496.97 77 585	\$1437.58 0 574	\$1433.60 0 569
20	\$1495.35 21 585	\$1499.70 76 584	\$1439.52 0 571	\$1435.81 0 566
25	\$1497.35 21 582	\$1502.84 75 583	\$1441.46 0 568	\$1438.01 0 563
30	\$1499.36 21 579	\$1506.03 74 583	\$1443.39 0 565	\$1440.22 0 560
35	\$1501.78 20 576	\$1509.16 73 582	\$1445.33 0 562	\$1442.42 0 557
40	\$1504.92 20 575	\$1511.65 72 580	\$1447.27 0 559	\$1444.62 0 554
45	\$1508.06 20 573	\$1513.68 71 577	\$1449.20 0 556	\$1446.83 0 551
50	\$1511.19 19 572	\$1515.72 70 575	\$1451.14 0 553	\$1449.03 0 548
55	\$1514.33 19 570	\$1517.75 69 572	\$1453.07 0 550	\$1451.24 0 545
60	\$1517.47 19 569	\$1519.78 68 570	\$1455.01 0 547	\$1453.63 0 542

**Table 10.55 Case G Daily Cost (\$), Battery Size (kWhr),  
and Net Demand (kW) on a Low Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1488.43 0 601	\$1507.43 0 610	\$1439.78 0 583	\$1426.99 0 578
5	\$1494.70 0 601	\$1513.59 0 610	\$1445.25 0 583	\$1433.14 0 578
10	\$1500.96 0 601	\$1519.75 0 610	\$1450.72 0 582	\$1439.28 0 578
15	\$1507.23 0 601	\$1525.92 0 609	\$1456.19 0 582	\$1445.43 0 578
20	\$1513.50 0 600	\$1532.08 0 609	\$1461.66 0 581	\$1451.57 0 578
25	\$1519.77 0 600	\$1538.24 0 609	\$1467.12 0 581	\$1457.72 0 578
30	\$1526.04 0 600	\$1544.41 0 609	\$1472.59 0 580	\$1463.86 0 577
35	\$1532.31 0 600	\$1550.57 0 609	\$1478.06 0 580	\$1470.00 0 577
40	\$1538.58 0 600	\$1556.74 0 609	\$1483.53 0 579	\$1476.15 0 577
45	\$1544.85 0 600	\$1562.90 0 608	\$1489.00 0 579	\$1482.29 0 577
50	\$1551.12 0 600	\$1569.06 0 608	\$1494.47 0 578	\$1488.44 0 577
55	\$1557.39 0 600	\$1575.23 0 608	\$1499.94 0 578	\$1494.58 0 577
60	\$1563.66 0 599	\$1581.39 0 608	\$1505.41 0 578	\$1500.73 0 577

**Table 10.56 Case G Daily Cost (\$), Battery Size (kWhr), and Net Demand (kW) on a High Solar Day for 610 kW.**

PV Array Size	Winter	Spring	Summer	Fall
0	\$1488.43 0 601	\$1507.43 0 610	\$1439.78 0 583	\$1426.99 0 578
5	\$1490.35 0 598	\$1509.35 0 607	\$1441.71 0 580	\$1429.20 0 575
10	\$1492.28 0 594	\$1511.28 0 605	\$1443.65 0 577	\$1431.40 0 572
15	\$1494.21 0 591	\$1513.20 0 602	\$1445.58 0 574	\$1433.60 0 569
20	\$1496.14 0 588	\$1515.12 0 599	\$1447.52 0 571	\$1435.81 0 566
25	\$1498.07 0 584	\$1517.05 0 597	\$1449.46 0 568	\$1438.01 0 563
30	\$1500.00 0 581	\$1518.97 0 594	\$1451.39 0 565	\$1440.22 0 560
35	\$1502.37 0 578	\$1520.90 0 591	\$1453.33 0 562	\$1442.42 0 557
40	\$1505.50 0 577	\$1522.82 0 588	\$1455.92 0 560	\$1444.62 0 554
45	\$1508.64 0 575	\$1524.74 0 586	\$1458.69 0 558	\$1446.83 0 551
50	\$1511.77 0 574	\$1526.67 0 583	\$1461.45 0 556	\$1449.03 0 548
55	\$1514.90 0 572	\$1528.59 0 580	\$1464.22 0 555	\$1451.24 0 545
60	\$1518.04 0 571	\$1530.51 0 578	\$1466.99 0 553	\$1453.63 0 542

## **Vita**

Benjamin David Kroposki was born on January 22, 1968 in Wichita, Kansas. After graduating from Greenville Senior High School in 1986, he entered Virginia Polytechnic Institute and State University. There he received his Bachelor of Science degree in Electrical Engineering in 1990, specializing in the power area. He pursued his Master of Science degree in Electrical Engineering at Virginia Polytechnic Institute and State University and graduated in August, 1992. His interests include photovoltaic and other alternative energy systems, expert systems, computer applications, and environmental engineering.