Project # ENC 9220

# Solar Photovoltaics for Homeowners

An Interactive Qualifying Project
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## Preface

I found that this project brought back many happy childhood memories of my parent's camp. My parent's first bought the camp when I was a small child, and I remember that I couldn't wait to visited it on weekends and during vacations. The camp is situated in the middle of nowhere, yet everything was there. I strongly believe my love of nature and the environment developed during my visits to this home. I thank my parent's for providing me with such a resource from which to build memories and values.

Shira A. McWaters

Throughout my childhood, I have been interested in the alternative energies. This project has allowed me to investigate one of the alternative power sources, solar photovoltaics. I have found, that I have a great interest in the development of the alternative energies and solar photovoltaics, this has encouraged me to seriously think of going on to carry out graduate work in the field of solar power, and possibly study other alternative power sources in the process.

Mehmet H. Duymazlar

## Acknowledgements

The authors of the project would like to acknowledge and thank the invaluable assistance several individuals provided to help complete the project. These individuals include, John Bzura, Ph.D., of New England Electric System, Dorothy Bergin of Mobil Solar Energy Corporation, Steven Strong of Solar Design Associates Inc., Ed. Kern Ph.D. of Ascension Technology, and Miles Russell of Ascension Technology.

Finally, we would like to thank Professor Edward Clarke for providing assistance and guidance throughout the project.

## Abstract

The primary objective of this report is to offer homeowners an introductory guide to photovoltaic systems.

Background information concerning the history, components, and design of PV systems are discussed. A cost analysis of a PV Stand Alone system and PV-Grid system are presented as examples. Information concerning the Gardner Project in Gardner, Massachusetts is included to show homeowners that a working PV community exists. Professionals capable of giving design advice and providing solar components are identified as well.

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## Literature Review

The New Solar Electric Home the photovoltaics how-to handbook by Joel Davidson was very helpful. Mr. Davidson's book is easy to read and very informative. Mr. Davidson's book provides insight to the different components in a photovoltaic system such as how they work, why they are needed, and what the homeowner should look for when purchasing the equipment. Mr. Davidson also provides a Photovoltaic System design which is not extremely difficult to follow. Mr. Davidson's design methodology involves using insolation or yearly average charges, temperature correction charts, factoring in battery, inverter, and wire losses, and determining the number of days of autonomy needed for the design. Mr. Davidson's design methodology is more involved. However, it provides the homeowner with a better understanding of the system as a whole.

The Solar Electric Independent Home Book by Fowler Solar Electric Inc. was very helpful. This book offers the reader insight to the different components in a photovoltaic system. The book is filled will diagrams and pictures that help the reader to visualize and understand PV systems. Fowler Solar Electric has included a design methodology that is very easy to follow. Fowler Electric has simplified the process and eliminated the need to calculate in different losses and influencing factors. I found Fowler Electric's design technique helpful and compared it to Mr. Davidson's. This book also provide helpful background information concerning PV components as well.

The Solar Electric House by Steven J. Strong with William G. Scheller was also helpful. This book also offers the reader insight to the different components in a photovoltaic system and hybrid systems as well.

## A Word of Caution

The purpose of this report is to offer the interested homeowner assistance and to encourage the safe, and wise use of photovoltaics. The reader is expected to use safe practices at all times and use good judgement in the selection of materials, methods, and professionals used. It is up to the reader and professional help to verify the safety and validity of the photovoltaic system. It is strongly recommended that the reader consult a professional in the field and refer to the National Electric Code.

Neither the authors nor Worcester Polytechnic Institute assume any liability resulting from the use of this report. Any applications made from the information in this report are the sole responsibility of the reader.

## Objectives

The objective of this IQP report is to provide homeowners with an introductory guide to photovoltaic systems and to provide homeowners with a list of photovoltaic professionals and companies they can contact for components and guidance. Information concerning the history, usage, components, and design methods will be discussed.

Information concerning the Gardner Project, which is a community of 30 homes in Gardner, Massachusetts, each home retrofitted with a 2.2 KWhr PV system, will be included. The Gardner Project information will serve two purposes. First, the Gardner information will act as an existing model of an actual working PV-Grid connected community. Homeowners can use the Gardner Project as a reference guide if they are interested in a PV-Grid connected system. Secondly, the Gardner Project will act as a reference guide for future WPI students interested in the Gardner Project or similar projects. We have collected as much information as possible on the Gardner Project to satisfy this objective.

## Procedures

Since, we only had seven weeks to finish this IQP report we organized a list of procedures, which we tried to follow to the best of our ability. Listed below are the steps taken in order to complete this project.

1. During D 92 Term we reviewed some basic PV books to provide us with good background knowledge concerning PV systems. From this information we wrote a Pre-

Qualifying Project (PQP), which was submitted to Professor Clarke at the end of D "92" term.

2. Prior to the beginning of E "92" we reviewed much of the information concerning PV systems and the Gardner Project. We also interviewed and talked to a variety of professionals who were involved with the Gardner Project. We attended a workshop at Sunnyside Solar to give us some hands-on background.

3. At the beginning of the E "92" term we started to meet with Professor Clarke, weekly, for approximately 3 hours each meeting. Our meetings continued until the end of the semester.

4. We visited the community involved in the Gardner Project and took many pictures. We also stopped and talked to a few homeowners, at the Gardner community, as well.

5. During E "92" term we utilized the best design information available to homeowners in New England (i.e. Photocomm Inc., Fowler Solar Electric Inc., Sunnyside Solar Inc.)

6. During E "92" term we finished reviewing the information concerning PV systems and the Gardner Project and started writing the report.

# Chapter One

# Introduction to Photovoltaics

## 1.1 Photovoltaic History a Brief Discussion

The knowledge of solar energy is not new to this half of the century. The first photovoltaic (PV) effect was noticed more than a century ago, in 1839, by E. Becquerel. From Becquerel's initial find other discoveries followed and in turn the field of solar and photovoltaic energy has improved.

The first major usage of photovoltaic cells began with the space program. For the space program photovoltaics offered an efficient and cost effective method of powering satellites. The first PV powered satellite used in space was Vanguard I. Using PV's in the space program promoted the research on photovoltaics. However, inadvertently the space program's usage of PV's, also gave the public the idea that photovoltaics were extremely complicated and expensive, and therefore not applicable for terrestrial use. It wasn't until the 1970's energy crunch that PV's were seriously consider for home use. At that time people in research, government, and industry had high hopes of improving the manufacturing and production of photovoltaics, so that PV would become a reliable source of inexpensive electricity available to all households. The Department of Energy even predicted the cost of photovoltaic electricity into the year 1986. In reality, these cost predictions fell short, as figure 1.1 indicates.

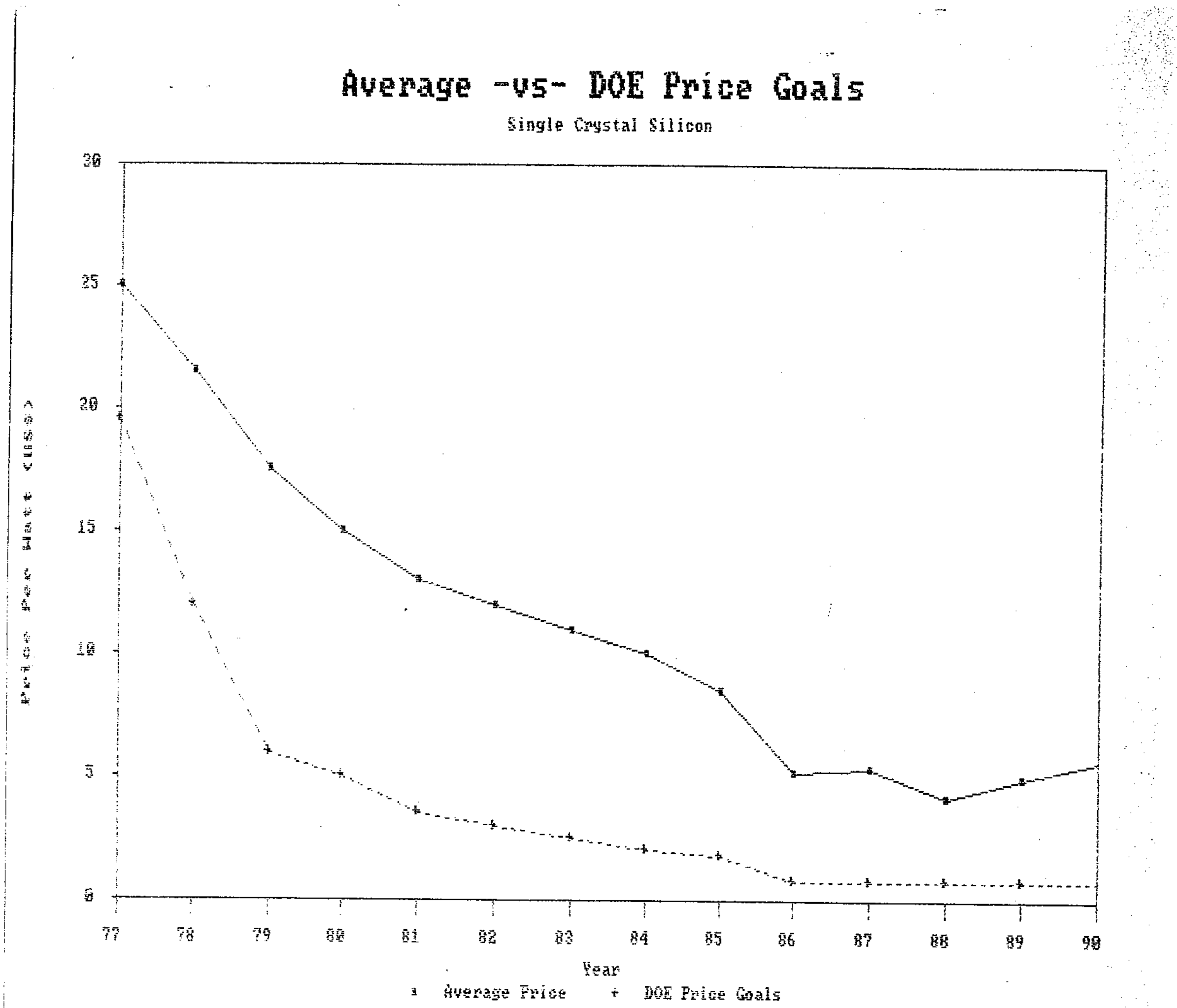


Figure 1.1 Average -vs- DOE Price Goals per Watt

Reference Sources The New Solar Electric Home by Joel Davidson and Photovoltaic Insider's Report, Edited by Richard Curry May 1992 Vol. XI No. 5.

## 1.2 The Production of PV's and why PV's are not more widely used.

Unfortunately, photovoltaic systems have not become as widely established as people in industry, government, and research once thought it would. This lack of utility or household usage can be linked to many factors, such as the decrease in oil prices, making coal and other fossil fuel generated electricity more cost effective than photovoltaic electricity. The United States has the world's single largest supply of coal. Coal generated electricity supplies much of the U.S. electrical needs. Therefore, the main source of electricity is still produced from existing power plants; not enough photovoltaic products are produced and sold to decrease the cost of PV modules through mass production. This unfortunately makes photovoltaic systems initially more costly than the already established fossil fuel systems.

The production of solar cells is a complex technology, which also contributes to the cost of the system. Photovoltaic production requires large amounts of capital and the use of expensive sophisticated equipment. The wafer cutting process has improved from the beginning, when much was wasted during the cutting process and even hand labor was required at times. Although much improvement as been recorded from the early stages of photovoltaic history, the end of photovoltaic research is far from over. Worldwide photovoltaic production is currently about 50 Megawatts per year. The cost of PV modules will come down as the methods of production improve and the quantities of PV modules manufactured increase to the hundreds and thousands of Megawatts scale. Will this decrease in cost occur any time in the near future? The answer to that question is unfortunately, no. The cost of PV systems will not decrease until large enough quantities are sold, and large enough quantities are not being sold because the cost is not competitive with the traditional systems.

Another factor slowing photovoltaic progress is enormous amounts of money are tied up in the already established systems. In any large industrial society, water, electricity, transportation, and communication are key components to its existence. If any radical change is made to any one of these components billions of dollars would be involved. This money would come from the taxpayers, who are already stretching their dollars. Therefore, utility companies are reluctant to change the entire system. However, some utility companies are exploring the use of photovoltaic systems to help with peak load conditions. Pacific Gas and Electric in California and New England Power Service Company in Massachusetts are two companies that have been prominent leaders.

**1.3 Why Large Scale PV Systems Have Not Been Built.**

The amount of usable sunlight available to man is approximately 4,500 times greater than the current energy sources. "To put the magnitude of the sun's power into perspective, at noon the solar energy striking an area 70 miles long by 70 miles wide, if converted into photovoltaic electricity, would equal the peak capacity of all the earth's existing power plants. A solar cell power plant covering only 1% of the Sahara Desert would produce all the electricity consumed on this planet."[1] This statement is quite impressive and some may ask why such a system is not, currently or in the near future, being developed? Although such a system would be beneficial to all people on this planet realistically, it would be impossible to construct at this time. First, the size of the system would be enormous with approximately 1.2 trillion watts, and would cost, at today's price's, approximately 6.3 trillion dollars. Even if such an endeavor was started the world's current level of photovoltaic production is only 50 megawatts per year. Therefore, in order to complete such a system, the world's production of photovoltaics would have to increase by 24,000 times its original production capacity. Even if the world's production of photovoltaics could be increased 10 times its current level to 500 megawatts per year, and 500 megawatts were installed each year, it would take approximately 2400 years to complete. Another problem that would be faced, in order to produce such a large scale system would be, world cooperation. Even if the world's production was capable of manufacturing photovoltaics on such a large scale level, there is no guarantee that all the countries and nations in the world would cooperate and contribute their portion of time, energy and money.

If we examine the figures in a different manner we can determine the size of a PV system the U.S. would need to supply all its electrical power. Currently, the U.S. uses approximately 25% of the world's energy. If we use this figure and recalculate the total size of the PV system needed, the system's size would be approximately 300 billion

[1] Davidson Joel, <u>The New Solar Electric Home: the photovoltaic how-to handbook.</u> Ann Arbor, Michigan, ATTEC, 1990, Page 1.

watts and would cost, using today's price's, approximately 1.5 trillion dollars. However, if such a system could be manufactured it is possible that the price of installation would decrease to $1 per watt, thus lowering the cost of the system to 300 billion dollars. If we had the capability of manufacturing such a system it is feasible to assume that it could be completed over a 10 to 20 year period, thereby lowering the cost to approximately, 30 billion to 15 billion dollars each year until the completion of the system. However, there would be other factors that would need consideration. First, the cost of 300 billion dollars only included the photovoltaic modules, and not the enormous infrastructure that would need to be built in order to support the numerous arrays. Secondly, labor and miscellaneous items such as wiring, batteries, inverters, etc. are not included in the figure and would add a considerable sum to the already sizable cost. Thirdly, security would need consideration not only from the power utilities constructing such a system but from the government as well. Armed forces and the most advanced and expensive security equipment would need to be used to prevent possible sabotage. Fourthly, the geographic location of the area would need to be stable, void of earthquakes or tremors. Unfortunately, in the southwest which would be the best location for the system, there are many areas that experience periodic tremors. There are a variety of other concerns that would need to be addressed as well. Even if all the concerns could be eliminated there still remains the factor that world wide solar module production is not large enough to produce such a system. Even by sizing the system down to 300 billion watts, the PV system is still 6000 times greater than the current photovoltaic production level. An enormous investment would be needed to create solar cell manufacturing plants capable of producing the number of solar modules needed to construct such a system.

Although theoretically such a large scale photovoltaic system capable of supplying the U.S. electrical needs is possible, realistically producing such a large scale PV system is not possible either at the present time or in the near future.

## 1.4 The Photovoltaic Process.

A common question asked by homeowners is how does the photovoltaic system work? A photovoltaic cell is a solid state electrical device. A PV cell is able to convert a percentage, approximately 10% to 20%, of the energy from the sun into usable electricity. Sunlight, which is pure energy, enters the PV cell and transmits some energy to the cell. Photons are absorbed by the PV cell's surface and electrons are set free. A built in potential barrier in the PV cell reacts with these moving electrons, to produce a voltage, (called photo-voltage). This photo-voltage can be used to drive a current through a circuit, which consists of wires. The wires provide a path for the current to flow to a single load or many loads (i.e. appliances, lights).

The voltage produced from the PV cell is DC (Direct Current) voltage, which can be used to operate most DC electric appliances. However, some appliances need AC (Alternating Current) voltage to operate. Therefore, the DC voltage generated from the solar cells must be conditioned. This is accomplished by using inverters, which produce a sinusoidal (AC) voltage. This conditioning allows all modern appliances to be run from the DC voltage generated from the PV cells.

Another question asked by homeowners, is how does the PV system work if it is cloudy or at night? If the electricity produced by the PV cells is not immediately used, it can be stored in batteries as a chemical reaction, which can then be utilized as electricity at a later time. A battery will produce DC voltage, and therefore conditioning may be required depending on the appliances being used. Batteries are generally used in remote (stand alone) homes, which are independent from the utility grid. However, there are homes that incorporate PV and grid working together. In this case batteries are not needed. Instead of relying on energy stored in batteries the system automatically switches from the PV system to the grid system and vice versa when needed. It should be noted that with a grid-PV system special precautions must by taken to ensure the safety of linemen. With a grid-PV system the electrical current can flow from the line to the house and from the house to the line. If linemen are working on what they believe is a dead line, it is imperative that electricity will not flow from your house to the line, so as not to cause harmful or fatal accidents. Avoidance of this mishap can ba accomplished by charge control centers in the home, which are usually located in the basement and includes the inverter, which is an electrical device that can change DC current to AC current.

### 1.5 Common Questions Asked by Homeowners.

Some common questions asked by homeowners are where can I purchase photovoltaic modules and whom do I contact, can I use a PV system to heat my home, what are the costs involved, and can a photovoltaic system work in geographic areas other than the southwest? The answer to the last question is, yes. Photovoltaics are not limited to just the sun belt states, PV systems can be used in all parts of the country. In New England alone, there may be more than one or two thousand homeowners who have installed photovoltaic systems, to power all or part of their electrical needs.

There are a select number of photovoltaic professionals who can be contacted for information and help, some of these are; Jeff Fowler, from Fowler Solar Electric Inc. Mr. Fowler's Company is located in Worthington, Massachusetts. Richard Gottlieb and Carol Levin, from Sunnyside Solar, are located in Brattleboro, Vermont. Steve Strong, from Solar Design Associates, is located in Harvard, Massachusetts. Photocomm, Inc., one of the largest PV distributors, is located in Scottsdale, Arizona. There are other individuals as well as companies who specialize in photovoltaics. Many of these professionals offer personal assistance as well as photovoltaic workshops. All these professionals are pioneers in the photovoltaic field, working to provide a reliable and clean alternative to fossil fuel systems.

The question that asks if a home can be heated by a photovoltaic system has a yes/no answer. There has been research in this area and some very knowledgeable and crafty suppliers and PV owners have been able to use some of the excess heat produced from the PV array to heat some of their water supply. However, at this time we are not aware of any photovoltaic system that has been designed to heat a home and also provide electricity as a hybrid system. To design a heating system with the current photovoltaic technology is not possible. Homeowners must look for an alternative way of heating for their homes, (i.e oil, gas, wood, passive solar).

The purpose of this report is to answer the previously mentioned questions more thoroughly and to offer guidance to the interested homeowner. This report will include a chapter listing professionals and companies that homeowners can contact for help and guidance. The report will also include a chapter and reference material on a community in Gardner, Massachusetts. This Gardner community receives electricity not only from the utility grid but also from many photovoltaic systems. This section can offer guidance and act as a reference source for interested homeowners.

### 1.6 A Carefully Thought Out Process - Remember Safety First!

At this point we would like to encourage interested homeowners to "do their homework". A carefully throughout and well researched plan will offer the most reliable and safe results. We encourage interested homeowners to read a variety of photovoltaic books. It should be noted that even though designing a photovoltaic system is not extremely complicated it is a good idea to consult with a professional in the field - even if only to double check your own work. A photovoltaic system is an electrical system and care must be taken at all times to avoid injury - REMEMBER SAFETY FIRST!

# Chapter Two

# A Review of Electricity

The purpose of this chapter is to review some of the common terminology used with electrical systems. The material reviewed is not difficult and will help you understand the concepts of designing a photovoltaic system.

## 2.1 Current

Current is defined as the overall net charge flowing through a wire, within one second. The symbol for current is (I) and the term Ampere is used to define the current. Current is similar to water flowing through a pipe.

## 2.2 Voltage

Voltage (E or V) is the potential difference measured in volts. The voltage can be considered the driving force of the electrical system. If you picture water flowing through a pipe, the voltage is similar to the force that is pushing the water through that pipe.

## 2.3 Direct Current

Direct Current (DC) is current that flows in one direction only, from positive to negative, it cannot reverse its direction, without reversing the leads. All the current and voltage in Direct Current are one direction, meaning that they do not change direction with time, as figure 2.1 indicates.

### 2.4 Alternating Current

Alternating Current (AC) functions as its name suggests. AC current is current that flows in one direction and then the other, positive to negative and vise versa in a rhythmic pattern. All current and voltage in Alternating Current flow back and forth, often in a sinusoidal pattern as figure 2.1 indicates.

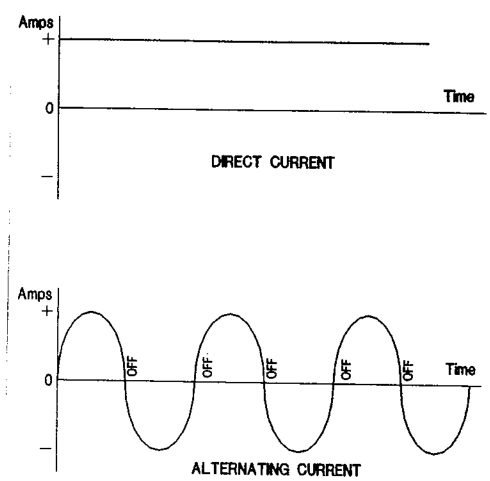


Figure 2.1 Direct and Alternating Current

Reference Source The Solar Electric Independent Home Book, by Fowler Solar Electric Inc., Published by Fowler Solar Electric Inc., 1991. Page 16-6.

## 2.5 Resistance

Resistance is the opposition, resisting force, to the current flow. Resistance can be compared to the following: Take a book and push it with your finger across a smooth polished surface, like a dining room table. Make a mental note on how much effort is took to push the book. Then take the same book and try pushing it in the same manner across a rough surface, like a rug. You should be able to feel the difference between the two. During both observations there was some force that was resisting the movement of the book. Pushing the book across a smooth surface was easier than pushing it across the rug. Therefore, there must be less resistance between the book and smooth surface than that of the rough surface. Why, use this analogy? Different electrical appliances have different levels of resistance. Resistance also depends on the size of the wire used as well as the material of which it is constructed and should be as small as possible. This factor becomes important in the designing of a photovoltaic system. The Resistance (R) is measured in Ohms.

## 2.6 Power

Power is the rate at which electrical energy is consumed or used. The unit of power is the watt (W). Every appliance is rated according to the amount of power (watts) that appliance needs to use in order to operate properly. For example, a 19 inch colored TV may be rated at 81 watts. Which means the TV needs to consume at least 81 watts of electricity to operate.

### 2.7 Energy

Energy is the amount of power used during a specific period of time. If you watch a TV rated at 81 watts for one hour the energy used is 81 watt-hours (Whr). If you look at your electric bill you will see that the power utility bills you by the amount of energy used. For example, during the service period of 4/10/92 to 5/12/92 the amount of energy consumed by the McWaters' family (one of the authors), was 394.0 KWH (kilowatt-hours). Kilo means one thousand, therefore 394.0 KWH equals 394,000 watt-hours of energy, which was consumed during a 32 day period. If you divide the total energy used by the time period this energy was used in (days) you can calculate your daily energy consumption.

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Energy used = 394 KWH/Number of Days (32) = 12.31 KWH used daily (on average)

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The electricity consumed by the McWaters' household could be decreased by conservation methods. Before designing a photovoltaic system an energy audit should be performed on your household usage of electricity. Conservation will be discussed later in the report.

Power (watts), Voltage (E or V), Current (I), and Resistance (R) are related through Ohm's Law as is illustrated in figure 2.2.

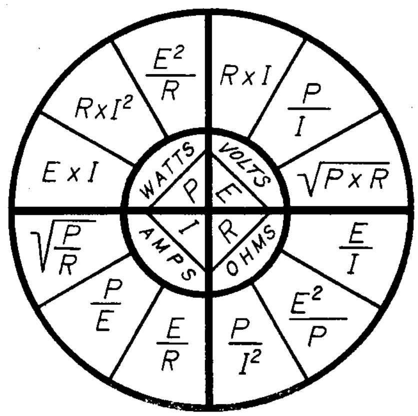



Figure 2.2 Ohm's Law

Reference source Ugly's Electrical-References by George V. Hart, United Printing Arts, Houston, Texas, 1978, Page 1.

The Ohm's Law chart listed in Figure 2.2 can be simplified into the following chart.

| Power(watts) | Current(amps) | Voltage(volts) | Resistance(ohms) |
|---|---|---|---|
| P = V X I | I = V/R | V = I X R | R = V/I |
| $P = I^2$ X R | I = P/V | V = P/I | $R = V^2$ /P |
| $P = V^2$ /R | I = SQRT(P/R) | V = SQRT(P X R) | $R = P/I^2$ |

Figure 2.3. Revised Ohm's Law Chart

## 2.8 Series and Parallel Circuits

In a Series circuit all electrical components are connected end to end, in series, and the voltage adds up from connection to connection. However, the current (amperes) is common throughout. A Series connection can be made by connecting a positive terminal to a negative terminal until all the connections are completed as is illustrated in figure 2.4 a.

In a Parallel circuit this response is reversed and the currents (amperes) add up from connection to connection, and the voltage remains common throughout all parallel circuits. A parallel connection is made by connecting a positive terminal to a positive terminal and a negative terminal to a negative terminal as is illustrated in figure 2.4 b. Series and Parallel connections are made in order to obtain the correct voltage and current the PV system has been designed for. Both will be discuss more thoroughly in a later chapter.

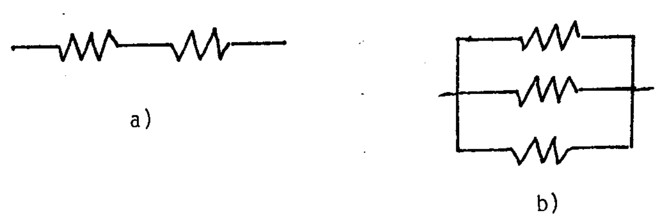



Figure 2.4 a) Series Circuit, b) Parallel Circuit

## 2.9 Safety First

Electricity can cause shocks or burns which in turn can cause a person bodily damage and in the worst cases can cause death. Whenever anyone, professional or a do-it-yourselfer, attempts to work with electricity they should keep this in mind. A photovoltaic system is no exception to this rule. Even though a PV system receives its power from the sun it is still an electrical system capable of causing bodily harm if dangerous levels of current and voltage are combined as is illustrated in figure 2.5.

Again, we cannot over stress the importance of safety and wise installation practices, and use of your photovoltaic system . Follow all standard safety procedures, use common sense, review the National Electric Code and talk to your local Electrical Inspector concerning any local rules and regulations. We understand the desire to keep costs to a minimum. However, we recommend that you hire a professional or at least have them double check your own work. The extra money spent on a professional will be well worth the money spent. Installation done by a professional will ensure yourself, and others, that you have a reliable, safe, and dependable system. For your convenience, listed in Appendix B are the Suggested Practices of Photovoltaic Power Systems and The National Electric Code.

| Amperes | | Bodily Effect |
|---|---|---|
| 1 to 5 | milliAmps | Discernible |
| 5 to 12 | milliAmps | Painful |
| 13 to 15 | milliAmps | Threshold of involuntary muscle contraction ('let-go' value) after which it is physically impossible to release grasp. |
| 20 to 50 | milliAmps | Severe pain and loss of consciousness, although heart and lungs continue to function; if contact is short the effects may not be serious |
| 50 to 75 | milliAmps | Tetany (paralysis) with no pulse nor respiration; when flow of blood to the brain ceases (usually with 5 minutes) damage is irreparable. |
| 100 to 1500 | milliAmps | Ventricular fibrillation (disturbance to the co-ordinate action of the main blood pumping chambers), destroying the heart's natural rhythm, with almost instantaneous death. |
| 1500 milliAmps and up | | Contraction of heart muscles but not necessarily fibrillation; respiratory system may or may not be paralyzed. |

The "let-go" current is greater than 13 - 15 mA for D.C. and for frequencies below 5 Hz and above 500 Hz.

Figure 2.5 List of dangerous levels of current and the bodily damage that can be sustained.

Reference source Electrical Engineer's Reference Book, 13th Edition, Edited by M.G. Say, London - Butterworths, 1973. Page 24-2.

**Figure 2.5** List of dangerouse levels of current and the bodily damage that can be sustained.

Reference source Electrical Engineer's Reference Book, 13th Edition, Edited by M.G. Say, London-Butterworths, 1973, Page 24-2

# Chapter Three

# Using Photovoltaics

# Choosing the Right Location for Your PV Array - Not Necessarily South

# When does A PV System Become Affordable

### 3.1 Photovoltaic Versatility

One of the more desirable traits of photovoltaics is that they are modular. If money is tight, the interested homeowner can start out with a small system that is within the homeowner's budget. As the homeowner's budget dictates more PV modules can be added to increase the size of their system. This modular trait of photovoltaics allows the user to mix their existing PV modules with, not only, additional PV modules put with different electrical producing systems as well. PV-Grid, PV-Generator, PV-Wind, are a few examples of Hybrid systems that combine solar photovoltaics with another electrical producing system. The objective of this report is to introduce homeowners to Photovoltaic systems. Hybrid systems, such as, PV-Generator and PV-Wind will be discussed only briefly. Homeowners interested in Hybrid PV systems are encouraged to explore the different options available.

### 3.2 When Does A PV System Become Affordable?

It was stated in an earlier chapter, that photovoltaics have not become as widely used as once hoped. Economically the photovoltaic market cannot compete with the low cost traditional system. This statement is true if the existing or future home is near a utility line. Economically, it would be more costly to install a photovoltaic system then it would be to connect or remain on utility power. Homeowners involved in this type of situation must make the decision of whether or not they want to spend the extra money or forget about using power generated from the sun. The homeowners who decide in favor of installing a PV system do so for other reasons other than money. Many are concerned about the environment and want to use clean power generated from the sun. Others may just want to remove themselves from the bureaucracy of the system and solar photovoltaics give them the power and freedom to do so.

A photovoltaic system becomes more affordable the further away the home is situated from a utility line. The transition point is approximately one-half mile (2640 ft). This distance will vary depending on the installation rates charged by your local utility company and the size of your PV system. As little as five years ago the cost of installation ranged from 4$ to 16$ per foot in the U.S. For a home situated one-half mile from a utility connection, installation costs calculate out to be approximately $10,560 to $42,240. It becomes quite clear that the further a home is from a utility connection the more cost effective a PV system becomes. A cost comparison will be made in chapter 5 to illustrate this point.

### 3.3 Conservation and Photovoltaic's

A key component in designing an affordable PV system is conservation of energy consumed. This does not mean that homeowners need to live without the modern comforts. Conservation means the energy users become more energy conscious. This should be the case, regardless if the homeowners are designing systems that will connect to or be independent of the existing utility grid. In either case, conservation will lower the home's daily power consumption. When homeowners use alternative energy, such as photovoltaics, they have created their own power plant. With any good power plant, proper management of the power consuming loads is essential. In a sense the homeowner not only owns his own power plant but is also the manager of that plant as well.

The size of a PV system will depend on the electrical needs of the household. As the daily consumption load increases the size of the PV system must increase as well. Before designing a PV system the homeowner should perform an energy audit. A walk through each room in the house will tell the homeowners what appliances they are using and how much power is being consumed. The voltage, ampere, and watt ratings of each appliances can be found next to the UL label, which can be located somewhere on the appliance (top, bottom, or sides). From the walk through, the homeowner may be able to make changes and as a result lower his daily power consumption. It is possible for some homeowners to cut their current electrical bill in half just by conserving energy.

### 3.3.1 Methods of Conservation

Conserving energy is not a difficult task. All it takes is good common sense. Homeowners need to ask themselves do I need to use an electric can opener or can I use a hand held opener? Do I need to use the garbage disposal to compact trash or can I do it manually? Do I need to leave a light on all night? Do I need to run the air conditioner at this time or can it wait? There are many other different questions the homeowner needs to ask as well. Once the questions have been asked the homeowner will find that there are many daily tasks they can do manually, and appliances that they can use to save on electricity.

Newly purchased appliances should be as energy efficient as possible. When shopping for new appliances homeowners should compare different models, their efficiency, and determine what best fits their needs. Many new appliances list their efficiency rating on a tag that is easy to read. Industry is slowly changing its ways and is producing more efficient appliances.

Changing a home's type of lighting can be the quickest and easiest way to conserve energy. Many homes use inefficient incandescent bulbs to generate light. The fact is that an incandescent bulb is a better generator of heat than it is of light. Most incandescent bulbs produce only approximately 5% to 10% light and the rest of the energy is converted into heat. Fluorescent bulbs are the most energy efficient bulbs that are available to the public. Fluorescent bulbs are capable of producing light at a lower wattage than incandescent bulbs. For example an Osram AC efficient 15W fluorescent light bulb will produce as much light as a 60W incandescent bulb. That is 45 watts less than the incandescent bulb. If you run the 15W fluorescent bulb for approximately 2 hours daily you would consume only 30 Watt hours of energy. If you ran the 60W incandescent bulb, for the same amount of time, you would consume 120 watt hours of energy, 300% more energy. The picture shown below has three rows of light bulbs. The light produced by each row is approximately equal, however the watt rating of the bulbs are different in each row. The top row are incandescent bulbs (largest watt rating) and they use 8.5 amps of current. The middle row are Halogen bulbs (second highest watt rating) and they use 3.5 amps of current. The bottom row are fluorescent bulbs (lowest watt rating) and they only use 2.0 amps of current.

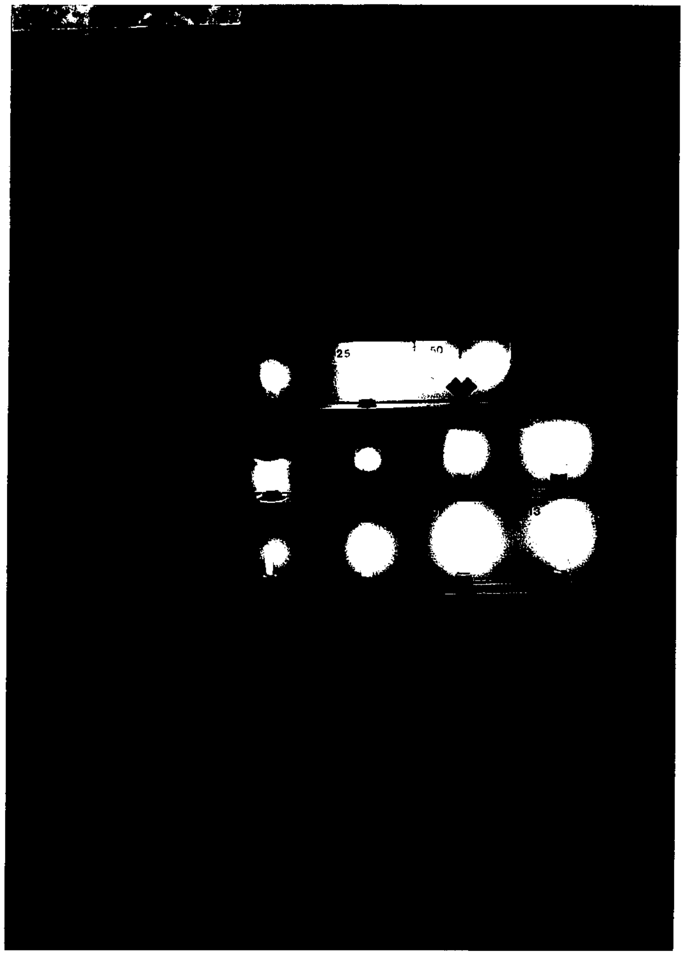



Figure 3.1 A picture of different watt rated light bulbs with different ampere consumptions. Taken by authors at Sunnyside Solar Workshop May 1992.

A new light bulb was recently featured in Newsweek Magazine, June 15, 1992 page 67. This bulb, called the "Radio-Wave Bulb", is highly efficient, with a greater efficiency level than the current fluorescent bulbs. This bulb does not incorporate the use of filament as does the standard incandescent bulb. Instead, there are coils around the base which produce radio waves. The radio waves excite the electrons inside the mercury vapor, which is inside the bulb, and photons are emitted. The photon are then absorbed by the phosphorous coating on the inside of the bulb. The absorbed photons excited electrons in the coating, which then emit visible light. It is believed that the bulb can last up to 18 years before replacement and will cost approximately $15.

The purpose of this section was to give the homeowner an introduction to saving energy. There are many different methods of conserving energy that have not been listed. There are a variety of energy conscious books on the market that supply many helpful tips. Purchasing an energy conscious book is well worth the money spent and is recommended to all homeowners.

### 3.4 Finding the Right Location For your PV - Not Necessarily South

The location of the PV array should be decided before designing a PV system. The best spot, in the Northern regions, is in a location that faces true south. The sun rises in the east and follows a semicircular path and then sets in the west. When an array is positioned towards true south, the amount of sunlight striking the array is maximized, which in turn will maximize the power output of the array. Although the best direction to face a PV array is true south there are other directions the array can be angled at and still produce comparable power. In a study done by WPI students Chuck Le, John F. Moran Jr., and Torkis Simandjuntak, during an earlier IQP, and using data provided by the U.S. Weather Service, it was shown that the solar insolation did not decrease dramatically if the PV array was angled toward the southeast or southwest, especially in the summer. If the array was angled towards the east or west the solar insolation decreases some, but not to a dramatic level. The study even showed that the north side of a roof receives some solar insolation. The insolation level was much lower on the north side, and placing a PV array on this side of the roof would be impractical. The solar insolation levels are represented in figure 3.2 for Bangor Maine and figure 3.3 for Boston Massachusetts. These graphs show that photovoltaics can be used in most geographical areas regardless of array angle, understanding that full output will not be reached. The information used to construct figures 3.2 and 3.3 was compiled by Mr. Moran and is represented in graphs found in Appendix D.

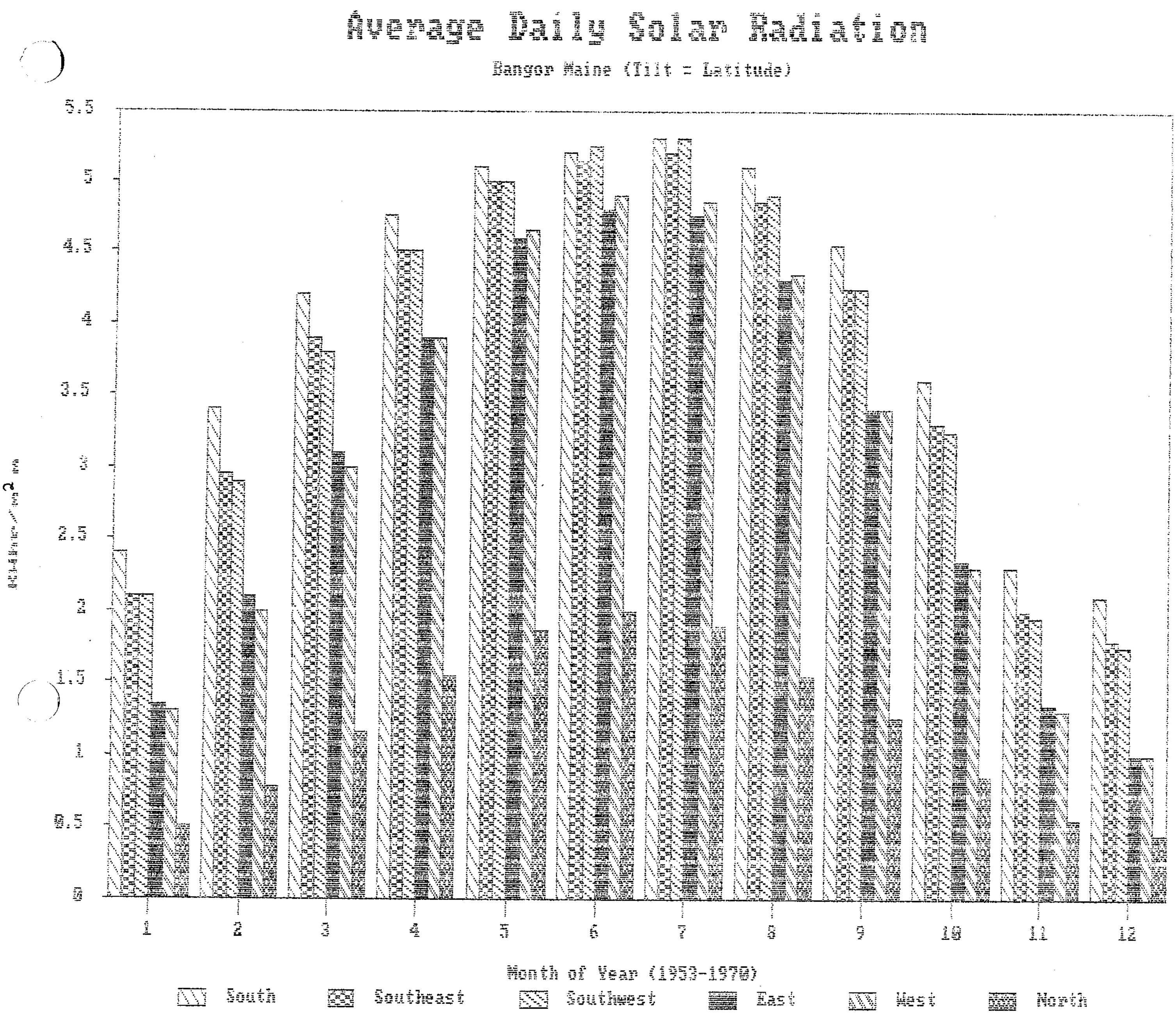



Figure 3.2 Average Daily Solar Radiation
Bangor, Maine (Tilt = Latitude)

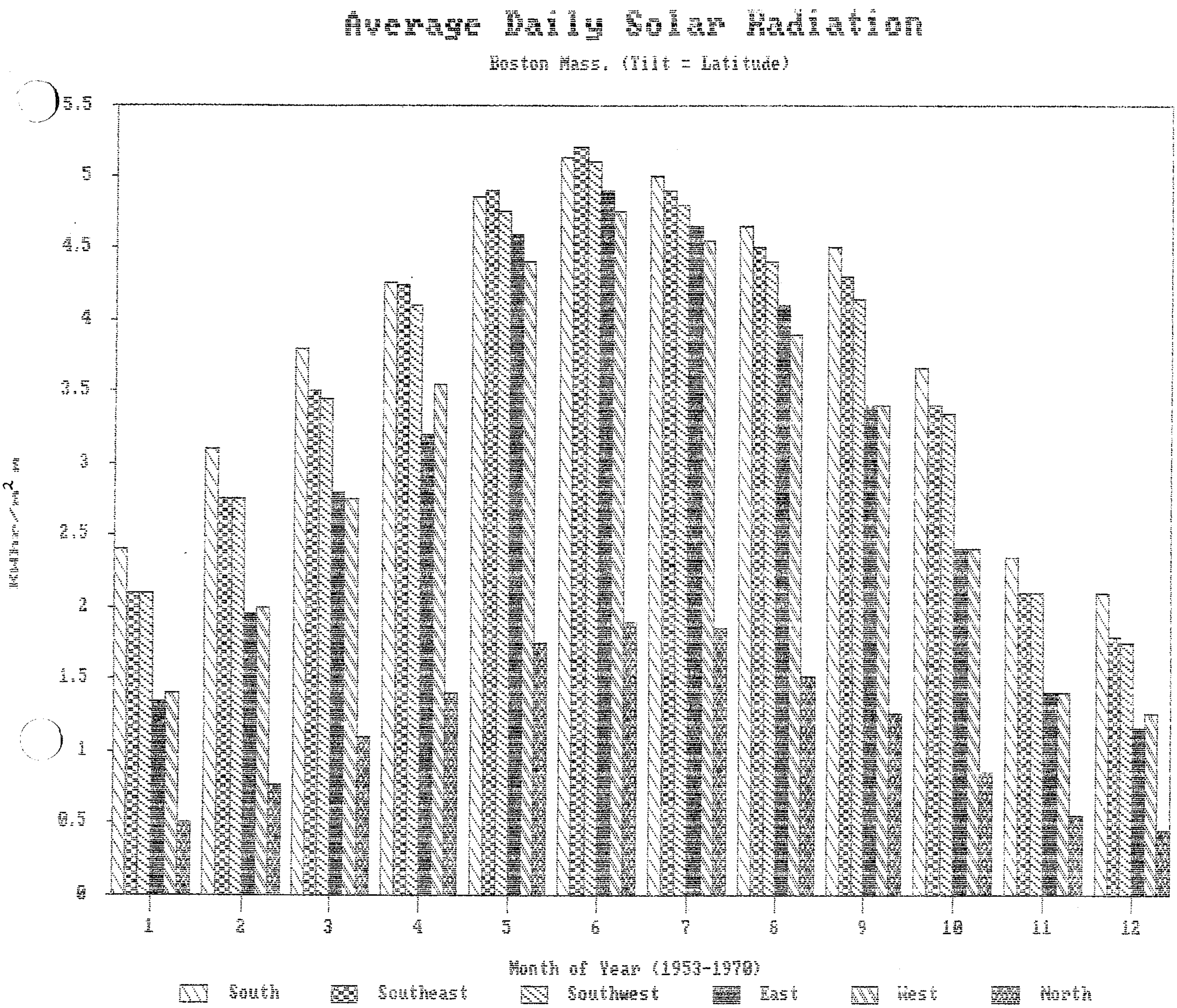



Figure 3.3 Average Daily Solar Radiation
Boston, Massachusetts (Tilt = Latitude)

In order to determine the best location for an array, one should locate a spot where the array will receive approximately six hours of unobstructed sunlight throughout the day. Shadowing from trees will decrease the power output from the array. A shadow cast from a limb on a tree halfway across a cell can decrease the power output of that cell by one-half. Therefore, potential shading must be considered when looking for a location for the array.

If you are not sure of the direction of true south it can be found in the following manner. Watch your local weather channel and make note of the time the sun is going to rise and set for the next day. From these times figure out the time span between dawn to dusk. Divide this number in half and add the resulting number to the scheduled sunrise time. This will give you the time for solar noon. Solar noon is the time when the sun reaches its highest point during the day. If you place a stick perpendicular to the ground at solar noon it will cast a shadow. From this shadow you can find the direction of true south and angle your PV array accordingly. The best tilt of the array to receive maximum solar insolation, is when the sunlight strikes the array panels at a 90 degree angle. The tilt of the array will depend on the PV system's design, and the method of mounting to be used. Adjustable mounts change the tilt of the array according to season. In the summer the array is tilted at (Latitude - 15 degrees). In the spring and fall the array's tilt equals the area's latitude. In the winter the array should be tilted at (Latitude + 15 degrees). The proper tilt of the array will be discussed more fully in chapter 4.

Weather is another factor that needs consideration when designing a PV system. Not all areas are like the southwest, where they receive what seems to be an endless supply of sunshine. In the Northeast it is not uncommon to have 3 to 5 cloudy days in a row. The PV arrays will not provide satisfactory power in cloudy weather. In order to receive power during these times extra storage capacity must be designed into the battery bank. The extra power stored in the battery banks will allow the homeowner to use electricity during cloudy weather and on a nightly basis. Designing for weather conditions will be discussed in chapter 4.

### 3.5 PV Illustrations and Flow Diagrams

A photovoltaic system is not complicated. In order to better understand the way PV systems work, a step by step illustration will be discussed.

#### 3.5.1. Stand Alone DC System

When the light from the sun strikes the solar array it causes electrons within the cells to move and produce a current across a built-in potential barrier. This current is then collected by the wires attached to the cells. From the cells, the current travels out through a wire towards the charge controller. The charge controller determines whether or not the battery bank needs charging or is full. If the battery bank is full, the charge controller can divert the current to appliances being used. If the battery bank is low and needs charging, the charge controller will allow the current to flow through to the batteries. In the batteries the energy is stored until it is needed. When power is needed it is drawn out of the battery bank and flows through a wire to the DC load junction box. In the junction box the current is transferred into the correct wire(s) so that it can power the desired load(s). A DC stand alone home will need to be wired appropriately for DC circuits. However, it is recommended that the homeowner wires his home for AC as well as DC circuits regardless of future use.

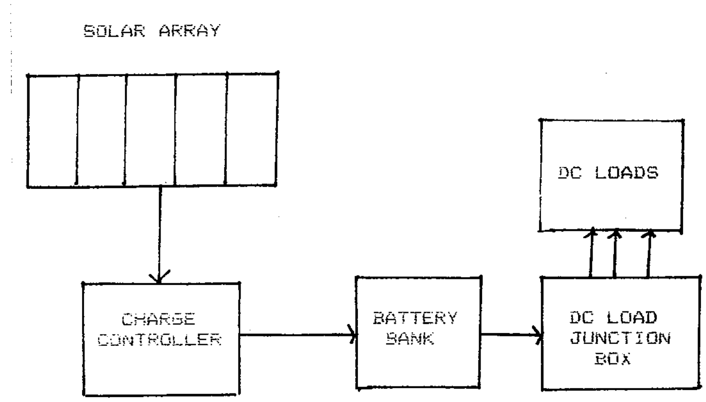



Figure 3.4 Small Stand Alone DC System Flow Chart.

### 3.5.2 Stand Alone AC System

A Stand Alone AC system operates the same way as a DC stand alone with a few changes. Again, the current from the solar cells travel through a wire to the charge controller. The charge controller decides whether to divert the current or let it pass. If the current is not diverted it travels to the battery bank. In the batteries the energy is stored until it is needed. When power is needed, by a load, it is drawn out of the battery bank and flows through a wire to the inverter. At the inverter low voltage DC current is transformed into higher voltage AC current. From the inverter the AC current travels towards the AC load junction box. In the junction box the current is transferred into the correct wire(s) so that it can power the desired load(s).

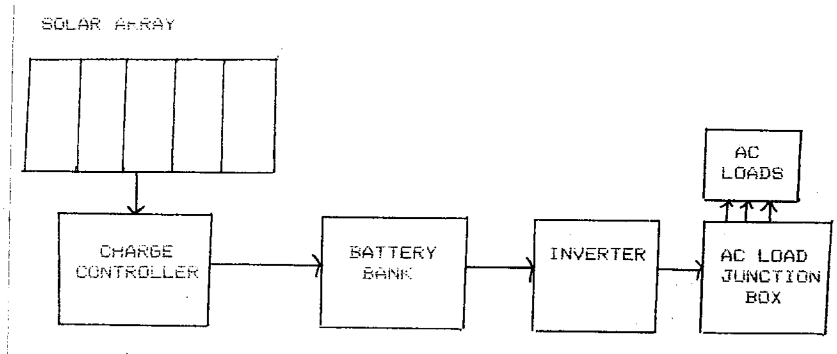



Figure 3.5 Small Stand Alone AC Flow Chart

### 3.5.3. Stand Alone DC/AC System

This system basically operates the same as a DC Stand Alone and AC Stand Alone system. Again, the current from the solar cells travels through a wire to the charge controller. From the charge controller the current can be used to power DC loads or used to charge the battery bank. If current is needed from the battery bank to power DC loads it will be used in that fashion, travel towards the DC junction box where it will be directed along the correct path to power the needed DC load. If current is needed from the battery bank to power AC loads it will be used in that fashion and travel to the inverter were it will be transformed from DC current to AC current. From the inverter the current flows into the AC junction box where it is directed along the correct path to power the needed AC load. It should be noted that AC and DC electricity requires two separate and different wiring systems. PV and home wiring will be reviewed more fully in chapter 4.

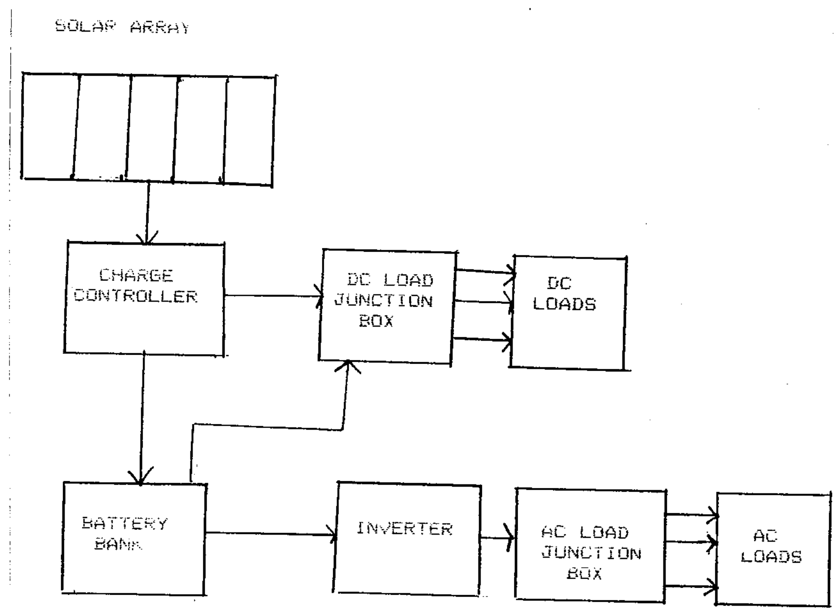



Figure 3.6 DC/AC Stand Alone System Flow Chart

### 3.5.4 PV-Grid DC/AC System

In a PV-Grid system a battery bank may or may not be used. If a battery bank is used it operates like the AC/DC Stand Alone System. It receives current produced by the array and follows the same path as the AC/DC Stand Alone from start to finish. If power is needed from the utility connection, to help supplement PV power, the current from the grid must travel from the grid towards the House load Center. If the system has a battery bank that needs charging and the PV array can not supply the charge the current from the utility will flow towards the DC-AC inverter. From the inverter the current flows through the line to the batteries were it is used to charge the bank.

If a battery bank is not used the system will run as previously described with the following exceptions. The flow from the array will travel towards the charge controller. From the charge controller the flow travels along a wire towards the inverter or to the DC junction box if DC loads need powering. At the inverter the current is transformed and passed along to the AC junction box where it is used to power AC loads. Power generated from the utility line will flow directly from the line into the AC junction box when needed. A PV/Grid home will be wired similar manner as a ordinary house and will function like one as well.

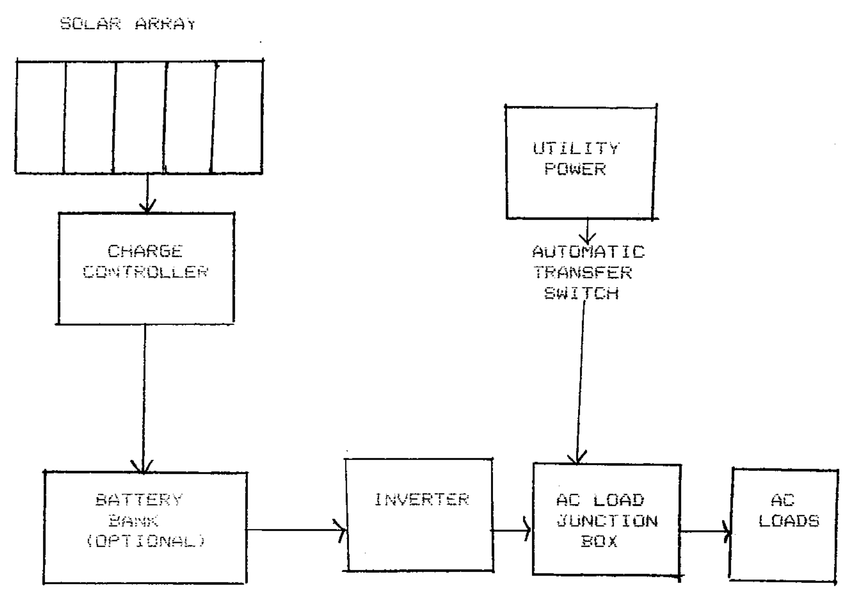



Figure 3.7 PV/Grid System Flow Chart

# Chapter Four

# The Components of a Photovoltaic System

### 4.1 The Photovoltaic System

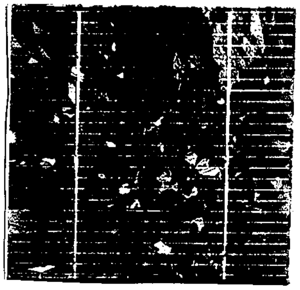
As stated earlier a photovoltaic system is not difficult to understand. The total PV system can be broken down into six components, which are listed below.

1. Solar Modules
2. Mounts
3. Charge Regulators
4. Batteries
5. Inverter
6. Wiring

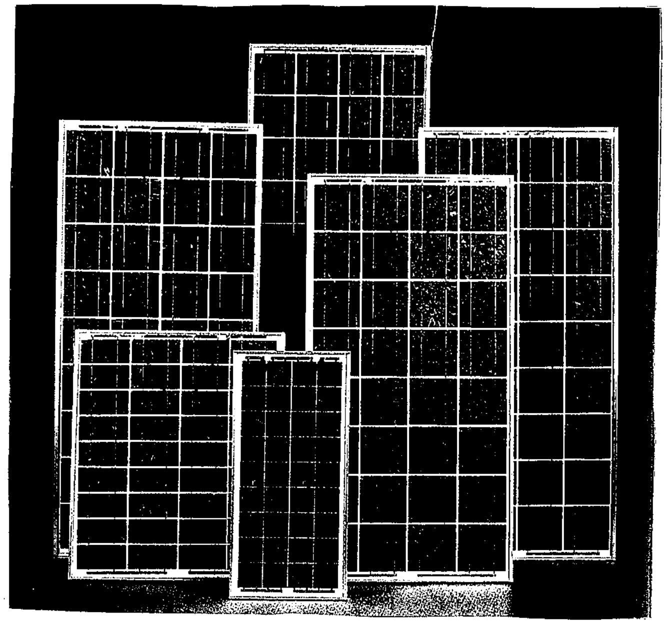
The purpose of this chapter is to give the homeowner some basic knowledge of these components and the role they play in a PV system.

#### 4.1.1 Modules

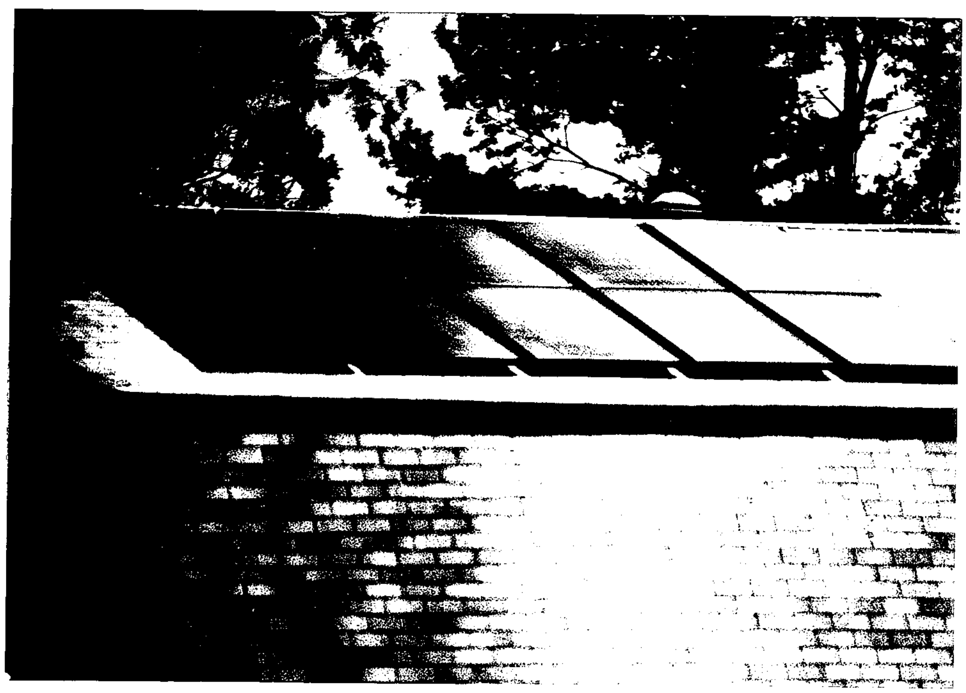
A photovoltaic module is a device that converts sunlight into usable electricity. A solar module is made up of smaller solar cells that produce approximately 0.5 volts of DC electricity. One-half a volt is a small voltage. In order to produce a usable voltage many of these individual solar cells are wired in series, when the cells are wired in series the voltage adds up. In a typical 12 to 16 volt module, 30 to 36 (approximately 0.5 volt), cells are connected in series. The combined solar cells are then incased in a strong sturdy frame and covered with a transparent covering, (i.e. glass, plastic), this is called a solar module. To produce a solar array two or more modules are connected in Series and/or Parallel. Figure 4.1 illustrates the differences between the solar cell, module, and array.



SOLAR CELL



MODULE



ARRAY

Figure 4.1 Solar Cell---------Module----------

The type of wiring of the modules, will depend on design requirements needed by the homeowner. If a homeowner wants to increase the voltage output of his array he will need to wire the modules together in series to receive the proper voltage. If the homeowner wants to increase the current output of the array he must wire the modules together in parallel. For example, a homeowner has determined that he needs a 24VDC, 9 Amp, rated PV array. The modules he plans to use are rated at 16V, 3.13 Amps. In order to receive the proper voltage and current the homeowner will have to wire the array in the following manner: two sets of three modules will need to be wired together in parallel (3.13 + 3.13 + 3.13 = 9.39amps) to receive the proper current output. Then the two (3 module) sets will need to be wired together in series (16 + 16 = 32V) to receive the proper voltage output, as is illustrated in figure 4.2.

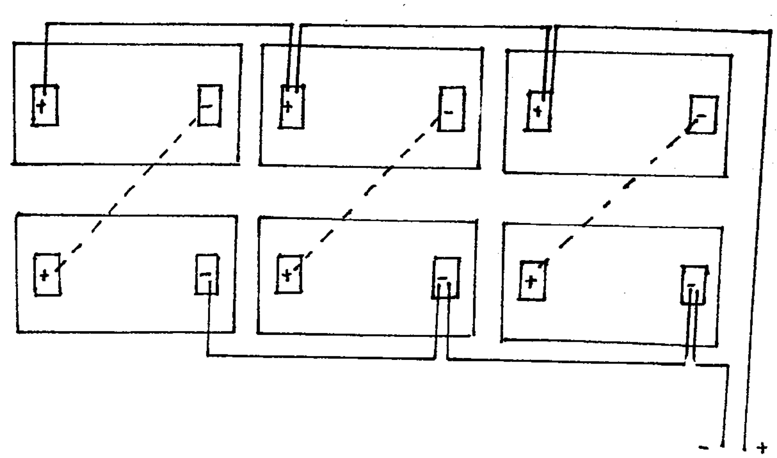



Figure 4.2 A 24 Volt (DC), 9 Amp Rated Array wired together in Series and Parallel.

Solar modules are sensitive to high temperatures. As the temperature increases the total voltage output, from the module, decreases. This factor is important in regions of high intense temperatures, such as the southwest. If your future or existing home is situated in a region subjected to high temperatures, this factor must be incorporated in the PV design. One method of compensation for the voltage lost due to high temperatures, is to use higher voltage modules in your array. Higher voltage (17V) modules are also sensitive to heat, their power output will decrease as higher temperatures are reached. However, the loss due to heat will be compensated for by the modules higher voltage rating and the modules will be able to provide the needed power output.

There are three standard modules on the market for homeowners, rated as 17, 16, 14.3 peak volts. Generally, a 17V module is used in areas with a hot climate as was previously discussed. A 16V module is used in areas with a moderate climate, like New England. The 14.3V modules are generally used only in the simplest PV systems, since their power output is not as high as the 16 or 17 volt modules.

### 4.1.2 Determining the Number of Modules Needed.

The number of modules required depends on the design of your photovoltaic system. If you are designing for a Stand Alone system that must meet all power requirements throughout the year, you will need a large system. If your design requires only enough electricity to power a summer vacation home, your system will be smaller than one designed for power production throughout the year.

As stated in the previous chapter, conservation of electricity is a key component to the size of your PV system. The more power you consume the larger the system you will need to design. The larger the system you design the more money it will cost. Stand Alone systems generally are very energy conscious to keep costs down. Some photovoltaic systems start out small and gradually increase in size as new modules are added.

Stand Alone PV system homeowners do not have the freedom to waste or overuse electricity as do utility connected homes. Stand Alone homeowners must watch their power consumption so that they do not run short of power. As stated in the previous chapter, homeowners must become the managers of their power plant, and good management means monitoring all power loads.

In a PV-Grid system, the homeowners are able to receive power not only from their PV system, but from the utility line as well. In this type of system the homeowner can start out with a small PV array used to help supplement their energy needs and lower their monthly utility bill. As money dictates they can add on until their PV system supplies most or all of their electrical needs. Their dependance on utility power can decrease to a point of little or no dependence. The homeowners can remain connected to the utility line and use it at times when extra power is needed. A PV-Grid homeowner has much more freedom to consume larger amounts of power. If their PV system cannot supply the needed power, the system will switch over to its utility connection, thus providing power for the needed load.

Determining the number of modules needed is not extremely difficult. One method of sizing has broken down the procedure into the four following steps:

1. Determining your daily power consumption and voltage requirements of the system.
2. Factor in losses due to wire resistance, battery efficiency, and inverter (AC power) efficiency.
3. Determine Array Peak Watts.
4. Determine Number of Modules Needed.

**Step Number One.**

To determine your daily power consumption you will need to determine the amount of power used by each appliance, and how long each appliance is used. The voltage of the system is determined by the voltage requirements of the appliances to be powered. For example, after completing an energy audit a homeowner checks his list to find the appliance with the highest voltage rating, and finds his water pump is the highest and is rated at 24V voltage. If the largest voltage to be power with the PV array is 24 volts than the voltage requirements of the system must be at least 24 volts and the array must be wired appropriately. Most PV systems are design to satisfy 24V or 48V requirements.

Chapter 5 will provide a more through step by step room audit example. For now, we will use 2000 kilowatt hours as the daily wattage consumed by a household.

**Step Number Two.**

In a PV system there are loses due to wire resistance and equipment inefficiencies. These losses must be factored into your design so that your power requirements will be met. Resistance in the siring contributes a 2.0% loss. Battery efficiency is generally 80%, and inverter efficiency is generally 90%. Using the 2000 KWHr daily consumption from step one you can determine the daily watt hours with the system losses factored in. This is accomplished with the following equation:

**Step 2. Example**

---

Watt Hour (step 1.) x 1.02 (Wire resistance) x 1.25 (Battery efficiency) X 1.11 (Inverter efficiency) = Adjusted Daily Watt Hours.

EX. 2000 KWHr X 1.02 X 1.25 X 1.11 = 2831 Adjusted Watt Hours.

---

**Step Number Three**

The third step determines the number of peak watts that the array must produce in order to meet the homeowners power requirements. The array peak watts is the number of watts the array will produce within a given period of time. The array peak watts is determined by dividing the adjusted watt hours (step 2) by the number of peak sun hours. The number of peak sun hours will depend on what type of system you are designing for. If you are designing for a Stand Alone system where power conditions must be met in the worst case conditions the number of peak sun hours will be the shortest peak hour time for your geographic area. To find the peak hours for your geographic area please refer to Appendix (A). For example, (using Appendix A), for Boston Massachusetts with an array tilted at latitude + 15 degrees the number of peak sun hours per day (worst condition) is 2.33 in December. If you are designing a system for a vacation home visited in the summer only the peak hours may be 5.7 hours, and again it will depend on the location of the home. For the proceeding example we will use 5.7 (summer) peak sun hours.

**Step 3. Example**

---

Adjusted Watt Hours (Step 2.) / Peak Sun Hours = Array Peak Watts

EX. 2831 Watt Hours / 5.7 Peak Sun Hours = 496 Array Peak Watts

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**Step Number Four**

The fourth step will determine the number of modules you will need to purchase to meet your power requirements. This is accomplished by dividing the Array Peak Watts by the Module's usable wattage. For this example we will use 16V, 3.13 amp, 50 Watt rated modules, and at least two modules will need to be wired together in series to produce the proper voltage. However, the actual voltage used from each module (for a 24VDC system) will only be 12 volts. The decrease in voltage output is due to the 24V voltage requirement. If two 16 volt modules are wired in series they can produce up to 32 volts of electricity. However, if the system is designed to supply a maximum of 24 volts, than only 24 volts out of the 32 volts produced will be used. Therefore the usable wattage output per module will be 12V x 3.13amps = 37.56 watts.

**Step 4. Example**

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Array Peak Watts (Step 3.) / Module's usable wattage = Number of Modules Needed

496 Array Peak Watts / 37.56 Watts = 13 Modules needed*

* Round up to 14 (16V, 3.13 amp, 50 watt rated modules).

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### 4.1.3 Comparing Modules

When the homeowner is ready to purchase PV modules it is wise to shop around and compare output ratings and prices. When comparing different modules follow some simple guidelines. If you are looking at only one type of module, (i.e. 16 volt), compare the maximum power point amps of each module in question. The maximum power point is the most efficient operating point for the module. Make sure the same standard conditions, ($KW/m^2$ @ 25 degrees Celsius), applies to all the modules in question. Also look at the IV (current-Voltage) curve of the modules. The IV curve is a graph that shows the relationship between the current and voltage. Keep in mind that the IV curve is just general information and not determined from exact information. All of this information can be found on the module's specification (spec) sheet.

Also listed on the spec sheet, are the types of materials used in constructing the module. The material used to cover the cells in the module should be strong enough to protect the fragile cells, and be transparent to allow as much sunlight through as possible. Flexible covers are made however, their ability to protect the solar cells is limited. The framing material is also listed on the spec sheets and should be considered. Common framing materials are wood, steel, aluminum, and anodized aluminum. When choosing a module look at the framing material and think of what type of maintenance program with which you wish to be involved. Wood looks nice. However, it needs regular protection from the weather. Steel can rust unless properly treated, and aluminum can pit and corrode if not treated properly. Homeowners should choose a module that will best suit their needs. The ultimate module should be well made, airtight, strong, weatherproof, long lasting, attractive, and require little or no maintenance. Many modules have 10 year warranties and last much longer with no maintenance needed.

### 4.1.4 Connecting Modules in Series and in Parallel

Once the proper number of modules have been determined their array installation should be determined. As stated in a previous chapter, if you need a larger voltage you would connect the modules in series. If you need a larger current would connect the modules in parallel. The same is true with the modules. If you want to charge a 24 volt battery bank and you have purchased 16 volt modules you would need to connect two of the 16V modules in series so that the battery bank would be charged properly, (16V + 16V = 32 V which is greater than 24 V. However, only 24V will be used.). If you wish your array to produce approximately 6 amps of current and your modules are rated at 3 amps each, you would need to connect two modules in parallel, (3 Amps + 3 Amps = 6 Amps).

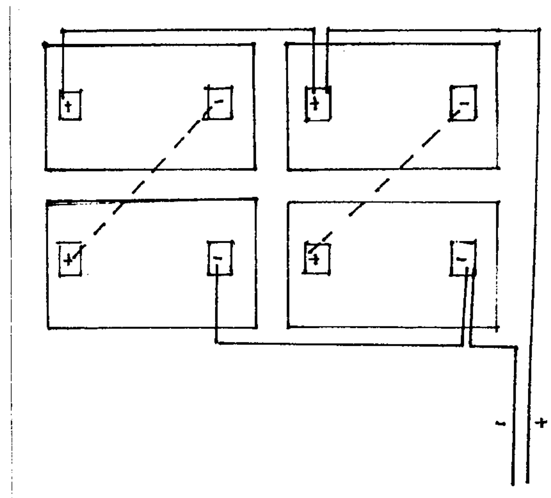


Figure 4.3 A 24V, 6Amp Array Wired in Series and in Parallel.

Each array design will be different and will depend on your own personal power requirements. Standard appliance do not give much flexibility but energy conservation will.

## 4.2 Mounting your Arrays

### 4.2.1 Introduction

Photovoltaic arrays can be mounted on a pole, the ground, the side of a wall, the roof, on a tracker or any other useful safe spot that receives plenty of direct sunshine. The best orientation to mount the modules is in a location that allows the sun's light to strike the module's surface at a 90 degree angle. When light hits the surface of the modules at a 90 degree angle the modules are able to produce their peak watt rating.

Determining the proper mounting that will provide optimum power output, will depend on the homeowner's needs and the size and location of the property. If the homeowner is using his PV system to supplement his current electrical needs, as in a PV-Grid System, the homeowner has more flexibility in choosing a mounting site and method. They can choose from any one of the four mounting methods to install their array.

Most PV-Grid homeowners roof mount their arrays. A roof mounted array conforms to the slope of the roof. This type of mounting offers a low array profile, meaning that the modules are not at variance with the roof, and can actually enhance the house's appearance. Roof mounts seem to blend in with the roof, they do not take up any yard space, and they require little or no maintenance or adjustment.

This is the case in Gardner Mass. where a 2.2 KW system was installed on each of thirty homes. The arrays are mounted on the roof in a stand-off method, which allows air circulation for array cooling and yet looks to be integral with the roof, and are at an angle of approximately 23 degrees above the horizontal. This mounting angle, which was determined by the roof slope, allows for maximum power production in the summer months. In fact in this community, the homes produce an excess of power in the summer. The excess power is in essence purchased from the homeowner by the power utility at billing price per Kwh, and used to power other residential homes without the benefit of solar PV. The Gardner system was designed as a experiment. The arrays where mounted so that no maintenance is required and the homeowner's lifestyles were not affected or altered in any way. Chapter 8 and 9 discuss the Gardner project more completely.

A vacation home used at only one particular time of the year can also be designed with some flexibility. If the PV system is designed to power a home during the summer months the system can be roof mounted in a fixed angle position that offers the maximum power output for that season. For the summer months the angle of the array will be flatter with the sun nearly high overhead. Since the sun is higher in the sky during the summer the flatter tilt of the array will allow the light to strike the surface of the modules at approximately a 90 degree angle during the day. The angle of tilt will depend on the latitude of your site. For the winter months the angle of the array will be more vertical to accommodate the sun's lower position in the sky. Again, this tilt will depend on the latitude of the site.

Stand Alone systems that must have all power requirements met throughout the year do not have the same freedom as the previously discussed systems. This type of Stand Alone system must try to capture as much sunlight throughout the day as possible. This can be accomplished by using tracking or adjustable mounts. This type of mounting is not low profile. However, the sunlight received will be greater than the low profile fixed arrays and the power produced will be greater as well.

### 4.2.2 Tracking Mounts

Tracking mounts track the path of the sun throughout the course of the day. Trackers are the most productive of all the different array mounts. They are able to increase the output of the array by 50% in summer, 30% in spring and fall, and by 10% in the winter.

There are three different types of trackers including, active, passive, and manual. An active tracker is driven by a motor. An active tracker is a very efficient system. However, since it is motor driven it must use some of the power it is collecting in order to operate. Since it has a motor with moving parts, an active tracker may need maintenance or repair.

A passive tracker is not driven by a motor. The frame of a passive tracker contains two tubes on either side that contain freon. Above the tubes are metal wings that cast a shadow on the tubes when light strikes them at an angle. Freon has a very low boiling temperature. If one tube is shaded and the other is not, the freon in the unshaded tube will boil. The gas produces from the freon boiling will travel over to the other tube. The extra weight in the shaded tube will cause the tracker to rotate slowly about its axis. This will continue until the tubes are equally shaded and the modules are facing the sunlight directly. As the sun tracks across the sky during the day, shadows are produced along the tubes which in turn causes the tracker to follow the path of the sun throughout the day.

Manual tracking takes effort on the homeowner's part. If the location of the array is easily accessible, then the homeowner can manually adjust the mount throughout the day. This could only be accomplished if the homeowner was home throughout the day and willing to make periodic adjustments.

### 4.2.3 Pole Mounts

A pole mount is an array that is mounted to a pole. The array can be placed on the top of the pole and be locked into place, at various angles, with the used of locking nuts. The pole should be securely fastened to the ground or structure to prevent it from being blown or knocked over.

### 4.2.4 Ground Mounts

Ground mounts are very accessible and easy to install. Most ground mounts are adjustable, due to their accessibility. The homeowner only has to adjust the array mount four times a year to improve the power output of the array during each season. The disadvantage of a ground mount is that there is an increased chance that damage might occur to the modules from falling or flying objects.

Snow coverage does not create a problem with ground mounts in New England. In New England, the tilt of the array should be at least 45 degrees above the horizontal and would allow for any snow coverage to slide off. PV Ground mounts in snow areas, such as New England, can even benefit from the snow coverage. If the array is tilted correctly, in a more vertical position, the array can receive an additional 15% more solar insolation due to the reflection of sunlight off the surface of the snow. The only problem that can occur in snow belt regions is ice, which can cover the arrays and not slide off, thus decreasing the array's power output.

### 4.2.5 Roof Mounts

Roof mounts are the most common of all the mounting systems. As stated in a earlier chapter you do not have to have a roof that faces directly south. This factor allows many homeowners with roofs oriented in directions other than due south, to take advantage of a roof mounted PV array. Roof mounted arrays can be fixed or adjustable. Fixed mounts are convenient because once they are installed the homeowner does not have to handle them again unless a problem occurs. Adjustable roof mounts produce more power then a fixed mount. However, adjustable mounts require the homeowner to climb onto their roofs to make the adjustment, which can be dangerous and annoying.

There are four different types of roof mounting, which include rack mounting, stand-off mounting, direct mounting, and integral mounting. Rack mounting requires sturdy racks to be used as mounts to support the PV array. Solar Hot Water Heater mounting attachments can be used and will be strong enough to support the PV array. Rack mounts are generally adjustable and used to optimize the amount of sunlight received during each season. Rack mounting should be kept as simple as possible to ensure easy installation. A PV array can last up to twenty or more years. Unfortunately, most roofing shingles will not last that long and will need replacing. This factor should be considered when installing a rack mount. If the array mount is easy to install, it should be easy to remove and easy to re-install once re-shingling or roof repair has been completed.

Stand-Off roof mounts are attached to the roof with an air space of approximately three inches between the array and the roof. Unfortunately, with roof mounts the slope of the roof may not allow the best angle for the PV array. When installing a Stand-Off mount sufficient spacing at, least three inches, should be left between the roof and array to allow for proper air flow. Air flow is important in keeping the modules cool so that they will operate properly. Like rack mounting, stand-off mounts should be easy to install in case they need to be removed. The arrays used on the homes in Gardner Mass., were installed with a stand-off mounting system. The attachments used to fasten the arrays to the roofs were specially designed for the project and allowed two men to install each array in approximately two hours. This low cost mounting system is very impressive and is discussed more fully in chapters 8 and 9.

Integral mounting is incorporated into the roof as part of the roofing material. The original hope of integrating the modules into the roof was to lower the cost of construction. The modules would take the place of roof sheathing and shingles, thus lowering costs. However, the modules used in this type of mounting must be very durable not only for weather conditions but for structural conditions as well. Since a PV array is subjected to cold and hot temperatures changes, the modules will shrink and expand accordingly. This changing in size of the modules can cause leakage problems when integrated into the existing roof, and therefore may not be a good choice due to the possible problems that could occur.

Direct mounting allows the modules to be used in place of shingles and provides a low profile array system. This type of mounting lowers construction cost some. However, there is no air flow space between the roof and modules to allow for cooling. This can cause a decrease in power production when the modules become too hot and overheat and might reduce the life span of the modules.

### 4.2.6 Array Angling

Adjustable PV array mounts should be adjusted four times during the year. The adjustment generally takes place during the beginning of each new season. Each adjustment will allow a maximum amount of sunlight to reach the PV array and in turn increase the array's power production. In the spring and fall the angle of the array to the ground should be equal to the latitude of the area. In the summer the angle should be equal to the latitude of the area minus 15 degrees, and in the winter the angle should be equal to the latitude of the area plus 15 degrees. With each adjustment the angle of sunlight striking the array will be closer to 90 degrees.

For a Fixed mount used year round, the array should be set at an angle equal to the latitude of the area plus 15 degrees to receive the maximum solar insolation during the winter. This fixed position will provide maximum power during the winter months however, during the summer months the array's full power rating will not be utilized. Luckily the number of useable sunlight hours is greatest in the summer months, which allows the array to produce the home's needed power requirements.

### 4.2.7 Grounding your Array

All array modules must be properly grounded for correct installation and to protect against power surges due to nearby lightning strikes. It is a good idea to refer to the National Electric Code and to talk with your local building and/or electrical inspector concerning grounding. The importance of grounding cannot be overstated.

When you ground something to the earth, you are lowering the grounded electrical system to a voltage near the earth's potential. Ungrounded electrical systems can have their system's potential increased. When this happens the system can spark, cause arcing, and can be hazardous. The grounding will protect homeowners from being shocked by allowing energy to easily flow to the ground through a wire, and not through a person which could be fatal.

## 4.3 Charge Controllers/Regulators

### 4.3.1 Why Regulate the Charge?

Voltage regulation provides good protection for the PV system and for the components. Regulating the voltage from the PV array protects the batteries from being overcharged. Overcharging the batteries may not be a problem in the winter, but it will be a problem in the summer, due to the increased hours of useable sunlight. Overcharging the batteries may sound like a good idea. However, overcharging the batteries should not occur unless you are equalizing the battery bank. Equalizing the battery bank is a slow controlled charge that helps restore the battery bank back to full capacity. An uncontrolled overcharging of the batteries can cause the water in the batteries to boil off. If this happens the missing water would need to be replaced, requiring additional maintenance. In a worst case scenario the batteries could be permanently damaged and would need replacement, which would be costly. Therefore, the need to regulate the voltage is important and necessary.

### 4.3.2 Regulators

A charge regulator is a device that regulates the voltage from the PV array. By regulating the voltage the charge controller protects the battery bank. The main function of the charge controller is to prevent the batteries from becoming overcharged. Some even protect the batteries from becoming overdrawn. In both cases, the regulator is helping ensure that the battery bank has a long useful life.

There are two types of regulators. The first is a shunt regulator. Shunt regulators use a transistor to control the flow of current from the array. If an excess amount of current is being produced the transistor can divert the current to a ground through a resistor bank, switch it to another load, or it can be given off as excess heat.

A Series regulator incorporates a transistor or relay, to control the current. They work in the same manner as shunt regulators by diverting the excess charge away from the full battery bank, thus providing overcharge protection.

Some regulators have what is called a trickle charge mode. The trickle charge mode diverts most of the current away from the batteries when full. However, the trickle charge mode does allow a small amount, approximately 1% to 5% of the battery bank's ampere hour capacity, to flow through to top the batteries off.

### 4.3.3 Self-Regulating Systems

Some PV systems can eliminate the need for buying a control regulator. These systems are generally small, using modules with approximately 30 cells and rated at a low voltage (14.5 Volts). A self-regulating system works in the following manner. If the Battery Bank is low the current from the array will recharge the batteries. As the state of charge increases the current provided by the array will decrease, thereby preventing the overcharging of the system's battery bank. A Self-regulating system sounds very appealing. However, certain standards must be met. First, you must have the correct battery size. Secondly, a self-regulating system must be used on a regular basis to prevent the batteries from becoming overcharged. If the homeowner wants to install a PV system at a vacation home, visited occasionally, a self-regulated system would not be appropriate. The last condition is the size of the system it must be small, approximately under 100 watts.

### 4.3.4 Blocking Diodes

A blocking diode is a device that prevents the current from flowing back into the array. This reversal of flow will occur when the voltage from the array is less than the voltage from the battery bank. Blocking Diodes inexpensive and add an additional safety feature to the PV system. Blocking Diodes stop the reversal of current flow within the system, but will allow easy current flow when the array is delivering current.

### 4.3.5 Comparing Regulators

A homeowner should compare different regulators produced by different manufactures to see what each manufacture has to offer. Many manufactures offer a variety of options. Check the features listed on the specification sheet and see if they match your present and future needs.

### 4.4 The Battery Bank

#### 4.4.1 Its Function.

A battery is a device that stores electricity produced from the PV array as DC power. Storing this electricity becomes useful at night, when the PV array is no longer producing power. At this time, the stored electricity can be taken out of the batteries and used to power loads. The battery bank, unfortunately does not supply an endless amount of electricity. A battery bank is capable of storing only the amount of electricity for which it was designed. Unfortunately, losses occur within the battery bank. The amount of retrievable electricity is less than the amount originally stored. This factor must be taken into consideration when designing the system's battery bank.

#### 4.4.2 Is a Battery Bank Necessary?

The necessity of a battery bank depends on what loads you want to operate with the power produced by the array and during what time of the day. Simple systems used to power fans, some water pumps, and other temporarily powered devices do not need a battery bank. However, these devices will not operate when the PV array is not producing power, from sunlight, which occurs nightly and on cloudy days. If a stand alone home wants to operate electrical loads during cloudy weather or at night, a battery bank must be used.

### 4.4.3 Different Types of Batteries.

There are many different types of batteries including primary batteries and secondary batteries. Primary Batteries are used once then are thrown away. A flashlight battery is an example of a primary battery. Secondary batteries are rechargeable and re-usable. Photovoltaic systems use secondary batteries to store power so that it can be used later when needed. There are different types of secondary batteries. A car battery is a secondary battery used to help start the engine of a car by providing a short spurt of electricity. Once the engine has started the battery stops supplying electricity and is recharged as the engine is running. Car and truck batteries are not good batteries to use in PV systems. Car batteries only have a rating of 10% depth of discharge for about 200 cycles. A cycle is one full trip following the sequences of operation and is presented in the following diagram.

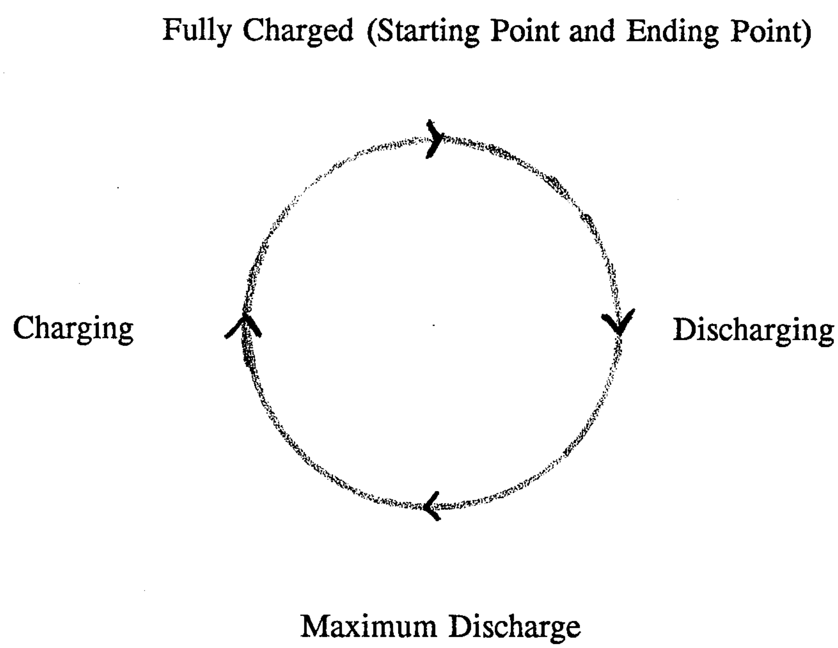


Figure 4.4 One Full Battery cycle

A good deep cycle battery usable for PV systems is designed to withstand numerous cycles of deep discharge. The depth of discharge (DOD) is the amount of electricity that has been taken out of the fully charged battery. A 20% depth of discharge means 20% of the electricity has been taken out of the battery. A good analogy is the following: You use a bank to store your hard earned money. Say you deposit $100 into a savings account. At a later date you withdraw $20 or 20% of your total savings. The same is true in a battery bank. You store electricity in your battery bank to be withdrawn at a later date. The more you withdraw the greater the depth of discharge.

A full battery (100% charged) can be discharged to a very low point. However, this is not a good idea. As the depth of discharge increases the life span of the battery bank decreases. It is a better idea to discharge the battery bank only 20% to 40% before recharging. This will increase the life span of the deep cycle batteries. Some may ask why do this? The answer is money. Deep cycle batteries are expensive. If you run them "dry" each time they are used, they will not last as long as when you only skim their surface. Discharging your battery bank only 20% to 40% will save you from buying a new set of batteries for another 4 to 6 years. This can increase the life span of your bank from approximately 6 years to 12 years.

### 4.4.4 Battery Voltage and Amperage Rating, Wet and Dry State, and Temperature Factors.

Batteries are often referred to by their voltage and amperage rating. The voltage of the battery is determined by the number of cells that are connected in series within the batteries' chamber. Each cell equals 2 volts therefore, a 6 volt battery has 3 cells and a 12 volt battery has 6 cells. Batteries can also be referred to as wet or dry. A wet battery is completely filled with the proper electrolyte solution and is ready to use if fully charged. A dry battery is a battery that needs to have the proper electrolyte solution added and needs to be fully charged before installation. The wet or dry state of a battery is important to know. As soon as the solution is added to the battery, the battery begins to age. If the battery has been in the wet state for a long period of time it will not last in the battery bank as long as freshly purchased dry batteries.

Temperature is another important factor to consider when using batteries. In very hot temperatures the batteries' capacity will increase. However, the life span of the batteries will decrease. In low temperatures, the capacity will decrease and the life span will increase. The ideal temperature range for a battery bank is between 60 to 70 degrees Fahrenheit, (16 to 21 degrees celsius). Temperature, climate, and potential use are all factors that are considered when sizing a battery bank. The temperature factor is listed in Appendix (A) and is used when sizing your battery bank. When sizing a battery bank you must determine whether or not the batteries will be subjected to fluctuations in temperature outside the 60 to 70 degree Fahrenheit range. If fluctuations do occur, choose the temperature that best describes the condition and find its corresponding factoring number. This number will then be used in the battery bank sizing.

### 4.4.5 Installation - Series and Parallel Connections

Care should be taken when installing batteries. Charged batteries can be a hazard because there is a lot of stored energy in them, they are very heavy, and contain acid. During the installation process try not to tip the batteries more than 25 degrees, this will help prevent the acid in the batteries from spilling. Also, it is not a good idea to store the battery bank on a cool concrete floor. The colder floor temperature will lower the capacity level of the batteries. The best place to store the batteries is on a temperature resistant surface, such as strong wood shelves, and in a separate room with plenty of ventilation.

When you are ready to connect your batteries together, make sure that the battery bank is disconnected from the PV array. Connecting to the PV array is the last step in the installation of the battery bank. All battery connections should be made with the proper wiring.

### 4.4.6 Battery Bank Sizing.

The size of your battery bank will depend on your power needs. As the amount of power consumed increases the number of batteries needed to supply that power will increase as well. The first step in sizing your battery bank is determining the watt hours used during the day. The number of days of autonomy (Multiplier Found in Appendix A), temperature fluctuations (Factoring Numbers Found in Appendix A), and the level of discharge will also need consideration when sizing a battery bank. Factoring temperature fluctuations and Depth of Discharge were discussed previously. The number of days of autonomy is the number of days your system should be able to supply power, from the battery bank, during bad weather. This is also referred to as the Multiplier Factor and can be found in Appendix A. A sizing example will be discussed more fully in chapter 5. For now, we will use 200 watt hrs/day as the daily power consumed by a household as an example. The batteries to be used are rated at 6 volts, 200 amphours, and the discharge level is 40%. When sizing a battery bank the following formulas can be used.

Formula 1. WHrs per Day / Battery Voltage rating = Amphrs/Day

Formula 2. (Amphrs/Day (formula 1.) x # days autonomy / DOD)/Battery Amphr rating = Number of Batteries needed

Example: (Using the above listed formulas)

Formula 1. 200 whrs/day / 6 volts = 33.3 amphrs/day

Formula 2. ((33.3 amphrs/day x 7 days) / .4 DOD)/200 amphr battery rating = 2.91 batteries needed*.

*(Round up to 3 (6V) batteries)

The number of amphrs that the battery bank needs to produce is equal to the (amphrs/day x # of days of autonomy / Depth of Discharge rate). Using the above example, (33.3 x 7 / .4) = 582.7 amphrs needed from the battery bank. In order to produce this amount of current, three 6 Volt batteries will need to be connected in Parallel. When batteries are connected in parallel the current adds up and the voltage remains the same. Therefore, with our example, the potential current in the battery bank supplied by connecting 3 - (200 amphr batteries) in parallel will equal 600 amphours.

To wire batteries in parallel you need to connect the negative terminal of the first battery to the negative of the second terminal and so on. You also wire the positive terminals in the same manner. Figure 4.6 a) is a diagram of batteries wired in parallel.

Most PV battery banks are wired as 12 volts or 24 volts, large systems can be 48 volts and up. In order to achieve the correct voltage for your battery bank you would need to connect the batteries in series. Series connections result in the voltage from each battery adding up. Therefore, for a 12 volt battery bank using 6 volt batteries the homeowner would need to connect two 6 volt batteries together in series. A series connection is made by wiring the opposite terminals of the batteries together. Figure 4.5 b) is a diagram of batteries wired in series.

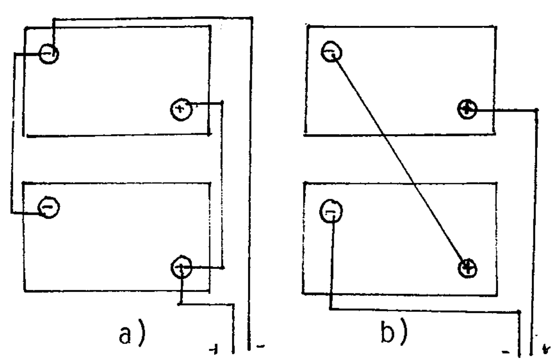


Figure 4.5 a) Batteries wired in Parallel; b) Batteries wired in Series

As stated before, most systems start at 12 volts and work their way up. If we use the previous example, a 12 volt 600 amphr battery bank would require 6 - 6 volt batteries. In order to achieve a 12 volt 600 amphr battery bank, you would need to connect two sets of three (200 amp rated) batteries together in parallel, and then connect the two sets (of three batteries) together in series. Figure 4.6 is a diagram of a 12 volt 600 amphr battery bank.

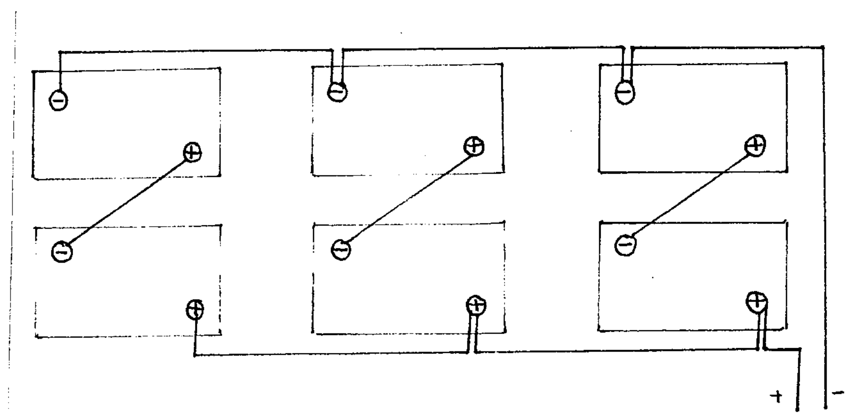


Figure 4.6 A 12 Volt 600 amphr Battery bank wired in Parallel and in Series.

### 4.4.7 Battery Housing

Housing your battery bank in a proper location will help ensure a long battery bank life and minimized some of the dangers associated with batteries. As stated earlier batteries are sensitive to temperature. The battery bank housing should be kept between

60 to 70 degrees Fahrenheit if possible. The location that is housing the batteries, should be large enough to provide proper storage and working space if needed. The room should also be well ventilated to disperse any hydrogen that may be produced from the batteries overcharging.

Proper ventilation can be accomplished in a variety of ways. Batteries can be stored in a ready made box with a venting tube that exits to the outside. If a battery box is not used then the area should be large enough to disperse possible hydrogen build up. Opens at the bottom and top of the door to the battery room is recommended. It is also recommended that the room have a vent near the ceiling that opens to the outside. The homeowner should never store the battery bank in a room with an open flame or with equipment that sparks. Again, this is due to the possible hydrogen build up.

The location of the battery bank should be in a central location with respect to the junction boxes, inverter, etc. Placing the battery bank in a central location also helps cut down on the wiring. Since the battery has enough stored energy to melt metal objects, it is a good idea to cover the top of the batteries. This will help prevent any unwanted objects from falling on top of the batteries and causing damage.

Good common sense should be used when storing, using, or working with your battery bank. Listed here for your convenience are a few Battery "do's and don'ts". 1. Remember to store batteries off concrete or dirt floors. 2. Batteries are heavy so make sure that the shelves are strong enough to support the battery bank. 3. There should be no standing water in the room and a constant room temperature should be kept, if possible. 4. Enclose the battery bank, if possible, to prevent dust build up and objects from falling on top on the battery terminals. 5. The location of the batteries should be easy to get to if needed. 6. There should be no open flames or sparks in the room. 7. Keep all unwanted animals, children, and adults out of the room by locking the room's door or posting a large sign indicating the room is off limits. 8. Make certain that the space is well ventilated to disperse hydrogen fumes.

### 4.4.8 Comparing Batteries

When the homeowner is ready to purchase a battery bank it is recommended that the homeowner compares different batteries and determines their pro's and con's. New batteries are a better choice than used batteries. Used batteries can be unreliable unless you know that the previous owner took good care of them, but there may not be much of a life cycle left in them. Homeowner should try not to mix and match batteries of different ages or quality. When batteries are hooked up to a battery bank, the best batteries will work only as good as the worst battery in the connection. If the homeowner purchases new batteries of equal quality the battery bank will operate more efficiently.

Batteries can be sold as wet or dry. As stated earlier a wet battery already has the electrolyte solution added. This eliminates the need to fill the batteries. The disadvantage to wet batteries is that a battery starts to age as soon as the electrolyte has been added. If you are purchasing wet batteries check the manufacturers date and how long they have been in the wet state. A dry battery has not had the electrolyte solution added. Dry batteries are fresher then wet. However, you will have to add the electrolyte solution and charge them before installation. When purchasing dry batteries it is a good idea to check the manufacturers date. Whether you are buying wet or dry batteries try to purchase them within the first six months of manufacturing.

Maintenance free batteries can be used in PV systems. These batteries have been filled and sealed prior to purchase. They need no additional water and will not gas if charged at no more than their maximum charging voltage and current. However, if your charge controller fails and overcharges, maintenance free batteries will gas. Since they are sealed there is no way to add additional water. Another shortcoming of maintenance free batteries is that they need to be recharged fully within a few days after being discharged. This is not a problem during the sunnier summer months. However, in the winter, long stretches of cloudy weather are not uncommon. During long stretches of cloudy weather the battery banks cannot fully recharge. Maintenance free batteries do not work well in this type of condition.

Industrial Deep Cycle batteries can also be used in PV systems. One thing to consider is that they are made to order and are more expensive than the standard deep cycle batteries.

Standard deep cycle batteries used by the telephone company, golf carts, etc. are the most widely used battery in PV systems. The standard deep cycle battery will require some periodic maintenance such as cleaning or equalizing. A good deep cycle battery is very reliable and will have a long life if properly maintained. The average life of a good deep cycle battery bank is approximately 6 years. If the homeowner provides proper housing, maintenance, and a depth of discharge no greater than 40% the average life span of the battery bank can increase to approximately 12 years.

When you are ready to purchase your batteries do a comparison by looking at different manufactured brands. While doing a comparison make sure the same standard conditions apply to each battery in question. Compare the amphrs of the batteries and look at the batteries' specification sheet for details. Check the number of cycles it is capable of handling and its recommended depth of discharge. If the cycling is not listed check the inner plate thickness. The thicker the plate the more cycles the battery is capable of handling. If the plate thickness is not available look at the weights of the individual batteries. As the thickness of the plates increases so does the weight of the battery, which will indicate a greater number of cycles. It is also recommended to the homeowner that they talk to their local battery dealer or PV supplier for additional battery information. The type of battery bought by the homeowner will vary according to their own personal needs.

### 4.5 Inverters

#### 4.5.1. Their Function.

An inverter is an electrical device that changes low voltage DC current, stored in the batteries or generated from the PV array, into high voltage AC current. If a PV system is designed to power only DC appliances/lights an inverter is not needed. However, many household appliances, lights, and tools require AC current in order to operate. PV systems that operate AC loads will need an inverter. When designing a PV system it is always a good idea to design your system so that you can eventually power

AC loads.

### 4.5.2 Inverter Current Patterns

There are three different types of inverters. The square wave inverter transforms DC current into a fluctuating square wave pattern. This type of wave is suitable for some loads, but certainly not suitable for equipment requiring a pure sine wave. The second type of inverter produces a stepped up or modified square wave. The wave produced by this inverter more closely resembles the sine wave produced by the utility power plant. Some appliances are designed to function on current that resembles the sine wave pattern produced by the utility company. If the homeowner owns any such appliances they will need to purchase a modified inverter. The most expensive inverter is the sine wave inverter. The wave produced from this inverter matches the wave produced by a utility company. Some sensitive test equipment will only operate with current that fluctuates in sinusoidal pattern, and would require a sine wave inverter to operate.

### 4.5.3 Inverters and Sizing

The size of the inverter will depend on your maximum combined AC load. Generally combining the water pump power surge and the washing machine power surge will give you the largest combined AC load. The size of the inverter should be able to withstand power surges up to four times greater than your maximum combined AC load. There is a difference between a the initial power surge and the power required to operate the appliance. A power surge is a brief increase in current flow to initially start the appliance. Normal operating power is the wattage needed to run the appliance after it has been initially started. The greater the power surge requirement the larger and more costly the inverter. The homeowner can decrease the size of the inverter by using as many appliances as possible that run on DC current, including lighting. The homeowner can also decrease the size of the needed inverter by not running large power consuming appliances at the same time. By managing the times appliances are running it is possible to decrease the combined AC load down to one large appliance instead of two or three. It should be noted, that if you plan to operate a large power consuming tool or appliance with your PV system, you will have to purchase an inverter that can handle the load properly.

There are a variety of inverters on the market with numerous options. Cascading or tandem inverters are capable of combining their load ratings together to supply a large load. This is handy if you want to power an occasional large load, but do no want to buy a large inverter. Cascading inverters will combined their power ratings to meet the power surge requirements. For example, if you wish to power a load that requires 5000 watts but do not want to purchase a 5000 watt inverter, you can purchase two 2500 watt cascading or tandem inverters. When the 5000 watt load is needed, the two inverters will combine their ratings together, (2500 + 2500 = 5000), to meet the load requirement.

Digital sine wave inverters can also be used in a PV system. They produce a sine wave and can power just about any tool, appliance, or piece of equipment. They are also very efficient.

Rotary or motor inverters have a motor that runs on a alternator. Rotary inverters produce a fluctuating sine wave current. They are very durable but have a lower efficiency rating. Most good inverters are rated between 90% to 95 % efficient. A motor inverter is approximately 65% efficient. Their lower efficiency comes from being rotating machinery.

### 4.5.4 Inverter Options

There are a variety of different option that are available and may be incorporated into the inverter. If the homeowner's PV system is going to be connected to the utility grid the inverter used must have a safety shut down option. When a PV system is connected to the utility grid, extra care must be taken to protect linemen. If the power in the utility line is shut off, and linemen are prepared to work on that line, it is imperative that your PV system does not send power back into the grid. The inverter must be able to detect the power failure in the utility line and prevent the power from the PV system from flowing to the powerless line. The inverter must also be able to detect the return of power in the utility line and must be able to reconnect the PV system and function as before.

If your system is a stand alone system an important option is the load demand feature. An inverter that is installed in the system consumes between 8 to 40 watts, even if it is not powering a load. The load demand option lowers the amount of wattage consumed by the inverter when it is not in use, down to 1 to 4 watts. Over a long period of time the amount of power saved with this option adds up.

There are a variety of other options that have not been discussed. When a homeowner is shopping for an inverter he should review the spec sheets and see what options are included in the inverter. The homeowner should always choose an inverter that will power his current and future needs as well.

### 4.6 Wiring

The purpose of this section is to offer the homeowner an introduction to the importance of wiring. This section only covers some of the basics and should not be used as a guideline. It is recommended that the homeowner consult with an electrician on home wiring. There are also a variety of Do-It-Yourself Wiring Books on the market written by qualified professionals.

The wiring of the PV system ties all the components together. The voltage produced from a PV system is low voltage. Since it is low voltage the wire needed to carry the current, from the array to the batteries or DC loads, must be larger than standard AC current carrying wire. Current produced from utility power plants is AC current at high voltage. AC current is able to travel longer distances on smaller wires with less resistance because of the higher voltage and lower current. If DC current was transferred through the utility lines the wires would have to be very large in order to compensate for the power losses due to resistance to the higher DC current.

Since the current produced by a PV system is low voltage DC but high current, it is important that you plan the location of your system to minimize wire losses. It is helpful to keep the battery bank as close to the array as possible. If your home has not been wired it is important to wire for both AC and DC current. Even if you initially plan to use loads that require only DC current, eventually you may want to include AC in your system. Both the AC and DC circuits will be wired separately. It is very important that you follow all local codes and the National Electrical Code as well. It is also wise to hire a professional electrician to wire your system or at least have them double check your work. Remember a properly installed PV system is a safer and more reliable system.

When you are wiring your array together make sure you note all the positive (+) and negative (-) terminals and the color wire used for each terminal. Try to use the same colors with the same type of terminal throughout the system, to avoid confusion and increase safety. You may even want to make up a chart and keep it in a readily available location so you can refer to it when needed. When wiring your array it is important that all wires are securely fastened and they do not hang or flap around. When you are wiring AC circuits long lengths of 12 or 14 gauge wire can be used with minimal voltage drop. With DC current the circuits must be individually designed and wired according to use. It is wise to wire for future needs as opposed to immediate needs. When wiring a DC circuit it is helpful to use the wire loss tables found in appendix (?). This table is calculated with a 2% resistance loss in the wires. It tells you what size wire to use with the appropriate current rating and the distance to that particular outlet.

All circuits must be properly fused to protect against short circuiting. It is also a good idea to keep the polarity the same in each outlet to avoid confusion. For example if the left side of the outlet has been wired as positive make sure all the outlets in the house are wired the same way. Again, it is a good idea to draw a wiring schematic of the house so you can refer to it as you wire. The entire system should also be grounded to prevent harmful shocks, fires and other electrical hazards. Remember your PV system is an electrical system, always think of safety first.

For the homeowners convenience we have included in Appendix D a variety of PV component Specification sheets.

# Chapter Five

# Designing a Stand Alone System

## 5.1 Introduction

Designing a photovoltaic system is not extremely difficult but does require care and professional skills. It is a good idea to review more than one method of sizing, and to think the entire design process through from start to finish. The purpose of this chapter is to introduce the homeowner to photovoltaic system designing. If a homeowner chooses to design his own system, it is recommended that he have a photovoltaic professional double check his design.

When I started to write this chapter I had to decide on what type of structure I would be designing a system for. Originally I had hopes of designing a PV system suitable for my own home. However, since I already receive my electricity from the utility grid I decided that I should design something different. I thought about the design for awhile and kept thinking of my parent's camp in the Adirondack Mountains in New York State. My parents have owned their camp since I was a child and many happy childhood memories were born there. Originally, the camp was a small one room cabin, which became larger as additions were slowly added on. We did not have electricity, running water, or indoor plumbing - we roughed it. I never missed the comforts of our modern home, I felt living without the comforts gave the camp a romantic and nostalgic quality, and in fact was disappointed when my parent's finally had electricity installed. It was from these memories that I decided to base my PV design. The example used in this chapter will be for a stand alone home similar to my parent's camp but fictitious in nature.

The fictitious home is a small 25x25 two story gambrel. The longitudinal length of the house is situated in an approximately east to west direction. The pitch to the top portion of the roof is 6" to 12" or approximately 27 degrees from the horizontal. The home is located in Newcomb N.Y. which is at approximately 44 degrees latitude.

The structure is currently being used as a weekend get away and during the summer a vacation home. Eventually the owners would like to move there permanently. At the present time the home is heated by wood and space propane heaters. The refrigerator and stove both operate on propane and lighting is provided by large windows and Kerosene lamps. There is a well and water is retrieved by a generator run pump. If hot water is needed the water must be heated on the stove (wood and/or gas).

The owner's plan is to do some renovation in the future and possibly add an addition to the current structure. Since renovations are planned, the first improvement will be to add electricity. The home is situated approximately one-half mile from the nearest utility line, and would cost the homeowners approximately $18,500 to connect to the utility grid. Since the cost of connecting to the utility grid is so expensive the homeowners chose to design their own PV system and compare its cost to the utilities'.

The system that the homeowners plan to design is for an AC/DC Stand Alone. Since the homeowners plan to live at the site, in the near future, they would like to design a system that will maximize obtainable sunlight. The property consists of one acre of land and receives plenty of sunshine between 10:00 AM to 2:00 PM, on sunny days. Prior to these times there are trees that cast shadows over the proposed site. A tracking mount or ground mount would be the first choices to increase electrical output. However, since the owners are not yet living at the site, the thought of having an expensive tracker or ground mount susceptible to vandalism ruled this out. The next choice was to use an adjustable rack that would be mounted on top of the roof. The adjustable mount will maximize the amount of sunlight received during each season. The slope of the roof is approximately 27 degrees above the horizontal and would allow for seasonal adjustments, as is indicated below.

Winter Angle = Latitude + 15 degrees = 44 + 15 = 59 degrees

Spring & Fall Angle = Latitude = 44 degrees

Summer Angle = Latitude - 15 degrees = 44 - 15 = 29 degrees

The homeowners plan to install energy efficient DC bulbs and as many DC appliances as possible to keep the size of the inverter small. The generator will be kept and used to power tools during construction and whenever extra power is needed.

In order to keep the cost of wiring down the battery bank will be placed in a central location reserved in the cellar. A special battery box will be built and hydrogen fumes will be vented out through a pipe to the outdoors. The climate is moderate so 16 Volt (12V Nominal), 3.13 amp, 50 Watt rated modules will be used.

**5.2 Step One - Determining your Electrical Needs.**

The method of sizing used is taken from The New Solar Electric Home: the photovoltaic how-to handbook. by Joel Davidson. Mr. Davidson's approach is simple, understandable and very affective. This first step in sizing a PV system is to do a room by room analysis of the appliances and lighting used. The analysis can consist of up to three separate lists. The first list generally consist of only the essential appliances and lighting needed. The second list generally consists of the first list plus a few more additional appliances. The third list consists of the first and second, and the remaining appliances and lights the homeowners may wish to power.

During the room by room audit the homeowner should list next to each appliance the wattage that appliance/light uses, the amount of time the homeowner uses that item, and the number of times during the week. From this step the homeowner will be able to calculate their daily power consumption.

### 5.3 Step 2 - Adjusted Daily Watt Hours

In a PV system some of the power will be lost due to resistance in the wires, battery inefficiency, and inverter inefficiency. Since power is lost in the system it will take away power needed to operate appliances. Therefore, this power loss must be added to the homeowners daily power consumption so that the proper amount of electricity will be produced. The second step accomplishes this task by adding the losses to the daily watt hours calculated in step one.

### 5.4 Step 3 - Determining Array Peak Watts

In the third step, the number of peak watts needed to be produced by the PV array is calculated. This is accomplished by dividing the adjusted daily watts hours in step two by the number of peak sun hours needed for the design. The number of peak sun hours will vary according to geographic location, the time of year, and design specifications. As the number of peak sun hours decrease the array peak watts must be increased. Peak sun hours for spring, summer, winter, and fall were discussed in Chapter four more fully.

### 5.5 Step 4 - Determining the Number of Modules Needed.

There is a relationship between the number of modules in the array and the size of the battery bank. The battery bank can only be as large as the number of modules in the array allows. To ensure the number of modules is correct and corresponds to the size of the battery bank, the module's usable watt output should be used in the calculation. The number of modules needed is calculated by dividing the array peak watts (from step 3) by the module's usable wattage output. If an odd number or fraction is calculated round up to the nearest even number.

### 5.6 Step 5 - Determining Battery Bank Size.

The fifth step calculates the battery bank size. This is accomplished by multiplying the following factors together. Daily watt hours (from step 2), Multiplier factor (found in Appendix A), depth of discharge factor, and temperature correction factor (found in Appendix A). As stated in chapter four, the Multiplier factor, also referred to as the number of days of autonomy, is the number of successive days the battery bank should be able to supply power during cloudy weather. The Depth of Discharge is the level to which the homeowner wishes to drain his batteries. The recommended level of discharge is only 20% to 40%. A temperature correction factor should be used if the batteries will be subjected to periods of freezing temperatures.

### 5.7 Design Example

**List One Step One.** Room by Room Electrical Analysis

Please note that all lights are high efficiency DC fluorescent bulbs.

| Desc. | Quantity | | Watts Used | | Hrs Used/Day | | Days Used/Week | / 7 | | Ave. WHrs/Day |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Kitchen | | | | | |
| Light | 1 | x | 22W | x | 3 hrs | x | 7days | / 7 | = | 66.00 |
| Light | 1 | x | 15W | x | 1 hr | x | 7days | / 7 | = | 15.00 |
| Light | 1 | x | 15W | x | .5 hrs | x | 7days | / 7 | = | 7.50 |
| Blender(AC) | 1 | x | 250W | x | .25 hrs | x | 1day | / 7 | = | .89 |
| | | | | | Livingroom | | | | | |
| Light | 2 | x | 15W | x | 1.5 hrs | x | 7days | / 7 | = | 45.00 |
| TV(AC) | 1 | x | 81W | x | 3 hrs | x | 7days | / 7 | = | 243.00 |
| Radio(AC) | 1 | x | 5W | x | .25 hrs | x | 5days | / 7 | = | .89 |
| | | | | | Bathroom | | | | | |
| Light | 2 | x | 8W | x | 1 hr | x | 7days | / 7 | = | 16.00 |
| | | | | | Hall | | | | | |
| Light | 1 | x | 8W | x | .25 hrs | x | 7days | / 7 | = | 2.00 |
| | | | | | Bedroom (Total of three, one light/room) | | | | | |
| Light | 3 | x | 15W | x | .25 hrs | x | 7days | / 7 | = | 11.25 |

Cellar

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Light | 1 | x | 15W | x | .5 hrs | x | 7days | / 7 | = | 7.50 |
| Light | 2 | x | 22W | x | .5 hrs | x | 7days | / 7 | = | 22.00 |

Miscellaneous

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vacuum (AC) | 1 | x | 650W | x | .25 hrs | x | 7days | / 7 | = | 162.50 |
| Washer(AC) | 1 | x | 550W | x | .5 hrs | x | 3days | / 7 | = | 117.80 |
| Waterpump | 1 | x | 72W | x | 1 hr | x | 7days | / 7 | = | 72.00 |

---

Maximum. AC Surge = 650W (Vacuum Cleaner)

Total Daily WHrs = 797.37Whrs

---

Future List Items

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stereo(AC) | 1 | x | 16W | x | 1 hr | x | 2days | / 7 | = | 4.57 |
| PC(AC) | 1 | x | 80W | x | 1 hr | x | 5days | / 7 | = | 57.14 |
| VCR(AC) | 1 | x | 33W | x | 2 hrs | x | 2days | / 7 | = | 18.18 |
| Hairdryer | 1 | x | 180W | x | .25 hrs | x | 7days | / 7 | = | 45.00 |
| Toaster oven (AC) | 1 | x | 1500W | x | .25 hrs | x | 2days | / 7 | = | 107.14 |

Maximum AC Surge = 1500W Toaster/oven Total Daily WHrs = 232.03 Whrs.

Total Daily WHrs(List 1.) 797.37 + 232.03 = 1029.40 Daily WHrs

**Step 2. Adjusted Watt Hours**

---

Daily Whrs (From step 1) x 1.02 Wire losses x 1.25 Battery efficiency x 1.11 inverter efficiency (use only if powering AC Loads) = Adjusted Daily Watt Hours

---

Since the homeowners will be using AC rated appliances inverter efficiency must be factored in.

**From List One.**

797.37 Daily Whrs x 1.02 x 1.25 x 1.11= 1288 Whrs

**From Future List**

1029.40 Daily Whrs x 1.02 x 1.25 x 1.11 = 1456 Whrs.

---

**Step 3. Array Peak Watts**

---

Adjusted Whrs (From step 2) / Geographic Peak Sun Hrs (Average or Worst case found in Appendix A) = Array's Peak Wattage

---

The homeowners have decided to design their system to supply electricity during a worst case scenario.

**From List One.**

1288.47 Whrs / 2.43 Peak Sun Hours (Worst Case) = 530.23 Array Peak watts

**Future List**

1456.85 Whrs / 2.43 Peak Sun Hours = 599.52 Array Peak Watts

---

**Step 4. Number of Solar Modules Needed**

---

**1. Module's Actual Watt Rating** = The Amount of voltage actually used from module x module's amp rating.

2. Number of Array Peak Watts / Module's Actual Watt Rating = **number of Modules Needed**

---

**From List One.**

1.Module's Usable Watt output = 12 V (usable from a 16 V rated module) x 3.13 Amps = 37.56W

2. 530.23 Array Peak Watts / 37.56 Usable Watts = 14 Modules

**From Future List.**

2. 599.52 Array Peak Watts / 37.56 Usable Watts = 15 (Use 16 Modules)*

(* Round up to closest even #, when designing a 24VDC System)

---

**Step 5. Battery Bank Sizing**

---

Adjusted WHrs (Step 2) x Multiplier Factor (Found in Appendix A) x 2.5 (40% Depth of Discharge) x Temperature Correction Factor (Found in Appendix A) = Battery Bank Watt Hour Capacity

---

Since the homeowners will be housing the battery bank in their cellar, the batteries will not be subjected to drastic temperature changes thus the temperature correction factor can be omitted.

**From List One**

1288 Whrs. x 11.8 (Multiplier Factor) x 2.5 (DOD) = 38,000 Whr Battery Bank Capacity

**From Future List.**

1456 Whrs. x 11.8 x 2.5 = approx. 42,000 Whr Battery Bank Capacity

---

**Number of Batteries Needed**

---

Battery Bank WHr / Batteries's Whr rating = Number of Batteries Needed

---

The homeowners have decided to use batteries rated at 6 Volts 350 Amphrs. The Wattage rating is 2100 Whrs (6V x 350Amphrs = 2100 Whrs)

**From List One.**

38,000 / 2100 Whr rating = 18 - 6 Volt 350 Amp Batteries Needed

**From Future List.**

42,000 Whrs / 2100 Whr rating = 20 - 6 Volt 350 Amp Batteries Needed.

---

Since there is only a difference of two batteries between the first list and the future list, it would be wise to purchase the extra two batteries at this time. The battery bank should be set up in the following manor: four sets of 5 - 6 V batteries should be wired in parallel. The four sets, wired in parallel, should then be connected in series. This arrangement will give the homeowners a 24 DC Volt, 1750 Amp, 42,000W rated battery bank, as the calculations below indicate.

Battery Bank Voltage Rating: 4 - 6 Volt Batteries Connected in Series.

(6V + 6V + 6V + 6V = 24V)

Battery Bank Ampere Rating: 5 - 350 Amp (6V) Batteries Connected in Parallel.

(350 Amps + 350 Amps + 350 Amps + 350 Amps + 350 Amps = 1750 Amphrs)

Battery Bank Wattage Rating: Watts = Volts X Amps = (24 Volts x 1750 Amps = 42,000 Watts)

Listed in figure 5.1 are diagrams illustrating the battery bank and PV module connections.

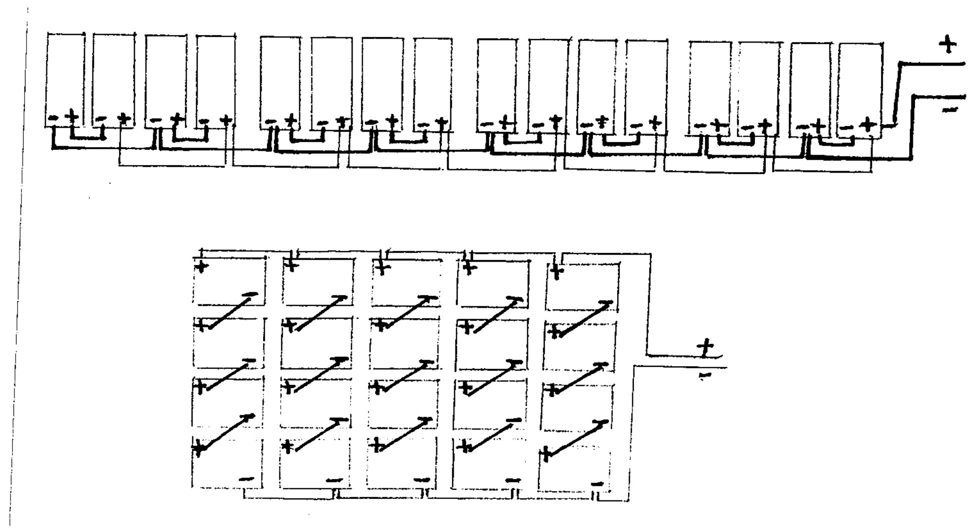

Figure 5.1 Design's PV Array and Batteries Wiring using 6V, 350 Amp Batteries.

**5.8 Cost Analysis**

16 - 50 Watt Modules @ $330..............................................$5280

20 - 6 Volt 350 Amp Trojan L-16 Batteries @ $195......................$3900

1 - 24 Volt 2500 Watt Trace inverter......................................$1350

Miscellaneous Items (i.e. Charge Controller, Battery interconnects, Module interconnects, Array Disconnect Circuit Breaker, Charge Controller Disconnect Box, Wiring, Adjustable Mounting Rack)

Approximately...........................................................$1500

Total Cost of a 24 V Photovoltaic System Designed for Worst Case

Weather..............................................................$12,030

Average Cost to connect to Utility Grid @ $7.00/foot............$18,480

Total Savings $ 18,480 - $ 12,030 = $6451 on first purchase, plus free electricity from the sun from that time on.

The prices used will vary according to manufacturer. The above example shows that it is possible to receive electricity in a Stand Alone home, without sacrificing too many of the modern conveniences. The cost analysis clearly shows how cost affective photovoltaic systems can be.

After doing a cost analysis, the homeowner can modify the design. Instead of designing for a worst case condition, the homeowner can design the system based on yearly averages. By revising the design, using yearly averages, it is possible to reduce the number of modules and batteries needed. A back-up generator can be used to supplement electrical needs during winter months or long periods of cloudy weather. To prevent the battery bank from being discharged completely, load management can be enforced as well.

In the example, the homeowner used 11.8 days of autonomy. The probability of this geographic area receiving approximately 12 simultaneous days of cloudy weather is low. A much more reasonable number to used would be five. Using 5 days of autonomy, the battery bank size is reduced to 18,210 Whrs. Using the same batteries as before and making the proper calculations, 10 (round up to 12 for a 24VDC system) - 6V, 350 Amp batteries would be required, costing approximately $2340. However, it is possible to lower the cost of the battery bank even further. If 6V, 200 Amp rated batteries are used, 16 batteries would be required. The cost of a 6V, 200 Amp battery is approximately $80, therefore the battery bank would cost approximately $1280, which is a savings of approximately $2620 from the original battery bank design.

The number of modules required can be reduced as well by using yearly peak sun hour averages. If four peak sun hours are used in the calculations, instead of 2.43 sun hours, 10 modules would be required, costing approximately $3300. By revising the battery bank size and the number of modules needed, the cost of the photovoltaic system is reduced from approximately $12,000 to $7000.

The purpose of this section was to show homeowners that photovoltaic systems can be cost affective. The homeowner is not locked into one design, different options are available even for Stand Alone photovoltaic systems. Homes that are connected to the grid have much more flexibility than Stand Alone's. As stated in a previous chapter utility connected homes can design a small PV system to help supplement power needs, and gradually increase in size as money dictates, which will be discussed in chapter 7.

Hybrid systems can save homeowners money by reducing the initial cost of the photovoltaic system. In addition to lowering initial costs, hybrid systems also prevent electricity from being wasted. PV systems designed to supply all electrical needs, year round, waste power in the summer, spring, and fall months. During the summer, and to a lesser extent in the spring and fall, excess power will be produced from a PV array designed to supply power during worst case conditions. Hybrid systems allow the PV systems to be designed to supply ample power for the summer, spring, and fall months, and then uses a generator, etc. to supply extra power during the winter months, thus preventing electricity from being wasted. Hybrid systems will be discussed briefly in chapter 6.

# Chapter Six

# PV/Hybrid and Passive Solar Systems

## 6.1 Introduction

Some photovoltaic systems incorporate solar PV's with other power producing technology, and are referred to as hybrid systems. The purpose of this chapter is to offer the homeowner a brief introduction to hybrid photovoltaic systems and passive solar systems. Any homeowners who are interested in hybrid or passive systems are encouraged to investigate this area more fully. Check with your local library and photovoltaic supplier for additional information and help.

## 6.2 PV/Generator System

A PV/Generator system (PV/GEN) utilizes power produced from a photovoltaic array and from a gas generator. One of the benefits of a PV/GEN system is that it can lower the initial costs of installing a photovoltaic system. The photovoltaic system does not have to be designed for a worst case situation, since the generator will be able to supply additional power when needed. The generator can be used to power DC as well as AC loads, depending on the type of current the generator produces. If the generator produces DC current an inverter will be needed to power AC loads. If the generator produces AC current a rectifier will be needed to power DC loads.

The disadvantage of a PV/GEN system is that the generator operates on gas, which is not as clean as solar energy. The generator is also powered by a gas engine which will require periodic maintenance and repair. In order to operate the generator at top efficiencies, it should not be used to power small loads or when the PV modules can supply the needed power. Power from the generator should not be utilized until large loads are needed or until cloudy weather demands the generator's use.

PV/GEN systems can be used for many power requirements. From small household loads, to loads needed to power small communities and villages. There is a company in Buckley WA, that manufactures portable solar generators. They are designed to track the sun throughout the day and can produce power up to 9 kilowatts. There is even a 1 kilowatt system that can fold up and fit in the back of a pick-up truck. There is also another company in the US that produces portable PV/GEN systems large enough to power small villages. These systems incorporate the latest in engineering and technology and are fairly expensive.

### 6.3 PV/Wind System.

A PV/Wind system produces electricity from its PV array and from a Windcharger. A windcharger is an electrical device that is powered by the wind. The wind strikes the blades of the windcharger which causes them to turn. The turning blades operate the generator, which in turn produces electricity that can power AC and DC loads. Again if the generator produces DC current an inverter will be needed to power AC loads. If the generator produces AC current a rectifier will be needed to power DC loads.

Electricity generated from the wind is another clean alternative to electricity produced from fossil fuel power plants. In the sunny summer months the PV array will operate closest to its fullest capacity. However, in the winter months the array's production drops. Electricity generated from the wind does not operate to its fullest during the sunny summer months. However, this is not the case in the more windy winter months. During the winter the windcharger is able to produce power closer to its capacity. Therefore, in a PV/Wind system the two independent electrical sources are able to compliment one another, thus supplying a more constant source of electricity throughout the year.

A PV/Wind system is only usable in certain locations. Prior to designing a PV/Wind system, wind speed readings should be studied for extended periods. If your home is located in a low wind area, (i.e. surrounded by tall trees, in a valley), the home may not receive a high enough wind speed to operate a PV/Wind system properly. Another consideration is that a windcharger will also take up yard space for its tower. If your property is small in size, a windcharging system may not be appropriate.

Since windchargers are located on top of tall towers they may be subjected to wind gusts. If the wind gust is strong enough damage may occur to the windcharger and repair may be needed. The windcharger also operates a generator that has moving parts that will require periodic maintenance and repair. If the home is situated in a more residential area, neighbors may object to the tall unsightly tower and from any noise the generator might make.

### 6.4 Passive Solar Housing

Passive systems use the sun's energy to heat a home, even at night. This is done with the use of absorbers. An absorber is material that absorbs the heat from the sun's energy and stores it for later use. This is accomplished in the following manner. The sun's energy will travel through glass and strike the absorber's surface. The absorber soaks up the heat from the sun slowly throughout the day. The absorber is heating because it is absorbing the energy from the sun. As long as the absorber does not lose much energy to its surroundings it will continue to increase in temperature. At night the process is reversed. At this time the absorber has a higher temperature than its surrounding area. When this happens the absorber radiates heat to the cooler areas. The process is then repeated during the next day.

Passive homes must by properly insulated to prevent the heat from the absorber from being lost through the walls. Double pane windows should be used in regions of moderate and warm climates. Colder climates such as in New England, should use windows with 3 to 4 layers of glass to prevent excess heat loss at night or during the cold weather seasons.

Absorbers can be made from a variety of materials. The best absorbers are dull and very dark in color. Brick, concrete, stone, and water in drums are a few of the better absorbers. The efficiency of the absorbers will depend on the type of material used and the size of the absorbing area. The larger and darker the absorber, that is in direct light, the more heat will be absorbed and radiated.

Passive solar homes require precise calculations and planning prior to being built. It is a good idea to consult with a professional in the field. Steve Strong is an architect from Solar Design Associates, Inc. in Harvard Massachusetts. Mr. Strong is an accomplished professional not only in the field of solar photovoltaics but in passive solar systems as well. Mr. Strong designed the Impact 2000 house, in Brookline

Massachusetts, which is a state-of-the-art passive solar home. This home receives much of its heat from the sun, and receives its electricity from a PV/utility grid system.

# Chapter Seven

# Grid Connected PV Systems

### 7.1 Reasons For Using PV While Connected to the Utility Grid

Solar photovoltaic generated electricity is more expensive than power purchased from the utility grid. If your home is currently connected to the grid and you want to gain some independence from the expense of a monthly electric bill, from the electricity that is consumed in your home, then solar PV is useful. PV electricity will allow the homeowner to generate his own electricity to power the household electrical supply and to reduce his need for utility generated power. Installing a modular solar PV system allows the homeowner to partially or fully escape from the rising cost of electricity from the utility grid.

The ability to start with a small PV system, and enlarge it as money allows is, one of the beneficial options with the design of PV systems. Homeowners can start with a small system that would run DC lighting in the house, or run small AC loads through a inverter, and gradually enlarge the system to run all AC loads. Finally the homeowners can enlarge the system so that it will generate enough electricity during the summer to support the household and also produce excess electricity that can be sold to the utility grid.

A special benefit, from using PV systems in a home, is that the consumption of electricity in the home can be decreased by an considerable amount through conservation. As stated earlier, the first step in designing a PV system for the home is to perform an energy audit on all the rooms in the home. When a homeowner performs this audit, in his home, he realizes how much power he has been using. From the audit, the homeowner should realize that he must reduce his consumption to make the installation of a PV system worth while. If the homeowner installs a PV system and there is no conservation of electricity, the homeowner will not benefit from the PV system, to a large extent as he would if conservation was used.

A PV system will increase the value of a home. The cost of a PV system will not be lost if the homeowner decides to sell the home after the installation. The PV system is an attractive selling point. Although a homeowner would not want to install a PV system on his home and then sell his home immediately thereafter, the homeowners may wish to sell later on, and a PV system is an added benefit. Perspective buyers looking to purchase a house will find that a house that will provide them with electricity free of environmental damage and cost is an added bonus.

A homeowner planning on designing a PV system for his home, and to connect to the power utility grid may want to incorporate a switching device. This device will allow him to receive power from his PV system in the event of a power outage from the power utility. Currently, most homes that have PV systems connected to the power utility grid have protection devices that will disconnect them from the grid in the event of a power outage. This is to protect the linemen that are working on the line due to the power outage. If the correct protection is included, the homeowner may be able to design a system that will allow him to receive power and protect the line at the same time.

A good reason to install a PV system on your home is to make a statement about the electricity generated by the power utility companies. In the United States the majority of the electricity produced is generated by coal fired generating plants. The coal fired generating plants produce large amounts of carbon dioxide, sulfur dioxide, and nitric oxides which contributes to the green house effect, smog, and other environmental problems.

### 7.2 Metering Method for a Grid Connected PV System

There are three methods of metering a grid connected PV system, namely, (1) Simultaneous buy and sell metering, (2) Dual ratchet metering, (3) Single net metering. figure 7.1 illustrates the different methods of metering.

The Simultaneous buy and sell metering is a method that will meter, using watt-hour meters, the amount of electricity generated from the PV system that is fed into the utility grid. This meter, in essences, sells all electricity back to the utilities from the PV array to be used to power other homes without the benefit of solar PV. There is another meter, also used, that measures all the electricity used by the household; this meter is the buying meter, which the utility uses for billing proposes. This method of metering is one that does not allow the homeowner to get full credit for the power generated from the PV system, because the electricity generated is bought by utilities at a price less than that charged to the homeowner.

The Dual ratchet metering method is one that will meter the amount of power being fed into the utility grid from the PV system on one meter, this power is the excess that the home does not use. Then the incoming utility power is metered on another meter. Both are watt-hour meters that run in only one direction, one ratchet for incoming power and another ratchet for outgoing power.

The Single net metering method is a single watt-hour meter metering system. The one meter will measure the net amount of energy used by the household and bill according to the net amount used. Therefore, the homeowner will get the same price for the power produced by their PV system as they pay for power used from the utility grid. In this method the homeowner is paying for the net amount of power used by the home, at the set rate utilities have for each kilowatt-hour of energy. This method of metering is the one most used and excepted by utilities, for residential metering systems. the Single net metering is the same method used on the Gardner Massachusetts project by New England Electric Systems that will be discussed in chapter 8 and 9.

The method of metering will vary by state so the homeowner must consult with his own power utility before installing a PV system connected to the grid. There are also federal regulations on the price the utilities must pay small generating plants for power.

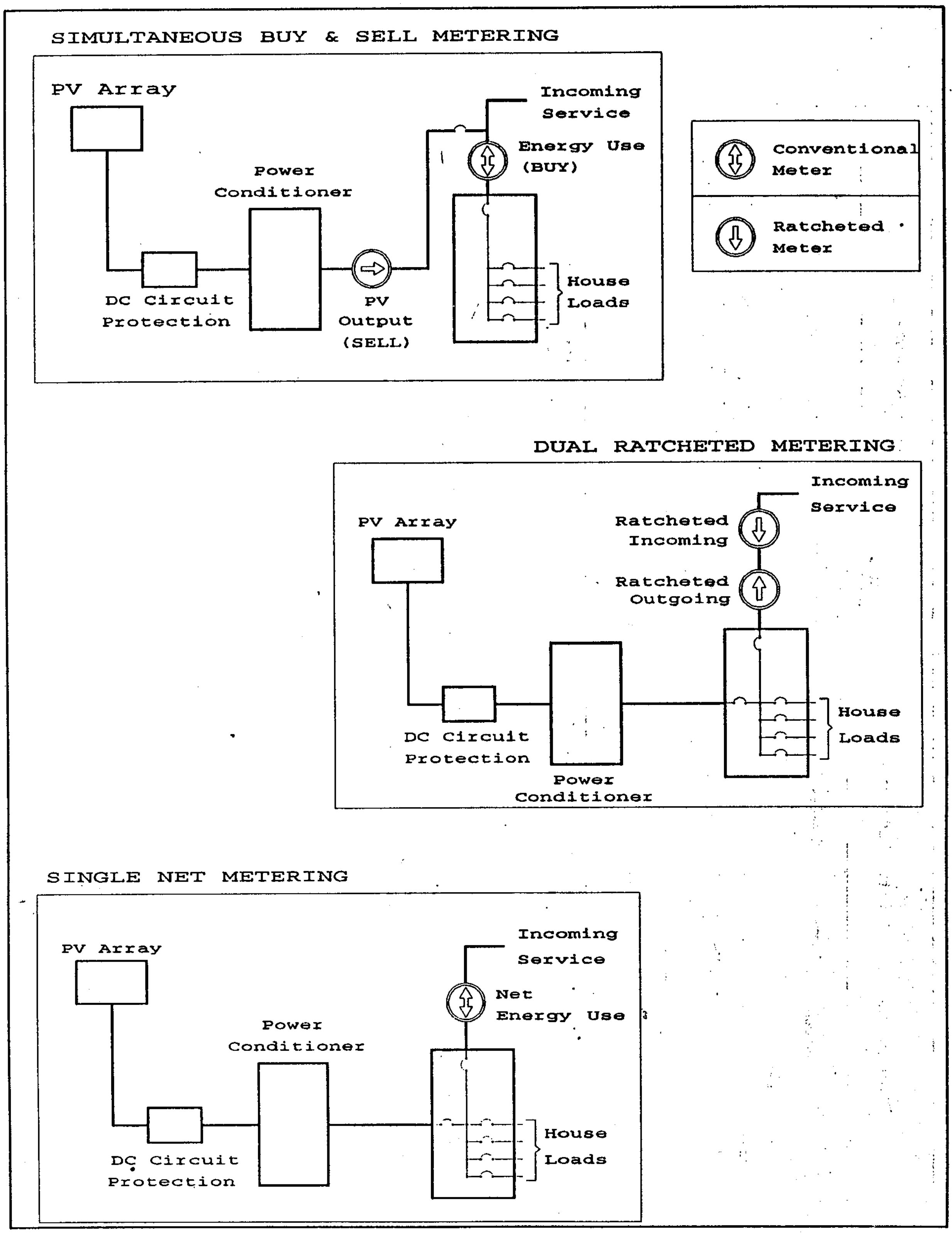


figure 7.1 Three Residential PV System Metering Options
Prepared By Ascension Technology,Inc. For EPRI.

### 7.3 Sizing a PV/Grid System

Sizing a PV system for a house that is connected to the utility grid leaves the homeowner with many options. Since PV systems are modular the homeowner can start with a well planned small system and add on as money allows. Being connected to the grid allows the homeowner freedom since they do not have to worry if the PV system is too small. If the PV system does not generate enough electricity for the home's consumption the connection to the utility grid gives the homeowner the security of receiving additional power if needed. This security allows the homeowner to size the PV system according to his budget and not according to his need, as does a stand alone PV system.

One of the first things that must be done to help the homeowner save on his electric bill is determine how much power (kilowatt-hours) the household is consuming. Before the homeowner installs a PV system on his home he must practice energy conservation. This will reduce his need for electricity from both the utility grid and/or a PV system. Since the electricity generated from the PV system is expensive compared to utility generated electricity, it will pay for the household to reduce energy consumption. The average cost for each watt-hour of electricity in the U.S. is $0.12 per kilowatt-hour, and as mentioned at the Sunnyside Solar Workshop that the average cost of electricity generated from a PV system is about $1.42 per kilowatt-hour. Therefore, the generation of power from a PV system is about 12 times more expensive to the homeowner then power generated and bought from the utility grid.

If the homeowner plans on starting small and enlarge his system later there must be careful planning involved. The number of modules that is first installed must be the correct amount to allow the inverter to convert the dc power to the correct ac power (Voltage and Current). The inverter has specific input voltages and currents (wattage), which must be determined when designing the system. The homeowner must consult with the utility. The utilities have a way of evaluating the inverter and the PV system the homeowner wants to connect to the grid.

The inverter must be chosen for future expansion, in order for the PV system to be enlarged in the future. The possibility of using an inverter that is rated below future expansion is possible. Two inverters may be run in parallel with the correct equipment, this will allow the inverters to run closer to their maximum power output and their highest efficiency as well. For example, there could be a 500 W inverter on a start up system and the planned expansion is another 500 W inverter, with the regulation equipment and another 500 W inverter, the system can be enlarged. If this regulation equipment was not correctly sized the PV system would need a 1000 W inverter, before the enlargements could be made. The system would be running at a low efficiency, because the inverter would be running at half its rated input rating which is very inefficient.

A PV system that is connected to the utility grid does not need batteries for storage of the energy that is generated by the PV system. The homeowner has the option of incorporating batteries into the design to so that his home will receive electricity even during power outages. However, batteries will be an added unnecessary cost.

As mentioned in chapter 4, the mounting surface for the PV modules is best if it has southern exposure. With a grid connected system the array does not have to face completely south or have the correct tilt from horizontal, as long as the homeowner does not need to use the modules to their full extent. This is being mentioned because some homes may have exposures different from south and still want to install a PV system connected to the grid, and it is possible for them to do so.

Sizing of a PV system for a home that in the future would like to be totally independent from the utility grid can use the sizing method used in chapter 5. When designing with the method in chapter 5, the efficiencies of the batteries do not need to be incorporated into the calculations. Then as money allows, the PV system can be enlarged to the size that will allow the independence the homeowner would like. If the homeowner only wants to supplement his power use with a PV system then he can design according to the amount of money he is willing to spend. An audit of his energy consumption must be done to decrease the home's need for power.

**7.4 Requirements and Selling Back to the Utility Grid**

A PV/Grid homeowner must consult with the utility company. The utility company and the homeowner must have a contract for the price that will be paid for the power generated and used by the homeowner. Utility companies will look at the individuals PV system and conditioning equipment to evaluate if the system is adequate, reliable, and safe. The inverter for the PV system must be one that creates a sinusoidal wave of AC power in order for it to be connected to the utility grid.

The Public Utility Regulatory Policies Act of 1978 (PURPA) put into federal law the requirement that utilities buy electricity from co-generators and small power producers at a reasonable rate. This is from "qualifying facilities". The "reasonable rate" is the full avoided cost to utilities that a small power producer creates. The homeowner's PV system, as long as it is a qualifying facility, should get this same rate for the power generated. This rate is below the per kilowatt-hour rate the utilities charge for power sold to homeowners.

### 7.5 Advantages and Disadvantages of a PV/Grid System

**ADVANTAGES**

1. Saving money on monthly electricity bills.
2. Adds value to the house.
3. Gaining independence from the utility and from the monthly bills.
4. System can be enlarged as available money and needed demands.
5. If battery banks are incorporated, the home can receive power during utility power outages.
6. The ability to sell power to the utility that is not used by the household.
7. The homeowners does not have to purchase a battery bank for storage.

**DISADVANTAGES**

1. Initial cost of PV system is high.
2. Cost per kilowatt-hour of power is larger than the utilities' price.
3. Cloudy days reduce the amount of power produced.
4. Small solar arrays need seasonal adjustments to maximize production.

# Chapter Eight

# Gardner Photovoltaic Project

## 8.1 Introduction to Gardner Project

New England Electric System (NEES) has been conducting a photovoltaic (PV) system research and demonstration project in Gardner, Massachusetts, which is located approximately 50 miles west of Boston. The research is being conducted by one of NEES subsidiaries - Massachusetts Electric Company (MECo). The project was started in 1986 and has been collecting data from the PV systems for the last several years. The project consists of 30 residential homes each retrofitted with photovoltaic systems rated at 2.2 KW (KiloWatts) DC power, which is a total of 10 PV panels (5 series X 2 parallel). The amount of AC power is limited by the inverters to 1.8 KW because of energy lost in the inverter, converting dc power to ac power. All the homes are connected to the same substation; which is used to determine how much of an effect the PV systems have on a particular single feeder. The photovoltaic panels (Mobil Ra180) were supplied by Mobil Solar Energy Corporation of Billerica, the panel life expectancy is 30 years. The design of the system was done by Ascension Technology of Waltham. The construction coordinator was Solar Design Associates, in Harvard, Massachusetts and the inverters were made by American Power Conversion Corporation of Burlington, Massachusetts. The inverters are expected to have an operating life of at least 10 years.

The main objectives of this project are as written in a paper by John J. Bzura, Ph.D.: (1) to gather information about the performance, reliability and cost effectiveness of residential photovoltaic systems; (2) record the PV system electricity production during the year, and mostly during the peaking load periods; (3) display PV system components made in Massachusetts, and (4) study the effects that a group of PV systems generating electricity would have on a single feeder.(Ref.#1)

NEES has also installed solar PV systems on five commercial or institutional buildings in Gardner, Massachusetts. Including city hall, the town library, a Burger King restaurant, a furniture store, and the local community college (Mount Wachusett Community College). The generating capacity of these systems range from 1.8 to 7.3 kilowatts of dc power. All the systems are connected to the 3-phase power grid. The specifications for the commercial PV modules (Ra30) are in Appendix C.

### 8.2 System Set-Up

In order for NEES to get accurate results, as to the effects the PV system will have on the loads and substations, the houses were not changed in any way other than installing the PV system. The homeowners were told they did not have to change their life styles or take any conservation measures in their homes. Some of the homeowners did make some adjustments to their power consumption, as people in a normal community would. None of the houses have central air conditioning. However, 6 of the houses have window-mounted A/C units. Of all the homes, 11 of them have electric baseboard heat, which is a very inefficient method of heating a home. Figure 8.1 illustrates the block diagram of the system set-up, and figure 8.2 illustrates the PV array wiring and physical layout. The specification on the system's components can be seen in Appendix C.

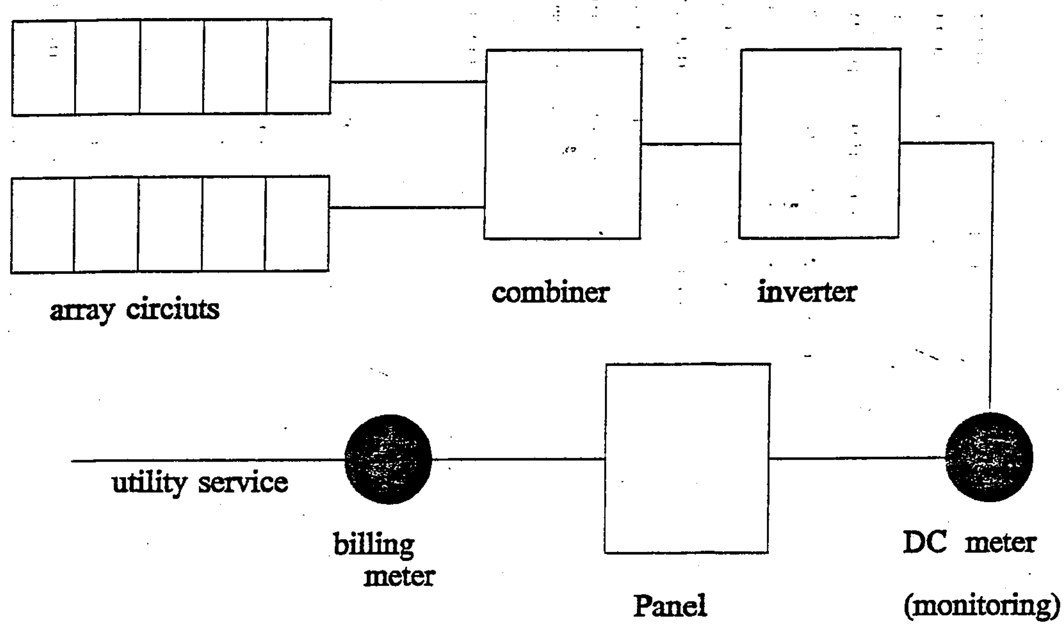


figure 8.1 System Single Line Block Diagram

Most of the 30 Gardner homes are of the ranch type, with basements and split level houses. The average area of living space is 1,100 square feet. They all have a Southern exposure, and have roofs with an average pitch of 23 degrees. The PV modules are mounted to the roof with brackets that leave a about a three inch space in between the roof and modules to allow cooling. The mounting brackets are shown in figures 8.3 and 8.4.

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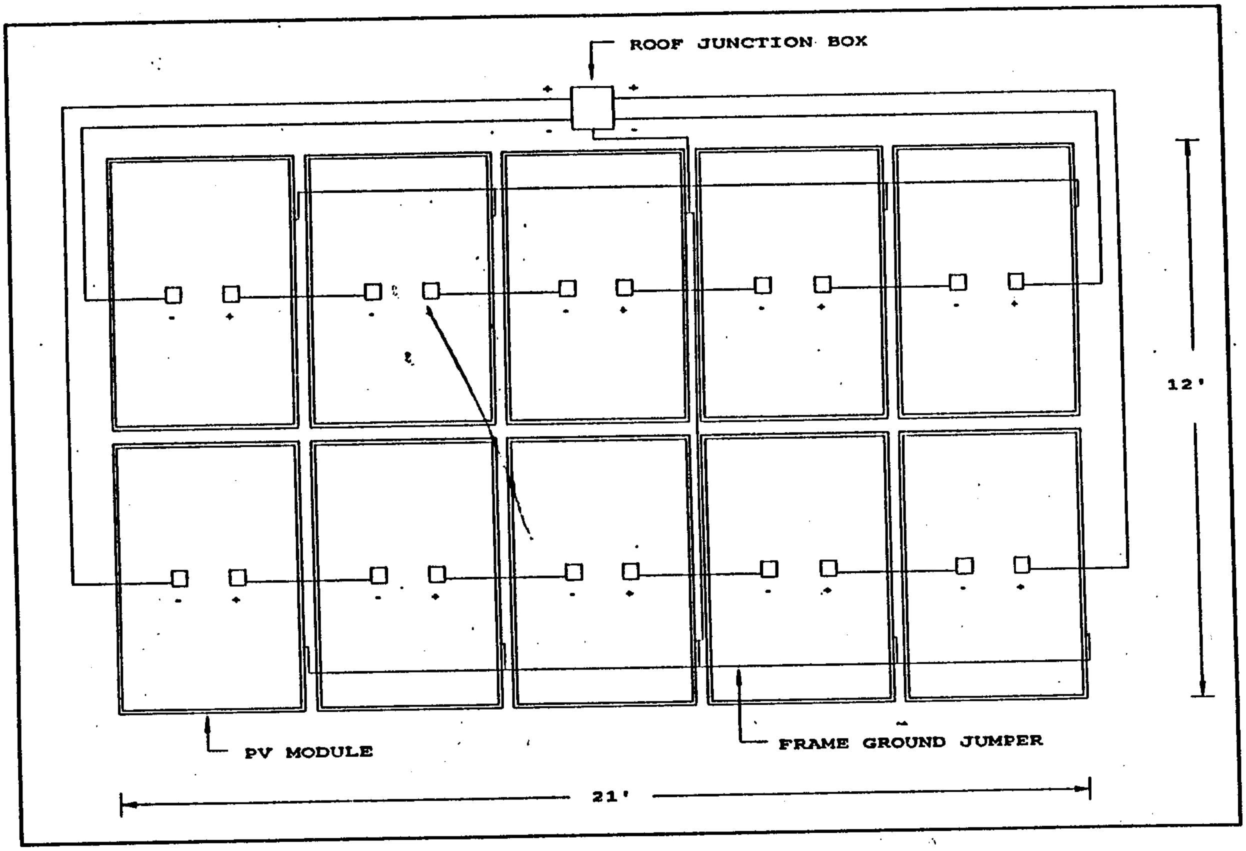



figure 8.2 Wiring and Physical Layout of the Gardner Arrays

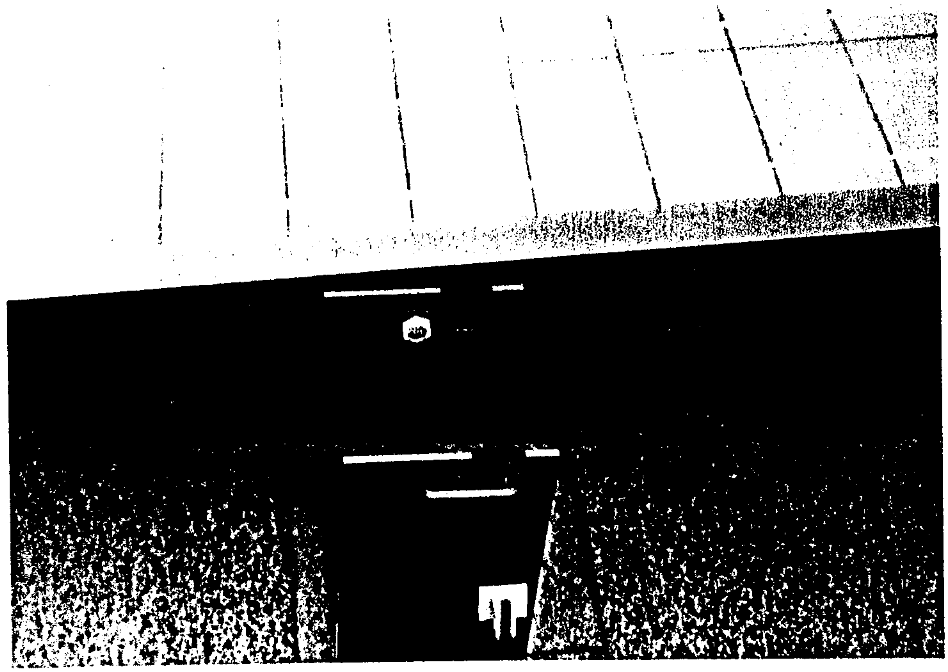


figure 8.3 Detail of Roof Jack to Photovoltaic Panel Attachment

The roof jacks support the photovoltaic panels and are designed for simple and quick array installation. Several roof jacks are shown below.

Reference Source #7

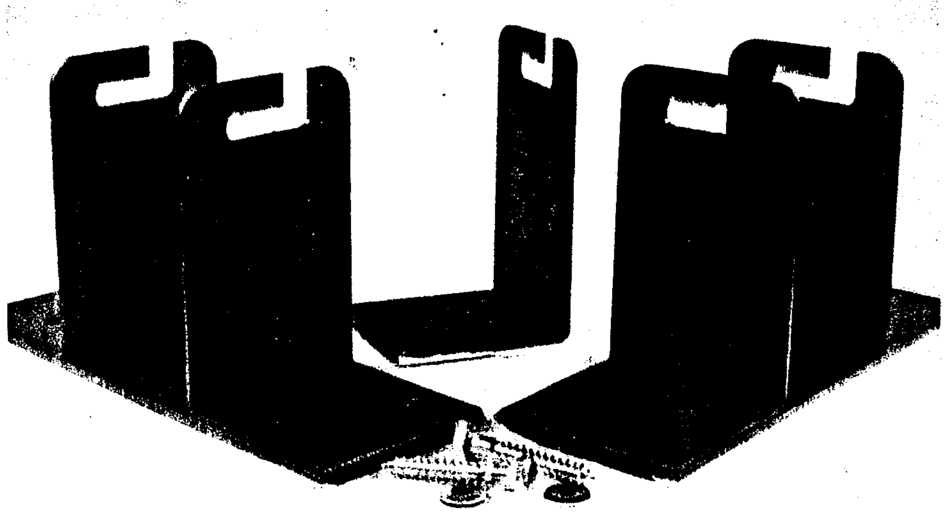


figure 8.4 Interior and End Roof Jacks

The Gardner homes are equipped with ten solar PV modules, Mobil Solar Corporation's Ra180 modules (specifications can be found in Appendix C). There are 2 rows of 5 series modules, integrated into the roof-top array, which is capable of producing 2.2 KW of DC power under full sunlight. Each module produces 50 Volts, and is capable of 4.4 Amps, therefore, each string of 5 series modules produces 1.1 KW at 250 Volts DC. The Array is wired to a string combiner, this connects the two strings together and serves other purposes. The string combiner contains surge protection components, string isolation switches, blocking diodes and a grounding resistor network. The surge protection component will protect the PV system from surges caused by a nearby lighting strike. The string isolation switches can disconnect the dc power and allow connections to be tested. The resistor network ties one wire of each of the strings to a ground through a high resistance (100,000 ohms). This will limit the current flow to the ground in case of a short somewhere in the string, as well as provide a point of connection for testing and/or checking for ground faults.

From this string combiner the system is wired to an inverter which has an input (DC) power limitation of 1.9 KW. This inverter will convert the DC power from the PV system to AC power for in house use and if there is an excess of power produced it is fed into the utility grid were it can be used by other homeowners connected to the utility grid. The inverters are completely automatic. Once the inverter is installed and initially turned on the homeowner does not have to do anything. The inverter will disconnect the PV unit from the utility grid as soon as power is lost at the grid. The unit will also shut off the PV system from the house wiring if there is not enough sunlight striking the modules to produce power, therefore, allowing power to be drawn from the utility grid.

The house metering system includes a watt-hour meter that can rotate in both directions; this meter is used for billing as in any normal house. Rotation in the normal direction, is for power being used from the utility grid. The rotation in the opposite direction is for power being fed back into the grid from the PV system, allowing the homeowners to get the same price for the power as they pay for power. This method of metering is most attractive to a PV owner, because he or she receives full credit for the excess power produced and sold by the utility grid to supply other houses. The homes also have one other meter that measures the amount of power produced from the PV system, this is for data collection purposes. Figure 8.5 illustrates the PV systems output and the household power use.

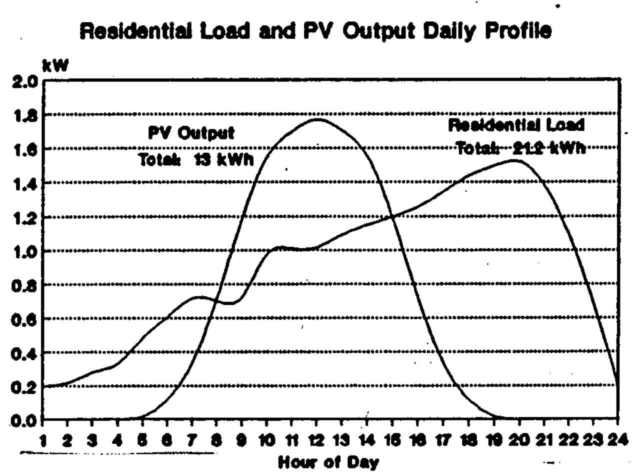



figure 8.5

Graph Prepared By Ascension Technolgy, Inc.
For EPRI. Ref. Source #8

## 8.3 Amount of Power Generation and Used

The power generation from the systems is one of the most important elements of the experiment to NEES, and is the most important to the homeowners' as they are saving money on electric bills. The power output data is useful to see when the PV system reaches its peak output, and how it coincides with the peaking load of NEES. It was found from the experiment that the PV systems output peaked shortly after the utilities system experienced their peak load. About 60% of the PV system's total daily power output is supplied during the utilities's peaking load periods (REF.#3). Since the PV system is producing the majority of its power during peaking load periods, and the PV homes are not using all of the power produced, the excess can be used to supply other homes, thereby reducing the utilities power production during peak load periods. The power produced one day in August and how it relates to NEES peaking load period can be seen in figure 8.6. The average yearly energy production averaged over two years from the units was 2,212 KWh.

### 8.3.1 Summer Power Generation

Summer (the months of June, July and August). The peak output of the system is during the summer months with an average monthly output of 261 KWh. It is during the summer months that the PV system helps most on providing power during the utilities peak need. During these months power from the PV system is fed into the utility grid to be used by other homes. Monthly power production can be seen in figure 8.7.

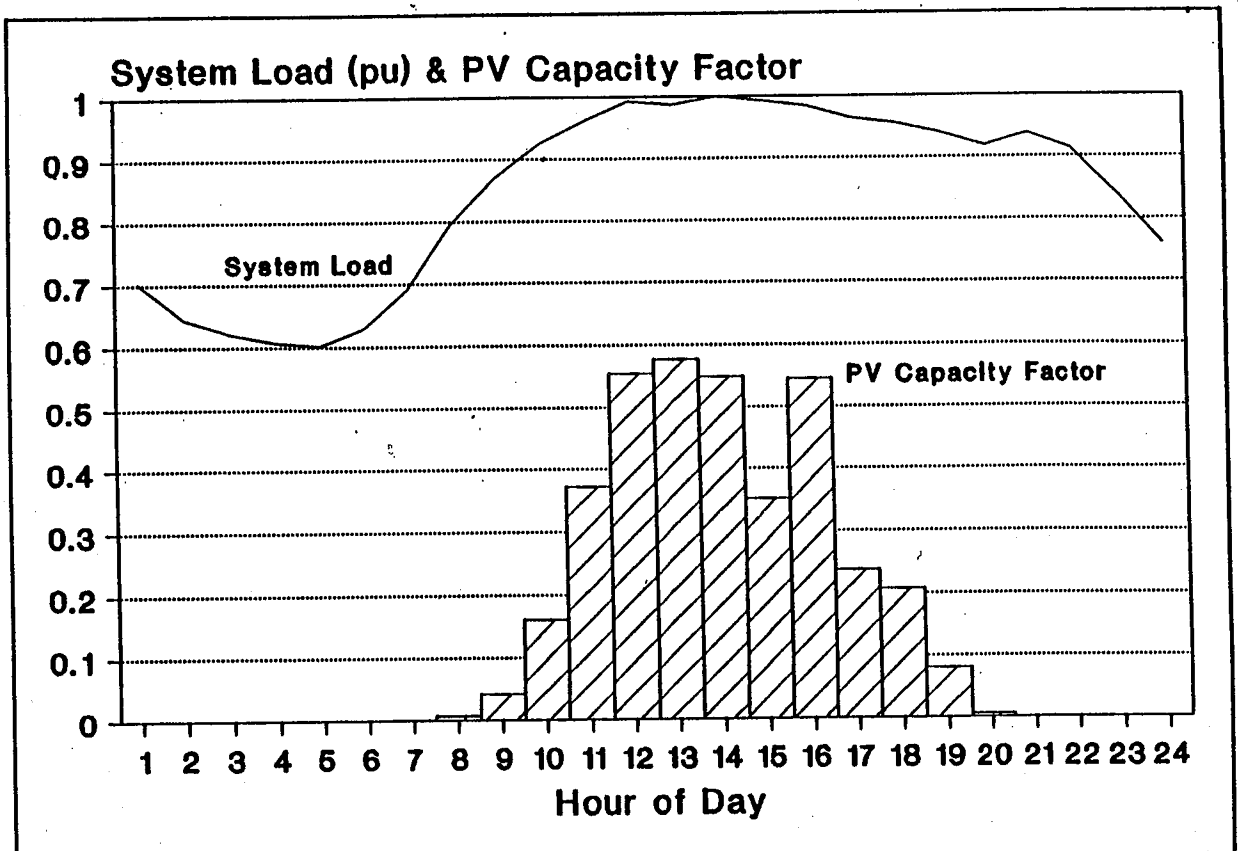



figure 8.6 . **Hourly PV Generation and NEES System Load on August 10, 1988.** Prepared By Ascension Tschnology,Inc. For EPRI.

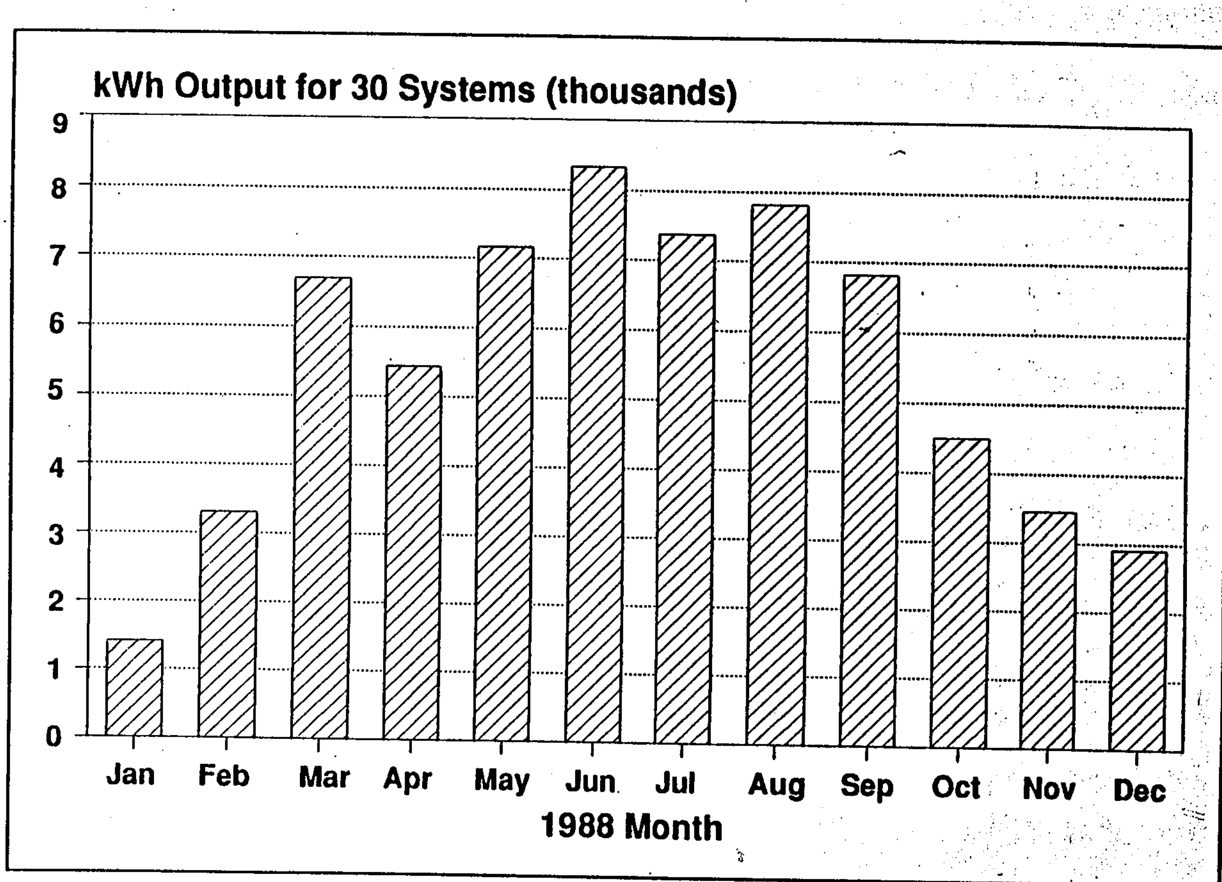



figure 8.7 . **Monthly Energy Production in 1988 for All 30 Gardner PV Systems**. Prepared By Ascension Technology, Inc. For EPRI

### 8.3.2 Fall Power Generation

Fall (the months of September, October and November). The average monthly output for the fall was 171 KWh. This is the second least amount of power produced throughout the year by the PV system. Refer to figure 8.7.

### 8.3.3 Winter Power Generation

Winter (the months of December, January and February). The average monthly output for the winter was 93 KWh. This is the least amount of power produced throughout the year. This is the result of the angle and position of the modules on the roof of the house, and the low angle of the sun in the sky during the winter. These factors cause very little power to be produced from the array. Refer to figure 8.7. During the winter months the values shown are more likely to change than data collected from other months. The unpredictable amounts of snow tends to make the power production of the PV systems vary.

### 8.3.4 Spring Power Generation

Spring (the months of March, April and May). The average monthly output for the Spring was 213 KWh. The amount of power produced during the spring can be seen in figure 8.7.

## 8.4 Acceptance of the PV System

### 8.4.1 Homeowners

When the homeowners were approached with the idea, from NEES, to install PV systems on their homes, most were skeptical. The skepticism may have been caused by NEES, a power utility company, approaching homeowners and offering to give the homeowners power producing systems for their homes. This may have seemed unusual to the homeowners, since utility companies generally sell power to homeowners instead of giving it away. Most of the homeowners did not know what a PV system was nor how it worked. NEES described the systems to the homeowners and explained what they would be doing with the systems. Since the homeowners would be producing their own power they would not have to pay as much on their monthly electric bill, and this would be a major benefit to them. The homeowners were also informed that ownership of the systems would be turned over to them at the completion of the experiments, and this caused some concern. If the system broke down after the transfer of ownership was completed the homeowners would have to pay for the repairs. Repairing the system could be very expensive, putting a added burden on the homeowner. From the beginning of the project the PV systems have run flawlessly, and have had only seven inverter failures throughout the thirty houses. All the failures were very simple, five of the failures were from cold solder joints and were easily corrected and the other two were caused by a transistor malfunction.

The PV systems solar collector's are mounted directly on the roofs of the homes, in a way that makes them look attractive. The homeowners feel that the PV systems will increase the value of their homes and make them more attractive to prospective buyers, in the event they decided to sell. The array on the roof looks like ten large sun-windows on the house and is pleasing to the eye. The systems supply some of the power needed by the homes, without polluting the air, as is the case when power is generated from fossil fuel power plants. The knowledge that they are producing environmentally friendly electricity is satisfying to some of the homeowners.

Ascension Technology Inc. sent a mail-in questionnaire to the homeowners in August of 1989 and received approximately fifteen in response. The questions asked can be seen in table 8.1. Most responses showed that homeowners were very happy with the systems and the solar collectors appearance, except for one homeowner who did not believe that the system was supplying power. Some of the responses to other benefits of the system question were: "the ability to sell back power", "adds value to the house", and "produces clean power". Comments on the appearance of the modules: "looks real good", "can hardly notice them", "they are aesthetically pleasing", and "neat, conform to roof line". Overall the homeowners are very pleased with the performance of the systems.

The average savings on the homeowners electric bills were approximately $200 a year. The monthly electric bills after PV installation ranged from a low of $5 for a home with good conservation to a high of $250 for a home with electric baseboard heat. This savings is beneficial to the homeowners. However, it is not large enough to justify paying about $18,000 for equipment and installation of a PV system.(Ref.#8) Of course in this case, NEES paid for all of the PV systems.

Table 8.1 Ascension Technology, Inc., Questionnaire

TYPICAL QUESTIONS ASKED OF ALL GARDNER PV HOMEOWNERS

How long have you lived in your home?
Was PV a factor in your decision to purchase?
How was PV explained to you and by whom?
How much money does your PV system save you each year?
Do you see benefits to PV other than saving you money?
Please comment on the appearance of the solar panels on your roof.
Do you think others would want a PV system like yours?
What have your high, low and average electric bills been?
Are you more aware of energy use because of your PV system?
What would you pay for a PV system that saves you $200 per year?
How would you prefer to finance a PV system on your next home?
Have there been any repairs made on your system?
Please provide any other comments.

Since the shingles on the roof have a life expectancy of about twenty years, some of the homeowners wanted to know how they would replace shingles with the modules on the roof. Since the systems were designed to be easily installed in two hours, the solar modules could be taken off while the roof is being re-shingled and then replaced the same day with ease. NEES had agreed to do the removing of the system for the re-roofing and then replace them when that work is done. The homeowners are very pleased with the installation. The systems required only a minimum amount of repair and maintenance or none at all. An option for a homeowner that has a PV system on their home an the roof needs re-shingling, is to only replace the shingles that were not covered by the PV modules. Shingles decay from direct sunlight. Since the PV modules cover a large portion of the roof the shingles under the PV array would be preserved and would not need replacing.

### 8.5 Information Learned from the Project

#### 8.5.1 Knowledge Gained by the Homeowners

Most homeowners believed that they would save large amounts of money with PV systems on their homes. However, the homeowners soon realized that although they are saving money, the amount saved did not meet with their expectations. The Sunsine 2000's power indicator lights, which was added by a professor at MIT, is beneficial. The lights on the inverter help the homeowners understand their power consumption and production more fully. The lights provide the homeowners with a visual representation as to the amount of power they are producing from their array. This understanding has lead to some of the homeowners practicing energy conservation to further reduce their electric bills, and may be one of the most important advantages to having a PV system.

In response to the question of other benefits of the system one of the homeowners believed that their system would produce power during a grid power outage. This however, is not true. The PV system will be able to produce power but, the system is disconnected from the utility grid in the event of a power outage, therefore the PV system is also disconnected from the household use.

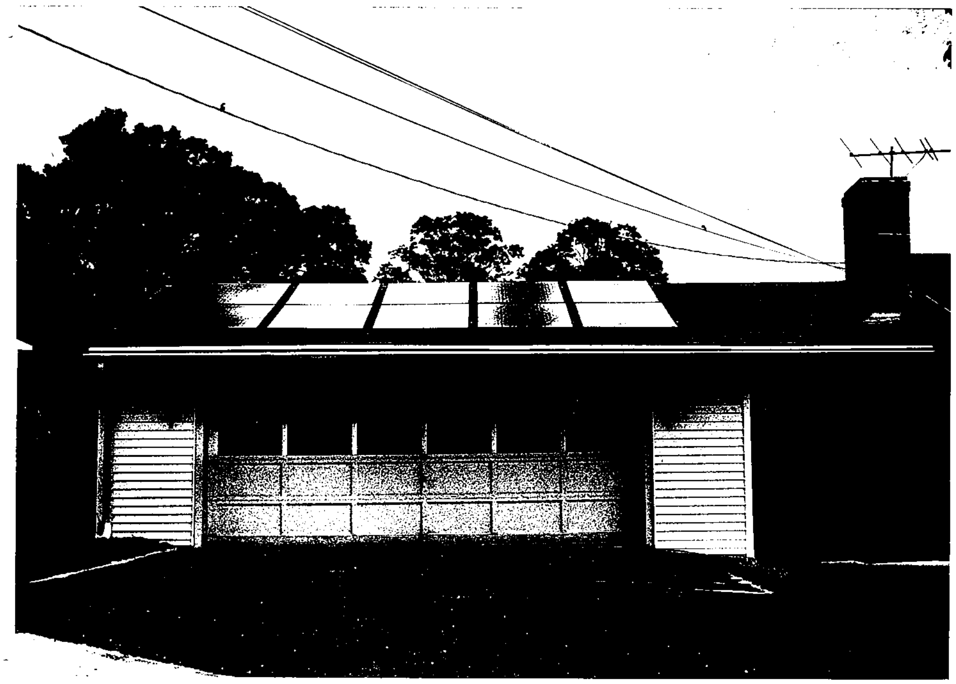
With the net energy metering system on the Gardner homes it does not matter when the homeowners use the solar generated electricity. Homeowners will get full credit for the extra power they produce during the day and will be billed for the power they consume from the utilities during the night or cloudy days.

### 8.5.2 Knowledge Gained by New England Electric Systems

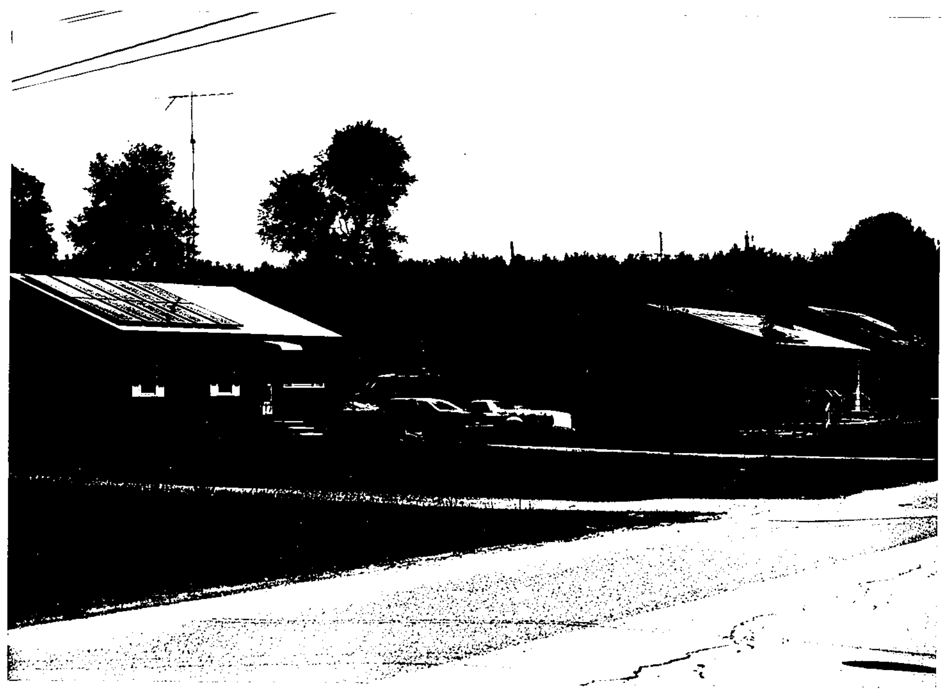
The research conducted, with funding provided by Electric Power Research Institute, was to study the effects of their cluster of PV systems on one substation. The research conducted included the following effects: (1) Steady State and Slow Transients, (2) Fats Transients, (3) Harmonics, (4) and Overall Performance of Distribution Systems. The results from the monitoring did not show any disadvantages from the use of residential mounted PV systems, connected to the utility power grid.

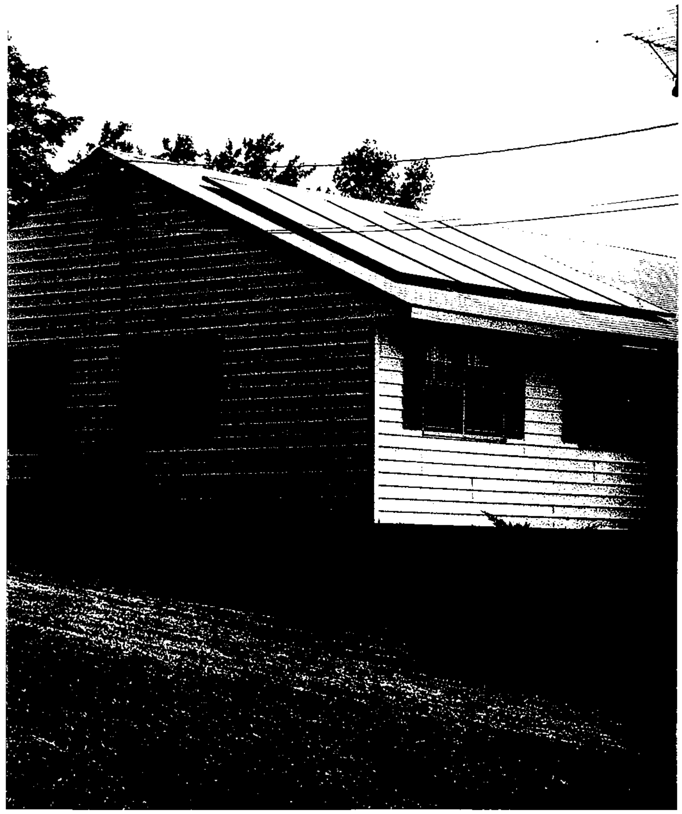
From the experiments conducted before the installations, on the Gardner homes, by MIT's Northeast Residential Experiment Station (NERES), NEES had found that the Sunsine 2000 is a reliable power conditioner to use on the homes. The mounting brackets that were used on the homes were also designed by the NERES.

The correlation of the NEES peak load and the PV system peak output period is one of the many benefits of the PV systems. The experience of the interconnection of PV systems owned by households has allowed NEES to evaluate other PV system homeowners, wanting to interconnect to the grid. This is just some of the knowledge gained from this project. The learning of PV/Grid connect systems most likely will continue for a long time.

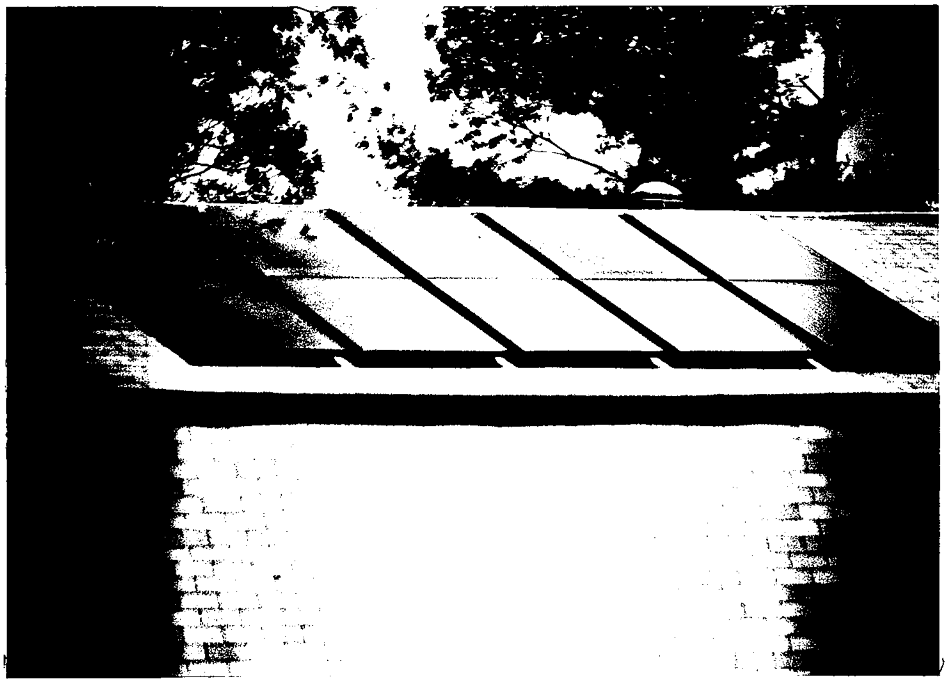


PV Array Mounted On Gardner Homes





PV Array And Metering On
Gardner, MA Homes; NEES Project



Single Net Metering System On Gardner, MA Homes; NEES Project.

Substation For The Gardner Homes

# Chapter Nine

# Gardner Project Conclusions

### 9.1 How Efficient was the System?

#### 9.1.1 Economically for the Homeowners

From the homeowner's perspective the PV systems are very economical. The main reason for this is that they did not have to pay for the equipment, installation, and maintenance of the PV system. The $1.3 million spent to install and monitor the performance of the systems was paid for by New England Electric Systems. The homeowners were provided with a PV system that, on the average, save their home $200 per year in electric bills. This savings provides an economic benefit to the homeowners. For the life of the system the homeowners can expect a savings on their electric bills of approximately $6,000, or $200 per year for 30 years.

Once NEES has completed their data collection and experiments with the PV systems in Gardner the ownership of the systems will be transferred to the homeowners. This is a financial benefit to the homeowners, since it will boost the value of their homes. The homeowners have also gained a small power plant that is capable of generating 2.2 KW of electricity that is clean and free, for their homes.

Another benefit for the homeowners is that they now can see how much power they are consuming on the LED (Light Emitting Diode), which shows the power being produced and consumed by the household. After seeing the amount of power consumed by their homes some of the homeowners have decided to conserve more energy then they were conserving before the installation of the PV system. This has caused their monthly electric bills to decrease even further. Homeowners that plan to design a PV system for their homes need to realize that the amount of power being consumed by their household will affect the size of the PV design. With the systems in Gardner, the homeowners learned after the installation that it pays to conserve electricity.

### 9.1.2 Economically for New England Electric Systems

The economics for NEES are very different than for the homeowners. The PV systems and maintenance have cost NEES 1.3 million dollars to date. They did not plan on the project to be economical. The purpose was to collect information on the effects and reliability of a solar PV system. The objective was not to make money or save money by not having to generate utility electricity for a few homes.

NEES has found from monitoring the systems and reviewing their own load data, that the peak output from the PV systems mostly corresponded to their summer peaking load period, as mentioned earlier. These PV systems have each reduced NEES peaking load by 1.2 KW (Ref.#1). This in turn decreases the cost of generating electricity for the peaking load periods for NEES. Utilities have three different types of power generating plants. One is the Base-load Plant which generates electricity 24-hours a day and 7-days a week, stopping only for maintenance. A Cycling Plant will operate from early in the day to later in the afternoon. And finally there is the Peaking Plant, which will operate fewer hours then the Cycling Plant and generate power just to cover the peak loads of the system. The PV systems on the Gardner homes are acting as a peaking plant, providing extra power during peak load periods. The PV systems in Gardner are not as large as a peaking plant but the PV systems are proving to be effective in decreasing the burden on a generating plant.

Since the PV systems are on the houses that they supply, there is almost no line loss in the system wiring. Usually line loss occurs from the resistance in the lines that are supplying the substations and houses. Since the substation and power lines feeding the thirty homes does not need to carry as much current, the line loss is decreased. As mentioned in a previous chapter, line energy power loss is: Current squared times the resistance of the wires. Therefore the less current flowing in the wires, the less the power loss in the lines, thus saving money for NEES and not wasted it as heat in the wires.

### 9.1.3 Power Generation and Consumption

The Mobil Solar Corporation's Ra180 solar module used on the homes in Gardner have an efficiency of about 11-12%. This means that about only one tenth of the sun's energy striking the module is converted into usable electricity. This efficiency rating is normal for single crystal silicon solar PV modules produced for consumer use.

The American Power Conversion's Sunsine UI-2000C inverter which was installed in 29 of the homes has an efficiency of 93% at peak power output. This inverter, as mentioned earlier, has a peak input dc power of 1.9 KW. The peak output power from the inverter is 1.8 KW of ac power. The other inverter used was a Omnion Series 2200 which has a efficiency of 95% and has a peak dc power input of 2.2 KW. The peak output power of the inverter is 2.0 KW of ac power.

The wiring was sized for minimum power loss, due to heating of the wires.

Therefore, the system efficiency is decreased mostly by the inefficiency of the inverter.

The power generated from the PV systems, is first used to supply power to the corresponding PV home, and then any excess power is sent into the grid to be used to by other homes. These PV systems work very well in reducing the power needed from the substation, to power the 30 homes in Gardner with the PV systems on their roofs.

The power consumption of the homes was normal for a community of that type. However, the homes with the PV systems used less power because of the PV's. The Gardner PV homeowners also tend to conserve even more electricity, since they can visually see the power they are consuming.

### 9.1.4 Environmentally

Environmentally the PV systems produce power free of any particulate and other chemicals ($CO_2$, $SO_2$, NOx), which are produced when generating electricity from a fossil fuel burning plant. Therefore, a PV system is a sound way to generate electricity for your home. PV systems do not present any risk of health to the people in the community. Since the modules are not made with toxic or radioactive materials there will be no problem in disposing of them in approximately 30 years when they begin to fail.

The same amount of power produced by the PV systems, if produced by a coal burning power plant, would create large amounts of Carbon Dioxide, Sulfur Dioxide, and Nitric Oxides. The systems have also saved on resources of fossil fuels used in the production of electricity.

### 9.2 How Successful is the Gardner Project?

#### 9.2.1 Success for NEES

The information that has been collected at Gardner on the PV-Grid connected systems is and will be very valuable to people wanting to connect to the grid with a PV system of their own and also to other utility companies. NEES has found that the PV systems help reduce the utility line loss, since there is a smaller current flowing in the wires to the homes.

The PV systems on the homes have been working very well. Some of the PV systems have been working for seven years without any problems, and the problems that have occurred were minor problems. During the summer the systems produce excess power that is fed into the power utility's grid to be used by other homes. This extra power is just one of the many benefits of the PV systems. Another benefit, is that the peak output of the PV systems during the summer, offsets the need for the utility company to produce more electricity during the peaking load period, because both peaks occurred at about the same time.

#### 9.2.2 Success for the homeowners

The homeowners are very pleased with the PV systems and the help they have received from NEES. As stated earlier, only a few of the systems have had problems and those problems were corrected promptly.

Some of the homeowners believed that their electric bill would be reduced by larger amounts then the average $200 per year. This lack of reduction is the only complaint that was obvious. However, the reduction seen in their electric bills was still a benefit even though the reduction did not meet the homeowners expected savings.

The PV systems have helped the homeowners realize the amount of electricity they are consuming. Since the homeowners can see the amount of power used, some have succeeded in reducing their electric bills even more. NEES and EPRI continue to add monitoring devices to the PV systems to further understand the effects of the systems. This means that the systems are checked on a regular basis, allowing the homeowners to be worry free.

# Chapter Ten

# Photovoltaic Professionals and Companies

# or

# How Do I Seek Advice and Purchase Solar Components

As stated in the introduction, two common questions asked by homeowners are where can I purchase photovoltaic modules and equipment, and whom do I contact? The purpose of this chapter is to provide the homeowner with an introduction to a select number of photovoltaic professionals, companies, and organizations that can be contacted for help. The following briefly describes Photocomm Inc., Sunnyside Solar Inc., Fowler Solar Electric Inc., Talmage Engineering, Solar Design Associates, and several others all available in New England, (Photocomm through catalog ordering).

## 10.1 Photocomm Inc.

Photocomm Inc. headquarter's is located on 7681 East Gray Road, Scottsdale, Arizona 85260, # 1-800-223-9580 or 602-948-8003. Photocomm Inc. offers a variety of photovoltaic systems (Home, RV, and Marine), hybrid systems (Wind, Generator, and Hydroelectric), and passive solar hot water heating. Photocomm Inc. sells high efficiency lighting, and appliances as well. Remote homes and recreational vehicles (RV's) have been the core of Photocomm's business. However, Photocomm has also supplied photovoltaic systems for Street and Advertising Lighting, Telecommunications, Telemetry, Cathodic Protection, and Railroad applications.

Photocomm's Design Guide and Catalog (free from Photocomm) is informative. The catalog provides a brief introduction to the different components used in photovoltaic systems and their purpose. The design guide is simple and one of the easiest to follow. The design method is based on four steps. The first step is calculating the watt hours consumed daily. The second step is locating the area's appropriate solar zoning identification on the sizing map, which is identified by letters from A to F. The homeowner should choose the letter that most closely identifies his geographical area. The third step incorporates a System Selection Chart. The system selection chart consists of the different zones, different watt hours, and the appropriate system number. To use the system selection chart the homeowner would find his zone identification, from the sizing map. The homeowner would then find the zoning identification on the top of the chart. The column under the zoning ID consists of different watt hours. The homeowner should find the number that most closely resembles his own power requirements. Once the correct number (WHrs) is found the homeowner would read over to the left to find the appropriate system number. The last step uses the Solar Electric Modules & Battery Selection Chart. Once the homeowner has determined the appropriate system number he will need to use this chart. The homeowner finds the row that corresponds to his system number and the chart indicates the number of 50 Watt modules needed and the recommended battery bank size.

The design section of Photocomm's catalog also describes two different battery bank sizing methods. The first method is a rough battery estimate, the second is a safe battery method. Both are very easy to use and involve two very simple mathematical equations. Once the appropriate number of modules and batteries are determined the homeowner can chose to purchase one of Photocomm's photovoltaic kits or purchase individual components. Photocomm also offers introductory guidance to module angling, and battery installation. The catalog has diagrams of five basic battery wiring designs that homeowners can use as references.

Although Photocomm's design guide is one of the easiest to use, it has its limitations. By simplifying the design methodology, the homeowner may have to choose a system that is smaller or larger than his actual needs. Another limitation in the design is its lack of flexibility. If the homeowner has gone through the design process and wishes to determine the number of modules needed he must use 50 watt rated modules. The design chart does not include modules with different wattage ratings, which limits the homeowner to using 50 watt rated modules. Photocomm's design guide provides the homeowner with an easy design process if Photocomm products are purchased. However, Photocomm's design guide becomes more difficult if components and products from different manufacturers and suppliers are utilized. If problems like the above^Ioccur, homeowners could contact their nearest Photocomm dealer and discuss his plans, concerns, and electrical needs and in the process have any questions and problems answered.

### 10.2 Sunnyside Solar Inc.

Sunnyside Solar Inc. is a family owned and run business. Richard Gottlieb and Carol Levin founded Sunnyside Solar and have been in business since 1982. Their address is RD 4 Box 808 Green River Road, Brattleboro, Vermont 05301, # 802-254-4670. Sunnyside Solar Inc. specializes in remote and non-remote photovoltaic systems. They sell a variety of photovoltaic components including modules, batteries, and inverters. They also sell water pumps, refrigerators, lighting and used equipment as well.

Richard Gottlieb has dedicated much, if not all, of his career to the field of photovoltaics. Mr. Gottlieb was involved in using photovoltaics on the Vanguard I satellite, (the first satellite to be powered by solar PV's). Mr. Gottlieb has even traveled to Russia to share his knowledge and enthusiasm of solar photovoltaics. Mr. Gottlieb is a qualified solar photovoltaic professional capable of answering questions and problems concerning photovoltaics.

Sunnyside Solar offers a hands-on seminar workshop that is held monthly, spring through fall. The number of people per workshop is limited to eight. By limiting the number, Richard and Carol are able to personalize the program for each individual. The workshop is informative, interesting, and fun. Each person who attends receives a large packet of photovoltaic information. This packet can by taken home reviewed and utilized at a later date. The workshop consists of the following: an introduction to photovoltaics (history and development, basic definitions, and different types of systems). A review of the different components in a photovoltaic system. Sizing techniques for a small residential PV system. Economics - cost of system, life cycle costs. A tour of the 320W PV system, water pumping system, and refrigeration at Sunnyside. A hands on workshop, which involves setting up a PV system and powering a lighting display. The workshop ends with a question and answer session. The authors of this report participated in one of Sunnyside's workshops. After taking the workshop the only negative comment that can be made is that we wished we could have received the packet of information prior to the seminar. The packet provided, contains a variety of information which raised new questions. If the packet could be received prior to the seminar, homeowners could' review the information and have any questions ready. The homeowners would also be more prepared for the workshop and may understand the concepts of the seminar more fully.

System design and guidance is also offered by Sunnyside Solar. According to Richard Gottlieb the systems are priced three ways. In the first way, Sunnyside Solar would install the system, at about $30 per watt (400 watt system would cost approximately $12,000). In the second way the components are prepared by Sunnyside and the homeowner installs the system himself. The price in this second method is approximately $20-$25 per watt (400 watt systems would cost approximately $8000-$10,000). In the third method the system is installed completely by the homeowner. The homeowner purchases the individual components, brings them home, and installs them. The third method is generally accomplished after the homeowner has taken Sunnyside's workshop or is already knowledgeable in the area of solar photovoltaics. The cost of installing the third systems is approximately $15 per watt (400 watt system would cost approximately $6000).

Generally, Sunnyside Solar tests all equipment before it leaves the shop. If a homeowner's system needs repair, Sunnyside offers a repair service. If Sunnyside is unable to repair the broken component, they will loan the homeowner a replacement until the broken component is fixed or replaced.

Sunnyside's catalog is relatively small. It lists the components of a photovoltaic system (i.e. modules, batteries, inverter), lights, refrigerators, water pumps, used PV equipment if available, and informative PV books. Many components are kept in stock and can be shipped immediately. Components that must be ordered will take up to 8 to 10 weeks before delivery.

### 10.3 Fowler Solar Electric Inc.

Jeff Fowler founded Fowler Solar Electric Inc. in 1981. The business in currently run by Mr. Fowler, Lea Fowler, and Steve Schulze. Fowler Solar Electric Inc. is located at 13 Bashen Hill Road, Worthington, Massachusetts 01098, # 413-238-5974 or 413-238-4275. To fully appreciate the services provided by Fowler Solar Electric, the homeowner should review the Fowler catalog and the book titled The Solar Electric Independent Home Book. Both the book and catalog compliment each other. The catalog provides a brief introduction to the components of a photovoltaic system and the equipment and services supplied by Fowler Electric. The book takes off where the catalog ends and helps the homeowner develop a better understanding of photovoltaic systems and how they work. Fowler Electric offers a variety of photovoltaic components (i.e. modules, batteries, charge controllers), a PV/Generator hybrid system, lighting, refrigerators, water pumps, gas space heaters, a gas water heater, and used equipment if available. Fowler Electric also holds periodic workshops in different areas throughout the northeast. The majority of their business comes from remote homeowners. These homes consist of full time residences, summer vacation homes, and cabins.

The Solar Electric Independent Home Book also provides homeowners with a photovoltaic system design. The design method is more involved than Photocomm's method of sizing. However, it is not extremely difficult to understand if one has read the book. They have simplified the process and have eliminated the need to directly include battery inefficiencies, by finding the usable wattage of the modules initially. Once the usable wattage is determined the seasonal daily usable output is determined. This is accomplished by multiplying the usable module wattage by the number of usable hours of sun. The last step in determining the systems array size is dividing the average daily load in whrs by the seasonal usable output in whrs, which will give the number of modules needed. From the array size the battery bank size can be established. Again, Fowler Electric has simplified the process down to one of two simple equations. For homes in the Northeast the equation used is (30 Watt-hours x Module Wattage Rating x Number of Modules). Since the battery bank size equation incorporates the number of modules in the array you cannot over or under design the battery bank.

Fowler Electric's method of sizing requires a few more calculations and the use of more charts than Photocomm's. However, Fowler Electric has simplified the process and eliminated the need to calculate in wire losses, battery and inverter inefficiencies, number of days of autonomy, and temperature factors. They have been able to eliminate these factors only after years of workable and reliable experience. However, there may be some homeowners who want exact calculations and all details factored in. In this case, the homeowner cannot use Fowler Electric's method of sizing. If a situation like this occurs the homeowner could contact Fowler Electric for consultation and exact design specifications, have Fowler Electric perform the design, or choose to use a different sizing design.

Through experience Fowler Electric has found that many homeowners purchase photovoltaic systems not according to electrical needs but according to total cost. Most homeowners purchase a PV system that is within their economic means. Fowler Electric has designed PV kits that range in size and price, and hence address this issue. Each kit is available in a basic, intermediate, and advanced model. If a homeowner would like to purchase a kit and cannot find one to match his needs, Fowler Electric will design a kit to meet the homeowner's need or price range. We have included a few pages from Fowler Electric's Catalog which show the contents of the kits and the design schematics. The schematic designs of Fowler Electric's kits are very professional and deserve recognition. They are neat, easy to follow, are of high quality, and provide the homeowner with a visual representation of the systems layout.

### 10.4 Talmage Engineering

Talmage Engineering was founded by Peter Talmage. Talmage Engineering is located at P.O. Box 497A No. 438A Beachwood Road, Kennebunkport, Maine 04046, # 207-967-5945. Talmage Engineering supplies photovoltaic components, Hybrid systems (PV/Wind, PV/Generator), lighting, appliances, water pumps, solar hot water systems, and low flush toilets. Talmage Engineering's catalog provides a brief introduction to the different PV and Hybrid systems. The catalog also provides a sizing design. The design uses the following steps. First the daily amphrs are determined. Next the daily amphrs are adjusted to compensate for battery inefficiency. The third step requires the homeowner to locate his site on a solar potential map and find the yearly average sun light hours for that area. The forth step determines the PV array's current output. This is accomplished by dividing the adjusted amphrs by the number of full sun hours. The fifth step determines the number of modules needed for the array. This is accomplished by dividing the array's current output by the module's amp output rating. The battery bank sizing method depends on the type of battery used and the number of days of autonomy needed, neither of which is difficult. Talmage's sizing method is more involved than Photocomm's but is no more difficult than Fowler Electric's. If exact figures are needed, Peter Talmage can be contacted for questions and consultation.

In Talmage's catalog there are five PV kits called models (the basic, small home, medium home, large home, and utility interface power system). Each model provides the corresponding specifications and schematic diagrams. The diagrams are similar to Fowler Electric's and provide the homeowner with a visual representation of the system's layout. The only difference is Talmage's specifications and schematics diagrams include a select few appliances such as a Sun Frost Refrigerator, radio, TV, and lights.

### 10.5 Solar Design Associates Inc.

Steven Strong who founded Solar Design Associates Inc. is an Architect. Solar Design Associates in located in Harvard, Massachusetts 01451-0242, # 508-456-6855. Mr. Strong has designed numerous photovoltaic systems, including those for the 30 homes involved in the Gardner Project. (Please refer to chapters 8 and 9). Solar Design Associates also provides renewable energy systems engineering, PV system installation, Energy independent residences, and passive solar system designs. As an architect, Steven Strong is able to design complete homes. If homeowners are interested in building a environmentally responsive home, Mr. Strong would be a qualified profession to contact.

**10.6 Miscellaneous Professional, Companies, and Organizations**

Listed below are the names and addresses of other PV professionals, companies, and organizations that can be contacted for information and help.

Professionals and Companies

**Solar Works Inc.** is located on 64 Main Street, Montpelier, Vermont 05602, # 802-223-7804. This company is owned by Leigh Seddon and has been in business since 1980.

**Skyline Engineering** is located at P.O. Box 134, Applewood Lane, Temple, New Hampshire 03084, Telephone # 603-878-1600, Fax # 603-878-4643. This company is run by Rob Wills and Anita Sorensen.

**Independent Power and Light** is located at RR1 Box 3054, Hyde Park, Vermont, 05655, # 802-888-7194. This company is run by David Palumbo.

**System Electric** is located at P.O. Box 67, Lyndon, Vermont 05849, # 802-626-

5537. The sales manager of this company is Hal Gorsser.

**Solar Alternatives** is located at P.O. Box 739, Brattleboro, Vermont 05301, # 802-257-4528. The owner and president of this company is Jim Kirby.

**Solar Applications** is located at 22 S. Main Street, Brattleboro, Vermont 05301, # 802-257-7493. This company was founded by Alain Ratheau in 1977.

**Bershire Photovoltaic Services, Inc.** is located at P.O. Box 615, North Adams, Massachusetts 01247, # 802-694-1226. This company is run by Chris Kilfoyle.

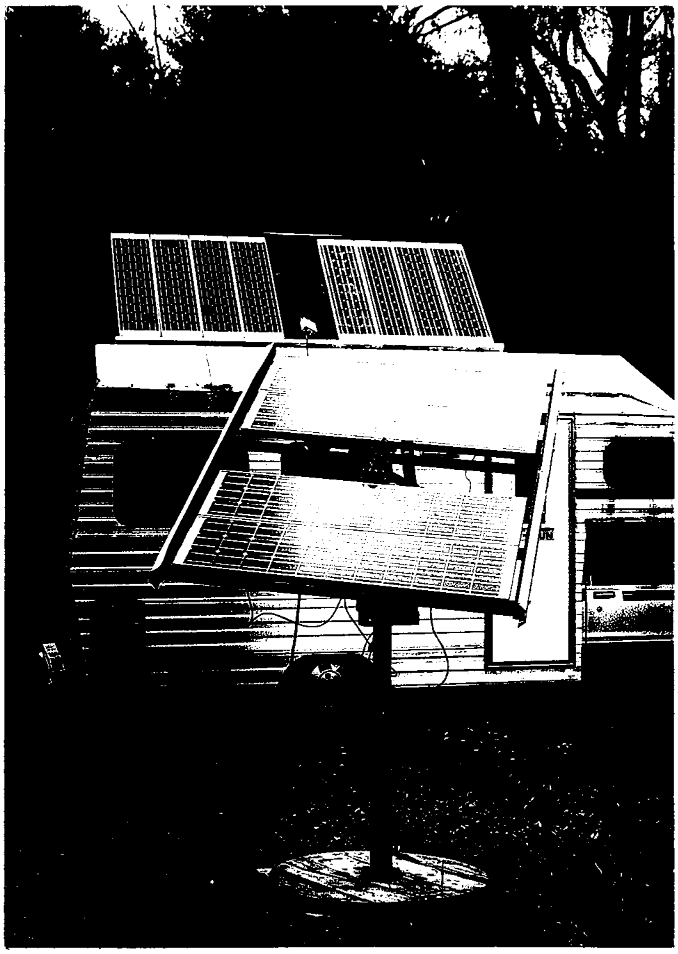
**Sunweaver** is located at 330B Rt.4 Northwood, New Hampshire 03261, # 603-942-5863. This company is owned by Norma Koski.

**Organizations that can be contacted for additional information.**

**The Northeastern Sustainable Energy Association (NESEA)** is located at 23 Ames Street, Greenfield, Massachusetts 01301, # 413-774-6051.

**Peoples Association for Clean Energy (PACE)** is located at 101 Lawton Road, Cannon, Connecticut 06019.

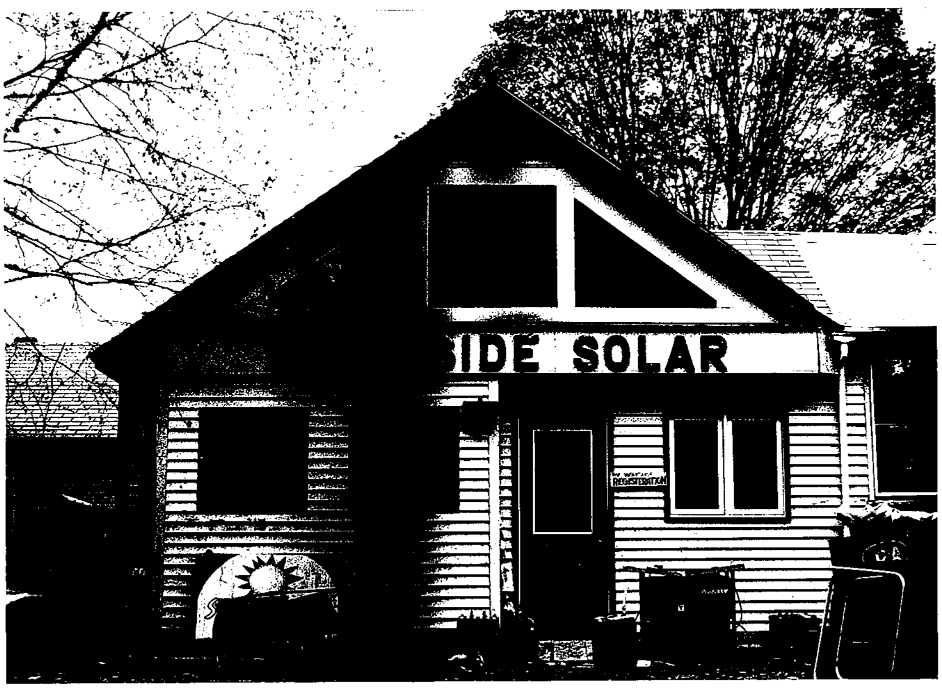
**American Solar Energy Society (ASES)** is located at 2400 Central Avenue, Suite G-1, Boulder, Colorado 80301.



Array Mounted on Passive Tracker

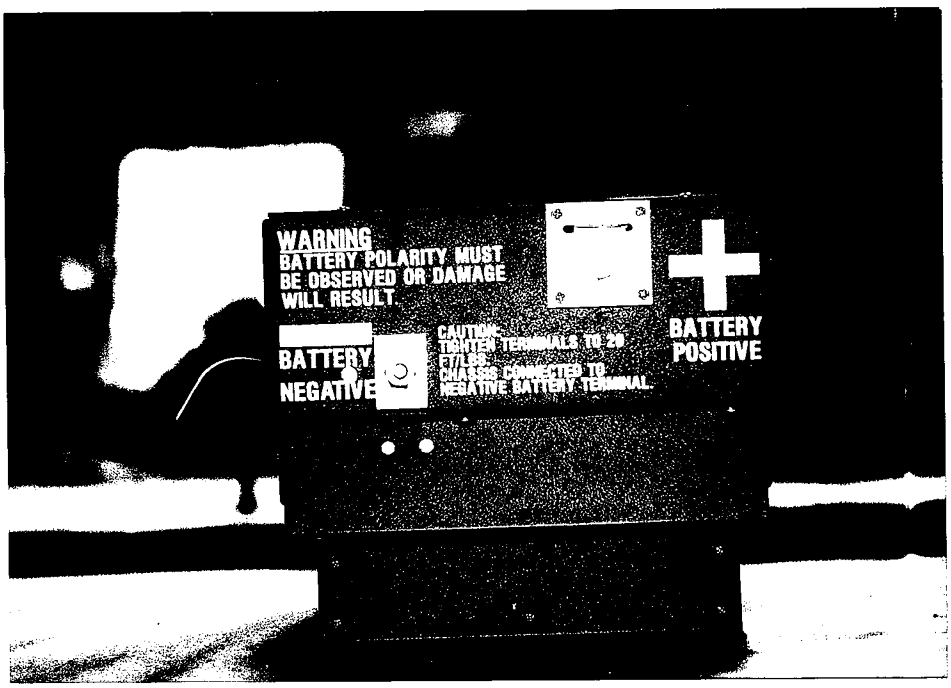
Rear Side of Array on Passive Tracker

Pictures taken during workshop held at
Sunnyside solar Inc.

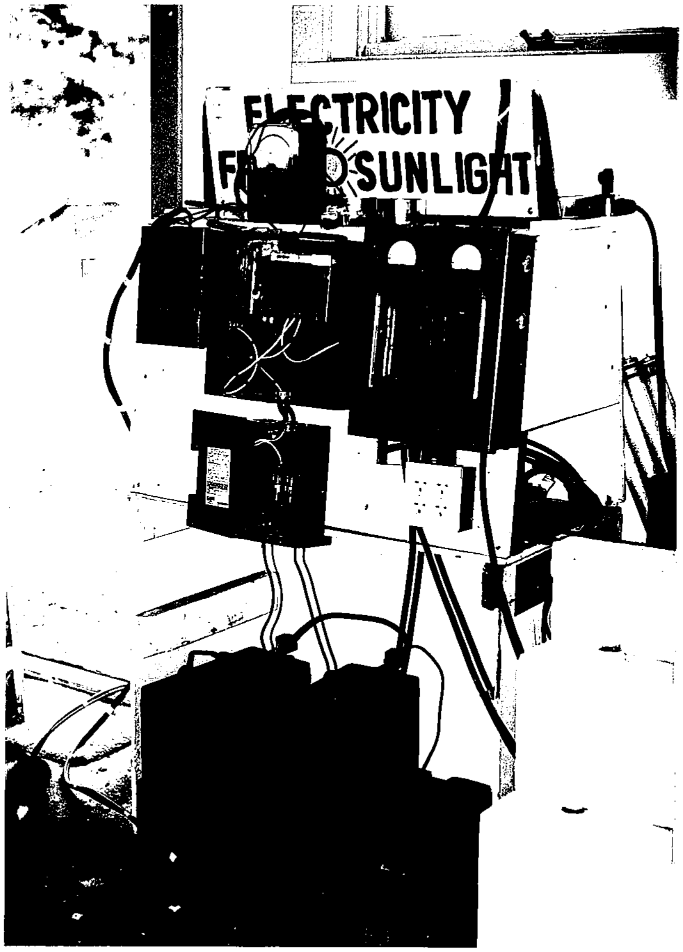



Sunnyside Solar Located in Brattleboro Vermont
Pictures taken during workshop in May 1992

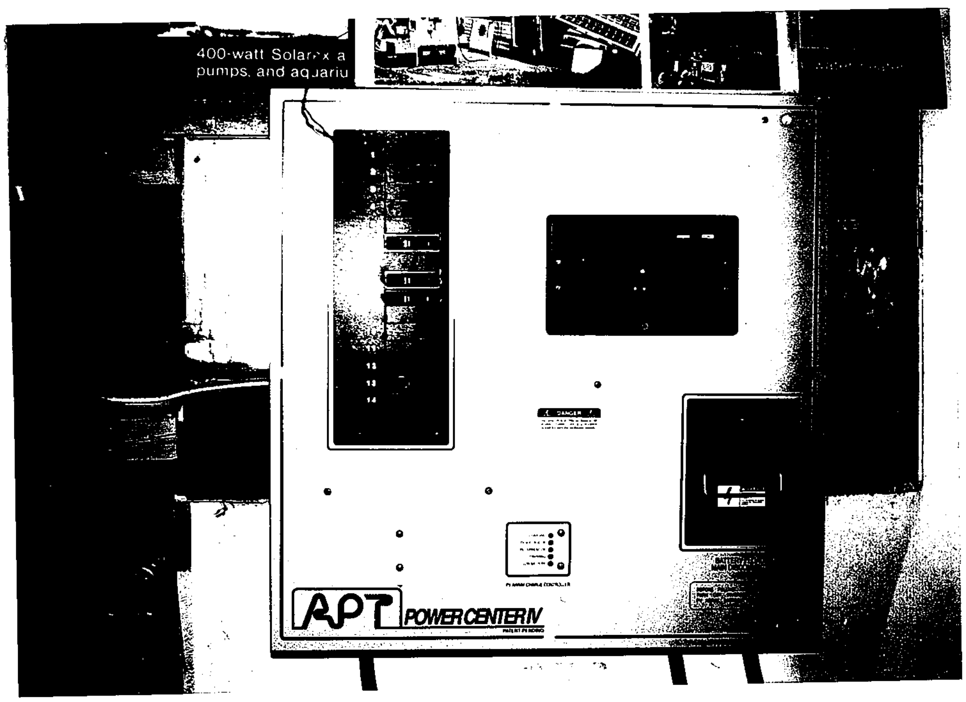

Front View of a Trace Inverter Picture Taken During
Workshop held at Sunnyside Solar




Rear View of a Trace Inverter, Picture Taken During
Workshop held at Sunnyside Solar



Wiring From Array on Passive Tracker to the Battery Bank
Picture taken during Workshop held at Sunnyside Solar




Control Panel would contain all the components in the above picture, but in a very neat and easily excessible box.
Picture taken during Workshop held at Sunnyside Solar.

# SYSTEM NUMBER ONE 12V 100 peak watts

| | | |
|---|---|---|
| 2 | 50 watt modules | $660 |
| 4 | 6V batteries 200 amp-hr | 320 |
| 1 | 30 amp charge controller | 89 |
| 4 | battery interconnects | 14 |
| 2 | module interconnects | 4 |
| 1 | array disconnect circuit breaker | 35 |
| 1 | charge controller disconnect box | 35 |
| | | Total $1157 |

## OPTIONAL COMPONENTS

600 watt inverter $550 (with 25 amp battery charger add $100)

## SUMMER USE

12V TV

12V stereo, tapedeck, radio

6 - 13 watt 12V fluorescent lights 4-6 hrs/day

## WINTER USE

4 - 13 watt 12V fluorescent lights 4 hrs/day

TV or stereo - limited use or substituted for a light

## OPTIONS

1. AC generator for AC loads and a battery charger to charge battery bank.

2. Greater weekend use balanced by lesser weekday use.

This small system will release a remote site home from the world of gas and oil lamps. It will also provide music, which is often the other motivating reason for seeking an alternative electricity to replace an AC generator. During the long days of summer, a couple will have a surplus of electricity if they use only the low wattage appliances listed. In winter, the system must be budgeted. A backup 12V charger is the answer, preferably one of those fifty pound models with the little wheels. You will need it only once a week and only in winter. This needs to be powered by a small AC generator. If possible, borrow both of them in times of no sun.

A small inverter with high motor surging capabilities (like the Trace 600 watt model) will power a vacuum cleaner, blender, or drill. These are large wattage appliances, so expect to use them only in times of much sun.

This system has larger module to battery ratio than the following systems. This larger battery bank helps to get you through long no sun periods while also providing a good sized bank for supplemental charging.

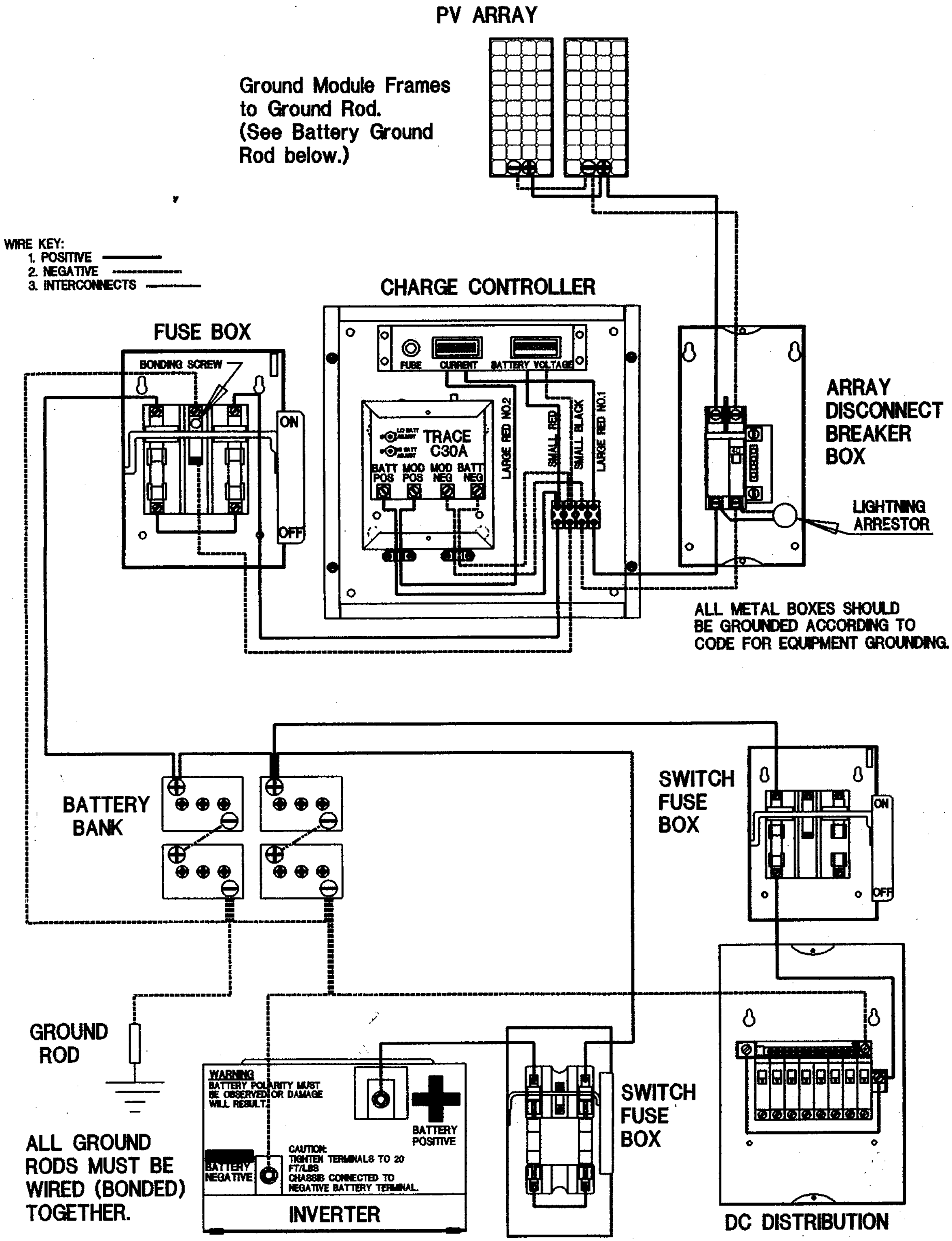



Figure 9-1 System Number One Diagram

# SYSTEM NUMBER THREE 24V 400 peak watts

| | | |
|---|---|---|
| 8 | 50 watt panels | $2640 |
| 12 | 6V batteries 200 amp-hr | 960 |
| 1 | 30 amp charge controller/meters | 180 |
| 1 | Trace 2500 watt inverter | 1350 |
| 13 | battery interconnects | 45 |
| 10 | module interconnects | 20 |
| 1 | array disconnect circuit breaker | 35 |
| 1 | charge controller disconnect box | 35 |
| | | Total $5265 |

## OPTIONS

1. 100 amp DC inverter fusebox for inverter $100
2. 52 amp programmable battery charger for Trace inverter $220

## SUMMER USE

12V TV, stereo, or radio [use efficient 24V to 12V converter]
evening lighting needs
water pumping
vacuum cleaner, skill saw, blender, small AC appliances

## WINTER USE

12V TV, stereo, or radio
4 24V fluorescent lights 4 hrs/day
conservative water pumping
limited small AC appliances

## SYSTEM OPTIONS

1. Add 3500 watt AC generator and 24V battery charger to create a PV/GEN hybrid.
2. Add two more modules.

This system is 50% larger than System Two. The most important difference is the change from a 12V system to a 24V system. Twenty four volt systems require smaller wires than 12V systems. We believe this is worth the higher price paid for 24V fluorescent lights. Incandescent light bulbs are available from dealers and are priced similarly to 12V bulbs. Medium sized inverters run on 24V. This system is small in modules (and thus in the amount of watt-hr produced), but it has the ability with the 2500 watt inverter, to power a deep well pump, a table saw, or other medium sized motors which create high surges. The system can be expanded to meet more loads simply by adding more modules.

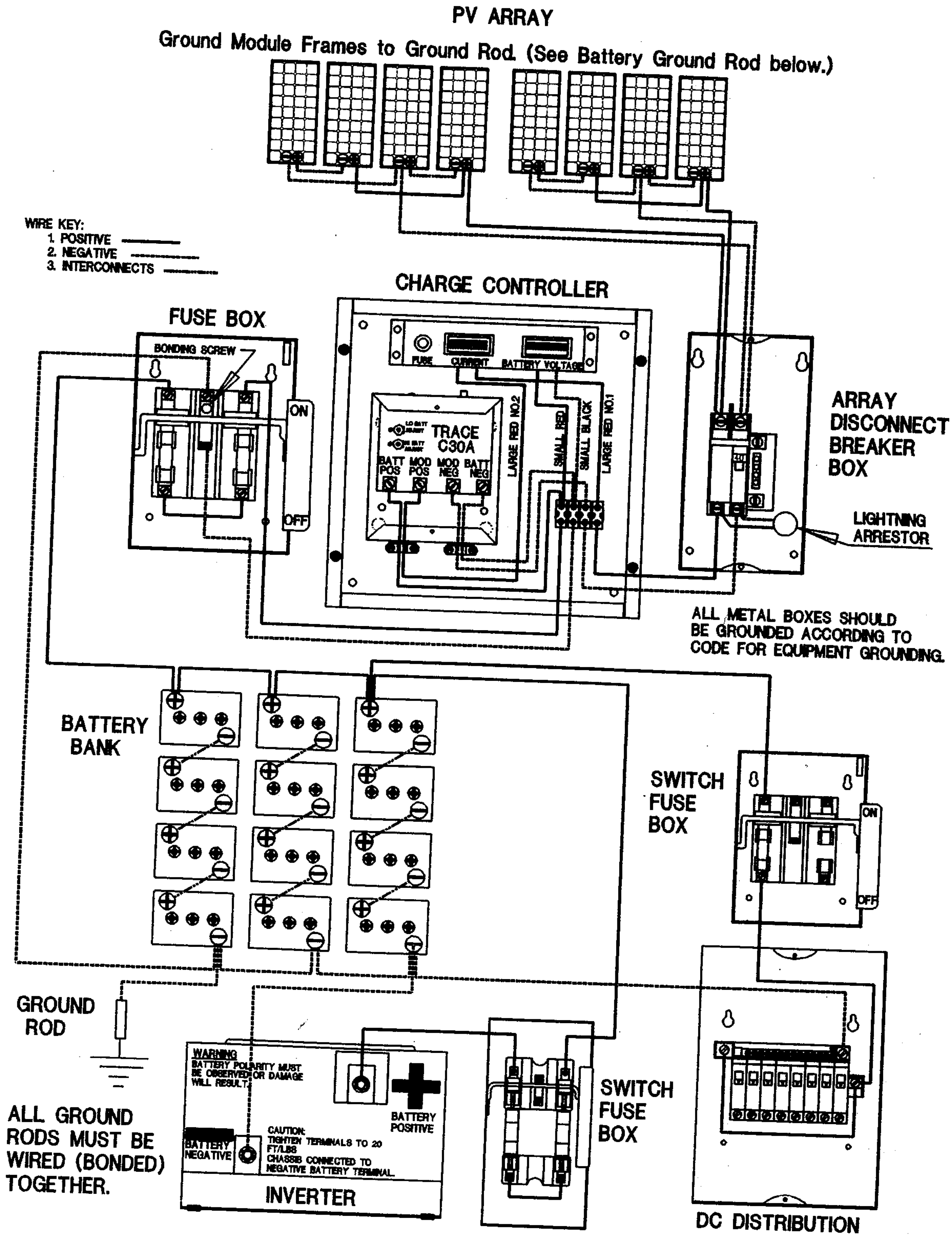



Figure 9-3 System Number Three Diagram

# SYSTEM NUMBER FIVE 24V 1200 peak watts

| | |
|---|---|
| 24 50 watt modules | $7920 |
| 24 6V batteries 200 amp-hr | 1920 |
| 2 Trace 2500 watt inverters | 2700 |
| 1 Trace inverter stacking option | 200 |
| 28 battery interconnects | 98 |
| 28 module interconnects | 56 |
| 2 30 amp charge controllers/meters | 360 |
| 2 array disconnect circuit breaker | 70 |
| 2 charge controller disconnect box | 70 |
| Total | $13,394 |

## OPTIONS

1. Two 52 amp programmable battery chargers for Trace inverters $440

2. Additional batteries may be added for northern climates.

## SUMMER USE

This is an expanded version of the previous system. The inverter size has been doubled to meet larger heavy loads.

## WINTER USE

This system may have been chosen to eliminate the need for a backup generator in the winter. If the winter loads have increased over the previous system loads, then a generator and inverter charger option is still desirable.

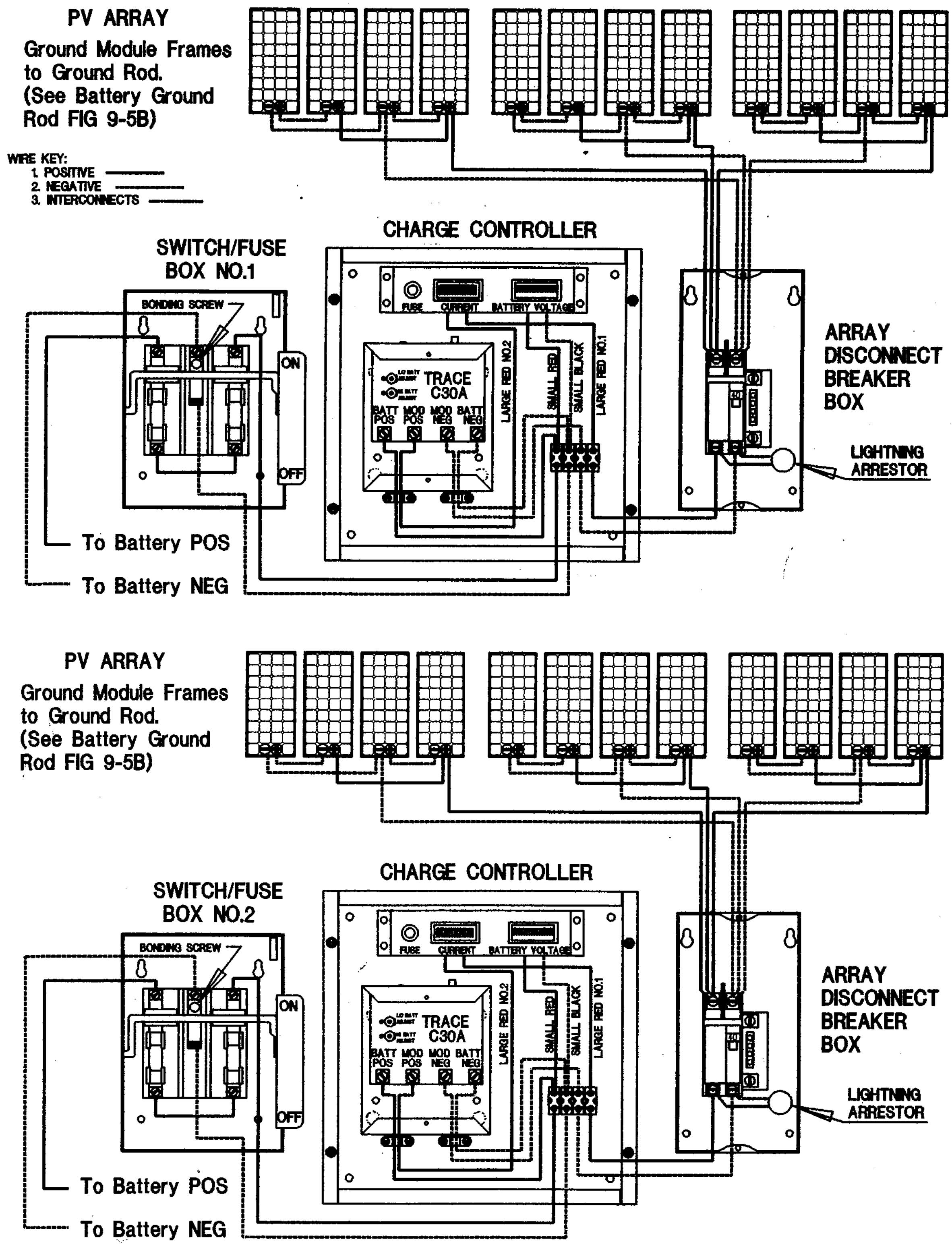



Figure 9-5A System Number Five Diagram Part A.

## Summary and Conclusions

One objective of this IQP project was to provide homeowners with a introduction to photovoltaic systems. We accomplished this goal by providing the homeowner with good back ground information concerning the history and usage of photovoltaic systems. From this basic background the homeowner was able to review the information concerning the different components in a PV system and different sizing techniques. A cost analysis of a Stand Alone PV system was examined and compared to the cost of connecting to a utility line situated one-half mile away. The cost analysis clearly illustrates the cost effectiveness of PV systems installed in remote homes. The cost analysis was broken down further to demonstrate to the homeowner that he is not limited to one design. The revised cost analysis shows, that economically it is more practical for a remote homeowner to design a hybrid system to supply his power needs. A hybrid system will lower the initial cost of the system and prevent any excess power generated from being wasted. A Hybrid PV system will also supply a more constant amount of power throughout the year.

Another goal of this IQP project was to provide homeowners with a list of photovoltaic professionals and companies they could contact for components and additional PV information. This goal was accomplished in chapter ten, where a select few PV professionals and companies, such as Photocomm Inc., Fowler Solar Electric Inc., Sunnyside Solar Inc, Talmage Engineering, and Solar Design Associates Inc. were provided.

New England Electric Systems has provided valuable information concerning the interconnection of PV systems to the utility grid, with their research and demonstration project in Gardner, Massachusetts. The 30 Gardner homes, involved in the project, are evidence that the interconnection of photovoltaics with a utility power grid is possible, and beneficial not only to the homeowners but to the power utility companies as well. The thirty homes in Gardner have been working flawlessly since the installation of the PV systems. The Gardner Project has shown to homeowners and utility companies one possible way of connecting to the power grid. The information obtained from the project will give power utility companies the ability to evaluate other residential PV systems and their impact if interconnected to the grid.

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# Appendix A

# PV Design

# Information

## 12 VOLT 2% WIRE LOSS TABLE

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DISTANCE in FEET | | | | | | | | | |
| 1 | 12 | 45 | 70 | 115 | 180 | 290 | 456 | 720 | ~ | ~ | ~ |
| 2 | 24 | 22 | 35 | 57 | 90 | 145 | 228 | 360 | 580 | 720 | 912 |
| 4 | 48 | 10 | 17 | 27 | 45 | 72 | 114 | 180 | 290 | 360 | 456 |
| 6 | 72 | 7 | 12 | 17 | 30 | 47 | 75 | 120 | 193 | 243 | 305 |
| 8 | 96 | 5 | 8 | 14 | 22 | 35 | 57 | 90 | 145 | 180 | 228 |
| 10 | 120 | 4 | 7 | 11 | 18 | 28 | 45 | 72 | 115 | 145 | 183 |
| 15 | 180 | 3 | 4 | 7 | 12 | 19 | 30 | 48 | 76 | 96 | 122 |
| 20 | 240 | # | 3 | 5 | 9 | 14 | 22 | 36 | 57 | 72 | 91 |
| 25 | 300 | # | # | 4 | 7 | 11 | 18 | 29 | 46 | 58 | 73 |
| 30 | 360 | # | # | 3 | 6 | 9 | 15 | 24 | 38 | 48 | 61 |
| 40 | 480 | # | # | # | 4 | 7 | 11 | 18 | 29 | 36 | 45 |
| 50 | 600 | # | # | # | # | 5 | 9 | 14 | 23 | 29 | 36 |

## 12 VOLT 5% WIRE LOSS TABLE

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DISTANCE in FEET | | | | | | | | | |
| 1 | 12 | 113 | 175 | 275 | 450 | 710 | ~ | ~ | ~ | ~ | ~ |
| 2 | 24 | 56 | 87 | 138 | 225 | 355 | 576 | 900 | ~ | ~ | ~ |
| 4 | 48 | 25 | 43 | 68 | 113 | 178 | 288 | 450 | 725 | 900 | ~ |
| 6 | 72 | 18 | 30 | 43 | 75 | 119 | 188 | 300 | 481 | 600 | 760 |
| 8 | 96 | 13 | 21 | 36 | 56 | 88 | 144 | 225 | 363 | 450 | 570 |
| 10 | 120 | 11 | 17 | 28 | 45 | 71 | 113 | 180 | 290 | 360 | 457 |
| 15 | 180 | 7 | 11 | 17 | 30 | 47 | 75 | 120 | 193 | 240 | 304 |
| 20 | 240 | # | 8 | 13 | 22 | 36 | 56 | 90 | 145 | 180 | 229 |
| 25 | 300 | # | # | 11 | 17 | 28 | 45 | 72 | 115 | 145 | 183 |
| 30 | 360 | # | # | 8 | 15 | 23 | 37 | 60 | 96 | 120 | 152 |
| 40 | 480 | # | # | # | 11 | 17 | 28 | 45 | 72 | 90 | 114 |
| 50 | 600 | # | # | # | # | 13 | 22 | 36 | 57 | 72 | 91 |

## 12 VOLT 10% WIRE LOSS TABLE

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DISTANCE in FEET | | | | | | | | | |
| 1 | 12 | 225 | 350 | 575 | 900 | ~ | ~ | ~ | ~ | ~ | ~ |
| 2 | 24 | 113 | 175 | 288 | 450 | 726 | ~ | ~ | ~ | ~ | ~ |
| 4 | 48 | 50 | 87 | 138 | 225 | 363 | 563 | 908 | ~ | ~ | ~ |
| 6 | 72 | 37 | 60 | 87 | 150 | 238 | 375 | 600 | 963 | ~ | ~ |
| 8 | 96 | 27 | 42 | 72 | 113 | 178 | 285 | 450 | 725 | ~ | ~ |
| 10 | 120 | 22 | 35 | 57 | 90 | 143 | 228 | 363 | 575 | 725 | 915 |
| 15 | 180 | 15 | 22 | 35 | 60 | 95 | 150 | 240 | 383 | 480 | 610 |
| 20 | 240 | # | 17 | 27 | 45 | 77 | 113 | 180 | 288 | 363 | 458 |
| 25 | 300 | # | # | 22 | 35 | 57 | 90 | 145 | 230 | 290 | 365 |
| 30 | 360 | # | # | 17 | 30 | 47 | 75 | 120 | 193 | 243 | 305 |
| 40 | 480 | # | # | # | 22 | 35 | 57 | 90 | 145 | 180 | 228 |
| 50 | 600 | # | # | # | # | 27 | 45 | 72 | 115 | 145 | 183 |

~ OVER 1000 FEET
# EXCEEDS AMPACITY
NOTE: DISTANCE IS FROM POWER SOURCE TO THE LOAD NOT THE ROUND TRIP DISTANCE.

Solar Sizing Data Taken From The Solar Electric Independent Home Book, Written By: Fowler Solar Electric Inc. Worthington, Massachusetts, 1991.

24 VOLT 2% WIRE LOSS TABLE

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DISTANCE in FEET | | | | | | | | | |
| 1 | 24 | 90 | 140 | 230 | 360 | 580 | 912 | ~ | ~ | ~ | ~ |
| 2 | 48 | 45 | 70 | 115 | 180 | 290 | 456 | 720 | ~ | ~ | ~ |
| 4 | 96 | 20 | 35 | 55 | 90 | 145 | 228 | 360 | 580 | 720 | 912 |
| 6 | 144 | 15 | 24 | 35 | 60 | 95 | 150 | 240 | 386 | 486 | 610 |
| 8 | 192 | 11 | 17 | 29 | 45 | 71 | 114 | 180 | 290 | 360 | 456 |
| 10 | 240 | 9 | 14 | 23 | 36 | 57 | 91 | 145 | 230 | 290 | 366 |
| 15 | 360 | 6 | 9 | 14 | 24 | 38 | 60 | 96 | 153 | 192 | 244 |
| 20 | 480 | # | 7 | 11 | 18 | 29 | 45 | 72 | 115 | 145 | 183 |
| 25 | 600 | # | # | 9 | 14 | 23 | 36 | 58 | 92 | 116 | 146 |
| 30 | 720 | # | # | 7 | 12 | 19 | 30 | 48 | 77 | 97 | 122 |
| 40 | 960 | # | # | # | 9 | 14 | 23 | 36 | 58 | 72 | 91 |
| 50 | 1200 | # | # | # | # | 11 | 18 | 29 | 46 | 58 | 73 |

24 VOLT 5% WIRE LOSS TABLE

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DISTANCE in FEET | | | | | | | | | |
| 1 | 24 | 226 | 350 | 550 | 900 | ~ | ~ | ~ | ~ | ~ | ~ |
| 2 | 48 | 112 | 175 | 276 | 450 | 710 | ~ | ~ | ~ | ~ | ~ |
| 4 | 96 | 50 | 87 | 137 | 226 | 356 | 576 | 900 | ~ | ~ | ~ |
| 6 | 144 | 37 | 60 | 87 | 150 | 238 | 376 | 600 | 962 | ~ | ~ |
| 8 | 192 | 27 | 42 | 72 | 112 | 177 | 288 | 450 | 726 | 900 | ~ |
| 10 | 240 | 22 | 35 | 57 | 90 | 142 | 226 | 360 | 580 | 720 | 914 |
| 15 | 360 | 15 | 22 | 35 | 60 | 95 | 150 | 240 | 386 | 480 | 608 |
| 20 | 480 | # | 17 | 27 | 45 | 72 | 112 | 180 | 290 | 360 | 458 |
| 25 | 600 | # | # | 22 | 35 | 57 | 90 | 145 | 230 | 290 | 366 |
| 30 | 720 | # | # | 17 | 30 | 47 | 75 | 120 | 192 | 240 | 304 |
| 40 | 960 | # | # | # | 23 | 35 | 57 | 90 | 145 | 180 | 228 |
| 50 | 1200 | # | # | # | # | 27 | 45 | 72 | 115 | 145 | 182 |

24 VOLT 10% WIRE LOSS TABLE

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DISTANCE in FEET | | | | | | | | | |
| 1 | 24 | 450 | 700 | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 2 | 48 | 226 | 350 | 576 | 900 | ~ | ~ | ~ | ~ | ~ | ~ |
| 4 | 96 | 100 | 175 | 276 | 450 | 726 | ~ | ~ | ~ | ~ | ~ |
| 6 | 144 | 75 | 120 | 175 | 300 | 476 | 750 | ~ | ~ | ~ | ~ |
| 8 | 192 | 55 | 85 | 145 | 226 | 356 | 570 | 900 | ~ | ~ | ~ |
| 10 | 240 | 45 | 70 | 115 | 180 | 286 | 456 | 726 | ~ | ~ | ~ |
| 15 | 360 | 30 | 45 | 70 | 120 | 190 | 300 | 480 | 766 | 960 | ~ |
| 20 | 480 | # | 35 | 55 | 90 | 145 | 226 | 360 | 576 | 726 | 916 |
| 25 | 600 | # | # | 45 | 70 | 115 | 180 | 290 | 460 | 580 | 730 |
| 30 | 720 | # | # | 35 | 60 | 95 | 150 | 240 | 386 | 486 | 610 |
| 40 | 960 | # | # | # | 45 | 70 | 115 | 180 | 290 | 360 | 456 |
| 50 | 1200 | # | # | # | # | 55 | 90 | 145 | 230 | 290 | 366 |

~ OVER 1000 FEET

\# EXCEEDS AMPACITY

NOTE: DISTANCE IS FROM POWER SOURCE TO THE LOAD NOT THE ROUND TRIP DISTANCE.

## 120 VOLT 2% WIRE LOSS TABLE

DISTANCE in FEET

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 120 | 450 | 700 | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 2 | 240 | 225 | 350 | 575 | 900 | ~ | ~ | ~ | ~ | ~ | ~ |
| 4 | 480 | 100 | 175 | 275 | 450 | 725 | ~ | ~ | ~ | ~ | ~ |
| 6 | 720 | 75 | 120 | 175 | 275 | 450 | 725 | ~ | ~ | ~ | ~ |
| 8 | 960 | 55 | 85 | 145 | 225 | 355 | 570 | ~ | ~ | ~ | ~ |
| 10 | 1200 | 45 | 70 | 120 | 190 | 300 | 480 | 765 | 960 | ~ | ~ |
| 15 | 1800 | 30 | 45 | 70 | 120 | 190 | 300 | 480 | 765 | 960 | ~ |
| 20 | 2400 | # | 35 | 55 | 90 | 145 | 225 | 360 | 575 | 725 | 915 |
| 25 | 3000 | # | # | 45 | 70 | 115 | 180 | 290 | 460 | 580 | 730 |
| 30 | 3600 | # | # | # | 60 | 95 | 150 | 240 | 385 | 485 | 610 |
| 40 | 4800 | # | # | # | 45 | 70 | 115 | 180 | 290 | 360 | 455 |
| 50 | 6000 | # | # | # | # | 55 | 90 | 145 | 230 | 290 | 365 |

## 120 VOLT 5% WIRE LOSS TABLE

DISTANCE in FEET

| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 120 | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 2 | 240 | 563 | 875 | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 4 | 480 | 250 | 438 | 688 | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 6 | 720 | 188 | 300 | 438 | 750 | ~ | ~ | ~ | ~ | ~ | ~ |
| 8 | 960 | 138 | 213 | 363 | 563 | 888 | ~ | ~ | ~ | ~ | ~ |
| 10 | 1200 | 113 | 175 | 288 | 450 | 713 | ~ | ~ | ~ | ~ | ~ |
| 15 | 1800 | 75 | 113 | 175 | 300 | 475 | 750 | ~ | ~ | ~ | ~ |
| 20 | 2400 | # | 87 | 138 | 225 | 363 | 563 | 900 | ~ | ~ | ~ |
| 25 | 3000 | # | # | 113 | 175 | 288 | 450 | 725 | ~ | ~ | ~ |
| 30 | 3600 | # | # | 87 | 150 | 238 | 375 | 600 | 963 | ~ | ~ |
| 40 | 4800 | # | # | # | 113 | 175 | 288 | 450 | 725 | 900 | ~ |
| 50 | 6000 | # | # | # | # | 138 | 228 | 363 | 575 | 725 | 913 |

## 120 VOLT 10% WIRE LOSS TABLE

DISTANCE in FEET

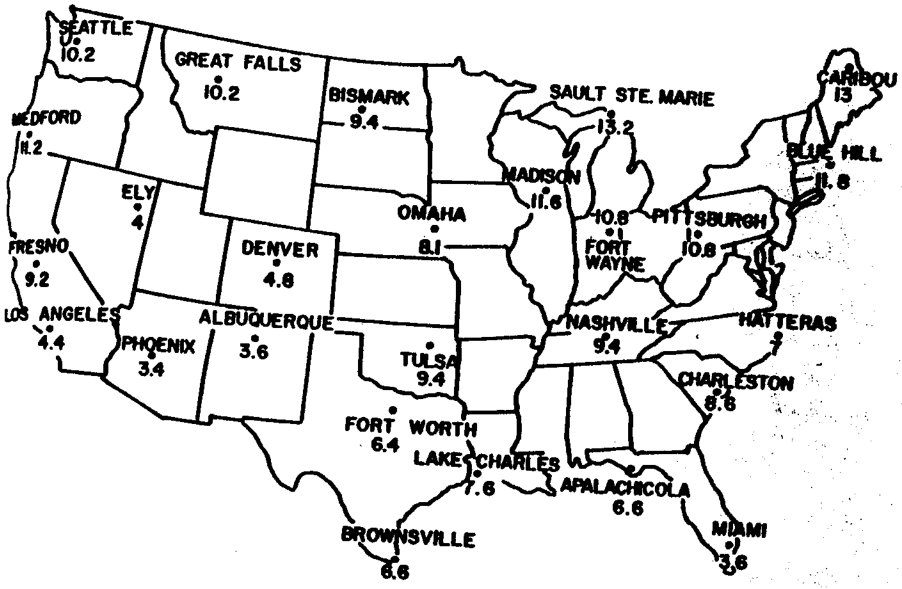
| AMPS | WATTAGE | 14ga | 12ga | 10ga | 8ga | 6ga | 4ga | 2ga | 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 120 | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 2 | 240 | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 4 | 480 | 500 | 876 | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 6 | 720 | 376 | 600 | 876 | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 8 | 960 | 276 | 426 | 726 | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 10 | 1200 | 226 | 350 | 576 | 900 | ~ | ~ | ~ | ~ | ~ | ~ |
| 15 | 1800 | 150 | 226 | 350 | 600 | 950 | ~ | ~ | ~ | ~ | ~ |
| 20 | 2400 | 100 | 175 | 276 | 450 | 726 | ~ | ~ | ~ | ~ | ~ |
| 25 | 3000 | # | # | 226 | 350 | 576 | 900 | ~ | ~ | ~ | ~ |
| 30 | 3600 | # | # | 175 | 300 | 476 | 750 | ~ | ~ | ~ | ~ |
| 40 | 4800 | # | # | # | 226 | 350 | 576 | 900 | ~ | ~ | ~ |
| 50 | 6000 | # | # | # | # | 276 | 456 | 726 | ~ | ~ | ~ |

~ OVER 1000 FEET

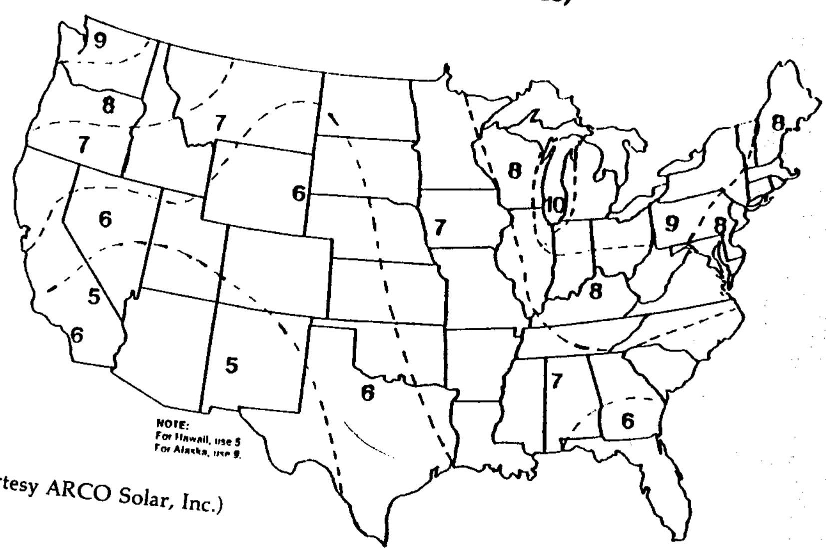
# EXCEEDS AMPACITY

NOTE: DISTANCE IS FROM POWER SOURCE TO THE LOAD NOT THE ROUND TRIP DISTANCE.

# BATTERY STORAGE REQUIREMENTS



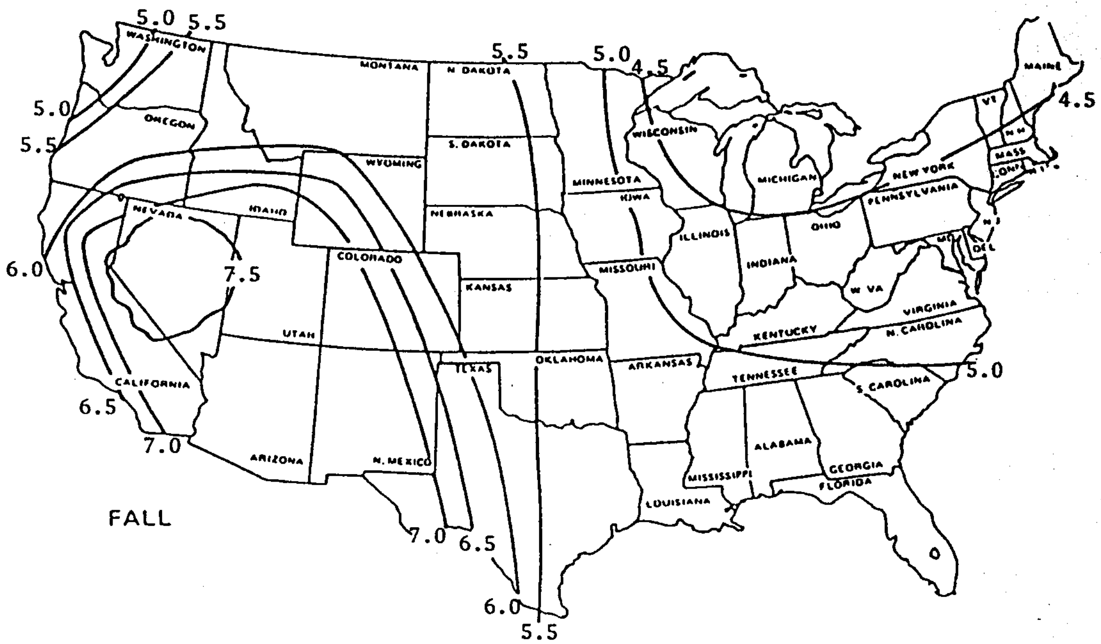

# MULTIPLIER FACTORS MAP
## (Continental United States)



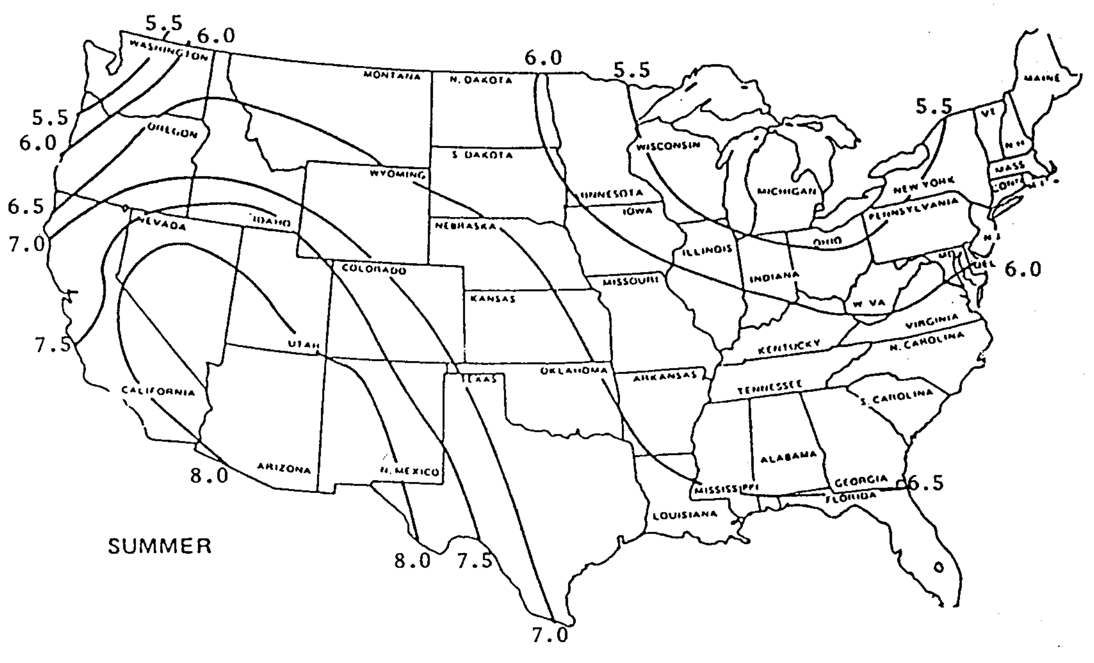

(Courtesy ARCO Solar, Inc.)

**Table 5.1: Temperature Correction Factors**

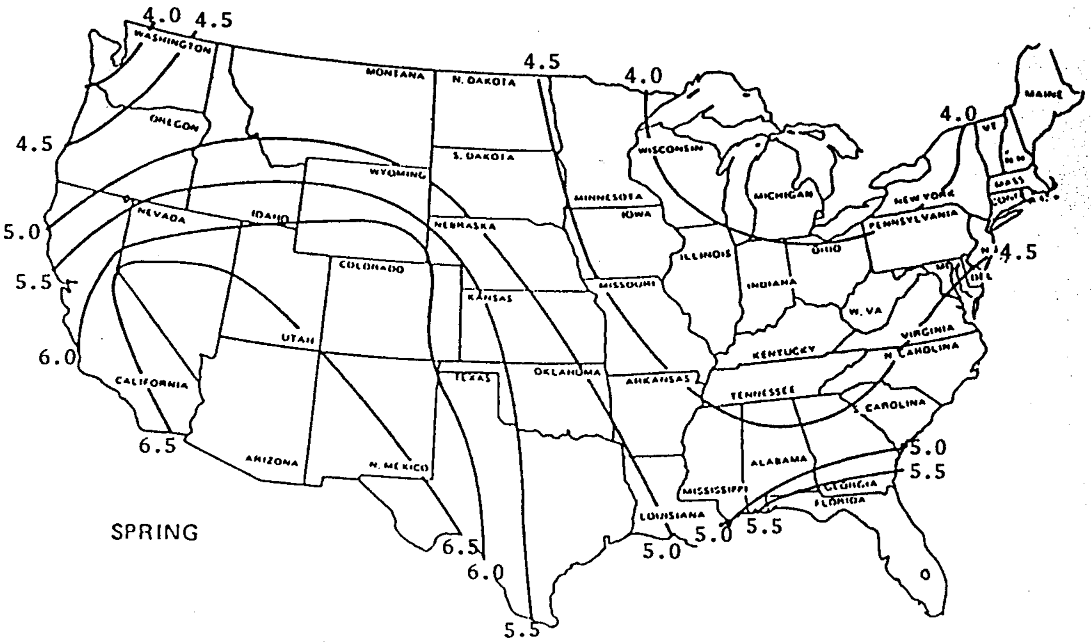
| Temperature °C | Correction Factor | Temperature °F |
|---|---|---|
| −10 | 1.10 | +14 |
| −15 | 1.55 | + 5 |
| −20 | 2.05 | − 4 |
| −25 | 2.75 | −13 |
| −30 | 3.50 | −22 |
| −35 | 4.25 | −31 |



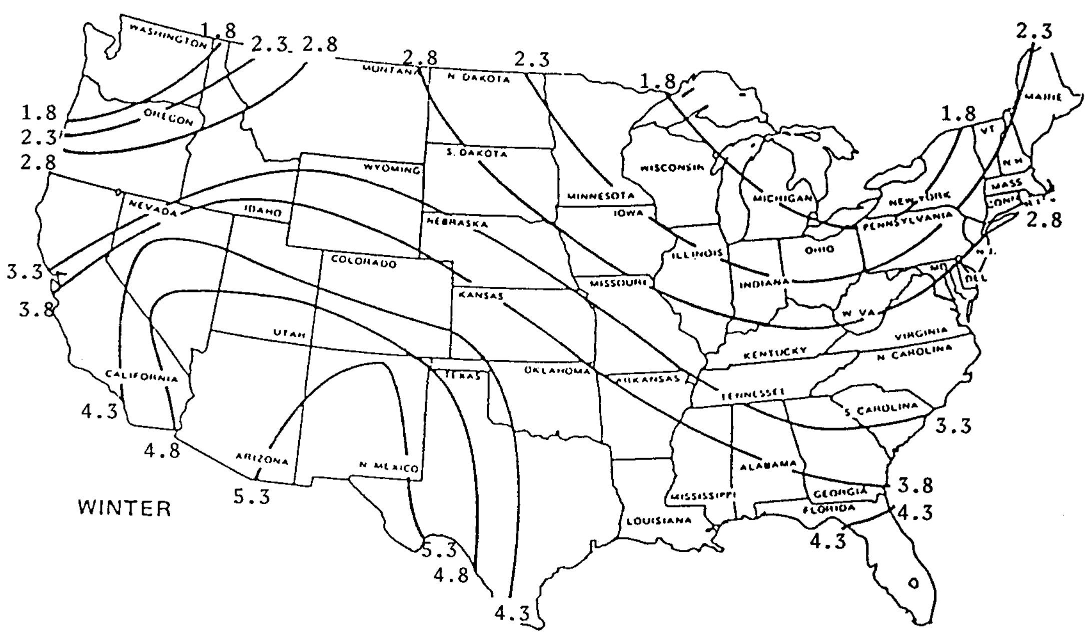

AVERAGE DAILY PEAK SUN HOURS FOR FALL SEASON (Aug., Sept., Oct.) FOR ARRAY ANGLE EQUAL TO LATITUDE (Courtesy of DOE)




AVERAGE DAILY PEAK SUN HOURS FOR SUMMER SEASON (May, June, July) FOR ARRAY ANGLE OF LAT. (-) 15 Deg. (Courtesy of DOE)




AVERAGE DAILY PEAK SUN HOURS FOR SPRING SEASON (Feb., Mar., Apr.) FOR ARRAY ANGLE EQUAL TO LATITUDE (Courtesy of DOE)




AVERAGE DAILY PEAK SUN HOURS FOR WINTER SEASON (Nov., Dec., Jan.) FOR ARRAY ANGLE OF LAT. (+) 15 Deg. (Courtesy of DOE)

# INSOLATION DATA BY SEASON (Courtesy of DOE)

AVERAGE DAILY INSOLATION AVAILABILITY
FOR A SURFACE TILTED AT LATITUDE - 15 DEGREES (KWH/M2)

| SITE | WINTER D.J.F | SPRING M.A.M | SUMMER J.J.A | FALL S.O.N | ANNUAL |
|---|---|---|---|---|---|
| ALBUQUERQUE | 4.92 | 7.59 | 7.90 | 6.35 | 6.70 |
| ATLANTA | 3.12 | 5.51 | 5.85 | 4.43 | 4.74 |
| AUSTIN | 3.78 | 5.35 | 6.42 | 4.84 | 5.10 |
| BIRMINGHAM | 3.08 | 5.35 | 5.58 | 4.47 | 4.62 |
| BISMARCK | 2.96 | 5.36 | 6.73 | 4.07 | 4.79 |
| BOSTON | 2.36 | 4.49 | 5.40 | 3.59 | 3.97 |
| BROWNSVILLE | 3.49 | 5.72 | 6.67 | 4.74 | 5.16 |
| BRYCE CANYON | 4.87 | 7.39 | 7.65 | 6.24 | 6.55 |
| CARIBOU | 2.46 | 5.09 | 5.35 | 2.97 | 3.98 |
| COLUMBIA | 2.90 | 5.39 | 6.34 | 4.38 | 4.77 |
| DAGGETT | 4.63 | 7.59 | 8.23 | 6.14 | 6.66 |
| DALLAS-FORT WORTH | 3.53 | 5.43 | 6.77 | 4.95 | 5.18 |
| DENVER | 4.52 | 6.75 | 7.16 | 5.75 | 6.06 |
| DETROIT | 2.13 | 4.65 | 5.72 | 3.57 | 4.03 |
| ELKO | 4.12 | 6.62 | 8.15 | 5.85 | 6.19 |
| EL PASO | 5.11 | 7.72 | 7.83 | 6.24 | 6.73 |
| FAIRBANKS | 0.54 | 5.03 | 4.83 | 1.96 | 3.11 |
| FRESNO | 3.17 | 7.12 | 8.33 | 5.90 | 6.14 |
| GREAT FALLS | 2.69 | 5.47 | 7.04 | 4.27 | 4.88 |
| HONOLULU | 4.19 | 5.76 | 6.27 | 5.11 | 5.34 |
| LAS VEGAS | 5.02 | 8.03 | 8.19 | 6.35 | 6.91 |
| MADISON | 2.68 | 5.04 | 5.95 | 3.75 | 4.36 |
| MEDFORD | 1.98 | 5.55 | 7.60 | 4.25 | 4.87 |
| MIAMI | 4.13 | 5.72 | 5.33 | 4.57 | 4.94 |
| NASHVILLE | 2.61 | 5.01 | 6.02 | 4.08 | 4.44 |
| NEW ORLEANS | 3.42 | 5.55 | 5.65 | 4.68 | 4.84 |
| OKLAHOMA CITY | 3.67 | 5.66 | 6.63 | 4.98 | 5.24 |
| OMAHA | 3.46 | 5.46 | 6.53 | 4.38 | 4.97 |
| ORLANDO | 4.02 | 6.00 | 5.51 | 4.68 | 5.06 |
| PHOENIX | 4.77 | 7.80 | 7.84 | 6.26 | 6.68 |
| PITTSBURGH | 1.90 | 4.33 | 5.39 | 3.41 | 3.76 |
| RALEIGH-DURHAM | 3.00 | 5.22 | 5.66 | 4.16 | 4.52 |
| SACRAMENTO | 3.07 | 6.76 | 8.32 | 5.62 | 5.96 |
| SAN DIEGO | 4.31 | 6.21 | 6.67 | 5.25 | 5.62 |
| SAN JUAN | 4.51 | 5.83 | 5.92 | 4.99 | 5.32 |
| SEATTLE | 1.37 | 4.46 | 5.92 | 2.89 | 3.67 |
| SYRACUSE | 1.71 | 4.29 | 5.41 | 3.02 | 3.62 |
| WASHINGTON D.C. | 2.80 | 4.95 | 5.60 | 3.89 | 4.32 |

AVERAGE DAILY INSOLATION AVAILABILITY
FOR A SOUTH FACING SURFACE TILTED AT LATITUDE DEGREES (KWH/M2)

| | | | | | |
|---|---|---|---|---|---|
| ALBUQUERQUE | 5.70 | 7.57 | 7.49 | 6.92 | 6.92 |
| ATLANTA | 3.53 | 5.48 | 5.57 | 4.78 | 4.85 |
| AUSTIN | 4.32 | 5.34 | 6.08 | 5.21 | 5.24 |
| BIRMINGHAM | 3.47 | 5.32 | 5.32 | 4.80 | 4.73 |
| BISMARCK | 3.36 | 5.35 | 6.39 | 4.35 | 4.87 |
| BOSTON | 2.67 | 4.46 | 5.14 | 3.84 | 4.03 |
| BROWNSVILLE | 3.92 | 5.68 | 6.30 | 5.05 | 5.25 |
| BRYCE CANYON | 5.62 | 7.34 | 7.16 | 6.76 | 6.73 |
| CARIBOU | 2.77 | 5.09 | 5.10 | 3.15 | 4.04 |
| COLUMBIA | 3.28 | 5.37 | 6.01 | 4.71 | 4.85 |
| DAGGETT | 5.32 | 7.52 | 7.71 | 6.64 | 6.81 |
| DALLAS-FORT WORTH | 4.03 | 5.43 | 6.41 | 5.33 | 5.31 |
| DENVER | 5.22 | 6.73 | 6.76 | 6.22 | 6.24 |
| DETROIT | 2.39 | 4.64 | 5.43 | 3.78 | 4.07 |
| ELKO | 4.71 | 6.58 | 7.66 | 6.29 | 6.32 |
| EL PASO | 5.91 | 7.68 | 7.39 | 6.79 | 6.95 |
| FAIRBANKS | 0.60 | 5.02 | 4.62 | 2.05 | 3.09 |
| FRESNO | 3.54 | 7.05 | 7.82 | 6.34 | 6.20 |
| GREAT FALLS | 3.04 | 5.47 | 6.66 | 4.57 | 4.95 |
| HONOLULU | 4.74 | 5.73 | 5.93 | 5.49 | 5.48 |
| LAS VEGAS | 5.79 | 7.96 | 7.67 | 6.88 | 7.08 |
| MADISON | 3.02 | 5.05 | 5.66 | 3.99 | 4.14 |
| MEDFORD | 2.19 | 5.53 | 7.18 | 4.51 | 4.87 |
| MIAMI | 4.69 | 5.72 | 5.10 | 4.92 | 5.11 |
| NASHVILLE | 2.94 | 5.00 | 5.75 | 4.36 | 4.52 |
| NEW ORLEANS | 3.86 | 5.52 | 5.38 | 5.04 | 4.96 |
| OKLAHOMA CITY | 4.18 | 5.65 | 6.28 | 5.37 | 5.38 |
| OMAHA | 3.93 | 5.43 | 6.20 | 4.71 | 5.08 |
| ORLANDO | 4.57 | 5.96 | 5.26 | 5.05 | 5.21 |
| PHOENIX | 5.49 | 7.77 | 7.42 | 6.80 | 6.88 |
| PITTSBURGH | 2.11 | 4.29 | 5.15 | 3.62 | 3.80 |
| RALEIGH-DURHAM | 3.37 | 5.21 | 5.39 | 4.46 | 4.61 |
| SACRAMENTO | 3.47 | 6.70 | 7.80 | 6.03 | 6.01 |
| SAN DIEGO | 4.94 | 6.20 | 6.35 | 5.67 | 5.79 |
| SAN JUAN | 5.14 | 5.80 | 5.61 | 5.36 | 5.48 |
| SEATTLE | 1.51 | 4.43 | 5.66 | 3.03 | 3.67 |
| SYRACUSE | 1.90 | 4.27 | 5.16 | 3.20 | 3.64 |
| WASHINGTON D.C. | 3.17 | 4.93 | 5.33 | 4.16 | 4.41 |

## INSOLATION DATA BY SEASONS (Courtesy of DOE)

AVERAGE DAILY INSOLATION AVAILABILITY
FOR A SOUTH FACING SURFACE TILTED AT LATITUDE + 15 DEGREES (KWH/M2)

| SITE | WINTER D.J.F | SPRING M.A.M | SUMMER J.J.A | FALL S.O.N | ANNUAL |
|---|---|---|---|---|---|
| ALBUQUERQUE | 6.14 | 7.18 | 6.72 | 7.12 | 6.79 |
| ATLANTA | 3.78 | 5.20 | 5.03 | 4.91 | 4.73 |
| AUSTIN | 4.63 | 5.11 | 5.45 | 5.33 | 5.13 |
| BIRMINGHAM | 3.70 | 5.05 | 4.84 | 4.91 | 4.63 |
| BISMARCK | 3.57 | 5.09 | 5.73 | 4.43 | 4.71 |
| BOSTON | 2.83 | 4.24 | 4.66 | 3.89 | 3.91 |
| BROWNSVILLE | 4.18 | 5.42 | 5.64 | 5.15 | 5.10 |
| BRYCE CANYON | 6.04 | 6.91 | 6.32 | 6.90 | 6.55 |
| CARIBOU | 2.92 | 4.88 | 4.62 | 3.20 | 3.91 |
| COLUMBIA | 3.49 | 5.10 | 5.41 | 4.80 | 4.71 |
| DAGGETT | 5.70 | 7.07 | 6.80 | 6.77 | 6.59 |
| DALLAS-FORT WORTH | 4.31 | 5.21 | 5.75 | 5.45 | 5.18 |
| DENVER | 5.60 | 6.37 | 6.01 | 6.35 | 6.09 |
| DETROIT | 2.53 | 4.42 | 4.91 | 3.82 | 3.93 |
| ELKO | 5.03 | 6.22 | 6.78 | 6.38 | 6.11 |
| EL PASO | 6.38 | 7.28 | 6.60 | 6.99 | 6.81 |
| FAIRBANKS | 0.62 | 4.77 | 4.23 | 2.07 | 2.93 |
| FRESNO | 3.76 | 6.64 | 6.90 | 6.44 | 5.95 |
| GREAT FALLS | 3.23 | 5.22 | 5.95 | 4.64 | 4.77 |
| HONOLULU | 5.07 | 5.45 | 5.34 | 5.60 | 5.37 |
| LAS VEGAS | 6.21 | 7.49 | 6.78 | 7.02 | 6.88 |
| MADISON | 3.20 | 4.84 | 5.12 | 4.04 | 4.31 |
| MEDFORD | 2.30 | 5.25 | 6.40 | 4.54 | 4.64 |
| MIAMI | 5.01 | 5.47 | 4.67 | 5.07 | 5.05 |
| NASHVILLE | 3.12 | 4.77 | 5.24 | 4.44 | 4.40 |
| NEW ORLEANS | 4.11 | 5.26 | 4.88 | 5.16 | 4.85 |
| OKLAHOMA CITY | 4.48 | 5.39 | 5.64 | 5.49 | 5.25 |
| OMAHA | 4.19 | 5.16 | 5.58 | 4.80 | 4.94 |
| ORLANDO | 4.88 | 5.66 | 4.79 | 5.19 | 5.13 |
| PHOENIX | 5.91 | 7.36 | 6.65 | 6.99 | 6.73 |
| PITTSBURGH | 2.23 | 4.09 | 4.68 | 3.66 | 3.68 |
| RALEIGH-DURHAM | 3.57 | 4.97 | 4.88 | 4.55 | 4.49 |
| SACRAMENTO | 3.68 | 6.30 | 6.89 | 6.12 | 5.76 |
| SAN DIEGO | 5.29 | 5.30 | 5.73 | 5.80 | 5.68 |
| SAN JUAN | 5.51 | 5.53 | 5.04 | 5.48 | 5.39 |
| SEATTLE | 1.59 | 4.24 | 5.13 | 3.05 | 3.52 |
| SYRACUSE | 2.00 | 4.08 | 4.70 | 3.24 | 3.51 |
| WASHINGTON D.C. | 3.37 | 4.70 | 4.84 | 4.24 | 4.29 |

AVERAGE DAILY INSOLATION AVAILABILITY
FOR A SURFACE TRACKING ABOUT A NORTH - SOUTH AXIS
TILTED AT LATITUDE - 15 DEGREES (KWH/M2)

| | | | | | |
|---|---|---|---|---|---|
| ALBUQUERQUE | 6.34 | 10.13 | 10.60 | 8.32 | 8.86 |
| ATLANTA | 3.89 | 7.03 | 7.41 | 5.51 | 5.97 |
| AUSTIN | 4.80 | 6.75 | 8.27 | 6.14 | 6.50 |
| BIRMINGHAM | 3.80 | 6.78 | 7.00 | 5.57 | 5.80 |
| BISMARCK | 3.57 | 7.03 | 9.17 | 5.14 | 6.25 |
| BOSTON | 2.81 | 5.72 | 7.03 | 4.51 | 5.03 |
| BROWNSVILLE | 4.32 | 7.08 | 8.70 | 5.97 | 6.53 |
| BRYCE CANYON | 6.20 | 10.28 | 10.78 | 8.24 | 8.89 |
| CARIBOU | 2.93 | 6.61 | 7.14 | 3.63 | 5.09 |
| COLUMBIA | 3.44 | 6.84 | 8.55 | 5.55 | 6.12 |
| DAGGETT | 5.74 | 10.15 | 11.27 | 7.88 | 8.78 |
| DALLAS-FORT WORTH | 4.39 | 6.95 | 8.93 | 6.35 | 6.67 |
| DENVER | 5.76 | 9.09 | 9.73 | 7.49 | 8.03 |
| DETROIT | 2.54 | 5.88 | 7.36 | 4.33 | 5.04 |
| ELKO | 5.10 | 9.05 | 11.43 | 7.60 | 8.32 |
| EL PASO | 6.63 | 10.35 | 10.43 | 8.25 | 8.93 |
| FAIRBANKS | 0.60 | 6.67 | 6.85 | 2.33 | 4.14 |
| FRESNO | 3.80 | 9.55 | 11.55 | 7.57 | 8.15 |
| GREAT FALLS | 3.20 | 7.07 | 9.70 | 5.44 | 6.37 |
| HONOLULU | 5.21 | 7.12 | 7.91 | 6.48 | 6.69 |
| LAS VEGAS | 6.33 | 10.99 | 11.18 | 8.24 | 9.21 |
| MADISON | 3.17 | 6.49 | 7.67 | 4.62 | 5.50 |
| MEDFORD | 2.29 | 7.09 | 10.36 | 5.30 | 6.28 |
| MIAMI | 5.24 | 7.22 | 6.47 | 5.76 | 6.19 |
| NASHVILLE | 3.17 | 6.16 | 7.52 | 5.07 | 5.49 |
| NEW ORLEANS | 4.18 | 7.02 | 7.09 | 5.86 | 6.05 |
| OKLAHOMA CITY | 4.61 | 7.35 | 8.62 | 6.32 | 6.74 |
| OMAHA | 4.27 | 7.15 | 8.84 | 5.59 | 6.48 |
| ORLANDO | 4.99 | 7.66 | 6.82 | 5.82 | 6.33 |
| PHOENIX | 6.04 | 10.47 | 10.33 | 8.05 | 8.74 |
| PITTSBURGH | 2.23 | 5.37 | 6.80 | 4.12 | 4.55 |
| RALEIGH-DURHAM | 3.56 | 6.63 | 7.16 | 5.03 | 5.61 |
| SACRAMENTO | 3.67 | 8.96 | 11.46 | 7.11 | 7.82 |
| SAN DIEGO | 5.38 | 7.84 | 8.38 | 6.48 | 7.03 |
| SAN JUAN | 5.73 | 7.17 | 7.40 | 6.31 | 6.66 |
| SEATTLE | 1.57 | 5.61 | 7.82 | 3.49 | 4.64 |
| SYRACUSE | 2.00 | 5.41 | 6.88 | 3.63 | 4.50 |
| WASHINGTON D.C. | 3.40 | 6.33 | 7.20 | 4.80 | 5.45 |

# INSOLATION DATA BY SEASONS (Courtesy of DOE)

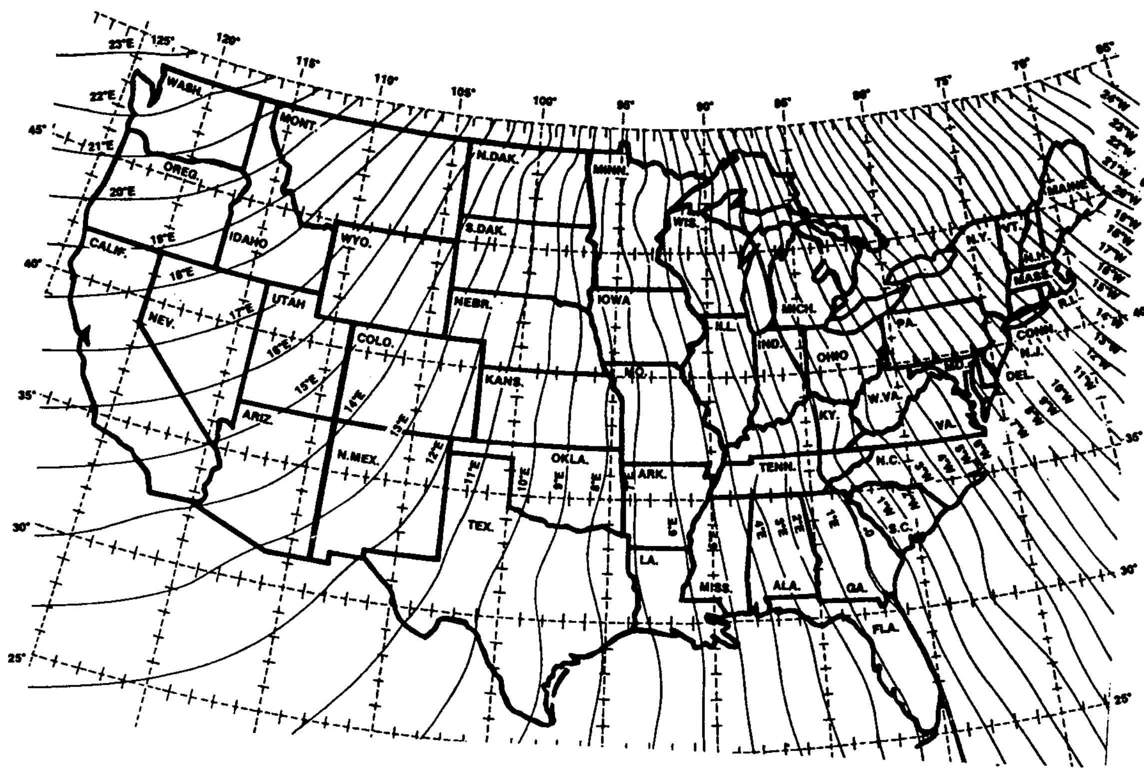
AVERAGE DAILY INSOLATION AVAILABILITY
FOR A SURFACE TRACKING ABOUT A NORTH - SOUTH AXIS
TILTED AT LATITUDE DEGREES (KWH/M2)

| SITE | WINTER D.J.F | SPRING M.A.M | SUMMER J.J.A | FALL S.O.N | ANNUAL |
|---|---|---|---|---|---|
| ALBUQUERQUE | 6.94 | 10.13 | 10.35 | 8.73 | 9.05 |
| ATLANTA | 4.21 | 7.03 | 7.26 | 5.77 | 6.08 |
| AUSTIN | 5.22 | 6.76 | 8.08 | 6.43 | 6.63 |
| BIRMINGHAM | 4.11 | 6.78 | 6.85 | 5.82 | 5.90 |
| BISMARCK | 3.89 | 7.05 | 9.00 | 5.37 | 6.34 |
| BOSTON | 3.07 | 5.72 | 6.89 | 4.69 | 5.10 |
| BROWNSVILLE | 4.67 | 7.08 | 8.48 | 6.21 | 6.62 |
| BRYCE CANYON | 6.80 | 10.29 | 10.53 | 8.64 | 9.08 |
| CARIBOU | 3.18 | 6.63 | 7.01 | 3.78 | 5.17 |
| COLUMBIA | 3.77 | 6.85 | 8.38 | 5.80 | 6.21 |
| DAGGETT | 6.30 | 10.15 | 11.00 | 8.26 | 8.95 |
| DALLAS-FORT WORTH | 4.79 | 6.97 | 8.73 | 6.65 | 6.80 |
| DENVER | 6.31 | 9.10 | 9.51 | 7.86 | 8.21 |
| DETROIT | 2.76 | 5.88 | 7.21 | 4.49 | 5.10 |
| ELKO | 5.58 | 9.08 | 11.18 | 7.95 | 8.46 |
| EL PASO | 7.24 | 10.35 | 10.17 | 8.65 | 9.12 |
| FAIRBANKS | 0.64 | 6.70 | 6.75 | 2.41 | 4.15 |
| FRESNO | 4.12 | 9.55 | 11.28 | 7.91 | 8.24 |
| GREAT FALLS | 3.50 | 7.09 | 9.50 | 5.68 | 6.46 |
| HONOLULU | 5.67 | 7.11 | 7.72 | 6.77 | 6.82 |
| LAS VEGAS | 6.96 | 10.99 | 10.91 | 8.64 | 9.39 |
| MADISON | 3.46 | 6.52 | 7.52 | 4.81 | 5.59 |
| MEDFORD | 2.47 | 7.10 | 10.14 | 5.49 | 6.32 |
| MIAMI | 5.69 | 7.23 | 6.34 | 6.03 | 6.32 |
| NASHVILLE | 3.43 | 6.17 | 7.37 | 5.29 | 5.58 |
| NEW ORLEANS | 4.53 | 7.02 | 6.93 | 6.13 | 6.17 |
| OKLAHOMA CITY | 5.02 | 7.36 | 8.43 | 6.63 | 6.87 |
| OMAHA | 4.64 | 7.16 | 8.66 | 5.85 | 6.59 |
| ORLANDO | 5.43 | 7.66 | 6.66 | 6.12 | 6.47 |
| PHOENIX | 6.61 | 10.46 | 10.08 | 8.45 | 8.91 |
| PITTSBURGH | 2.41 | 5.37 | 6.67 | 4.29 | 4.70 |
| RALEIGH-DURHAM | 3.86 | 6.64 | 7.01 | 5.26 | 5.70 |
| SACRAMENTO | 3.99 | 8.96 | 11.20 | 7.43 | 7.91 |
| SAN DIEGO | 5.89 | 7.86 | 8.20 | 6.81 | 7.19 |
| SAN JUAN | 6.23 | 7.16 | 7.22 | 6.59 | 6.81 |
| SEATTLE | 1.69 | 5.61 | 7.67 | 3.60 | 4.66 |
| SYRACUSE | 2.16 | 5.41 | 6.75 | 3.77 | 4.53 |
| WASHINGTON D.C. | 3.70 | 6.34 | 7.05 | 5.02 | 5.54 |

AVERAGE DAILY INSOLATION AVAILABILITY
FOR A SURFACE TRACKING ABOUT A NORTH - SOUTH AXIS
TILTED AT LATITUDE + 15 DEGREES (KWH/M2)

| SITE | WINTER D.J.F | SPRING M.A.M | SUMMER J.J.A | FALL S.O.N | ANNUAL |
|---|---|---|---|---|---|
| ALBUQUERQUE | 7.24 | 9.85 | 9.78 | 8.85 | 8.94 |
| ATLANTA | 4.38 | 6.85 | 6.90 | 5.86 | 6.01 |
| AUSTIN | 5.44 | 6.61 | 7.64 | 6.51 | 6.56 |
| BIRMINGHAM | 4.28 | 6.61 | 6.52 | 5.90 | 5.83 |
| BISMARCK | 4.04 | 6.88 | 8.55 | 5.42 | 6.24 |
| BOSTON | 3.19 | 5.58 | 6.55 | 4.73 | 5.02 |
| BROWNSVILLE | 4.86 | 6.89 | 8.03 | 6.27 | 6.52 |
| BRYCE CANYON | 7.10 | 10.03 | 10.00 | 8.74 | 8.98 |
| CARIBOU | 3.30 | 6.50 | 6.71 | 3.80 | 5.09 |
| COLUMBIA | 3.92 | 6.66 | 7.99 | 5.86 | 6.12 |
| DAGGETT | 6.58 | 9.86 | 10.40 | 8.36 | 8.81 |
| DALLAS-FORT WORTH | 5.00 | 6.80 | 8.28 | 6.73 | 6.72 |
| DENVER | 6.59 | 8.87 | 9.02 | 7.95 | 8.12 |
| DETROIT | 2.86 | 5.74 | 6.86 | 4.53 | 5.01 |
| ELKO | 5.81 | 8.85 | 10.63 | 8.02 | 8.34 |
| EL PASO | 7.56 | 10.05 | 9.60 | 8.76 | 9.00 |
| FAIRBANKS | 0.66 | 6.53 | 6.51 | 2.42 | 4.05 |
| FRESNO | 4.28 | 9.29 | 10.70 | 7.99 | 8.08 |
| GREAT FALLS | 3.63 | 6.92 | 9.02 | 5.73 | 6.34 |
| HONOLULU | 5.89 | 6.91 | 7.29 | 6.86 | 6.74 |
| LAS VEGAS | 7.26 | 10.70 | 10.33 | 8.75 | 9.27 |
| MADISON | 3.58 | 6.37 | 7.15 | 4.86 | 5.50 |
| MEDFORD | 2.54 | 6.91 | 9.62 | 5.52 | 6.17 |
| MIAMI | 5.91 | 7.07 | 6.03 | 6.12 | 6.28 |
| NASHVILLE | 3.57 | 6.01 | 7.01 | 5.34 | 5.49 |
| NEW ORLEANS | 4.72 | 6.84 | 6.59 | 6.22 | 6.10 |
| OKLAHOMA CITY | 5.23 | 7.20 | 8.00 | 6.70 | 6.79 |
| OMAHA | 4.83 | 7.00 | 8.26 | 5.91 | 6.51 |
| ORLANDO | 5.66 | 7.47 | 6.34 | 6.21 | 6.42 |
| PHOENIX | 6.89 | 10.16 | 9.51 | 8.56 | 8.79 |
| PITTSBURGH | 2.50 | 5.24 | 6.35 | 4.32 | 4.61 |
| RALEIGH-DURHAM | 4.01 | 6.48 | 6.65 | 5.33 | 5.63 |
| SACRAMENTO | 4.14 | 8.71 | 10.61 | 7.49 | 7.76 |
| SAN DIEGO | 6.13 | 7.66 | 7.76 | 6.90 | 7.12 |
| SAN JUAN | 6.50 | 6.98 | 6.82 | 6.68 | 6.75 |
| SEATTLE | 1.74 | 5.47 | 7.32 | 3.63 | 4.56 |
| SYRACUSE | 2.23 | 5.28 | 6.42 | 3.80 | 4.45 |
| WASHINGTON D.C. | 3.84 | 6.18 | 6.71 | 5.08 | 5.46 |

MAP OF DEVIATION OF MAGNETIC NORTH FROM TRUE NORTH
(Adapted from Isogonic Chart of the USA, courtesy of Dept. of Commerce)



## INSOLATION DATA BY MONTH

| SITE ARRAY TILT | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JUNEAU | AK | LATITUDE: | | 58 DEGREES | | 22 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 1.04 | 1.70 | 2.57 | 3.72 | 4.07 | 4.28 | 4.02 | 3.47 | 2.73 | 1.74 | 1.24 | .68 | 951.8 | 2.6 |
| LATITUDE : | | 1.16 | 1.81 | 2.57 | 3.53 | 3.71 | 3.86 | 3.67 | 3.28 | 2.72 | 1.83 | 1.39 | .78 | 922.7 | 2.5 |
| LATITUDE +15: | | 1.22 | 1.82 | 2.43 | 3.18 | 3.24 | 3.32 | 3.20 | 2.96 | 2.58 | 1.83 | 1.45 | .83 | 853.6 | 2.3 |
| KING SALMON | AK | LATITUDE: | | 58 DEGREES | | 41 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 1.25 | 2.22 | 3.68 | 4.40 | 4.73 | 4.68 | 4.38 | 3.73 | 3.54 | 3.08 | 2.07 | 1.08 | 1183.5 | 3.2 |
| LATITUDE : | | 1.39 | 2.36 | 3.72 | 4.19 | 4.32 | 4.22 | 4.00 | 3.54 | 3.57 | 3.32 | 2.35 | 1.25 | 1164.2 | 3.2 |
| LATITUDE +15: | | 1.46 | 2.37 | 3.56 | 3.78 | 3.77 | 3.63 | 3.48 | 3.19 | 3.41 | 3.36 | 2.49 | 1.34 | 1090.5 | 3.0 |
| KODIAK | AK | LATITUDE: | | 57 DEGREES | | 45 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 1.13 | 1.92 | 3.50 | 4.38 | 4.35 | 4.65 | 4.46 | 4.20 | 3.55 | 3.06 | 1.90 | .99 | 1160.0 | 3.2 |
| LATITUDE : | | 1.26 | 2.03 | 3.53 | 4.16 | 3.98 | 4.20 | 4.08 | 3.99 | 3.58 | 3.29 | 2.15 | 1.13 | 1137.8 | 3.1 |
| LATITUDE +15: | | 1.31 | 2.02 | 3.37 | 3.76 | 3.47 | 3.61 | 3.55 | 3.60 | 3.42 | 3.32 | 2.27 | 1.20 | 1062.9 | 2.9 |
| NOME | AK | LATITUDE: | | 64 DEGREES | | 30 MINUTES | | | | | | | | | |
| LATITUDE -15: | | .34 | 1.56 | 3.29 | 4.63 | 5.14 | 5.40 | 4.57 | 3.74 | 3.53 | 2.59 | 1.16 | .01 | 1095.5 | 3.0 |
| LATITUDE : | | .38 | 1.65 | 3.32 | 4.39 | 4.69 | 4.85 | 4.15 | 3.54 | 3.58 | 2.79 | 1.32 | .01 | 1055.8 | 2.9 |
| LATITUDE +15: | | .40 | 1.65 | 3.17 | 3.96 | 4.06 | 4.14 | 3.60 | 3.19 | 3.42 | 2.82 | 1.39 | .01 | 968.4 | 2.7 |
| BIRMINGHAM | AL | LATITUDE: | | 33 DEGREES | | 34 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 2.75 | 3.53 | 4.44 | 5.39 | 5.72 | 5.83 | 5.58 | 5.57 | 5.01 | 4.54 | 3.44 | 2.70 | 1658.7 | 4.5 |
| LATITUDE : | | 3.02 | 3.73 | 4.49 | 5.19 | 5.31 | 5.33 | 5.17 | 5.36 | 5.08 | 4.87 | 3.84 | 3.05 | 1657.0 | 4.5 |
| LATITUDE +15: | | 3.14 | 3.74 | 4.31 | 4.75 | 4.68 | 4.63 | 4.57 | 4.91 | 4.89 | 4.94 | 4.03 | 3.23 | 1577.2 | 4.3 |
| MOBILE | AL | LATITUDE: | | 30 DEGREES | | 41 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 3.11 | 3.92 | 4.74 | 5.51 | 5.78 | 5.69 | 5.30 | 5.25 | 4.89 | 4.72 | 3.64 | 2.94 | 1688.3 | 4.6 |
| LATITUDE : | | 3.43 | 4.16 | 4.80 | 5.31 | 5.37 | 5.22 | 4.93 | 5.06 | 4.95 | 5.06 | 4.07 | 3.32 | 1694.8 | 4.6 |
| LATITUDE +15: | | 3.58 | 4.19 | 4.63 | 4.87 | 4.75 | 4.55 | 4.36 | 4.64 | 4.77 | 5.14 | 4.28 | 3.53 | 1620.9 | 4.4 |
| MONTGOMERY | AL | LATITUDE: | | 32 DEGREES | | 18 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 2.87 | 3.66 | 4.56 | 5.56 | 5.85 | 5.99 | 5.67 | 5.62 | 5.01 | 4.67 | 3.59 | 2.87 | 1703.1 | 4.7 |
| LATITUDE : | | 3.17 | 3.88 | 4.61 | 5.36 | 5.43 | 5.47 | 5.26 | 5.42 | 5.08 | 5.01 | 4.02 | 3.25 | 1703.0 | 4.7 |
| LATITUDE +15: | | 3.29 | 3.89 | 4.43 | 4.91 | 4.78 | 4.75 | 4.64 | 4.96 | 4.89 | 5.08 | 4.22 | 3.45 | 1622.1 | 4.4 |
| FORT SMITH | AR | LATITUDE: | | 35 DEGREES | | 20 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 3.03 | 3.75 | 4.56 | 5.23 | 5.90 | 6.33 | 6.37 | 6.11 | 5.27 | 4.64 | 3.55 | 2.94 | 1756.2 | 4.8 |
| LATITUDE : | | 3.37 | 3.98 | 4.61 | 5.03 | 5.46 | 5.76 | 5.88 | 5.89 | 5.35 | 4.98 | 3.99 | 3.34 | 1754.8 | 4.8 |
| LATITUDE +15: | | 3.52 | 4.00 | 4.43 | 4.60 | 4.81 | 4.98 | 5.16 | 5.38 | 5.15 | 5.05 | 4.20 | 3.56 | 1669.3 | 4.6 |
| LITTLE ROCK | AR | LATITUDE: | | 34 DEGREES | | 44 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 2.93 | 3.73 | 4.54 | 5.21 | 5.95 | 6.38 | 6.27 | 6.04 | 5.30 | 4.71 | 3.47 | 2.84 | 1746.4 | 4.8 |
| LATITUDE : | | 3.24 | 3.96 | 4.59 | 5.01 | 5.51 | 5.82 | 5.80 | 5.82 | 5.38 | 5.06 | 3.89 | 3.22 | 1744.7 | 4.8 |
| LATITUDE +15: | | 3.39 | 3.98 | 4.41 | 4.59 | 4.85 | 5.03 | 5.09 | 5.32 | 5.19 | 5.14 | 4.09 | 3.43 | 1659.4 | 4.5 |
| PHOENIX | AZ | LATITUDE: | | 33 DEGREES | | 26 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 4.19 | 5.21 | 6.36 | 7.67 | 8.26 | 8.28 | 7.66 | 7.46 | 7.13 | 6.11 | 4.83 | 4.02 | 2348.9 | 6.4 |
| LATITUDE : | | 4.74 | 5.62 | 6.51 | 7.40 | 7.60 | 7.48 | 7.06 | 7.20 | 7.32 | 6.66 | 5.52 | 4.66 | 2366.3 | 6.5 |
| LATITUDE +15: | | 5.02 | 5.72 | 6.31 | 6.76 | 6.60 | 6.36 | 6.15 | 6.57 | 7.10 | 6.83 | 5.89 | 5.03 | 2260.9 | 6.2 |
| PRESCOTT | AZ | LATITUDE: | | 34 DEGREES | | 39 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 4.30 | 5.14 | 6.30 | 7.44 | 8.11 | 8.34 | 7.12 | 6.82 | 6.97 | 6.09 | 4.94 | 4.15 | 2304.2 | 6.3 |
| LATITUDE : | | 4.88 | 5.54 | 6.45 | 7.18 | 7.47 | 7.53 | 6.57 | 6.58 | 7.16 | 6.64 | 5.66 | 4.83 | 2327.1 | 6.4 |
| LATITUDE +15: | | 5.18 | 5.64 | 6.24 | 6.56 | 6.50 | 6.41 | 5.74 | 6.01 | 6.94 | 6.81 | 6.05 | 5.23 | 2229.6 | 6.1 |
| TUCSON | AZ | LATITUDE: | | 32 DEGREES | | 7 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 4.42 | 5.35 | 6.47 | 7.66 | 8.23 | 8.24 | 7.21 | 7.06 | 6.90 | 6.08 | 4.94 | 4.18 | 2335.1 | 6.4 |
| LATITUDE : | | 5.00 | 5.77 | 6.63 | 7.39 | 7.57 | 7.44 | 6.65 | 6.81 | 7.07 | 6.62 | 5.65 | 4.85 | 2356.1 | 6.5 |
| LATITUDE +15: | | 5.30 | 5.87 | 6.42 | 6.74 | 6.57 | 6.33 | 5.81 | 6.22 | 6.84 | 6.79 | 6.02 | 5.25 | 2255.1 | 6.2 |
| WINSLOW | AZ | LATITUDE: | | 35 DEGREES | | 1 MINUTES | | | | | | | | | |
| LATITUDE -15: | | 4.19 | 5.15 | 6.34 | 7.47 | 8.01 | 8.19 | 7.24 | 7.00 | 6.90 | 6.01 | 4.90 | 4.04 | 2295.2 | 6.3 |
| LATITUDE : | | 4.75 | 5.55 | 6.49 | 7.21 | 7.37 | 7.39 | 6.67 | 6.74 | 7.07 | 6.54 | 5.61 | 4.69 | 2314.0 | 6.3 |
| LATITUDE +15: | | 5.03 | 5.64 | 6.28 | 6.57 | 6.40 | 6.29 | 5.81 | 6.15 | 6.84 | 6.70 | 5.99 | 5.07 | 2213.3 | 6.1 |

Stand-Alone Flat-plate Photovoltaic Power Systems: System Sizing and Life-Cycle Costing Methodology for Federal Agencies (Courtesy of DOE)

| SITE<br>ARRAY TILT | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DAGGETT | CA | LATITUDE: 34 DEGREES 52 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.02 | 4.92 | 6.29 | 7.44 | 8.01 | 8.36 | 8.03 | 7.82 | 7.20 | 5.98 | 4.68 | 3.90 | 2334.1 | 6.4 |
| LATITUDE : | | 4.55 | 5.30 | 6.44 | 7.18 | 7.38 | 7.55 | 7.40 | 7.56 | 7.41 | 6.53 | 5.35 | 4.52 | 2348.6 | 6.4 |
| LATITUDE +15: | | 4.82 | 5.38 | 6.24 | 6.56 | 6.42 | 6.43 | 6.43 | 6.90 | 7.19 | 6.69 | 5.71 | 4.89 | 2241.3 | 6.1 |
| EL TORO | CA | LATITUDE: 33 DEGREES 40 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.85 | 4.65 | 5.60 | 6.25 | 6.39 | 6.65 | 7.29 | 7.00 | 6.07 | 5.17 | 4.24 | 3.73 | 2036.4 | 5.6 |
| LATITUDE : | | 4.33 | 4.98 | 5.71 | 6.02 | 5.91 | 6.05 | 6.73 | 6.76 | 6.20 | 5.59 | 4.81 | 4.30 | 2051.4 | 5.6 |
| LATITUDE +15: | | 4.57 | 5.05 | 5.52 | 5.51 | 5.20 | 5.22 | 5.87 | 6.17 | 5.99 | 5.69 | 5.10 | 4.63 | 1963.7 | 5.4 |
| FRESNO | CA | LATITUDE: 36 DEGREES 46 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.72 | 3.89 | 5.59 | 6.89 | 7.69 | 8.26 | 8.31 | 8.04 | 7.27 | 5.81 | 3.90 | 2.50 | 2158.6 | 5.9 |
| LATITUDE : | | 3.01 | 4.14 | 5.70 | 6.64 | 7.08 | 7.46 | 7.64 | 7.76 | 7.48 | 6.33 | 4.41 | 2.83 | 2146.5 | 5.9 |
| LATITUDE +15: | | 3.14 | 4.17 | 5.51 | 6.07 | 6.18 | 6.36 | 6.63 | 7.08 | 7.26 | 6.48 | 4.68 | 3.00 | 2025.7 | 5.5 |
| LONG BEACH | CA | LATITUDE: 33 DEGREES 49 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.77 | 4.56 | 5.61 | 6.28 | 6.37 | 6.48 | 7.09 | 6.83 | 5.94 | 5.05 | 4.14 | 3.62 | 2001.8 | 5.5 |
| LATITUDE : | | 4.24 | 4.89 | 5.72 | 6.06 | 5.90 | 5.91 | 6.55 | 6.59 | 6.06 | 5.45 | 4.69 | 4.18 | 2015.9 | 5.5 |
| LATITUDE +15: | | 4.48 | 4.95 | 5.53 | 5.54 | 5.18 | 5.11 | 5.73 | 6.02 | 5.86 | 5.55 | 4.98 | 4.49 | 1929.4 | 5.3 |
| LOS ANGELES | CA | LATITUDE: 33 DEGREES 56 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.78 | 4.57 | 5.65 | 6.32 | 6.36 | 6.43 | 7.12 | 6.76 | 5.88 | 5.02 | 4.16 | 3.65 | 1999.6 | 5.5 |
| LATITUDE : | | 4.25 | 4.89 | 5.76 | 6.10 | 5.89 | 5.86 | 6.57 | 6.52 | 5.99 | 5.41 | 4.72 | 4.21 | 2014.3 | 5.5 |
| LATITUDE +15: | | 4.48 | 4.96 | 5.57 | 5.58 | 5.18 | 5.07 | 5.75 | 5.96 | 5.79 | 5.51 | 5.00 | 4.53 | 1928.6 | 5.3 |
| NEEDLES | CA | LATITUDE: 34 DEGREES 46 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.15 | 5.23 | 6.49 | 7.59 | 8.19 | 8.44 | 7.84 | 7.45 | 7.21 | 6.07 | 4.87 | 4.09 | 2362.5 | 6.5 |
| LATITUDE : | | 4.70 | 5.65 | 6.65 | 7.33 | 7.54 | 7.62 | 7.22 | 7.19 | 7.42 | 6.62 | 5.58 | 4.76 | 2381.9 | 6.5 |
| LATITUDE +15: | | 4.98 | 5.76 | 6.45 | 6.69 | 6.56 | 6.48 | 6.29 | 6.57 | 7.20 | 6.79 | 5.96 | 5.16 | 2277.5 | 6.2 |
| OAKLAND | CA | LATITUDE: 37 DEGREES 44 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.05 | 3.97 | 5.22 | 6.32 | 6.85 | 7.12 | 7.19 | 6.78 | 6.19 | 4.89 | 3.66 | 2.98 | 1955.4 | 5.4 |
| LATITUDE : | | 3.40 | 4.23 | 5.31 | 6.09 | 6.32 | 6.46 | 6.62 | 6.53 | 6.33 | 5.28 | 4.13 | 3.40 | 1951.7 | 5.3 |
| LATITUDE +15: | | 3.56 | 4.27 | 5.12 | 5.56 | 5.54 | 5.55 | 5.78 | 5.96 | 6.12 | 5.37 | 4.37 | 3.64 | 1851.7 | 5.1 |
| RED BLUFF | CA | LATITUDE: 40 DEGREES 9 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.53 | 3.58 | 4.95 | 6.36 | 7.39 | 7.87 | 8.31 | 7.79 | 7.00 | 5.24 | 3.29 | 2.44 | 2033.9 | 5.6 |
| LATITUDE : | | 2.80 | 3.79 | 5.02 | 6.11 | 6.80 | 7.11 | 7.63 | 7.51 | 7.19 | 5.68 | 3.70 | 2.77 | 2013.7 | 5.5 |
| LATITUDE +15: | | 2.92 | 3.81 | 4.83 | 5.57 | 5.93 | 6.07 | 6.61 | 6.85 | 6.96 | 5.79 | 3.89 | 2.94 | 1893.3 | 5.2 |
| SACRAMENTO | CA | LATITUDE: 38 DEGREES 31 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.55 | 3.69 | 5.27 | 6.63 | 7.55 | 8.11 | 8.35 | 7.92 | 7.11 | 5.47 | 3.53 | 2.45 | 2090.9 | 5.7 |
| LATITUDE : | | 2.81 | 3.91 | 5.36 | 6.38 | 6.95 | 7.33 | 7.67 | 7.65 | 7.31 | 5.94 | 3.98 | 2.77 | 2073.2 | 5.7 |
| LATITUDE +15: | | 2.93 | 3.94 | 5.17 | 5.83 | 6.06 | 6.25 | 6.65 | 6.97 | 7.09 | 6.07 | 4.20 | 2.94 | 1951.6 | 5.3 |
| SAN DIEGO | CA | LATITUDE: 32 DEGREES 44 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.90 | 4.70 | 5.64 | 6.25 | 6.18 | 6.26 | 6.74 | 6.65 | 5.95 | 5.16 | 4.31 | 3.79 | 1994.8 | 5.5 |
| LATITUDE : | | 4.39 | 5.04 | 5.75 | 6.03 | 5.72 | 5.72 | 6.23 | 6.42 | 6.07 | 5.58 | 4.89 | 4.37 | 2014.9 | 5.5 |
| LATITUDE +15: | | 4.63 | 5.11 | 5.56 | 5.52 | 5.04 | 4.95 | 5.46 | 5.87 | 5.87 | 5.68 | 5.19 | 4.71 | 1934.5 | 5.3 |
| SAN FRANCISCO | CA | LATITUDE: 37 DEGREES 37 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.04 | 3.93 | 5.22 | 6.31 | 6.90 | 7.19 | 7.41 | 7.00 | 6.35 | 4.94 | 3.64 | 2.94 | 1975.5 | 5.4 |
| LATITUDE : | | 3.39 | 4.19 | 5.30 | 6.08 | 6.36 | 6.52 | 6.82 | 6.75 | 6.49 | 5.33 | 4.11 | 3.36 | 1970.1 | 5.4 |
| LATITUDE +15: | | 3.55 | 4.22 | 5.11 | 5.55 | 5.57 | 5.60 | 5.95 | 6.16 | 6.28 | 5.43 | 4.34 | 3.59 | 1867.3 | 5.1 |
| SANTA MARIA | CA | LATITUDE: 34 DEGREES 54 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.51 | 4.31 | 5.56 | 6.25 | 6.60 | 7.12 | 7.22 | 6.88 | 6.11 | 5.26 | 4.11 | 3.52 | 2023.8 | 5.5 |
| LATITUDE : | | 3.93 | 4.61 | 5.66 | 6.03 | 6.11 | 6.46 | 6.67 | 6.64 | 6.25 | 5.70 | 4.66 | 4.06 | 2032.8 | 5.6 |
| LATITUDE +15: | | 4.14 | 4.66 | 5.47 | 5.51 | 5.36 | 5.56 | 5.82 | 6.06 | 6.04 | 5.82 | 4.95 | 4.36 | 1940.4 | 5.3 |
| SUNNYVALE | CA | LATITUDE: 37 DEGREES 25 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.17 | 4.04 | 5.32 | 6.39 | 7.05 | 7.42 | 7.55 | 7.17 | 6.41 | 5.03 | 3.74 | 3.02 | 2019.1 | 5.5 |
| LATITUDE : | | 3.54 | 4.31 | 5.41 | 6.15 | 6.50 | 6.72 | 6.95 | 6.91 | 6.55 | 5.43 | 4.22 | 3.45 | 2013.9 | 5.5 |
| LATITUDE +15: | | 3.72 | 4.34 | 5.21 | 5.62 | 5.68 | 5.76 | 6.05 | 6.30 | 6.34 | 5.53 | 4.46 | 3.69 | 1908.7 | 5.2 |
| COLORADO SPRINGS | CO | LATITUDE: 38 DEGREES 49 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.17 | 4.81 | 5.66 | 6.39 | 6.60 | 7.17 | 6.86 | 6.72 | 6.51 | 5.72 | 4.50 | 3.92 | 2100.9 | 5.8 |
| LATITUDE : | | 4.74 | 5.18 | 5.77 | 6.15 | 6.09 | 6.50 | 6.32 | 6.48 | 6.67 | 6.23 | 5.16 | 4.57 | 2126.1 | 5.8 |
| LATITUDE +15: | | 5.04 | 5.27 | 5.57 | 5.62 | 5.34 | 5.59 | 5.53 | 5.91 | 6.45 | 6.38 | 5.50 | 4.95 | 2042.8 | 5.6 |
| DENVER | CO | LATITUDE: 39 DEGREES 45 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.01 | 4.65 | 5.65 | 6.24 | 6.62 | 7.12 | 7.05 | 6.82 | 6.45 | 5.55 | 4.29 | 3.75 | 2076.2 | 5.7 |
| LATITUDE : | | 4.56 | 5.01 | 5.76 | 6.00 | 6.11 | 6.46 | 6.50 | 6.57 | 6.60 | 6.04 | 4.90 | 4.36 | 2095.9 | 5.7 |
| LATITUDE +15: | | 4.84 | 5.08 | 5.56 | 5.48 | 5.35 | 5.55 | 5.67 | 6.00 | 6.39 | 6.17 | 5.22 | 4.72 | 2009.0 | 5.5 |
| GRAND JUNCTION | CO | LATITUDE: 39 DEGREES 7 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.65 | 4.56 | 5.70 | 6.59 | 7.38 | 7.86 | 7.65 | 7.28 | 6.86 | 5.70 | 4.41 | 3.66 | 2171.0 | 5.9 |
| LATITUDE : | | 4.12 | 4.89 | 5.81 | 6.34 | 6.79 | 7.10 | 7.03 | 7.02 | 7.03 | 6.20 | 5.03 | 4.25 | 2180.1 | 6.0 |
| LATITUDE +15: | | 4.35 | 4.96 | 5.61 | 5.78 | 5.92 | 6.06 | 6.12 | 6.39 | 6.81 | 6.34 | 5.36 | 4.58 | 2078.0 | 5.7 |

| SITE / ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PUEBLO CO** | LATITUDE: 38 DEGREES 17 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 4.12 | 4.73 | 5.68 | 6.46 | 6.69 | 7.36 | 7.15 | 6.97 | 6.55 | 5.67 | 4.49 | 3.86 | 2122.9 | 5.8 |
| LATITUDE : | 4.68 | 5.09 | 5.79 | 6.22 | 6.17 | 6.67 | 6.59 | 6.72 | 6.71 | 6.16 | 5.12 | 4.48 | 2142.6 | 5.9 |
| LATITUDE +15: | 4.97 | 5.16 | 5.59 | 5.68 | 5.40 | 5.71 | 5.74 | 6.13 | 6.49 | 6.30 | 5.46 | 4.85 | 2053.1 | 5.6 |
| **HARTFORD CT** | LATITUDE: 41 DEGREES 56 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.14 | 2.85 | 3.51 | 4.33 | 4.86 | 5.11 | 5.11 | 4.70 | 4.22 | 3.53 | 2.27 | 1.81 | 1352.9 | 3.7 |
| LATITUDE : | 2.35 | 3.00 | 3.53 | 4.15 | 4.49 | 4.66 | 4.72 | 4.51 | 4.26 | 3.76 | 2.51 | 2.02 | 1337.8 | 3.7 |
| LATITUDE +15: | 2.44 | 2.99 | 3.37 | 3.78 | 3.96 | 4.05 | 4.16 | 4.11 | 4.08 | 3.79 | 2.61 | 2.13 | 1262.1 | 3.5 |
| **GUANTANAMO BAY CU** | LATITUDE: 19 DEGREES 54 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 4.66 | 5.38 | 6.17 | 6.69 | 6.36 | 6.10 | 6.50 | 6.31 | 5.84 | 5.17 | 4.76 | 4.39 | 2079.2 | 5.7 |
| LATITUDE : | 5.27 | 5.79 | 6.31 | 6.48 | 5.93 | 5.62 | 6.06 | 6.12 | 5.96 | 5.56 | 5.40 | 5.07 | 2115.9 | 5.8 |
| LATITUDE +15: | 5.60 | 5.90 | 6.12 | 5.95 | 5.23 | 4.89 | 5.33 | 5.62 | 5.77 | 5.67 | 5.74 | 5.47 | 2046.1 | 5.6 |
| **WASHINGTON-STERLING DC** | LATITUDE: 38 DEGREES 57 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.44 | 3.15 | 3.98 | 4.77 | 5.32 | 5.76 | 5.62 | 5.30 | 4.81 | 4.02 | 2.86 | 2.16 | 1528.7 | 4.2 |
| LATITUDE : | 2.69 | 3.32 | 4.01 | 4.58 | 4.93 | 5.26 | 5.20 | 5.10 | 4.87 | 4.29 | 3.19 | 2.43 | 1518.5 | 4.2 |
| LATITUDE +15: | 2.80 | 3.33 | 3.85 | 4.19 | 4.35 | 4.56 | 4.58 | 4.66 | 4.68 | 4.34 | 3.34 | 2.57 | 1437.8 | 3.9 |
| **WILMINGTON DE** | LATITUDE: 39 DEGREES 40 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.49 | 3.25 | 4.11 | 4.85 | 5.30 | 5.71 | 5.65 | 5.32 | 4.76 | 3.97 | 2.90 | 2.26 | 1539.3 | 4.2 |
| LATITUDE : | 2.76 | 3.43 | 4.14 | 4.65 | 4.90 | 5.21 | 5.22 | 5.11 | 4.82 | 4.25 | 3.23 | 2.55 | 1530.0 | 4.2 |
| LATITUDE +15: | 2.87 | 3.44 | 3.97 | 4.25 | 4.32 | 4.51 | 4.59 | 4.66 | 4.63 | 4.29 | 3.39 | 2.70 | 1449.3 | 4.0 |
| **APALACHICOLA FL** | LATITUDE: 29 DEGREES 44 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.16 | 3.98 | 4.94 | 6.02 | 6.45 | 6.08 | 5.60 | 5.39 | 5.16 | 4.93 | 3.94 | 3.12 | 1788.9 | 4.9 |
| LATITUDE : | 3.49 | 4.22 | 5.01 | 5.81 | 5.98 | 5.56 | 5.21 | 5.21 | 5.24 | 5.31 | 4.42 | 3.54 | 1795.8 | 4.9 |
| LATITUDE +15: | 3.65 | 4.25 | 4.84 | 5.32 | 5.26 | 4.83 | 4.61 | 4.78 | 5.05 | 5.40 | 4.67 | 3.77 | 1716.4 | 4.7 |
| **DAYTONA BEACH FL** | LATITUDE: 29 DEGREES 11 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.56 | 4.29 | 5.19 | 6.02 | 6.07 | 5.57 | 5.51 | 5.36 | 4.94 | 4.45 | 3.89 | 3.32 | 1769.5 | 4.8 |
| LATITUDE : | 3.96 | 4.56 | 5.28 | 5.81 | 5.63 | 5.11 | 5.12 | 5.18 | 5.00 | 4.75 | 4.35 | 3.77 | 1780.2 | 4.9 |
| LATITUDE +15: | 4.15 | 4.60 | 5.09 | 5.32 | 4.96 | 4.46 | 4.53 | 4.75 | 4.81 | 4.80 | 4.58 | 4.02 | 1705.4 | 4.7 |
| **JACKSONVILLE FL** | LATITUDE: 30 DEGREES 30 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.40 | 4.16 | 5.14 | 5.95 | 6.03 | 5.73 | 5.56 | 5.42 | 4.85 | 4.40 | 3.81 | 3.18 | 1753.7 | 4.8 |
| LATITUDE : | 3.77 | 4.42 | 5.22 | 5.74 | 5.60 | 5.25 | 5.17 | 5.23 | 4.91 | 4.71 | 4.27 | 3.61 | 1761.6 | 4.8 |
| LATITUDE +15: | 3.95 | 4.46 | 5.03 | 5.26 | 4.94 | 4.57 | 4.57 | 4.80 | 4.73 | 4.76 | 4.50 | 3.85 | 1685.2 | 4.6 |
| **MIAMI FL** | LATITUDE: 25 DEGREES 48 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.74 | 4.50 | 5.27 | 5.90 | 5.71 | 5.25 | 5.46 | 5.17 | 4.76 | 4.46 | 3.99 | 3.69 | 1761.3 | 4.8 |
| LATITUDE : | 4.17 | 4.80 | 5.36 | 5.70 | 5.33 | 4.84 | 5.09 | 5.00 | 4.83 | 4.76 | 4.47 | 4.21 | 1781.2 | 4.9 |
| LATITUDE +15: | 4.38 | 4.85 | 5.16 | 5.24 | 4.72 | 4.24 | 4.52 | 4.60 | 4.65 | 4.82 | 4.71 | 4.50 | 1715.6 | 4.7 |
| **ORLANDO FL** | LATITUDE: 28 DEGREES 33 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.68 | 4.37 | 5.29 | 6.06 | 6.14 | 5.60 | 5.56 | 5.33 | 4.99 | 4.61 | 4.08 | 3.50 | 1801.8 | 4.9 |
| LATITUDE : | 4.10 | 4.65 | 5.38 | 5.86 | 5.71 | 5.14 | 5.18 | 5.15 | 5.06 | 4.94 | 4.59 | 3.99 | 1817.2 | 5.0 |
| LATITUDE +15: | 4.31 | 4.70 | 5.19 | 5.37 | 5.03 | 4.49 | 4.58 | 4.73 | 4.87 | 5.01 | 4.85 | 4.26 | 1744.9 | 4.8 |
| **TALLAHASSEE FL** | LATITUDE: 30 DEGREES 23 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.30 | 4.05 | 4.98 | 5.84 | 5.98 | 5.73 | 5.39 | 5.36 | 5.03 | 4.78 | 3.86 | 3.16 | 1748.3 | 4.8 |
| LATITUDE : | 3.66 | 4.31 | 5.06 | 5.63 | 5.55 | 5.25 | 5.02 | 5.17 | 5.10 | 5.13 | 4.33 | 3.58 | 1757.6 | 4.8 |
| LATITUDE +15: | 3.82 | 4.34 | 4.87 | 5.16 | 4.89 | 4.57 | 4.44 | 4.74 | 4.91 | 5.21 | 4.56 | 3.81 | 1682.6 | 4.6 |
| **TAMPA FL** | LATITUDE: 27 DEGREES 58 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.68 | 4.39 | 5.30 | 6.09 | 6.18 | 5.65 | 5.42 | 5.26 | 4.95 | 4.73 | 4.08 | 3.49 | 1802.0 | 4.9 |
| LATITUDE : | 4.10 | 4.68 | 5.40 | 5.88 | 5.74 | 5.19 | 5.05 | 5.09 | 5.02 | 5.07 | 4.59 | 3.98 | 1819.3 | 5.0 |
| LATITUDE +15: | 4.31 | 4.73 | 5.22 | 5.40 | 5.07 | 4.53 | 4.48 | 4.67 | 4.84 | 5.15 | 4.85 | 4.25 | 1748.7 | 4.8 |
| **ATLANTA GA** | LATITUDE: 33 DEGREES 39 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.80 | 3.55 | 4.47 | 5.43 | 5.72 | 5.81 | 5.59 | 5.51 | 4.89 | 4.50 | 3.55 | 2.76 | 1661.6 | 4.6 |
| LATITUDE : | 3.08 | 3.75 | 4.52 | 5.23 | 5.31 | 5.31 | 5.19 | 5.31 | 4.96 | 4.82 | 3.98 | 3.12 | 1661.3 | 4.6 |
| LATITUDE +15: | 3.21 | 3.76 | 4.34 | 4.79 | 4.68 | 4.62 | 4.58 | 4.86 | 4.77 | 4.89 | 4.18 | 3.32 | 1582.5 | 4.3 |
| **AUGUSTA GA** | LATITUDE: 33 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.94 | 3.72 | 4.59 | 5.58 | 5.75 | 5.78 | 5.55 | 5.37 | 4.84 | 4.57 | 3.69 | 2.97 | 1684.7 | 4.6 |
| LATITUDE : | 3.25 | 3.94 | 4.64 | 5.37 | 5.34 | 5.29 | 5.15 | 5.17 | 4.89 | 4.90 | 4.14 | 3.37 | 1687.5 | 4.6 |
| LATITUDE +15: | 3.38 | 3.96 | 4.46 | 4.92 | 4.71 | 4.59 | 4.55 | 4.74 | 4.71 | 4.97 | 4.36 | 3.58 | 1610.3 | 4.4 |
| **MACON GA** | LATITUDE: 32 DEGREES 42 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.97 | 3.70 | 4.65 | 5.60 | 5.81 | 5.83 | 5.50 | 5.53 | 4.92 | 4.63 | 3.74 | 2.94 | 1699.3 | 4.7 |
| LATITUDE : | 3.28 | 3.92 | 4.71 | 5.39 | 5.39 | 5.34 | 5.11 | 5.33 | 4.99 | 4.97 | 4.20 | 3.34 | 1703.3 | 4.7 |
| LATITUDE +15: | 3.42 | 3.94 | 4.53 | 4.94 | 4.76 | 4.64 | 4.51 | 4.88 | 4.80 | 5.05 | 4.42 | 3.55 | 1626.3 | 4.5 |
| **SAVANNAH GA** | LATITUDE: 32 DEGREES 8 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.06 | 3.77 | 4.75 | 5.66 | 5.72 | 5.60 | 5.49 | 5.21 | 4.63 | 4.48 | 3.70 | 3.02 | 1677.2 | 4.6 |
| LATITUDE : | 3.38 | 3.99 | 4.81 | 5.46 | 5.31 | 5.13 | 5.10 | 5.02 | 4.68 | 4.79 | 4.15 | 3.43 | 1681.1 | 4.6 |
| LATITUDE +15: | 3.52 | 4.01 | 4.63 | 5.00 | 4.68 | 4.47 | 4.50 | 4.59 | 4.49 | 4.85 | 4.36 | 3.65 | 1605.4 | 4.4 |

| SITE / ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BARBERS POINT HI | LATITUDE: | 21 DEGREES | 19 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 4.06 | 4.75 | 5.29 | 5.79 | 6.13 | 6.26 | 6.28 | 6.22 | 5.85 | 5.15 | 4.39 | 3.97 | 1951.9 | 5.3 |
| LATITUDE : | 4.54 | 5.07 | 5.38 | 5.61 | 5.72 | 5.74 | 5.85 | 6.02 | 5.96 | 5.53 | 4.94 | 4.54 | 1974.8 | 5.4 |
| LATITUDE +15: | 4.78 | 5.14 | 5.21 | 5.16 | 5.05 | 4.98 | 5.15 | 5.53 | 5.77 | 5.63 | 5.23 | 4.86 | 1900.3 | 5.2 |
| HILO HI | LATITUDE: | 19 DEGREES | 43 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.69 | 4.04 | 4.29 | 4.52 | 4.85 | 5.17 | 5.07 | 5.02 | 4.94 | 4.46 | 3.64 | 3.37 | 1614.9 | 4.4 |
| LATITUDE : | 4.09 | 4.29 | 4.35 | 4.39 | 4.56 | 4.79 | 4.76 | 4.88 | 5.01 | 4.76 | 4.03 | 3.81 | 1634.2 | 4.5 |
| LATITUDE +15: | 4.29 | 4.32 | 4.21 | 4.06 | 4.08 | 4.21 | 4.25 | 4.50 | 4.85 | 4.81 | 4.23 | 4.04 | 1577.0 | 4.3 |
| HONOLULU HI | LATITUDE: | 21 DEGREES | 20 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.97 | 4.60 | 5.22 | 5.67 | 6.07 | 6.21 | 6.22 | 6.21 | 5.84 | 5.10 | 4.27 | 3.85 | 1924.4 | 5.3 |
| LATITUDE : | 4.43 | 4.90 | 5.31 | 5.49 | 5.66 | 5.70 | 5.80 | 6.01 | 5.95 | 5.48 | 4.80 | 4.39 | 1944.7 | 5.3 |
| LATITUDE +15: | 4.65 | 4.96 | 5.13 | 5.05 | 5.00 | 4.95 | 5.11 | 5.52 | 5.76 | 5.57 | 5.07 | 4.69 | 1869.8 | 5.1 |
| BURLINGTON IA | LATITUDE: | 40 DEGREES | 47 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.63 | 3.46 | 4.21 | 5.07 | 5.82 | 6.42 | 6.48 | 6.09 | 5.23 | 4.45 | 3.11 | 2.31 | 1684.2 | 4.6 |
| LATITUDE : | 2.92 | 3.67 | 4.26 | 4.86 | 5.38 | 5.84 | 5.98 | 5.86 | 5.32 | 4.79 | 3.49 | 2.62 | 1674.1 | 4.6 |
| LATITUDE +15: | 3.06 | 3.68 | 4.08 | 4.44 | 4.73 | 5.03 | 5.23 | 5.35 | 5.12 | 4.86 | 3.68 | 2.78 | 1584.1 | 4.3 |
| DES MOINES IA | LATITUDE: | 41 DEGREES | 32 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.71 | 3.52 | 4.31 | 5.16 | 5.80 | 6.43 | 6.51 | 6.12 | 5.36 | 4.57 | 3.16 | 2.42 | 1707.7 | 4.7 |
| LATITUDE : | 3.02 | 3.74 | 4.35 | 4.94 | 5.35 | 5.84 | 6.00 | 5.88 | 5.45 | 4.92 | 3.55 | 2.75 | 1699.3 | 4.7 |
| LATITUDE +15: | 3.16 | 3.76 | 4.18 | 4.51 | 4.70 | 5.04 | 5.25 | 5.36 | 5.25 | 5.00 | 3.74 | 2.93 | 1609.3 | 4.4 |
| MASON CITY IA | LATITUDE: | 43 DEGREES | 9 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.71 | 3.53 | 4.34 | 5.06 | 5.90 | 6.40 | 6.49 | 6.19 | 5.34 | 4.46 | 3.00 | 2.31 | 1697.1 | 4.6 |
| LATITUDE : | 3.02 | 3.75 | 4.39 | 4.84 | 5.44 | 5.80 | 5.97 | 5.95 | 5.43 | 4.80 | 3.37 | 2.62 | 1685.9 | 4.6 |
| LATITUDE +15: | 3.17 | 3.77 | 4.21 | 4.41 | 4.76 | 5.00 | 5.22 | 5.42 | 5.23 | 4.86 | 3.54 | 2.79 | 1593.7 | 4.4 |
| SIOUX CITY IA | LATITUDE: | 42 DEGREES | 24 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.73 | 3.49 | 4.31 | 5.24 | 5.91 | 6.44 | 6.60 | 6.20 | 5.36 | 4.51 | 3.17 | 2.40 | 1716.6 | 4.7 |
| LATITUDE : | 3.04 | 3.71 | 4.35 | 5.03 | 5.45 | 5.84 | 6.08 | 5.96 | 5.45 | 4.86 | 3.57 | 2.73 | 1707.0 | 4.7 |
| LATITUDE +15: | 3.18 | 3.72 | 4.17 | 4.58 | 4.78 | 5.03 | 5.31 | 5.43 | 5.25 | 4.93 | 3.76 | 2.90 | 1615.2 | 4.4 |
| BOISE ID | LATITUDE: | 43 DEGREES | 34 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.33 | 3.57 | 4.95 | 6.18 | 7.13 | 7.48 | 8.20 | 7.55 | 6.87 | 5.20 | 3.23 | 2.30 | 1980.0 | 5.4 |
| LATITUDE : | 2.58 | 3.80 | 5.03 | 5.94 | 6.56 | 6.76 | 7.53 | 7.28 | 7.06 | 5.65 | 3.64 | 2.62 | 1962.5 | 5.4 |
| LATITUDE +15: | 2.69 | 3.82 | 4.84 | 5.41 | 5.73 | 5.79 | 6.53 | 6.63 | 6.84 | 5.77 | 3.84 | 2.78 | 1847.2 | 5.1 |
| LEWISTON ID | LATITUDE: | 46 DEGREES | 23 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.62 | 2.59 | 3.88 | 4.84 | 5.77 | 6.11 | 7.36 | 6.70 | 5.76 | 3.98 | 2.13 | 1.50 | 1593.0 | 4.4 |
| LATITUDE : | 1.76 | 2.71 | 3.91 | 4.63 | 5.31 | 5.54 | 6.76 | 6.44 | 5.87 | 4.27 | 2.37 | 1.68 | 1562.4 | 4.3 |
| LATITUDE +15: | 1.81 | 2.70 | 3.74 | 4.21 | 4.65 | 4.77 | 5.88 | 5.86 | 5.66 | 4.33 | 2.47 | 1.76 | 1458.1 | 4.0 |
| POCATELLO ID | LATITUDE: | 42 DEGREES | 55 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.59 | 3.73 | 5.19 | 6.14 | 7.13 | 7.53 | 8.15 | 7.67 | 6.95 | 5.47 | 3.54 | 2.49 | 2028.8 | 5.6 |
| LATITUDE : | 2.89 | 3.97 | 5.28 | 5.90 | 6.57 | 6.81 | 7.49 | 7.40 | 7.14 | 5.95 | 4.01 | 2.85 | 2018.7 | 5.5 |
| LATITUDE +15: | 3.02 | 4.00 | 5.09 | 5.38 | 5.74 | 5.84 | 6.51 | 6.75 | 6.93 | 6.09 | 4.25 | 3.04 | 1907.2 | 5.2 |
| CHICAGO IL | LATITUDE: | 41 DEGREES | 47 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.30 | 3.05 | 4.03 | 4.82 | 5.55 | 6.09 | 6.04 | 5.74 | 5.03 | 4.09 | 2.65 | 1.91 | 1562.9 | 4.3 |
| LATITUDE : | 2.54 | 3.22 | 4.06 | 4.62 | 5.13 | 5.54 | 5.57 | 5.51 | 5.11 | 4.39 | 2.96 | 2.14 | 1546.6 | 4.2 |
| LATITUDE +15: | 2.64 | 3.22 | 3.89 | 4.22 | 4.51 | 4.78 | 4.88 | 5.03 | 4.91 | 4.44 | 3.10 | 2.26 | 1457.9 | 4.0 |
| SPRINGFIELD IL | LATITUDE: | 39 DEGREES | 50 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.58 | 3.41 | 4.08 | 4.97 | 5.78 | 6.35 | 6.38 | 5.98 | 5.33 | 4.40 | 3.09 | 2.28 | 1663.6 | 4.6 |
| LATITUDE : | 2.86 | 3.61 | 4.12 | 4.77 | 5.34 | 5.78 | 5.88 | 5.75 | 5.42 | 4.73 | 3.46 | 2.58 | 1653.3 | 4.5 |
| LATITUDE +15: | 2.98 | 3.63 | 3.95 | 4.36 | 4.70 | 4.99 | 5.15 | 5.25 | 5.22 | 4.80 | 3.63 | 2.74 | 1564.5 | 4.3 |
| FORT WAYNE IN | LATITUDE: | 41 DEGREES | 0 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.95 | 2.73 | 3.50 | 4.46 | 5.18 | 5.57 | 5.53 | 5.27 | 4.65 | 3.80 | 2.31 | 1.65 | 1419.2 | 3.9 |
| LATITUDE : | 2.13 | 2.85 | 3.51 | 4.27 | 4.78 | 5.07 | 5.10 | 5.05 | 4.70 | 4.05 | 2.54 | 1.83 | 1397.2 | 3.8 |
| LATITUDE +15: | 2.19 | 2.84 | 3.35 | 3.89 | 4.21 | 4.40 | 4.48 | 4.60 | 4.51 | 4.09 | 2.64 | 1.91 | 1311.9 | 3.6 |
| INDIANAPOLIS IN | LATITUDE: | 39 DEGREES | 44 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.09 | 2.88 | 3.67 | 4.58 | 5.23 | 5.66 | 5.59 | 5.42 | 4.79 | 3.95 | 2.55 | 1.84 | 1469.6 | 4.0 |
| LATITUDE : | 2.28 | 3.02 | 3.69 | 4.39 | 4.84 | 5.17 | 5.17 | 5.20 | 4.85 | 4.22 | 2.82 | 2.05 | 1452.7 | 4.0 |
| LATITUDE +15: | 2.36 | 3.02 | 3.53 | 4.01 | 4.27 | 4.48 | 4.54 | 4.75 | 4.66 | 4.26 | 2.95 | 2.15 | 1369.2 | 3.8 |
| SOUTH BEND IN | LATITUDE: | 41 DEGREES | 42 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.77 | 2.57 | 3.56 | 4.57 | 5.34 | 5.83 | 5.75 | 5.55 | 4.76 | 3.78 | 2.25 | 1.52 | 1439.3 | 3.9 |
| LATITUDE : | 1.92 | 2.69 | 3.57 | 4.38 | 4.93 | 5.30 | 5.30 | 5.33 | 4.82 | 4.03 | 2.48 | 1.67 | 1414.3 | 3.9 |
| LATITUDE +15: | 1.97 | 2.67 | 3.42 | 4.00 | 4.34 | 4.59 | 4.66 | 4.86 | 4.63 | 4.07 | 2.58 | 1.73 | 1324.9 | 3.6 |
| DODGE CITY KS | LATITUDE: | 37 DEGREES | 46 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.67 | 4.46 | 5.31 | 6.20 | 6.47 | 7.14 | 7.11 | 6.79 | 6.14 | 5.31 | 4.05 | 3.47 | 2012.6 | 5.5 |
| LATITUDE : | 4.15 | 4.78 | 5.40 | 5.97 | 5.98 | 6.48 | 6.55 | 6.54 | 6.27 | 5.76 | 4.60 | 4.01 | 2023.5 | 5.5 |
| LATITUDE +15: | 4.38 | 4.84 | 5.21 | 5.45 | 5.24 | 5.57 | 5.72 | 5.97 | 6.07 | 5.88 | 4.88 | 4.31 | 1933.0 | 5.3 |

| SITE ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GOODLAND KS | LATITUDE: 39 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.67 | 4.28 | 5.19 | 6.05 | 6.39 | 7.13 | 7.19 | 6.81 | 6.07 | 5.34 | 4.07 | 3.47 | 1999.4 | 5.5 |
| LATITUDE : | 4.15 | 4.58 | 5.27 | 5.82 | 5.90 | 6.46 | 6.62 | 6.56 | 6.20 | 5.80 | 4.63 | 4.01 | 2008.8 | 5.5 |
| LATITUDE +15: | 4.38 | 4.63 | 5.08 | 5.31 | 5.17 | 5.54 | 5.77 | 5.98 | 5.98 | 5.92 | 4.92 | 4.32 | 1917.5 | 5.3 |
| TOPEKA KS | LATITUDE: 39 DEGREES 4 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.03 | 3.72 | 4.50 | 5.39 | 5.93 | 6.44 | 6.59 | 6.32 | 5.54 | 4.72 | 3.55 | 2.76 | 1781.4 | 4.9 |
| LATITUDE : | 3.38 | 3.95 | 4.55 | 5.18 | 5.48 | 5.85 | 6.08 | 6.08 | 5.64 | 5.08 | 4.00 | 3.15 | 1778.0 | 4.9 |
| LATITUDE +15: | 3.55 | 3.98 | 4.37 | 4.73 | 4.81 | 5.04 | 5.31 | 5.54 | 5.43 | 5.16 | 4.22 | 3.36 | 1688.6 | 4.6 |
| WICHITA KS | LATITUDE: 37 DEGREES 39 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.43 | 4.15 | 5.01 | 5.84 | 6.30 | 6.86 | 6.93 | 6.71 | 5.84 | 5.06 | 3.92 | 3.21 | 1926.1 | 5.3 |
| LATITUDE : | 3.85 | 4.43 | 5.09 | 5.62 | 5.82 | 6.23 | 6.39 | 6.47 | 5.96 | 5.47 | 4.44 | 3.69 | 1931.4 | 5.3 |
| LATITUDE +15: | 4.05 | 4.48 | 4.90 | 5.14 | 5.11 | 5.36 | 5.58 | 5.90 | 5.75 | 5.57 | 4.70 | 3.95 | 1841.3 | 5.0 |
| LEXINGTON KY | LATITUDE: 38 DEGREES 2 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.25 | 2.95 | 3.85 | 4.81 | 5.39 | 5.74 | 5.72 | 5.52 | 4.85 | 4.15 | 2.83 | 2.12 | 1528.7 | 4.2 |
| LATITUDE : | 2.46 | 3.10 | 3.88 | 4.62 | 4.99 | 5.23 | 5.28 | 5.30 | 4.91 | 4.43 | 3.14 | 2.37 | 1513.9 | 4.1 |
| LATITUDE +15: | 2.54 | 3.09 | 3.71 | 4.22 | 4.40 | 4.54 | 4.64 | 4.84 | 4.72 | 4.47 | 3.29 | 2.50 | 1429.3 | 3.9 |
| LOUISVILLE KY | LATITUDE: 38 DEGREES 11 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.26 | 3.00 | 3.87 | 4.78 | 5.31 | 5.76 | 5.67 | 5.51 | 4.86 | 4.14 | 2.82 | 2.14 | 1526.7 | 4.2 |
| LATITUDE : | 2.47 | 3.15 | 3.89 | 4.59 | 4.92 | 5.26 | 5.24 | 5.29 | 4.92 | 4.42 | 3.13 | 2.40 | 1512.8 | 4.1 |
| LATITUDE +15: | 2.55 | 3.14 | 3.73 | 4.19 | 4.34 | 4.56 | 4.61 | 4.83 | 4.73 | 4.47 | 3.27 | 2.53 | 1429.0 | 3.9 |
| BATON ROUGE LA | LATITUDE: 30 DEGREES 32 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.92 | 3.74 | 4.64 | 5.38 | 5.77 | 5.86 | 5.38 | 5.37 | 4.93 | 4.71 | 3.48 | 2.83 | 1675.1 | 4.6 |
| LATITUDE : | 3.22 | 3.96 | 4.70 | 5.19 | 5.36 | 5.37 | 5.01 | 5.18 | 5.00 | 5.06 | 3.88 | 3.19 | 1677.2 | 4.6 |
| LATITUDE +15: | 3.35 | 3.98 | 4.53 | 4.76 | 4.74 | 4.67 | 4.43 | 4.75 | 4.81 | 5.13 | 4.07 | 3.39 | 1600.1 | 4.4 |
| LAKE CHARLES LA | LATITUDE: 30 DEGREES 7 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.67 | 3.56 | 4.39 | 5.01 | 5.71 | 5.99 | 5.51 | 5.29 | 4.99 | 5.01 | 3.45 | 2.67 | 1651.9 | 4.5 |
| LATITUDE : | 2.91 | 3.75 | 4.44 | 4.83 | 5.31 | 5.48 | 5.12 | 5.11 | 5.06 | 5.39 | 3.84 | 3.00 | 1650.6 | 4.5 |
| LATITUDE +15: | 3.01 | 3.76 | 4.27 | 4.43 | 4.69 | 4.75 | 4.53 | 4.68 | 4.87 | 5.47 | 4.02 | 3.16 | 1571.8 | 4.3 |
| NEW ORLEANS LA | LATITUDE: 29 DEGREES 59 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.09 | 3.93 | 4.74 | 5.70 | 6.08 | 6.11 | 5.60 | 5.49 | 5.09 | 4.81 | 3.66 | 2.98 | 1743.3 | 4.8 |
| LATITUDE : | 3.41 | 4.17 | 4.81 | 5.50 | 5.65 | 5.59 | 5.21 | 5.30 | 5.17 | 5.17 | 4.09 | 3.37 | 1747.9 | 4.8 |
| LATITUDE +15: | 3.56 | 4.20 | 4.63 | 5.05 | 4.98 | 4.85 | 4.61 | 4.86 | 4.99 | 5.25 | 4.30 | 3.58 | 1669.2 | 4.6 |
| SHREVEPORT LA | LATITUDE: 32 DEGREES 28 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.93 | 3.77 | 4.56 | 5.18 | 5.82 | 6.27 | 6.20 | 6.05 | 5.33 | 4.85 | 3.67 | 2.94 | 1753.2 | 4.8 |
| LATITUDE : | 3.23 | 3.99 | 4.62 | 4.99 | 5.40 | 5.72 | 5.74 | 5.84 | 5.42 | 5.22 | 4.11 | 3.33 | 1753.8 | 4.8 |
| LATITUDE +15: | 3.37 | 4.01 | 4.44 | 4.57 | 4.76 | 4.95 | 5.05 | 5.34 | 5.22 | 5.30 | 4.32 | 3.54 | 1670.6 | 4.6 |
| BOSTON MA | LATITUDE: 42 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.17 | 2.86 | 3.69 | 4.37 | 5.02 | 5.50 | 5.43 | 4.93 | 4.67 | 3.74 | 2.34 | 1.97 | 1421.2 | 3.9 |
| LATITUDE : | 2.38 | 3.00 | 3.71 | 4.18 | 4.64 | 5.01 | 5.01 | 4.73 | 4.72 | 3.99 | 2.59 | 2.21 | 1405.3 | 3.9 |
| LATITUDE +15: | 2.47 | 2.99 | 3.54 | 3.81 | 4.08 | 4.34 | 4.40 | 4.31 | 4.53 | 4.02 | 2.70 | 2.33 | 1325.0 | 3.6 |
| BALTIMORE MD | LATITUDE: 39 DEGREES 11 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.55 | 3.28 | 4.13 | 4.87 | 5.29 | 5.69 | 5.63 | 5.25 | 4.79 | 4.01 | 2.94 | 2.29 | 1544.2 | 4.2 |
| LATITUDE : | 2.81 | 3.47 | 4.17 | 4.67 | 4.90 | 5.19 | 5.20 | 5.04 | 4.84 | 4.28 | 3.28 | 2.58 | 1534.8 | 4.2 |
| LATITUDE +15: | 2.93 | 3.47 | 3.99 | 4.26 | 4.31 | 4.50 | 4.57 | 4.60 | 4.65 | 4.32 | 3.44 | 2.73 | 1453.9 | 4.0 |
| PATUXENT RIVER MD | LATITUDE: 38 DEGREES 17 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.59 | 3.33 | 4.17 | 5.02 | 5.45 | 5.73 | 5.61 | 5.33 | 4.85 | 4.05 | 3.10 | 2.42 | 1572.7 | 4.3 |
| LATITUDE : | 2.86 | 3.52 | 4.21 | 4.82 | 5.04 | 5.23 | 5.19 | 5.12 | 4.91 | 4.32 | 3.47 | 2.74 | 1565.0 | 4.3 |
| LATITUDE +15: | 2.98 | 3.53 | 4.04 | 4.40 | 4.44 | 4.53 | 4.56 | 4.67 | 4.72 | 4.36 | 3.64 | 2.91 | 1484.2 | 4.1 |
| BANGOR ME | LATITUDE: 44 DEGREES 48 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.25 | 3.09 | 4.11 | 4.83 | 5.39 | 5.63 | 5.80 | 5.45 | 4.80 | 3.69 | 2.36 | 2.02 | 1504.8 | 4.1 |
| LATITUDE : | 2.49 | 3.27 | 4.15 | 4.62 | 4.97 | 5.12 | 5.34 | 5.22 | 4.86 | 3.95 | 2.63 | 2.29 | 1489.3 | 4.1 |
| LATITUDE +15: | 2.60 | 3.27 | 3.98 | 4.21 | 4.36 | 4.43 | 4.68 | 4.76 | 4.67 | 3.98 | 2.75 | 2.43 | 1404.1 | 3.8 |
| CARIBOU ME | LATITUDE: 46 DEGREES 52 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.21 | 3.24 | 4.40 | 4.78 | 4.93 | 5.33 | 5.51 | 5.10 | 4.26 | 3.07 | 1.85 | 1.74 | 1413.0 | 3.9 |
| LATITUDE : | 2.46 | 3.44 | 4.46 | 4.58 | 4.54 | 4.84 | 5.07 | 4.88 | 4.30 | 3.27 | 2.03 | 1.97 | 1394.9 | 3.8 |
| LATITUDE +15: | 2.57 | 3.46 | 4.28 | 4.16 | 3.99 | 4.19 | 4.44 | 4.44 | 4.12 | 3.28 | 2.11 | 2.08 | 1312.1 | 3.6 |
| PORTLAND ME | LATITUDE: 43 DEGREES 39 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.12 | 2.79 | 3.54 | 4.31 | 4.86 | 5.18 | 5.15 | 4.87 | 4.32 | 3.51 | 2.18 | 1.81 | 1359.8 | 3.7 |
| LATITUDE : | 2.33 | 2.93 | 3.56 | 4.13 | 4.49 | 4.72 | 4.75 | 4.67 | 4.36 | 3.74 | 2.41 | 2.03 | 1343.3 | 3.7 |
| LATITUDE +15: | 2.43 | 2.93 | 3.40 | 3.76 | 3.95 | 4.10 | 4.17 | 4.25 | 4.18 | 3.77 | 2.51 | 2.14 | 1265.6 | 3.5 |
| ALPENA MI | LATITUDE: 45 DEGREES 4 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 1.67 | 2.55 | 3.85 | 4.71 | 5.36 | 5.69 | 5.87 | 5.35 | 4.39 | 3.23 | 1.81 | 1.49 | 1400.8 | 3.8 |
| LATITUDE : | 1.82 | 2.66 | 3.88 | 4.50 | 4.94 | 5.16 | 5.40 | 5.12 | 4.43 | 3.42 | 1.98 | 1.70 | 1371.6 | 3.8 |
| LATITUDE +15: | 1.87 | 2.65 | 3.71 | 4.10 | 4.33 | 4.46 | 4.73 | 4.66 | 4.24 | 3.44 | 2.04 | 1.81 | 1280.1 | 3.5 |

| SITE ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DETROIT MI | LATITUDE: | | 42 DEGREES | | 25 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.83 | 2.71 | 3.61 | 4.63 | 5.32 | 5.66 | 5.70 | 5.24 | 4.65 | 3.69 | 2.19 | 1.58 | 1425.7 | 3.9 |
| LATITUDE : | 1.99 | 2.84 | 3.63 | 4.43 | 4.92 | 5.15 | 5.26 | 5.02 | 4.70 | 3.93 | 2.42 | 1.75 | 1401.6 | 3.8 |
| LATITUDE +15: | 2.05 | 2.83 | 3.47 | 4.04 | 4.32 | 4.46 | 4.61 | 4.58 | 4.51 | 3.96 | 2.51 | 1.83 | 1313.9 | 3.6 |
| FLINT MI | LATITUDE: | | 42 DEGREES | | 58 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.65 | 2.53 | 3.46 | 4.42 | 5.15 | 5.49 | 5.59 | 5.19 | 4.43 | 3.49 | 1.94 | 1.60 | 1369.4 | 3.8 |
| LATITUDE : | 1.79 | 2.64 | 3.47 | 4.24 | 4.76 | 5.00 | 5.16 | 4.98 | 4.48 | 3.72 | 2.13 | 1.82 | 1345.7 | 3.7 |
| LATITUDE +15: | 1.83 | 2.62 | 3.31 | 3.86 | 4.19 | 4.34 | 4.53 | 4.54 | 4.30 | 3.75 | 2.20 | 1.94 | 1261.1 | 3.5 |
| GRAND RAPIDS MI | LATITUDE: | | 42 DEGREES | | 53 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.78 | 2.57 | 3.69 | 4.68 | 5.46 | 5.93 | 5.95 | 5.62 | 4.71 | 3.63 | 2.03 | 1.60 | 1452.3 | 4.0 |
| LATITUDE : | 1.98 | 2.69 | 3.71 | 4.48 | 5.04 | 5.40 | 5.49 | 5.39 | 4.77 | 3.87 | 2.23 | 1.83 | 1428.6 | 3.9 |
| LATITUDE +15: | 2.08 | 2.68 | 3.55 | 4.09 | 4.43 | 4.67 | 4.81 | 4.92 | 4.58 | 3.90 | 2.32 | 1.95 | 1339.2 | 3.7 |
| HOUGHTON MI | LATITUDE: | | 47 DEGREES | | 10 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.23 | 1.96 | 3.54 | 4.61 | 5.18 | 5.56 | 5.76 | 5.19 | 3.88 | 3.01 | 1.58 | 1.05 | 1297.0 | 3.6 |
| LATITUDE : | 1.35 | 2.02 | 3.56 | 4.40 | 4.77 | 5.04 | 5.29 | 4.96 | 3.90 | 3.19 | 1.76 | 1.17 | 1262.7 | 3.5 |
| LATITUDE +15: | 1.40 | 1.98 | 3.40 | 4.00 | 4.18 | 4.36 | 4.62 | 4.51 | 3.73 | 3.20 | 1.84 | 1.23 | 1172.0 | 3.2 |
| SAULT STE. MARIE MI | LATITUDE: | | 46 DEGREES | | 28 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.52 | 2.56 | 3.93 | 4.66 | 5.26 | 5.49 | 5.74 | 5.16 | 4.00 | 2.96 | 1.58 | 1.48 | 1351.2 | 3.7 |
| LATITUDE : | 1.64 | 2.69 | 3.96 | 4.45 | 4.85 | 4.98 | 5.28 | 4.94 | 4.03 | 3.14 | 1.72 | 1.69 | 1321.4 | 3.6 |
| LATITUDE +15: | 1.69 | 2.68 | 3.79 | 4.05 | 4.25 | 4.31 | 4.62 | 4.49 | 3.86 | 3.15 | 1.76 | 1.80 | 1231.9 | 3.4 |
| TRAVERSE CITY MI | LATITUDE: | | 44 DEGREES | | 44 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.53 | 2.27 | 3.72 | 4.69 | 5.39 | 5.80 | 5.96 | 5.44 | 4.40 | 3.25 | 1.74 | 1.37 | 1388.7 | 3.8 |
| LATITUDE : | 1.70 | 2.36 | 3.74 | 4.49 | 4.97 | 5.27 | 5.49 | 5.21 | 4.45 | 3.46 | 1.90 | 1.55 | 1358.7 | 3.7 |
| LATITUDE +15: | 1.77 | 2.33 | 3.58 | 4.09 | 4.36 | 4.55 | 4.81 | 4.75 | 4.26 | 3.47 | 1.96 | 1.64 | 1267.1 | 3.5 |
| DULUTH MN | LATITUDE: | | 46 DEGREES | | 50 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.99 | 2.97 | 3.97 | 4.63 | 5.13 | 5.35 | 5.81 | 5.27 | 4.23 | 3.27 | 1.95 | 1.59 | 1405.7 | 3.9 |
| LATITUDE : | 2.20 | 3.14 | 4.00 | 4.43 | 4.73 | 4.86 | 5.34 | 5.05 | 4.27 | 3.49 | 2.15 | 1.79 | 1383.8 | 3.8 |
| LATITUDE +15: | 2.29 | 3.14 | 3.83 | 4.03 | 4.15 | 4.21 | 4.68 | 4.59 | 4.09 | 3.51 | 2.24 | 1.89 | 1298.1 | 3.6 |
| INTERNATIONAL FALLMN | LATITUDE: | | 48 DEGREES | | 34 MINUTES | | | | | | | | | |
| LATITUDE -15: | 1.93 | 3.05 | 4.13 | 4.94 | 5.38 | 5.62 | 6.04 | 5.60 | 4.45 | 3.32 | 1.86 | 1.63 | 1460.5 | 4.0 |
| LATITUDE : | 2.13 | 3.24 | 4.17 | 4.73 | 4.95 | 5.10 | 5.55 | 5.36 | 4.51 | 3.55 | 2.06 | 1.84 | 1436.4 | 3.9 |
| LATITUDE +15: | 2.22 | 3.25 | 3.99 | 4.29 | 4.33 | 4.40 | 4.85 | 4.88 | 4.32 | 3.57 | 2.14 | 1.95 | 1345.2 | 3.7 |
| MINNEAPOLIS-ST.PAUMN | LATITUDE: | | 44 DEGREES | | 53 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.31 | 3.29 | 4.16 | 4.84 | 5.41 | 5.84 | 6.16 | 5.73 | 4.81 | 3.81 | 2.43 | 1.85 | 1541.8 | 4.2 |
| LATITUDE : | 2.57 | 3.49 | 4.20 | 4.63 | 4.99 | 5.31 | 5.67 | 5.50 | 4.87 | 4.08 | 2.71 | 2.09 | 1525.4 | 4.2 |
| LATITUDE +15: | 2.69 | 3.50 | 4.03 | 4.22 | 4.38 | 4.59 | 4.96 | 5.01 | 4.68 | 4.12 | 2.83 | 2.21 | 1437.2 | 3.9 |
| ROCHESTER MN | LATITUDE: | | 43 DEGREES | | 55 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.31 | 3.16 | 4.02 | 4.70 | 5.28 | 5.76 | 5.95 | 5.60 | 4.72 | 3.77 | 2.42 | 1.88 | 1510.0 | 4.1 |
| LATITUDE : | 2.56 | 3.35 | 4.06 | 4.50 | 4.87 | 5.24 | 5.49 | 5.38 | 4.79 | 4.03 | 2.70 | 2.12 | 1494.0 | 4.1 |
| LATITUDE +15: | 2.67 | 3.36 | 3.89 | 4.10 | 4.28 | 4.54 | 4.81 | 4.90 | 4.60 | 4.07 | 2.82 | 2.24 | 1408.3 | 3.9 |
| COLUMBIA MO | LATITUDE: | | 38 DEGREES | | 49 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.64 | 3.41 | 4.19 | 4.99 | 5.82 | 6.33 | 6.55 | 6.21 | 5.24 | 4.47 | 3.13 | 2.38 | 1686.8 | 4.6 |
| LATITUDE : | 2.93 | 3.61 | 4.23 | 4.79 | 5.39 | 5.76 | 6.05 | 5.98 | 5.33 | 4.80 | 3.50 | 2.69 | 1676.9 | 4.6 |
| LATITUDE +15: | 3.05 | 3.62 | 4.06 | 4.38 | 4.74 | 4.98 | 5.30 | 5.46 | 5.13 | 4.87 | 3.68 | 2.86 | 1587.2 | 4.3 |
| KANSAS CITY MO | LATITUDE: | | 39 DEGREES | | 18 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.88 | 3.53 | 4.30 | 5.17 | 5.80 | 6.30 | 6.51 | 6.16 | 5.29 | 4.48 | 3.37 | 2.66 | 1718.9 | 4.7 |
| LATITUDE : | 3.21 | 3.74 | 4.34 | 4.96 | 5.36 | 5.72 | 6.00 | 5.93 | 5.37 | 4.81 | 3.78 | 3.02 | 1712.9 | 4.7 |
| LATITUDE +15: | 3.36 | 3.76 | 4.17 | 4.53 | 4.71 | 4.94 | 5.25 | 5.41 | 5.17 | 4.88 | 3.99 | 3.22 | 1624.9 | 4.5 |
| SPRINGFIELD MO | LATITUDE: | | 37 DEGREES | | 14 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.89 | 3.55 | 4.34 | 5.23 | 5.82 | 6.28 | 6.37 | 6.14 | 5.28 | 4.53 | 3.36 | 2.70 | 1720.5 | 4.7 |
| LATITUDE : | 3.21 | 3.76 | 4.38 | 5.02 | 5.38 | 5.72 | 5.88 | 5.91 | 5.36 | 4.87 | 3.76 | 3.06 | 1714.8 | 4.7 |
| LATITUDE +15: | 3.36 | 3.77 | 4.21 | 4.59 | 4.73 | 4.94 | 5.15 | 5.40 | 5.16 | 4.94 | 3.95 | 3.26 | 1627.2 | 4.5 |
| ST. LOUIS MO | LATITUDE: | | 38 DEGREES | | 45 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.72 | 3.46 | 4.28 | 5.12 | 5.79 | 6.34 | 6.34 | 5.99 | 5.28 | 4.45 | 3.20 | 2.42 | 1687.1 | 4.6 |
| LATITUDE : | 3.02 | 3.66 | 4.33 | 4.92 | 5.36 | 5.77 | 5.85 | 5.76 | 5.37 | 4.79 | 3.59 | 2.74 | 1679.1 | 4.6 |
| LATITUDE +15: | 3.16 | 3.68 | 4.15 | 4.50 | 4.71 | 4.99 | 5.13 | 5.26 | 5.17 | 4.85 | 3.77 | 2.91 | 1591.1 | 4.4 |
| JACKSON MS | LATITUDE: | | 32 DEGREES | | 19 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.88 | 3.71 | 4.66 | 5.49 | 5.98 | 6.14 | 5.88 | 5.73 | 5.16 | 4.72 | 3.54 | 2.83 | 1726.7 | 4.7 |
| LATITUDE : | 3.17 | 3.93 | 4.72 | 5.29 | 5.55 | 5.61 | 5.45 | 5.52 | 5.23 | 5.06 | 3.95 | 3.20 | 1725.1 | 4.7 |
| LATITUDE +15: | 3.30 | 3.94 | 4.54 | 4.84 | 4.89 | 4.86 | 4.80 | 5.05 | 5.04 | 5.14 | 4.14 | 3.39 | 1641.5 | 4.5 |
| MERIDIAN MS | LATITUDE: | | 32 DEGREES | | 20 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.84 | 3.66 | 4.51 | 5.33 | 5.73 | 5.96 | 5.62 | 5.60 | 4.96 | 4.66 | 3.51 | 2.79 | 1679.7 | 4.6 |
| LATITUDE : | 3.13 | 3.88 | 4.57 | 5.14 | 5.32 | 5.45 | 5.21 | 5.39 | 5.03 | 5.00 | 3.92 | 3.15 | 1679.2 | 4.6 |
| LATITUDE +15: | 3.25 | 3.89 | 4.39 | 4.71 | 4.69 | 4.73 | 4.60 | 4.94 | 4.84 | 5.07 | 4.11 | 3.34 | 1599.3 | 4.4 |

| SITE<br>ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BILLINGS MT | LATITUDE: | 45 DEGREES | 48 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.55 | 3.36 | 4.59 | 5.15 | 5.99 | 6.61 | 7.51 | 7.02 | 5.87 | 4.65 | 3.06 | 2.45 | 1792.7 | 4.9 |
| LATITUDE : | 2.85 | 3.57 | 4.65 | 4.93 | 5.52 | 5.99 | 6.90 | 6.76 | 5.99 | 5.02 | 3.48 | 2.81 | 1781.6 | 4.9 |
| LATITUDE +15: | 2.99 | 3.59 | 4.47 | 4.49 | 4.83 | 5.15 | 6.01 | 6.16 | 5.79 | 5.11 | 3.67 | 3.00 | 1683.0 | 4.6 |
| CUT BANK MT | LATITUDE: | 48 DEGREES | 36 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.28 | 3.20 | 4.50 | 5.10 | 5.93 | 6.22 | 7.25 | 6.68 | 5.57 | 4.36 | 2.89 | 2.17 | 1711.5 | 4.7 |
| LATITUDE : | 2.55 | 3.40 | 4.56 | 4.87 | 5.45 | 5.63 | 6.65 | 6.42 | 5.68 | 4.71 | 3.26 | 2.49 | 1696.8 | 4.6 |
| LATITUDE +15: | 2.67 | 3.42 | 4.38 | 4.43 | 4.77 | 4.84 | 5.79 | 5.85 | 5.47 | 4.78 | 3.44 | 2.66 | 1599.3 | 4.4 |
| DILLON MT | LATITUDE: | 45 DEGREES | 15 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.76 | 3.75 | 4.96 | 5.56 | 6.23 | 6.50 | 7.53 | 6.99 | 6.05 | 4.79 | 3.30 | 2.59 | 1858.4 | 5.1 |
| LATITUDE : | 3.09 | 4.00 | 5.04 | 5.32 | 5.73 | 5.89 | 6.91 | 6.72 | 6.18 | 5.19 | 3.73 | 2.97 | 1850.8 | 5.1 |
| LATITUDE +15: | 3.25 | 4.03 | 4.85 | 4.85 | 5.01 | 5.06 | 6.01 | 6.12 | 5.97 | 5.28 | 3.94 | 3.18 | 1751.6 | 4.8 |
| GLASGOW MT | LATITUDE: | 48 DEGREES | 13 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.13 | 3.08 | 4.37 | 5.09 | 5.73 | 6.22 | 6.93 | 6.53 | 5.48 | 4.34 | 2.82 | 2.12 | 1671.4 | 4.6 |
| LATITUDE : | 2.37 | 3.26 | 4.42 | 4.87 | 5.27 | 5.62 | 6.36 | 6.27 | 5.58 | 4.68 | 3.17 | 2.43 | 1654.7 | 4.5 |
| LATITUDE +15: | 2.48 | 3.27 | 4.24 | 4.42 | 4.61 | 4.84 | 5.54 | 5.71 | 5.38 | 4.75 | 3.34 | 2.59 | 1557.9 | 4.3 |
| GREAT FALLS MT | LATITUDE: | 47 DEGREES | 29 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.28 | 3.28 | 4.62 | 5.07 | 5.80 | 6.39 | 7.36 | 6.76 | 5.60 | 4.52 | 2.85 | 2.02 | 1723.5 | 4.7 |
| LATITUDE : | 2.55 | 3.48 | 4.68 | 4.85 | 5.33 | 5.79 | 6.76 | 6.50 | 5.71 | 4.88 | 3.21 | 2.31 | 1707.5 | 4.7 |
| LATITUDE +15: | 2.66 | 3.50 | 4.50 | 4.41 | 4.67 | 4.97 | 5.88 | 5.92 | 5.50 | 4.96 | 3.38 | 2.46 | 1608.4 | 4.4 |
| HELENA MT | LATITUDE: | 46 DEGREES | 36 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.18 | 3.13 | 4.44 | 5.04 | 5.82 | 6.20 | 7.36 | 6.70 | 5.67 | 4.41 | 2.90 | 2.13 | 1706.7 | 4.7 |
| LATITUDE : | 2.43 | 3.32 | 4.50 | 4.82 | 5.36 | 5.62 | 6.76 | 6.44 | 5.79 | 4.76 | 3.26 | 2.43 | 1690.7 | 4.6 |
| LATITUDE +15: | 2.53 | 3.33 | 4.32 | 4.39 | 4.69 | 4.84 | 5.88 | 5.87 | 5.58 | 4.83 | 3.44 | 2.59 | 1592.8 | 4.4 |
| LEWISTOWN MT | LATITUDE: | 47 DEGREES | 3 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.24 | 3.09 | 4.40 | 4.90 | 5.66 | 6.25 | 7.22 | 6.62 | 5.52 | 4.35 | 2.83 | 2.19 | 1684.1 | 4.6 |
| LATITUDE : | 2.49 | 3.27 | 4.45 | 4.68 | 5.20 | 5.66 | 6.62 | 6.35 | 5.62 | 4.69 | 3.18 | 2.50 | 1667.2 | 4.6 |
| LATITUDE +15: | 2.60 | 3.28 | 4.27 | 4.26 | 4.55 | 4.86 | 5.76 | 5.78 | 5.41 | 4.76 | 3.35 | 2.66 | 1569.7 | 4.3 |
| MILES CITY MT | LATITUDE: | 46 DEGREES | 26 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.43 | 3.32 | 4.61 | 5.23 | 5.94 | 6.52 | 7.22 | 6.88 | 5.80 | 4.59 | 3.10 | 2.38 | 1767.4 | 4.8 |
| LATITUDE : | 2.71 | 3.53 | 4.67 | 5.01 | 5.47 | 5.90 | 6.63 | 6.61 | 5.92 | 4.96 | 3.51 | 2.72 | 1755.3 | 4.8 |
| LATITUDE +15: | 2.84 | 3.54 | 4.48 | 4.56 | 4.78 | 5.07 | 5.77 | 6.02 | 5.71 | 5.04 | 3.70 | 2.91 | 1657.2 | 4.5 |
| MISSOULA MT | LATITUDE: | 46 DEGREES | 55 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.46 | 2.43 | 3.74 | 4.67 | 5.58 | 5.87 | 7.35 | 6.54 | 5.43 | 3.77 | 2.16 | 1.41 | 1537.4 | 4.2 |
| LATITUDE : | 1.58 | 2.55 | 3.77 | 4.47 | 5.14 | 5.33 | 6.76 | 6.28 | 5.54 | 4.04 | 2.40 | 1.57 | 1506.6 | 4.1 |
| LATITUDE +15: | 1.62 | 2.53 | 3.60 | 4.06 | 4.51 | 4.60 | 5.88 | 5.72 | 5.34 | 4.08 | 2.51 | 1.64 | 1405.2 | 3.8 |
| ASHEVILLE NC | LATITUDE: | 35 DEGREES | 26 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.93 | 3.65 | 4.54 | 5.41 | 5.57 | 5.63 | 5.47 | 5.27 | 4.73 | 4.40 | 3.56 | 2.82 | 1643.1 | 4.5 |
| LATITUDE : | 3.25 | 3.86 | 4.59 | 5.20 | 5.16 | 5.15 | 5.07 | 5.07 | 4.79 | 4.72 | 3.99 | 3.20 | 1645.1 | 4.5 |
| LATITUDE +15: | 3.40 | 3.88 | 4.42 | 4.76 | 4.55 | 4.48 | 4.47 | 4.64 | 4.60 | 4.78 | 4.21 | 3.41 | 1569.4 | 4.3 |
| CAPE HATTERAS NC | LATITUDE: | 35 DEGREES | 16 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.75 | 3.55 | 4.61 | 5.76 | 6.05 | 6.17 | 5.92 | 5.53 | 5.14 | 4.35 | 3.66 | 2.82 | 1714.8 | 4.7 |
| LATITUDE : | 3.04 | 3.76 | 4.66 | 5.55 | 5.60 | 5.62 | 5.48 | 5.32 | 5.22 | 4.66 | 4.11 | 3.20 | 1711.1 | 4.7 |
| LATITUDE +15: | 3.17 | 3.77 | 4.48 | 5.07 | 4.93 | 4.87 | 4.82 | 4.87 | 5.02 | 4.72 | 4.34 | 3.40 | 1625.9 | 4.5 |
| CHARLOTTE NC | LATITUDE: | 35 DEGREES | 13 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.91 | 3.64 | 4.57 | 5.50 | 5.72 | 5.83 | 5.64 | 5.50 | 4.93 | 4.51 | 3.62 | 2.88 | 1681.8 | 4.6 |
| LATITUDE : | 3.22 | 3.85 | 4.62 | 5.29 | 5.30 | 5.32 | 5.23 | 5.29 | 5.00 | 4.83 | 4.06 | 3.28 | 1682.8 | 4.6 |
| LATITUDE +15: | 3.36 | 3.87 | 4.44 | 4.84 | 4.67 | 4.62 | 4.60 | 4.84 | 4.81 | 4.90 | 4.28 | 3.49 | 1603.7 | 4.4 |
| CHERRY POINT NC | LATITUDE: | 34 DEGREES | 54 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.06 | 3.83 | 4.82 | 5.82 | 5.94 | 5.89 | 5.64 | 5.29 | 4.96 | 4.46 | 3.78 | 3.07 | 1721.2 | 4.7 |
| LATITUDE : | 3.40 | 4.07 | 4.88 | 5.61 | 5.50 | 5.38 | 5.23 | 5.09 | 5.03 | 4.79 | 4.26 | 3.51 | 1726.8 | 4.7 |
| LATITUDE +15: | 3.56 | 4.10 | 4.70 | 5.13 | 4.85 | 4.67 | 4.61 | 4.66 | 4.84 | 4.85 | 4.51 | 3.75 | 1649.7 | 4.5 |
| GREENSBORO NC | LATITUDE: | 36 DEGREES | 5 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.95 | 3.67 | 4.59 | 5.47 | 5.76 | 5.92 | 5.75 | 5.52 | 4.98 | 4.43 | 3.58 | 2.89 | 1689.5 | 4.6 |
| LATITUDE : | 3.28 | 3.89 | 4.64 | 5.26 | 5.33 | 5.40 | 5.32 | 5.30 | 5.05 | 4.75 | 4.02 | 3.28 | 1689.4 | 4.6 |
| LATITUDE +15: | 3.42 | 3.91 | 4.46 | 4.80 | 4.69 | 4.68 | 4.67 | 4.84 | 4.85 | 4.81 | 4.23 | 3.50 | 1608.9 | 4.4 |
| RALEIGH-DURHAM NC | LATITUDE: | 35 DEGREES | 52 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.83 | 3.55 | 4.44 | 5.34 | 5.58 | 5.66 | 5.47 | 5.22 | 4.81 | 4.25 | 3.40 | 2.74 | 1622.3 | 4.4 |
| LATITUDE : | 3.13 | 3.75 | 4.49 | 5.14 | 5.18 | 5.17 | 5.07 | 5.03 | 4.87 | 4.55 | 3.81 | 3.11 | 1622.5 | 4.4 |
| LATITUDE +15: | 3.27 | 3.77 | 4.32 | 4.70 | 4.57 | 4.50 | 4.48 | 4.60 | 4.69 | 4.60 | 4.01 | 3.31 | 1546.1 | 4.2 |
| BISMARCK ND | LATITUDE: | 46 DEGREES | 46 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.53 | 3.51 | 4.55 | 4.94 | 5.79 | 6.26 | 6.88 | 6.52 | 5.40 | 4.31 | 2.82 | 2.22 | 1697.8 | 4.7 |
| LATITUDE : | 2.83 | 3.75 | 4.61 | 4.73 | 5.33 | 5.67 | 6.32 | 6.26 | 5.51 | 4.65 | 3.18 | 2.54 | 1686.3 | 4.6 |
| LATITUDE +15: | 2.97 | 3.77 | 4.43 | 4.30 | 4.67 | 4.88 | 5.51 | 5.70 | 5.30 | 4.72 | 3.35 | 2.71 | 1592.8 | 4.4 |

| SITE ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FARGO ND | LATITUDE: | | 46 DEGREES | | 54 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.18 | 3.15 | 4.25 | 5.00 | 5.75 | 6.05 | 6.67 | 6.32 | 5.19 | 4.13 | 2.49 | 1.95 | 1618.6 | 4.4 |
| LATITUDE : | 2.42 | 3.34 | 4.30 | 4.79 | 5.29 | 5.49 | 6.13 | 6.07 | 5.28 | 4.44 | 2.79 | 2.22 | 1601.1 | 4.4 |
| LATITUDE +15: | 2.53 | 3.35 | 4.12 | 4.36 | 4.64 | 4.73 | 5.35 | 5.53 | 5.08 | 4.51 | 2.93 | 2.36 | 1507.0 | 4.1 |
| MINOT ND | LATITUDE: | | 48 DEGREES | | 16 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.11 | 2.99 | 4.10 | 4.99 | 5.80 | 6.00 | 6.62 | 6.29 | 5.18 | 4.18 | 2.52 | 1.92 | 1606.1 | 4.4 |
| LATITUDE : | 2.34 | 3.17 | 4.14 | 4.77 | 5.34 | 5.43 | 6.07 | 6.03 | 5.26 | 4.50 | 2.83 | 2.19 | 1586.7 | 4.3 |
| LATITUDE +15: | 2.45 | 3.18 | 3.97 | 4.33 | 4.66 | 4.68 | 5.29 | 5.49 | 5.06 | 4.56 | 2.97 | 2.33 | 1491.4 | 4.1 |
| GRAND ISLAND NE | LATITUDE: | | 40 DEGREES | | 58 MINUTES | | | | | | | | | |
| LATITUDE -15: | 3.10 | 3.75 | 4.62 | 5.62 | 6.13 | 6.80 | 6.89 | 6.50 | 5.63 | 4.86 | 3.58 | 2.86 | 1837.6 | 5.0 |
| LATITUDE : | 3.48 | 3.99 | 4.68 | 5.40 | 5.66 | 6.17 | 6.35 | 6.26 | 5.74 | 5.26 | 4.05 | 3.28 | 1836.5 | 5.0 |
| LATITUDE +15: | 3.66 | 4.02 | 4.50 | 4.93 | 4.97 | 5.31 | 5.55 | 5.71 | 5.54 | 5.35 | 4.29 | 3.52 | 1745.5 | 4.8 |
| NORTH OMAHA NE | LATITUDE: | | 41 DEGREES | | 22 MINUTES | | | | | | | | | |
| LATITUDE -15: | 3.00 | 3.66 | 4.48 | 5.16 | 5.81 | 6.43 | 6.55 | 6.22 | 5.08 | 4.46 | 3.06 | 2.56 | 1719.8 | 4.7 |
| LATITUDE : | 3.36 | 3.89 | 4.53 | 4.95 | 5.36 | 5.84 | 6.03 | 5.98 | 5.16 | 4.80 | 3.43 | 2.91 | 1712.3 | 4.7 |
| LATITUDE +15: | 3.53 | 3.91 | 4.35 | 4.51 | 4.71 | 5.03 | 5.27 | 5.45 | 4.96 | 4.87 | 3.61 | 3.11 | 1622.5 | 4.4 |
| NORTH PLATTE NE | LATITUDE: | | 41 DEGREES | | 8 MINUTES | | | | | | | | | |
| LATITUDE -15: | 3.31 | 3.95 | 4.91 | 5.73 | 6.17 | 6.87 | 7.09 | 6.67 | 5.88 | 5.09 | 3.74 | 3.13 | 1905.3 | 5.2 |
| LATITUDE : | 3.72 | 4.22 | 4.98 | 5.50 | 5.69 | 6.22 | 6.52 | 6.42 | 6.00 | 5.51 | 4.24 | 3.61 | 1907.1 | 5.2 |
| LATITUDE +15: | 3.92 | 4.25 | 4.79 | 5.01 | 4.98 | 5.35 | 5.68 | 5.85 | 5.79 | 5.62 | 4.49 | 3.87 | 1814.5 | 5.0 |
| SCOTTSBLUFF NE | LATITUDE: | | 41 DEGREES | | 52 MINUTES | | | | | | | | | |
| LATITUDE -15: | 3.29 | 3.98 | 4.85 | 5.55 | 6.02 | 6.78 | 7.12 | 6.75 | 6.08 | 5.01 | 3.61 | 3.02 | 1889.5 | 5.2 |
| LATITUDE : | 3.71 | 4.25 | 4.92 | 5.33 | 5.55 | 6.15 | 6.55 | 6.50 | 6.22 | 5.42 | 4.09 | 3.48 | 1892.9 | 5.2 |
| LATITUDE +15: | 3.91 | 4.29 | 4.74 | 4.87 | 4.87 | 5.29 | 5.72 | 5.93 | 6.01 | 5.53 | 4.33 | 3.73 | 1802.4 | 4.9 |
| CONCORD NH | LATITUDE: | | 43 DEGREES | | 12 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.14 | 2.78 | 3.54 | 4.35 | 4.90 | 5.16 | 5.19 | 4.83 | 4.22 | 3.45 | 2.17 | 1.77 | 1355.8 | 3.7 |
| LATITUDE : | 2.36 | 2.92 | 3.56 | 4.16 | 4.53 | 4.70 | 4.79 | 4.63 | 4.25 | 3.67 | 2.39 | 1.98 | 1337.6 | 3.7 |
| LATITUDE +15: | 2.45 | 2.91 | 3.40 | 3.79 | 3.98 | 4.08 | 4.20 | 4.21 | 4.07 | 3.69 | 2.49 | 2.08 | 1258.8 | 3.4 |
| LAKEHURST NJ | LATITUDE: | | 40 DEGREES | | 2 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.47 | 3.13 | 3.96 | 4.78 | 5.17 | 5.38 | 5.26 | 5.04 | 4.55 | 3.88 | 2.81 | 2.22 | 1480.9 | 4.1 |
| LATITUDE : | 2.73 | 3.30 | 3.99 | 4.58 | 4.78 | 4.90 | 4.86 | 4.83 | 4.60 | 4.13 | 3.13 | 2.50 | 1470.9 | 4.0 |
| LATITUDE +15: | 2.84 | 3.30 | 3.82 | 4.18 | 4.21 | 4.26 | 4.28 | 4.41 | 4.41 | 4.17 | 3.28 | 2.65 | 1392.8 | 3.8 |
| NEWARK NJ | LATITUDE: | | 40 DEGREES | | 42 MINUTES | | | | | | | | | |
| LATITUDE -15: | 2.47 | 3.15 | 3.98 | 4.76 | 5.23 | 5.44 | 5.46 | 5.16 | 4.63 | 3.90 | 2.72 | 2.14 | 1493.2 | 4.1 |
| LATITUDE : | 2.73 | 3.32 | 4.01 | 4.57 | 4.84 | 4.96 | 5.04 | 4.95 | 4.69 | 4.16 | 3.03 | 2.41 | 1483.1 | 4.1 |
| LATITUDE +15: | 2.85 | 3.33 | 3.85 | 4.17 | 4.26 | 4.31 | 4.43 | 4.52 | 4.50 | 4.20 | 3.18 | 2.55 | 1404.2 | 3.8 |
| ALBUQUERQUE NM | LATITUDE: | | 35 DEGREES | | 3 MINUTES | | | | | | | | | |
| LATITUDE -15: | 4.35 | 5.22 | 6.28 | 7.29 | 7.83 | 8.09 | 7.67 | 7.50 | 7.07 | 6.17 | 4.98 | 4.23 | 2334.2 | 6.4 |
| LATITUDE : | 4.94 | 5.62 | 6.43 | 7.03 | 7.21 | 7.30 | 7.06 | 7.24 | 7.26 | 6.73 | 5.70 | 4.92 | 2356.8 | 6.5 |
| LATITUDE +15: | 5.24 | 5.72 | 6.22 | 6.42 | 6.27 | 6.22 | 6.14 | 6.60 | 7.03 | 6.90 | 6.09 | 5.33 | 2257.0 | 6.2 |
| CLAYTON NM | LATITUDE: | | 36 DEGREES | | 27 MINUTES | | | | | | | | | |
| LATITUDE -15: | 4.24 | 4.88 | 5.92 | 6.69 | 6.86 | 7.31 | 7.05 | 6.89 | 6.51 | 5.80 | 4.62 | 4.04 | 2155.5 | 5.9 |
| LATITUDE : | 4.81 | 5.25 | 6.05 | 6.44 | 6.34 | 6.63 | 6.50 | 6.64 | 6.66 | 6.31 | 5.28 | 4.71 | 2179.6 | 6.0 |
| LATITUDE +15: | 5.11 | 5.33 | 5.84 | 5.88 | 5.55 | 5.69 | 5.68 | 6.06 | 6.45 | 6.46 | 5.63 | 5.10 | 2092.3 | 5.7 |
| FARMINGTON NM | LATITUDE: | | 36 DEGREES | | 45 MINUTES | | | | | | | | | |
| LATITUDE -15: | 4.19 | 5.09 | 6.10 | 7.02 | 7.59 | 8.06 | 7.66 | 7.44 | 7.05 | 6.04 | 4.76 | 3.94 | 2280.6 | 6.2 |
| LATITUDE : | 4.75 | 5.49 | 6.24 | 6.77 | 6.99 | 7.29 | 7.05 | 7.18 | 7.25 | 6.59 | 5.45 | 4.59 | 2301.7 | 6.3 |
| LATITUDE +15: | 5.05 | 5.59 | 6.03 | 6.18 | 6.10 | 6.22 | 6.14 | 6.55 | 7.03 | 6.76 | 5.83 | 4.96 | 2203.8 | 6.0 |
| ROSWELL NM | LATITUDE: | | 33 DEGREES | | 24 MINUTES | | | | | | | | | |
| LATITUDE -15: | 4.30 | 5.20 | 6.33 | 7.21 | 7.58 | 7.90 | 7.52 | 7.29 | 6.73 | 5.88 | 4.73 | 4.12 | 2276.3 | 6.2 |
| LATITUDE : | 4.87 | 5.61 | 6.48 | 6.96 | 6.99 | 7.14 | 6.93 | 7.03 | 6.89 | 6.40 | 5.40 | 4.78 | 2297.1 | 6.3 |
| LATITUDE +15: | 5.16 | 5.71 | 6.27 | 6.35 | 6.10 | 6.10 | 6.04 | 6.42 | 6.67 | 6.55 | 5.76 | 5.17 | 2199.6 | 6.0 |
| TRUTH OR CONSEQUENNM | LATITUDE: | | 33 DEGREES | | 14 MINUTES | | | | | | | | | |
| LATITUDE -15: | 4.64 | 5.53 | 6.62 | 7.60 | 7.89 | 8.01 | 7.28 | 7.20 | 6.82 | 6.10 | 5.13 | 4.37 | 2348.5 | 6.4 |
| LATITUDE : | 5.28 | 5.98 | 6.79 | 7.33 | 7.27 | 7.24 | 6.72 | 6.95 | 6.98 | 6.64 | 5.88 | 5.09 | 2377.3 | 6.5 |
| LATITUDE +15: | 5.61 | 6.09 | 6.58 | 6.69 | 6.32 | 6.18 | 5.86 | 6.34 | 6.76 | 6.81 | 6.29 | 5.52 | 2282.5 | 6.3 |
| TUCUMCARI NM | LATITUDE: | | 35 DEGREES | | 11 MINUTES | | | | | | | | | |
| LATITUDE -15: | 4.33 | 5.02 | 6.08 | 6.86 | 7.14 | 7.51 | 7.24 | 7.08 | 6.53 | 5.70 | 4.67 | 4.14 | 2201.1 | 6.0 |
| LATITUDE : | 4.91 | 5.41 | 6.21 | 6.61 | 6.59 | 6.80 | 6.67 | 6.83 | 6.68 | 6.20 | 5.34 | 4.82 | 2223.5 | 6.1 |
| LATITUDE +15: | 5.21 | 5.49 | 6.00 | 6.04 | 5.76 | 5.82 | 5.82 | 6.23 | 6.46 | 6.34 | 5.69 | 5.22 | 2132.1 | 5.8 |
| ZUNI NM | LATITUDE: | | 35 DEGREES | | 6 MINUTES | | | | | | | | | |
| LATITUDE -15: | 4.20 | 5.02 | 5.98 | 7.08 | 7.63 | 7.86 | 6.98 | 6.79 | 6.78 | 5.93 | 4.75 | 4.04 | 2223.0 | 6.1 |
| LATITUDE : | 4.76 | 5.40 | 6.11 | 6.83 | 7.03 | 7.11 | 6.44 | 6.54 | 6.94 | 6.46 | 5.43 | 4.69 | 2243.3 | 6.1 |
| LATITUDE +15: | 5.05 | 5.49 | 5.90 | 6.23 | 6.13 | 6.07 | 5.62 | 5.97 | 6.72 | 6.61 | 5.79 | 5.07 | 2148.6 | 5.9 |

| SITE / ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ELKO NV | LATITUDE: | 40 DEGREES | 50 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.25 | 4.31 | 5.44 | 6.34 | 7.17 | 7.67 | 8.18 | 7.84 | 7.28 | 5.80 | 4.01 | 3.16 | 2145.9 | 5.9 |
| LATITUDE : | 3.65 | 4.62 | 5.55 | 6.10 | 6.61 | 6.94 | 7.52 | 7.57 | 7.50 | 6.33 | 4.57 | 3.65 | 2149.4 | 5.9 |
| LATITUDE +15: | 3.85 | 4.67 | 5.35 | 5.57 | 5.77 | 5.94 | 6.53 | 6.90 | 7.28 | 6.49 | 4.86 | 3.92 | 2043.2 | 5.6 |
| ELY NV | LATITUDE: | 39 DEGREES | 17 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.84 | 4.69 | 5.93 | 6.68 | 7.17 | 7.61 | 7.60 | 7.46 | 7.31 | 6.04 | 4.48 | 3.63 | 2204.7 | 6.0 |
| LATITUDE : | 4.34 | 5.04 | 6.06 | 6.43 | 6.60 | 6.88 | 6.99 | 7.19 | 7.52 | 6.59 | 5.12 | 4.21 | 2220.7 | 6.1 |
| LATITUDE +15: | 4.60 | 5.11 | 5.85 | 5.87 | 5.76 | 5.89 | 6.08 | 6.56 | 7.29 | 6.75 | 5.46 | 4.54 | 2122.5 | 5.8 |
| LAS VEGAS NV | LATITUDE: | 36 DEGREES | 5 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 4.28 | 5.30 | 6.58 | 7.64 | 8.18 | 8.39 | 7.99 | 7.76 | 7.43 | 6.27 | 4.88 | 4.11 | 2398.8 | 6.6 |
| LATITUDE : | 4.86 | 5.72 | 6.74 | 7.37 | 7.52 | 7.56 | 7.35 | 7.49 | 7.64 | 6.85 | 5.59 | 4.79 | 2418.3 | 6.6 |
| LATITUDE +15: | 5.16 | 5.83 | 6.53 | 6.72 | 6.53 | 6.43 | 6.38 | 6.83 | 7.41 | 7.03 | 5.97 | 5.18 | 2311.4 | 6.3 |
| LOVELOCK NV | LATITUDE: | 40 DEGREES | 4 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.86 | 4.88 | 6.20 | 7.26 | 7.95 | 8.32 | 8.67 | 8.40 | 7.76 | 6.41 | 4.64 | 3.70 | 2376.4 | 6.5 |
| LATITUDE : | 4.37 | 5.26 | 6.34 | 6.99 | 7.31 | 7.49 | 7.95 | 8.10 | 7.99 | 7.02 | 5.31 | 4.29 | 2387.9 | 6.5 |
| LATITUDE +15: | 4.62 | 5.34 | 6.13 | 6.38 | 6.35 | 6.38 | 6.89 | 7.38 | 7.75 | 7.21 | 5.67 | 4.63 | 2274.7 | 6.2 |
| RENO NV | LATITUDE: | 39 DEGREES | 30 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.75 | 4.74 | 6.12 | 7.21 | 7.85 | 8.17 | 8.37 | 8.10 | 7.58 | 6.19 | 4.43 | 3.55 | 2316.2 | 6.3 |
| LATITUDE : | 4.24 | 5.10 | 6.26 | 6.95 | 7.22 | 7.37 | 7.68 | 7.82 | 7.80 | 6.78 | 5.06 | 4.12 | 2326.3 | 6.4 |
| LATITUDE +15: | 4.49 | 5.18 | 6.06 | 6.34 | 6.29 | 6.29 | 6.66 | 7.13 | 7.58 | 6.96 | 5.40 | 4.44 | 2215.6 | 6.1 |
| TONOPAH NV | LATITUDE: | 38 DEGREES | 4 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 4.23 | 5.20 | 6.54 | 7.47 | 7.99 | 8.41 | 8.38 | 8.14 | 7.63 | 6.45 | 4.90 | 4.10 | 2419.3 | 6.6 |
| LATITUDE : | 4.81 | 5.62 | 6.71 | 7.20 | 7.35 | 7.58 | 7.69 | 7.86 | 7.85 | 7.06 | 5.62 | 4.78 | 2439.2 | 6.7 |
| LATITUDE +15: | 5.10 | 5.71 | 6.49 | 6.57 | 6.39 | 6.44 | 6.67 | 7.16 | 7.62 | 7.26 | 6.01 | 5.18 | 2331.1 | 6.4 |
| WINNEMUCCA NV | LATITUDE: | 40 DEGREES | 54 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 3.26 | 4.27 | 5.48 | 6.59 | 7.37 | 7.79 | 8.36 | 7.97 | 7.35 | 5.81 | 4.01 | 3.18 | 2175.9 | 6.0 |
| LATITUDE : | 3.67 | 4.58 | 5.59 | 6.34 | 6.78 | 7.04 | 7.68 | 7.69 | 7.57 | 6.34 | 4.56 | 3.67 | 2178.2 | 6.0 |
| LATITUDE +15: | 3.87 | 4.63 | 5.40 | 5.79 | 5.92 | 6.02 | 6.67 | 7.02 | 7.35 | 6.50 | 4.85 | 3.95 | 2069.0 | 5.7 |
| YUCCA FLATS NV | LATITUDE: | 36 DEGREES | 57 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 4.25 | 5.07 | 6.39 | 7.42 | 7.98 | 8.27 | 8.21 | 7.90 | 7.44 | 6.25 | 4.75 | 4.07 | 2375.0 | 6.5 |
| LATITUDE : | 4.84 | 5.47 | 6.55 | 7.17 | 7.35 | 7.47 | 7.55 | 7.63 | 7.66 | 6.84 | 5.45 | 4.75 | 2396.5 | 6.6 |
| LATITUDE +15: | 5.14 | 5.57 | 6.35 | 6.54 | 6.40 | 6.37 | 6.56 | 6.96 | 7.45 | 7.03 | 5.83 | 5.14 | 2292.6 | 6.3 |
| ALBANY NY | LATITUDE: | 42 DEGREES | 45 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.08 | 2.77 | 3.57 | 4.40 | 4.86 | 5.24 | 5.35 | 4.98 | 4.32 | 3.41 | 2.09 | 1.68 | 1363.8 | 3.7 |
| LATITUDE : | 2.28 | 2.91 | 3.59 | 4.22 | 4.50 | 4.78 | 4.94 | 4.78 | 4.36 | 3.63 | 2.30 | 1.88 | 1344.6 | 3.7 |
| LATITUDE +15: | 2.37 | 2.90 | 3.43 | 3.84 | 3.96 | 4.15 | 4.34 | 4.35 | 4.18 | 3.65 | 2.39 | 1.97 | 1264.5 | 3.5 |
| BINGHAMTON NY | LATITUDE: | 42 DEGREES | 13 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.84 | 2.20 | 3.05 | 4.07 | 4.63 | 5.09 | 5.14 | 4.71 | 4.13 | 3.20 | 1.80 | 1.48 | 1259.3 | 3.5 |
| LATITUDE : | 2.05 | 2.27 | 3.04 | 3.89 | 4.28 | 4.64 | 4.74 | 4.51 | 4.16 | 3.39 | 1.96 | 1.67 | 1236.8 | 3.4 |
| LATITUDE +15: | 2.15 | 2.23 | 2.89 | 3.55 | 3.77 | 4.03 | 4.17 | 4.11 | 3.98 | 3.40 | 2.01 | 1.77 | 1159.4 | 3.2 |
| BUFFALO NY | LATITUDE: | 42 DEGREES | 56 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.65 | 2.27 | 3.18 | 4.34 | 4.96 | 5.47 | 5.52 | 5.04 | 4.25 | 3.26 | 1.78 | 1.43 | 1315.2 | 3.6 |
| LATITUDE : | 1.83 | 2.41 | 3.18 | 4.15 | 4.58 | 4.98 | 5.10 | 4.83 | 4.29 | 3.47 | 1.94 | 1.61 | 1291.3 | 3.5 |
| LATITUDE +15: | 1.92 | 2.42 | 3.03 | 3.78 | 4.03 | 4.32 | 4.48 | 4.40 | 4.12 | 3.48 | 2.00 | 1.71 | 1209.3 | 3.3 |
| CENTRAL PARK NY | LATITUDE: | 40 DEGREES | 47 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.19 | 2.82 | 3.70 | 4.48 | 5.07 | 5.18 | 5.22 | 4.89 | 4.40 | 3.65 | 2.38 | 1.84 | 1395.3 | 3.8 |
| LATITUDE : | 2.40 | 2.96 | 3.72 | 4.29 | 4.69 | 4.73 | 4.83 | 4.69 | 4.44 | 3.88 | 2.63 | 2.05 | 1380.0 | 3.8 |
| LATITUDE +15: | 2.49 | 2.95 | 3.56 | 3.92 | 4.14 | 4.12 | 4.25 | 4.28 | 4.26 | 3.91 | 2.74 | 2.16 | 1302.0 | 3.6 |
| LA GUARDIA NY | LATITUDE: | 40 DEGREES | 46 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 2.45 | 3.16 | 4.02 | 4.79 | 5.24 | 5.47 | 5.52 | 5.23 | 4.66 | 3.90 | 2.71 | 2.16 | 1501.8 | 4.1 |
| LATITUDE : | 2.71 | 3.34 | 4.05 | 4.60 | 4.85 | 4.98 | 5.10 | 5.02 | 4.72 | 4.17 | 3.02 | 2.44 | 1491.7 | 4.1 |
| LATITUDE +15: | 2.82 | 3.34 | 3.89 | 4.20 | 4.27 | 4.33 | 4.49 | 4.58 | 4.53 | 4.21 | 3.16 | 2.59 | 1412.3 | 3.9 |
| MASSENA NY | LATITUDE: | 44 DEGREES | 56 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.84 | 2.56 | 3.63 | 4.48 | 5.03 | 5.39 | 5.45 | 4.99 | 4.23 | 3.17 | 1.83 | 1.43 | 1341.4 | 3.7 |
| LATITUDE : | 2.02 | 2.68 | 3.65 | 4.29 | 4.64 | 4.90 | 5.02 | 4.78 | 4.28 | 3.37 | 2.00 | 1.58 | 1316.2 | 3.6 |
| LATITUDE +15: | 2.09 | 2.67 | 3.49 | 3.91 | 4.08 | 4.25 | 4.41 | 4.35 | 4.10 | 3.39 | 2.07 | 1.66 | 1231.7 | 3.4 |
| ROCHESTER NY | LATITUDE: | 43 DEGREES | 7 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.77 | 2.16 | 3.25 | 4.43 | 4.98 | 5.50 | 5.53 | 5.06 | 4.29 | 3.27 | 1.80 | 1.43 | 1325.1 | 3.6 |
| LATITUDE : | 1.97 | 2.23 | 3.25 | 4.24 | 4.60 | 5.00 | 5.09 | 4.85 | 4.33 | 3.47 | 1.96 | 1.61 | 1298.4 | 3.6 |
| LATITUDE +15: | 2.06 | 2.19 | 3.09 | 3.86 | 4.05 | 4.33 | 4.47 | 4.42 | 4.15 | 3.48 | 2.02 | 1.71 | 1213.6 | 3.3 |
| SYRACUSE NY | LATITUDE: | 43 DEGREES | 7 MINUTES | | | | | | | | | | | |
| LATITUDE -15: | 1.68 | 2.21 | 3.19 | 4.38 | 4.89 | 5.38 | 5.46 | 5.01 | 4.32 | 3.26 | 1.77 | 1.45 | 1310.7 | 3.6 |
| LATITUDE : | 1.82 | 2.29 | 3.19 | 4.18 | 4.52 | 4.90 | 5.03 | 4.80 | 4.36 | 3.45 | 1.93 | 1.64 | 1283.0 | 3.5 |
| LATITUDE +15: | 1.86 | 2.25 | 3.03 | 3.81 | 3.97 | 4.24 | 4.42 | 4.37 | 4.18 | 3.46 | 1.98 | 1.74 | 1198.3 | 3.3 |

| SITE<br>ARRAY TILT | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AKRON-CANTON | OH | LATITUDE: 40 DEGREES 55 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.79 | 2.49 | 3.41 | 4.45 | 5.17 | 5.58 | 5.54 | 5.28 | 4.64 | 3.71 | 2.23 | 1.54 | 1396.3 | 3.8 |
| LATITUDE : | | 1.94 | 2.59 | 3.42 | 4.27 | 4.79 | 5.09 | 5.12 | 5.07 | 4.69 | 3.96 | 2.45 | 1.69 | 1372.9 | 3.8 |
| LATITUDE +15: | | 1.99 | 2.57 | 3.27 | 3.90 | 4.22 | 4.42 | 4.50 | 4.63 | 4.50 | 3.99 | 2.55 | 1.76 | 1287.7 | 3.5 |
| CINCINNATI | OH | LATITUDE: 39 DEGREES 4 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.08 | 2.82 | 3.60 | 4.56 | 5.17 | 5.57 | 5.47 | 5.37 | 4.70 | 3.97 | 2.55 | 1.90 | 1454.5 | 4.0 |
| LATITUDE : | | 2.26 | 2.95 | 3.62 | 4.37 | 4.78 | 5.08 | 5.06 | 5.15 | 4.76 | 4.23 | 2.82 | 2.11 | 1436.8 | 3.9 |
| LATITUDE +15: | | 2.33 | 2.93 | 3.46 | 3.99 | 4.21 | 4.40 | 4.45 | 4.70 | 4.56 | 4.27 | 2.94 | 2.21 | 1353.6 | 3.7 |
| CLEVELAND | OH | LATITUDE: 41 DEGREES 24 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.80 | 2.29 | 3.26 | 4.43 | 5.21 | 5.59 | 5.67 | 5.24 | 4.54 | 3.56 | 2.05 | 1.55 | 1377.5 | 3.8 |
| LATITUDE : | | 2.00 | 2.37 | 3.26 | 4.24 | 4.82 | 5.09 | 5.23 | 5.03 | 4.58 | 3.79 | 2.25 | 1.76 | 1353.7 | 3.7 |
| LATITUDE +15: | | 2.10 | 2.33 | 3.11 | 3.87 | 4.24 | 4.41 | 4.59 | 4.58 | 4.40 | 3.82 | 2.32 | 1.87 | 1268.8 | 3.5 |
| COLUMBUS | OH | LATITUDE: 40 DEGREES 0 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.91 | 2.58 | 3.45 | 4.42 | 5.09 | 5.49 | 5.43 | 5.41 | 4.63 | 3.83 | 2.35 | 1.70 | 1410.4 | 3.9 |
| LATITUDE : | | 2.07 | 2.68 | 3.46 | 4.23 | 4.71 | 5.00 | 5.01 | 5.19 | 4.68 | 4.08 | 2.59 | 1.87 | 1388.7 | 3.8 |
| LATITUDE +15: | | 2.13 | 2.66 | 3.30 | 3.86 | 4.15 | 4.34 | 4.41 | 4.73 | 4.49 | 4.12 | 2.69 | 1.95 | 1304.3 | 3.6 |
| DAYTON | OH | LATITUDE: 39 DEGREES 54 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.07 | 2.79 | 3.62 | 4.60 | 5.26 | 5.68 | 5.60 | 5.43 | 4.77 | 3.93 | 2.48 | 1.80 | 1462.8 | 4.0 |
| LATITUDE : | | 2.26 | 2.93 | 3.64 | 4.41 | 4.87 | 5.18 | 5.18 | 5.21 | 4.83 | 4.19 | 2.75 | 2.00 | 1444.8 | 4.0 |
| LATITUDE +15: | | 2.33 | 2.92 | 3.48 | 4.03 | 4.30 | 4.49 | 4.56 | 4.76 | 4.64 | 4.23 | 2.86 | 2.10 | 1360.8 | 3.7 |
| TOLEDO | OH | LATITUDE: 41 DEGREES 36 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.87 | 2.67 | 3.57 | 4.55 | 5.33 | 5.69 | 5.74 | 5.36 | 4.69 | 3.79 | 2.25 | 1.60 | 1434.9 | 3.9 |
| LATITUDE : | | 2.04 | 2.79 | 3.59 | 4.36 | 4.92 | 5.18 | 5.29 | 5.15 | 4.74 | 4.04 | 2.48 | 1.77 | 1411.6 | 3.9 |
| LATITUDE +15: | | 2.10 | 2.77 | 3.43 | 3.98 | 4.33 | 4.49 | 4.65 | 4.69 | 4.55 | 4.07 | 2.58 | 1.85 | 1324.2 | 3.6 |
| YOUNGSTOWN | OH | LATITUDE: 41 DEGREES 16 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.77 | 2.21 | 3.13 | 4.18 | 4.91 | 5.33 | 5.37 | 4.97 | 4.35 | 3.48 | 1.99 | 1.53 | 1317.5 | 3.6 |
| LATITUDE : | | 1.97 | 2.28 | 3.13 | 4.00 | 4.54 | 4.86 | 4.96 | 4.76 | 4.39 | 3.70 | 2.17 | 1.73 | 1294.8 | 3.5 |
| LATITUDE +15: | | 2.06 | 2.25 | 2.98 | 3.65 | 4.00 | 4.21 | 4.36 | 4.34 | 4.20 | 3.72 | 2.24 | 1.84 | 1214.2 | 3.3 |
| OKLAHOMA CITY | OK | LATITUDE: 35 DEGREES 24 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.30 | 3.99 | 4.89 | 5.60 | 5.91 | 6.49 | 6.57 | 6.37 | 5.47 | 4.78 | 3.82 | 3.16 | 1837.9 | 5.0 |
| LATITUDE : | | 3.69 | 4.25 | 4.96 | 5.39 | 5.47 | 5.91 | 6.07 | 6.13 | 5.57 | 5.15 | 4.31 | 3.61 | 1841.6 | 5.0 |
| LATITUDE +15: | | 3.87 | 4.28 | 4.78 | 4.93 | 4.82 | 5.10 | 5.31 | 5.60 | 5.37 | 5.23 | 4.55 | 3.86 | 1755.8 | 4.8 |
| TULSA | OK | LATITUDE: 36 DEGREES 12 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.04 | 3.71 | 4.57 | 5.20 | 5.62 | 6.12 | 6.26 | 6.10 | 5.20 | 4.54 | 3.52 | 2.90 | 1729.3 | 4.7 |
| LATITUDE : | | 3.38 | 3.94 | 4.62 | 5.00 | 5.21 | 5.58 | 5.78 | 5.87 | 5.28 | 4.87 | 3.95 | 3.30 | 1728.5 | 4.7 |
| LATITUDE +15: | | 3.54 | 3.96 | 4.44 | 4.57 | 4.59 | 4.83 | 5.07 | 5.36 | 5.08 | 4.94 | 4.16 | 3.52 | 1645.0 | 4.5 |
| ASTORIA | OR | LATITUDE: 46 DEGREES 9 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.66 | 2.23 | 3.20 | 4.19 | 5.00 | 4.91 | 5.45 | 5.07 | 4.57 | 3.16 | 1.93 | 1.29 | 1300.5 | 3.6 |
| LATITUDE : | | 1.85 | 2.32 | 3.20 | 3.99 | 4.61 | 4.47 | 5.01 | 4.85 | 4.63 | 3.35 | 2.13 | 1.42 | 1274.8 | 3.5 |
| LATITUDE +15: | | 1.94 | 2.29 | 3.05 | 3.63 | 4.04 | 3.87 | 4.39 | 4.41 | 4.43 | 3.37 | 2.21 | 1.48 | 1191.7 | 3.3 |
| BURNS | OR | LATITUDE: 43 DEGREES 35 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.35 | 3.34 | 4.44 | 5.53 | 6.41 | 6.92 | 7.70 | 7.13 | 6.33 | 4.67 | 3.00 | 2.26 | 1831.1 | 5.0 |
| LATITUDE : | | 2.61 | 3.54 | 4.49 | 5.31 | 5.91 | 6.27 | 7.08 | 6.86 | 6.48 | 5.04 | 3.38 | 2.57 | 1813.6 | 5.0 |
| LATITUDE +15: | | 2.72 | 3.55 | 4.31 | 4.84 | 5.17 | 5.38 | 6.16 | 6.25 | 6.27 | 5.13 | 3.55 | 2.73 | 1707.5 | 4.7 |
| MEDFORD | OR | LATITUDE: 42 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.76 | 2.99 | 4.16 | 5.47 | 6.33 | 6.90 | 7.73 | 7.20 | 6.08 | 4.22 | 2.35 | 1.54 | 1728.7 | 4.7 |
| LATITUDE : | | 1.91 | 3.15 | 4.19 | 5.25 | 5.83 | 6.25 | 7.10 | 6.93 | 6.22 | 4.53 | 2.60 | 1.70 | 1695.6 | 4.6 |
| LATITUDE +15: | | 1.96 | 3.15 | 4.02 | 4.78 | 5.11 | 5.37 | 6.18 | 6.32 | 6.00 | 4.58 | 2.71 | 1.77 | 1581.9 | 4.3 |
| NORTH BEND | OR | LATITUDE: 43 DEGREES 25 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.03 | 2.89 | 3.90 | 5.03 | 5.79 | 6.04 | 6.57 | 6.03 | 5.24 | 3.85 | 2.57 | 1.91 | 1579.9 | 4.3 |
| LATITUDE : | | 2.23 | 3.04 | 3.92 | 4.82 | 5.33 | 5.49 | 6.05 | 5.80 | 5.33 | 4.12 | 2.86 | 2.15 | 1557.5 | 4.3 |
| LATITUDE +15: | | 2.31 | 3.04 | 3.75 | 4.39 | 4.68 | 4.74 | 5.28 | 5.28 | 5.12 | 4.16 | 3.00 | 2.27 | 1462.2 | 4.0 |
| PENDLETON | OR | LATITUDE: 45 DEGREES 41 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.62 | 2.57 | 3.95 | 5.07 | 6.02 | 6.52 | 7.54 | 6.91 | 6.00 | 4.18 | 2.23 | 1.49 | 1649.4 | 4.5 |
| LATITUDE : | | 1.76 | 2.69 | 3.98 | 4.85 | 5.55 | 5.91 | 6.93 | 6.64 | 6.14 | 4.50 | 2.48 | 1.66 | 1618.1 | 4.4 |
| LATITUDE +15: | | 1.81 | 2.68 | 3.81 | 4.41 | 4.86 | 5.08 | 6.03 | 6.05 | 5.93 | 4.56 | 2.59 | 1.74 | 1510.0 | 4.1 |
| PORTLAND | OR | LATITUDE: 45 DEGREES 36 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 1.59 | 2.25 | 3.31 | 4.37 | 5.18 | 5.37 | 6.38 | 5.70 | 4.68 | 3.16 | 1.88 | 1.46 | 1382.1 | 3.8 |
| LATITUDE : | | 1.76 | 2.34 | 3.31 | 4.18 | 4.77 | 4.89 | 5.87 | 5.46 | 4.74 | 3.35 | 2.07 | 1.66 | 1353.9 | 3.7 |
| LATITUDE +15: | | 1.84 | 2.31 | 3.16 | 3.80 | 4.19 | 4.23 | 5.13 | 4.97 | 4.55 | 3.37 | 2.15 | 1.77 | 1264.0 | 3.5 |
| REDMOND | OR | LATITUDE: 44 DEGREES 16 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.43 | 3.31 | 4.50 | 5.68 | 6.50 | 6.94 | 7.68 | 7.11 | 6.25 | 4.52 | 2.95 | 2.30 | 1833.4 | 5.0 |
| LATITUDE : | | 2.70 | 3.50 | 4.55 | 5.45 | 5.98 | 6.28 | 7.05 | 6.84 | 6.39 | 4.88 | 3.31 | 2.62 | 1814.4 | 5.0 |
| LATITUDE +15: | | 2.82 | 3.52 | 4.36 | 4.96 | 5.23 | 5.39 | 6.13 | 6.23 | 6.17 | 4.95 | 3.49 | 2.78 | 1706.8 | 4.7 |

| SITE / ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SALEM OR — LATITUDE: 44 DEGREES 55 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 1.68 | 2.39 | 3.50 | 4.58 | 5.42 | 5.61 | 6.72 | 6.04 | 5.14 | 3.34 | 1.98 | 1.53 | 1461.0 | 4.0 |
| LATITUDE : | 1.88 | 2.49 | 3.51 | 4.38 | 5.00 | 5.10 | 6.18 | 5.81 | 5.22 | 3.55 | 2.18 | 1.74 | 1434.1 | 3.9 |
| LATITUDE +15: | 1.97 | 2.47 | 3.36 | 3.99 | 4.39 | 4.41 | 5.40 | 5.29 | 5.03 | 3.58 | 2.26 | 1.86 | 1340.9 | 3.7 |
| ALLENTOWN PA — LATITUDE: 40 DEGREES 39 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 2.33 | 3.01 | 3.86 | 4.63 | 5.07 | 5.38 | 5.47 | 5.10 | 4.49 | 3.79 | 2.57 | 2.00 | 1452.4 | 4.0 |
| LATITUDE : | 2.57 | 3.17 | 3.89 | 4.44 | 4.69 | 4.91 | 5.05 | 4.89 | 4.54 | 4.04 | 2.85 | 2.24 | 1439.4 | 3.9 |
| LATITUDE +15: | 2.67 | 3.17 | 3.72 | 4.05 | 4.14 | 4.27 | 4.44 | 4.46 | 4.36 | 4.07 | 2.98 | 2.36 | 1360.1 | 3.7 |
| ERIE PA — LATITUDE: 42 DEGREES 5 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 1.59 | 2.20 | 3.28 | 4.48 | 5.10 | 5.58 | 5.69 | 4.82 | 4.41 | 3.43 | 1.81 | 1.34 | 1332.2 | 3.6 |
| LATITUDE : | 1.75 | 2.27 | 3.28 | 4.28 | 4.71 | 5.08 | 5.24 | 4.61 | 4.45 | 3.64 | 1.96 | 1.50 | 1303.8 | 3.6 |
| LATITUDE +15: | 1.82 | 2.24 | 3.12 | 3.90 | 4.14 | 4.40 | 4.60 | 4.20 | 4.26 | 3.66 | 2.02 | 1.59 | 1217.3 | 3.3 |
| HARRISBURG PA — LATITUDE: 40 DEGREES 13 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 2.34 | 3.02 | 3.86 | 4.62 | 5.11 | 5.47 | 5.45 | 5.10 | 4.59 | 3.80 | 2.60 | 2.07 | 1462.7 | 4.0 |
| LATITUDE : | 2.58 | 3.18 | 3.89 | 4.43 | 4.73 | 4.99 | 5.04 | 4.89 | 4.63 | 4.05 | 2.88 | 2.32 | 1449.2 | 4.0 |
| LATITUDE +15: | 2.68 | 3.18 | 3.72 | 4.04 | 4.17 | 4.33 | 4.43 | 4.46 | 4.44 | 4.08 | 3.01 | 2.45 | 1369.0 | 3.8 |
| PHILADELPHIA PA — LATITUDE: 39 DEGREES 53 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 2.42 | 3.11 | 3.95 | 4.69 | 5.14 | 5.49 | 5.45 | 5.18 | 4.62 | 3.87 | 2.78 | 2.17 | 1488.2 | 4.1 |
| LATITUDE : | 2.67 | 3.28 | 3.98 | 4.50 | 4.76 | 5.01 | 5.04 | 4.98 | 4.67 | 4.13 | 3.10 | 2.44 | 1478.5 | 4.1 |
| LATITUDE +15: | 2.78 | 3.28 | 3.82 | 4.11 | 4.20 | 4.35 | 4.43 | 4.54 | 4.49 | 4.17 | 3.24 | 2.59 | 1400.4 | 3.8 |
| PITTSBURGH PA — LATITUDE: 40 DEGREES 30 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 1.75 | 2.36 | 3.32 | 4.30 | 4.96 | 5.34 | 5.23 | 4.97 | 4.36 | 3.63 | 2.20 | 1.68 | 1343.8 | 3.7 |
| LATITUDE : | 1.88 | 2.45 | 3.33 | 4.12 | 4.59 | 4.87 | 4.83 | 4.77 | 4.41 | 3.87 | 2.42 | 1.91 | 1323.1 | 3.6 |
| LATITUDE +15: | 1.92 | 2.42 | 3.17 | 3.76 | 4.05 | 4.23 | 4.25 | 4.35 | 4.22 | 3.89 | 2.51 | 2.03 | 1243.0 | 3.4 |
| WILKES-BARRE-SCRANPA — LATITUDE: 41 DEGREES 20 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 1.98 | 2.69 | 3.54 | 4.39 | 4.92 | 5.33 | 5.41 | 5.00 | 4.37 | 3.70 | 2.18 | 1.67 | 1376.0 | 3.8 |
| LATITUDE : | 2.16 | 2.82 | 3.55 | 4.20 | 4.55 | 4.86 | 4.99 | 4.79 | 4.41 | 3.94 | 2.40 | 1.84 | 1355.7 | 3.7 |
| LATITUDE +15: | 2.22 | 2.80 | 3.39 | 3.83 | 4.01 | 4.22 | 4.39 | 4.37 | 4.22 | 3.97 | 2.49 | 1.93 | 1274.1 | 3.5 |
| KOROR ISLAND PN — LATITUDE: 7 DEGREES 20 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 4.14 | 4.72 | 5.04 | 5.36 | 5.05 | 4.72 | 4.65 | 4.70 | 4.73 | 4.56 | 4.29 | 3.93 | 1698.9 | 4.7 |
| LATITUDE : | 4.60 | 5.03 | 5.15 | 5.23 | 4.77 | 4.41 | 4.40 | 4.59 | 4.82 | 4.87 | 4.78 | 4.45 | 1736.1 | 4.8 |
| LATITUDE +15: | 4.84 | 5.10 | 5.00 | 4.85 | 4.27 | 3.91 | 3.95 | 4.27 | 4.68 | 4.95 | 5.04 | 4.75 | 1690.1 | 4.6 |
| KWAJALEIN ISLAND PN — LATITUDE: 8 DEGREES 44 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 4.69 | 5.32 | 5.57 | 5.50 | 5.23 | 5.20 | 5.16 | 5.34 | 5.01 | 4.64 | 4.35 | 4.28 | 1832.8 | 5.0 |
| LATITUDE : | 5.27 | 5.72 | 5.69 | 5.37 | 4.94 | 4.84 | 4.88 | 5.21 | 5.11 | 4.96 | 4.86 | 4.89 | 1876.2 | 5.1 |
| LATITUDE +15: | 5.58 | 5.82 | 5.53 | 4.97 | 4.41 | 4.27 | 4.36 | 4.82 | 4.96 | 5.04 | 5.13 | 5.26 | 1827.7 | 5.0 |
| WAKE ISLAND PN — LATITUDE: 19 DEGREES 17 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 4.45 | 5.11 | 5.79 | 6.16 | 6.41 | 6.37 | 6.02 | 5.90 | 5.56 | 5.11 | 4.75 | 4.36 | 2007.1 | 5.5 |
| LATITUDE : | 5.01 | 5.48 | 5.91 | 5.97 | 5.98 | 5.84 | 5.61 | 5.71 | 5.66 | 5.49 | 5.38 | 5.02 | 2039.2 | 5.6 |
| LATITUDE +15: | 5.30 | 5.56 | 5.72 | 5.48 | 5.26 | 5.06 | 4.96 | 5.25 | 5.47 | 5.58 | 5.71 | 5.41 | 1969.7 | 5.4 |
| SAN JUAN PR — LATITUDE: 18 DEGREES 26 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 4.33 | 4.96 | 5.69 | 5.95 | 5.68 | 5.67 | 5.86 | 5.80 | 5.33 | 4.89 | 4.47 | 4.05 | 1907.1 | 5.2 |
| LATITUDE : | 4.85 | 5.31 | 5.81 | 5.77 | 5.32 | 5.24 | 5.48 | 5.62 | 5.42 | 5.24 | 5.03 | 4.63 | 1938.3 | 5.3 |
| LATITUDE +15: | 5.12 | 5.38 | 5.63 | 5.31 | 4.72 | 4.58 | 4.85 | 5.17 | 5.24 | 5.32 | 5.33 | 4.97 | 1874.1 | 5.1 |
| PROVIDENCE RI — LATITUDE: 41 DEGREES 44 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 2.30 | 2.95 | 3.72 | 4.53 | 5.14 | 5.38 | 5.25 | 4.95 | 4.43 | 3.77 | 2.48 | 2.01 | 1428.2 | 3.9 |
| LATITUDE : | 2.53 | 3.10 | 3.74 | 4.34 | 4.75 | 4.90 | 4.85 | 4.75 | 4.47 | 4.02 | 2.76 | 2.26 | 1415.1 | 3.9 |
| LATITUDE +15: | 2.64 | 3.10 | 3.58 | 3.96 | 4.18 | 4.26 | 4.27 | 4.33 | 4.29 | 4.06 | 2.88 | 2.39 | 1337.0 | 3.7 |
| CHARLESTON SC — LATITUDE: 32 DEGREES 54 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 2.87 | 3.61 | 4.56 | 5.58 | 5.73 | 5.60 | 5.55 | 5.10 | 4.76 | 4.42 | 3.73 | 2.92 | 1656.9 | 4.5 |
| LATITUDE : | 3.17 | 3.82 | 4.62 | 5.38 | 5.33 | 5.14 | 5.15 | 4.91 | 4.82 | 4.73 | 4.19 | 3.31 | 1660.5 | 4.5 |
| LATITUDE +15: | 3.30 | 3.84 | 4.45 | 4.93 | 4.70 | 4.48 | 4.55 | 4.50 | 4.64 | 4.79 | 4.42 | 3.52 | 1585.6 | 4.3 |
| COLUMBIA SC — LATITUDE: 33 DEGREES 57 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 3.01 | 3.76 | 4.66 | 5.64 | 5.85 | 5.91 | 5.68 | 5.50 | 4.97 | 4.57 | 3.76 | 3.01 | 1714.5 | 4.7 |
| LATITUDE : | 3.34 | 3.99 | 4.72 | 5.44 | 5.42 | 5.41 | 5.27 | 5.30 | 5.04 | 4.91 | 4.23 | 3.43 | 1719.3 | 4.7 |
| LATITUDE +15: | 3.49 | 4.02 | 4.55 | 4.98 | 4.78 | 4.69 | 4.65 | 4.85 | 4.85 | 4.98 | 4.47 | 3.65 | 1642.0 | 4.5 |
| GREENVILLE-SPARTANSC — LATITUDE: 34 DEGREES 54 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 2.93 | 3.66 | 4.60 | 5.50 | 5.67 | 5.82 | 5.65 | 5.50 | 4.88 | 4.50 | 3.66 | 2.84 | 1680.4 | 4.6 |
| LATITUDE : | 3.25 | 3.88 | 4.66 | 5.30 | 5.26 | 5.32 | 5.24 | 5.30 | 4.94 | 4.83 | 4.11 | 3.22 | 1683.3 | 4.6 |
| LATITUDE +15: | 3.39 | 3.90 | 4.48 | 4.85 | 4.64 | 4.62 | 4.62 | 4.85 | 4.75 | 4.90 | 4.34 | 3.43 | 1606.1 | 4.4 |
| HURON SD — LATITUDE: 44 DEGREES 23 MINUTES | | | | | | | | | | | | | | |
| LATITUDE -15: | 2.42 | 3.16 | 4.18 | 5.13 | 5.84 | 6.37 | 6.84 | 6.46 | 5.50 | 4.48 | 3.00 | 2.17 | 1692.0 | 4.6 |
| LATITUDE : | 2.70 | 3.34 | 4.22 | 4.91 | 5.38 | 5.78 | 6.29 | 6.20 | 5.60 | 4.83 | 3.37 | 2.46 | 1677.5 | 4.6 |
| LATITUDE +15: | 2.82 | 3.35 | 4.04 | 4.47 | 4.72 | 4.98 | 5.48 | 5.65 | 5.39 | 4.90 | 3.54 | 2.62 | 1582.2 | 4.3 |

| SITE / ARRAY TILT | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIERRE | SD | LATITUDE: 44 DEGREES 23 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.68 | 3.42 | 4.57 | 5.43 | 6.14 | 6.66 | 7.13 | 6.83 | 5.86 | 4.83 | 3.31 | 2.43 | 1806.6 | 4.9 |
| LATITUDE : | | 3.00 | 3.63 | 4.63 | 5.21 | 5.65 | 6.03 | 6.56 | 6.57 | 5.98 | 5.22 | 3.74 | 2.78 | 1797.0 | 4.9 |
| LATITUDE +15: | | 3.15 | 3.65 | 4.45 | 4.74 | 4.95 | 5.18 | 5.71 | 5.99 | 5.77 | 5.31 | 3.95 | 2.96 | 1699.3 | 4.7 |
| RAPID CITY | SD | LATITUDE: 44 DEGREES 3 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.73 | 3.55 | 4.65 | 5.33 | 5.88 | 6.46 | 6.95 | 6.70 | 5.92 | 4.85 | 3.43 | 2.63 | 1799.9 | 4.9 |
| LATITUDE : | | 3.06 | 3.77 | 4.71 | 5.11 | 5.42 | 5.85 | 6.38 | 6.44 | 6.04 | 5.25 | 3.88 | 3.01 | 1794.2 | 4.9 |
| LATITUDE +15: | | 3.20 | 3.79 | 4.52 | 4.65 | 4.75 | 5.03 | 5.56 | 5.86 | 5.83 | 5.34 | 4.10 | 3.21 | 1700.4 | 4.7 |
| SIOUX FALLS | SD | LATITUDE: 43 DEGREES 34 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.62 | 3.38 | 4.30 | 5.15 | 5.90 | 6.36 | 6.71 | 6.25 | 5.40 | 4.47 | 3.09 | 2.33 | 1704.4 | 4.7 |
| LATITUDE : | | 2.92 | 3.59 | 4.34 | 4.94 | 5.44 | 5.77 | 6.18 | 6.00 | 5.49 | 4.82 | 3.48 | 2.65 | 1693.6 | 4.6 |
| LATITUDE +15: | | 3.06 | 3.61 | 4.17 | 4.50 | 4.77 | 4.97 | 5.39 | 5.47 | 5.29 | 4.89 | 3.66 | 2.82 | 1601.3 | 4.4 |
| CHATTANOOGA | TN | LATITUDE: 35 DEGREES 2 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.48 | 3.16 | 4.04 | 5.01 | 5.33 | 5.56 | 5.34 | 5.27 | 4.63 | 4.21 | 3.16 | 2.41 | 1540.7 | 4.2 |
| LATITUDE : | | 2.72 | 3.32 | 4.07 | 4.81 | 4.94 | 5.08 | 4.95 | 5.07 | 4.68 | 4.50 | 3.51 | 2.70 | 1533.0 | 4.2 |
| LATITUDE +15: | | 2.81 | 3.31 | 3.90 | 4.40 | 4.36 | 4.42 | 4.37 | 4.63 | 4.49 | 4.54 | 3.68 | 2.85 | 1454.4 | 4.0 |
| KNOXVILLE | TN | LATITUDE: 35 DEGREES 49 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.48 | 3.21 | 4.12 | 5.19 | 5.56 | 5.77 | 5.56 | 5.41 | 4.84 | 4.31 | 3.15 | 2.40 | 1583.2 | 4.3 |
| LATITUDE : | | 2.72 | 3.38 | 4.16 | 4.99 | 5.16 | 5.27 | 5.15 | 5.21 | 4.90 | 4.62 | 3.51 | 2.70 | 1576.1 | 4.3 |
| LATITUDE +15: | | 2.82 | 3.38 | 4.00 | 4.57 | 4.55 | 4.58 | 4.54 | 4.76 | 4.71 | 4.67 | 3.68 | 2.86 | 1495.4 | 4.1 |
| MEMPHIS | TN | LATITUDE: 35 DEGREES 3 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.73 | 3.52 | 4.42 | 5.30 | 5.81 | 6.19 | 6.07 | 5.93 | 5.14 | 4.63 | 3.37 | 2.65 | 1697.8 | 4.7 |
| LATITUDE : | | 3.01 | 3.71 | 4.46 | 5.10 | 5.38 | 5.64 | 5.62 | 5.71 | 5.21 | 4.97 | 3.76 | 2.99 | 1691.6 | 4.6 |
| LATITUDE +15: | | 3.13 | 3.72 | 4.29 | 4.66 | 4.73 | 4.88 | 4.93 | 5.21 | 5.01 | 5.04 | 3.95 | 3.18 | 1605.3 | 4.4 |
| NASHVILLE | TN | LATITUDE: 36 DEGREES 7 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.30 | 3.06 | 3.91 | 5.01 | 5.62 | 5.94 | 5.83 | 5.66 | 4.91 | 4.32 | 2.95 | 2.18 | 1574.0 | 4.3 |
| LATITUDE : | | 2.51 | 3.21 | 3.93 | 4.81 | 5.21 | 5.42 | 5.40 | 5.44 | 4.97 | 4.62 | 3.27 | 2.43 | 1559.6 | 4.3 |
| LATITUDE +15: | | 2.59 | 3.20 | 3.77 | 4.40 | 4.59 | 4.69 | 4.74 | 4.97 | 4.77 | 4.67 | 3.42 | 2.55 | 1472.9 | 4.0 |
| ABILENE | TX | LATITUDE: 32 DEGREES 26 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.63 | 4.34 | 5.42 | 5.94 | 6.28 | 6.70 | 6.59 | 6.32 | 5.49 | 4.90 | 4.03 | 3.57 | 1923.9 | 5.3 |
| LATITUDE : | | 4.06 | 4.63 | 5.51 | 5.72 | 5.82 | 6.10 | 6.09 | 6.09 | 5.58 | 5.27 | 4.54 | 4.10 | 1933.6 | 5.3 |
| LATITUDE +15: | | 4.27 | 4.68 | 5.32 | 5.24 | 5.12 | 5.26 | 5.34 | 5.57 | 5.38 | 5.36 | 4.80 | 4.40 | 1848.2 | 5.1 |
| AMARILLO | TX | LATITUDE: 35 DEGREES 14 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.09 | 4.80 | 5.76 | 6.59 | 6.82 | 7.23 | 7.03 | 6.87 | 6.26 | 5.53 | 4.47 | 3.93 | 2112.4 | 5.8 |
| LATITUDE : | | 4.62 | 5.16 | 5.88 | 6.35 | 6.30 | 6.56 | 6.48 | 6.63 | 6.40 | 5.99 | 5.09 | 4.56 | 2130.9 | 5.8 |
| LATITUDE +15: | | 4.89 | 5.23 | 5.68 | 5.80 | 5.51 | 5.63 | 5.66 | 6.05 | 6.18 | 6.12 | 5.42 | 4.93 | 2041.5 | 5.6 |
| AUSTIN | TX | LATITUDE: 30 DEGREES 18 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.24 | 4.00 | 4.81 | 5.13 | 5.66 | 6.30 | 6.49 | 6.19 | 5.43 | 4.83 | 3.76 | 3.21 | 1797.6 | 4.9 |
| LATITUDE : | | 3.58 | 4.25 | 4.87 | 4.95 | 5.26 | 5.75 | 6.01 | 5.98 | 5.52 | 5.18 | 4.20 | 3.64 | 1801.9 | 4.9 |
| LATITUDE +15: | | 3.74 | 4.28 | 4.69 | 4.54 | 4.65 | 4.98 | 5.27 | 5.47 | 5.33 | 5.26 | 4.42 | 3.88 | 1719.6 | 4.7 |
| BROWNSVILLE | TX | LATITUDE: 25 DEGREES 54 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.20 | 3.86 | 4.78 | 5.52 | 5.97 | 6.48 | 6.84 | 6.44 | 5.58 | 4.96 | 3.74 | 3.08 | 1641.3 | 5.0 |
| LATITUDE : | | 3.54 | 4.09 | 4.85 | 5.34 | 5.56 | 5.93 | 6.34 | 6.23 | 5.68 | 5.34 | 4.17 | 3.47 | 1843.4 | 5.1 |
| LATITUDE +15: | | 3.69 | 4.12 | 4.68 | 4.91 | 4.91 | 5.14 | 5.56 | 5.71 | 5.49 | 5.43 | 4.38 | 3.68 | 1756.7 | 4.8 |
| CORPUS CHRISTI | TX | LATITUDE: 27 DEGREES 46 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.23 | 3.97 | 4.73 | 5.23 | 5.77 | 6.39 | 6.75 | 6.35 | 5.62 | 4.99 | 3.81 | 3.11 | 1825.4 | 5.0 |
| LATITUDE : | | 3.57 | 4.21 | 4.80 | 5.05 | 5.37 | 5.84 | 6.25 | 6.14 | 5.72 | 5.37 | 4.26 | 3.51 | 1829.8 | 5.0 |
| LATITUDE +15: | | 3.73 | 4.24 | 4.62 | 4.64 | 4.75 | 5.06 | 5.49 | 5.62 | 5.53 | 5.46 | 4.48 | 3.73 | 1746.0 | 4.8 |
| DALLAS | TX | LATITUDE: 32 DEGREES 51 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.21 | 3.91 | 4.86 | 5.23 | 5.82 | 6.47 | 6.54 | 6.30 | 5.47 | 4.77 | 3.73 | 3.19 | 1812.3 | 5.0 |
| LATITUDE : | | 3.57 | 4.15 | 4.93 | 5.04 | 5.41 | 5.91 | 6.05 | 6.08 | 5.56 | 5.13 | 4.19 | 3.64 | 1816.3 | 5.0 |
| LATITUDE +15: | | 3.74 | 4.18 | 4.75 | 4.62 | 4.77 | 5.11 | 5.31 | 5.56 | 5.37 | 5.21 | 4.42 | 3.89 | 1732.7 | 4.7 |
| DEL RIO | TX | LATITUDE: 29 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.57 | 4.27 | 5.30 | 5.43 | 5.64 | 6.16 | 6.34 | 6.20 | 5.32 | 4.87 | 3.99 | 3.47 | 1844.1 | 5.1 |
| LATITUDE : | | 3.97 | 4.54 | 5.39 | 5.24 | 5.25 | 5.63 | 5.88 | 5.98 | 5.41 | 5.24 | 4.48 | 3.96 | 1855.9 | 5.1 |
| LATITUDE +15: | | 4.17 | 4.58 | 5.21 | 4.80 | 4.64 | 4.88 | 5.17 | 5.48 | 5.22 | 5.32 | 4.73 | 4.23 | 1777.7 | 4.9 |
| EL PASO | TX | LATITUDE: 31 DEGREES 48 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.49 | 5.51 | 6.62 | 7.65 | 8.02 | 8.12 | 7.56 | 7.39 | 6.89 | 6.20 | 5.06 | 4.30 | 2367.7 | 6.5 |
| LATITUDE : | | 5.10 | 5.96 | 6.79 | 7.39 | 7.39 | 7.34 | 6.97 | 7.14 | 7.07 | 6.77 | 5.80 | 5.01 | 2395.1 | 6.6 |
| LATITUDE +15: | | 5.42 | 6.08 | 6.59 | 6.75 | 6.43 | 6.26 | 6.08 | 6.52 | 6.86 | 6.94 | 6.20 | 5.43 | 2297.8 | 6.3 |
| FORT WORTH | TX | LATITUDE: 32 DEGREES 50 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.13 | 3.90 | 4.82 | 5.20 | 5.83 | 6.53 | 6.65 | 6.41 | 5.59 | 4.84 | 3.74 | 3.13 | 1820.3 | 5.0 |
| LATITUDE : | | 3.48 | 4.14 | 4.89 | 5.01 | 5.42 | 5.95 | 6.15 | 6.19 | 5.70 | 5.20 | 4.20 | 3.56 | 1823.3 | 5.0 |
| LATITUDE +15: | | 3.64 | 4.17 | 4.71 | 4.59 | 4.78 | 5.15 | 5.39 | 5.66 | 5.50 | 5.29 | 4.43 | 3.80 | 1738.1 | 4.8 |

| SITE ARRAY TILT | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HOUSTON | TX | LATITUDE: 29 DEGREES 59 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.84 | 3.64 | 4.33 | 4.86 | 5.48 | 5.79 | 5.65 | 5.39 | 4.94 | 4.57 | 3.46 | 2.76 | 1635.1 | 4.5 |
| LATITUDE : | | 3.11 | 3.85 | 4.38 | 4.69 | 5.11 | 5.31 | 5.25 | 5.21 | 5.01 | 4.90 | 3.85 | 3.10 | 1636.8 | 4.5 |
| LATITUDE +15: | | 3.24 | 3.86 | 4.22 | 4.31 | 4.53 | 4.62 | 4.64 | 4.78 | 4.83 | 4.97 | 4.04 | 3.29 | 1561.7 | 4.3 |
| KINGSVILLE | TX | LATITUDE: 27 DEGREES 31 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.29 | 4.02 | 4.75 | 5.28 | 5.77 | 6.22 | 6.51 | 6.12 | 5.39 | 4.88 | 3.76 | 3.12 | 1800.0 | 4.9 |
| LATITUDE : | | 3.63 | 4.26 | 4.81 | 5.10 | 5.37 | 5.69 | 6.04 | 5.92 | 5.48 | 5.24 | 4.20 | 3.53 | 1804.6 | 4.9 |
| LATITUDE +15: | | 3.80 | 4.29 | 4.64 | 4.69 | 4.75 | 4.94 | 5.31 | 5.42 | 5.29 | 5.32 | 4.42 | 3.75 | 1722.6 | 4.7 |
| LAREDO | TX | LATITUDE: 27 DEGREES 32 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.46 | 4.15 | 5.02 | 5.49 | 6.03 | 6.33 | 6.58 | 6.41 | 5.67 | 4.94 | 3.79 | 3.28 | 1862.0 | 5.1 |
| LATITUDE : | | 3.84 | 4.40 | 5.10 | 5.30 | 5.61 | 5.79 | 6.10 | 6.19 | 5.78 | 5.31 | 4.23 | 3.72 | 1868.4 | 5.1 |
| LATITUDE +15: | | 4.02 | 4.44 | 4.92 | 4.87 | 4.95 | 5.02 | 5.36 | 5.67 | 5.58 | 5.40 | 4.45 | 3.96 | 1784.3 | 4.9 |
| LUBBOCK | TX | LATITUDE: 33 DEGREES 39 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.25 | 5.04 | 6.18 | 7.04 | 7.40 | 7.69 | 7.44 | 7.19 | 6.39 | 5.65 | 4.68 | 4.05 | 2222.0 | 6.1 |
| LATITUDE : | | 4.82 | 5.43 | 6.32 | 6.80 | 6.83 | 6.97 | 6.86 | 6.94 | 6.54 | 6.13 | 5.34 | 4.71 | 2242.0 | 6.1 |
| LATITUDE +15: | | 5.11 | 5.52 | 6.11 | 6.21 | 5.96 | 5.97 | 5.98 | 6.34 | 6.33 | 6.27 | 5.70 | 5.09 | 2147.3 | 5.9 |
| LUFKIN | TX | LATITUDE: 31 DEGREES 14 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.99 | 3.84 | 4.65 | 5.20 | 5.76 | 6.24 | 6.18 | 5.98 | 5.20 | 4.95 | 3.73 | 3.02 | 1758.3 | 4.8 |
| LATITUDE : | | 3.30 | 4.06 | 4.71 | 5.01 | 5.35 | 5.70 | 5.73 | 5.77 | 5.28 | 5.33 | 4.17 | 3.42 | 1760.2 | 4.8 |
| LATITUDE +15: | | 3.44 | 4.09 | 4.53 | 4.59 | 4.72 | 4.93 | 5.04 | 5.28 | 5.08 | 5.41 | 4.39 | 3.64 | 1678.1 | 4.6 |
| MIDLAND-ODESSA | TX | LATITUDE: 31 DEGREES 56 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.30 | 5.12 | 6.36 | 7.08 | 7.50 | 7.76 | 7.36 | 7.15 | 6.37 | 5.71 | 4.75 | 4.17 | 2241.4 | 6.1 |
| LATITUDE : | | 4.87 | 5.51 | 6.52 | 6.84 | 6.93 | 7.04 | 6.80 | 6.91 | 6.52 | 6.21 | 5.42 | 4.84 | 2264.1 | 6.2 |
| LATITUDE +15: | | 5.16 | 5.61 | 6.32 | 6.26 | 6.05 | 6.02 | 5.94 | 6.31 | 6.31 | 6.36 | 5.78 | 5.24 | 2170.7 | 5.9 |
| PORT ARTHUR | TX | LATITUDE: 29 DEGREES 57 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.95 | 3.78 | 4.53 | 5.14 | 5.78 | 6.13 | 5.70 | 5.56 | 5.14 | 4.75 | 3.58 | 2.87 | 1701.5 | 4.7 |
| LATITUDE : | | 3.25 | 4.00 | 4.58 | 4.96 | 5.38 | 5.61 | 5.30 | 5.37 | 5.21 | 5.11 | 4.00 | 3.23 | 1704.2 | 4.7 |
| LATITUDE +15: | | 3.38 | 4.02 | 4.42 | 4.56 | 4.75 | 4.87 | 4.69 | 4.92 | 5.03 | 5.19 | 4.20 | 3.43 | 1626.2 | 4.5 |
| SAN ANGELO | TX | LATITUDE: 31 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.72 | 4.38 | 5.48 | 5.94 | 6.27 | 6.63 | 6.54 | 6.32 | 5.48 | 4.92 | 4.10 | 3.61 | 1929.2 | 5.3 |
| LATITUDE : | | 4.16 | 4.67 | 5.58 | 5.73 | 5.81 | 6.04 | 6.05 | 6.10 | 5.57 | 5.29 | 4.62 | 4.14 | 1940.3 | 5.3 |
| LATITUDE +15: | | 4.37 | 4.72 | 5.38 | 5.25 | 5.11 | 5.21 | 5.31 | 5.58 | 5.37 | 5.38 | 4.88 | 4.45 | 1856.2 | 5.1 |
| SAN ANTONIO | TX | LATITUDE: 29 DEGREES 32 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.32 | 4.08 | 4.85 | 5.15 | 5.85 | 6.30 | 6.54 | 6.23 | 5.52 | 4.85 | 3.79 | 3.24 | 1818.1 | 5.0 |
| LATITUDE : | | 3.68 | 4.33 | 4.92 | 4.96 | 5.44 | 5.75 | 6.06 | 6.01 | 5.61 | 5.21 | 4.24 | 3.68 | 1823.7 | 5.0 |
| LATITUDE +15: | | 3.85 | 4.37 | 4.74 | 4.56 | 4.80 | 4.98 | 5.32 | 5.51 | 5.42 | 5.29 | 4.47 | 3.92 | 1741.4 | 4.8 |
| SHERMAN | TX | LATITUDE: 33 DEGREES 43 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.15 | 3.82 | 4.69 | 5.19 | 5.71 | 6.42 | 6.41 | 6.26 | 5.48 | 4.80 | 3.73 | 3.09 | 1789.0 | 4.9 |
| LATITUDE : | | 3.50 | 4.05 | 4.75 | 5.00 | 5.30 | 5.85 | 5.93 | 6.03 | 5.58 | 5.16 | 4.19 | 3.53 | 1792.4 | 4.9 |
| LATITUDE +15: | | 3.66 | 4.08 | 4.57 | 4.58 | 4.68 | 5.06 | 5.20 | 5.52 | 5.38 | 5.25 | 4.43 | 3.76 | 1709.5 | 4.7 |
| WACO | TX | LATITUDE: 31 DEGREES 37 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.18 | 3.95 | 4.84 | 5.17 | 5.48 | 6.41 | 6.56 | 6.31 | 5.47 | 4.78 | 3.72 | 3.20 | 1799.0 | 4.9 |
| LATITUDE : | | 3.53 | 4.19 | 4.91 | 4.98 | 5.09 | 5.85 | 6.08 | 6.09 | 5.56 | 5.14 | 4.17 | 3.64 | 1803.3 | 4.9 |
| LATITUDE +15: | | 3.69 | 4.22 | 4.73 | 4.57 | 4.50 | 5.06 | 5.33 | 5.57 | 5.37 | 5.22 | 4.39 | 3.89 | 1720.8 | 4.7 |
| WICHITA FALLS | TX | LATITUDE: 33 DEGREES 58 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.47 | 4.18 | 5.10 | 5.70 | 6.22 | 6.73 | 6.68 | 6.39 | 5.57 | 4.91 | 3.93 | 3.39 | 1895.9 | 5.2 |
| LATITUDE : | | 3.87 | 4.46 | 5.18 | 5.49 | 5.77 | 6.13 | 6.17 | 6.16 | 5.67 | 5.29 | 4.44 | 3.90 | 1903.8 | 5.2 |
| LATITUDE +15: | | 4.07 | 4.50 | 5.00 | 5.03 | 5.07 | 5.29 | 5.41 | 5.63 | 5.48 | 5.39 | 4.70 | 4.18 | 1818.4 | 5.0 |
| BRYCE CANYON | UT | LATITUDE: 37 DEGREES 42 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 4.14 | 4.97 | 6.13 | 7.05 | 7.60 | 8.03 | 7.51 | 7.14 | 7.09 | 6.10 | 4.74 | 3.98 | 2267.0 | 6.2 |
| LATITUDE : | | 4.70 | 5.36 | 6.27 | 6.80 | 7.01 | 7.26 | 6.92 | 6.89 | 7.28 | 6.67 | 5.43 | 4.63 | 2288.9 | 6.3 |
| LATITUDE +15: | | 4.99 | 5.45 | 6.07 | 6.21 | 6.11 | 6.20 | 6.03 | 6.29 | 7.06 | 6.84 | 5.80 | 5.02 | 2192.4 | 6.0 |
| CEDAR CITY | UT | LATITUDE: 37 DEGREES 42 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 3.97 | 4.71 | 5.94 | 6.92 | 7.65 | 8.19 | 7.76 | 7.43 | 7.29 | 6.07 | 4.61 | 3.78 | 2262.1 | 6.2 |
| LATITUDE : | | 4.50 | 5.06 | 6.07 | 6.67 | 7.05 | 7.39 | 7.14 | 7.17 | 7.50 | 6.63 | 5.27 | 4.38 | 2278.0 | 6.2 |
| LATITUDE +15: | | 4.77 | 5.14 | 5.87 | 6.09 | 6.14 | 6.30 | 6.22 | 6.54 | 7.28 | 6.80 | 5.63 | 4.74 | 2176.3 | 6.0 |
| SALT LAKE CITY | UT | LATITUDE: 40 DEGREES 46 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.96 | 4.07 | 5.40 | 6.32 | 7.36 | 7.76 | 8.08 | 7.61 | 7.05 | 5.64 | 3.86 | 2.84 | 2100.2 | 5.8 |
| LATITUDE : | | 3.31 | 4.35 | 5.50 | 6.08 | 6.78 | 7.02 | 7.42 | 7.34 | 7.25 | 6.14 | 4.38 | 3.26 | 2096.1 | 5.7 |
| LATITUDE +15: | | 3.48 | 4.39 | 5.31 | 5.55 | 5.92 | 6.00 | 6.45 | 6.69 | 7.03 | 6.29 | 4.65 | 3.48 | 1986.1 | 5.4 |
| NORFOLK | VA | LATITUDE: 36 DEGREES 54 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | | 2.83 | 3.55 | 4.50 | 5.46 | 5.83 | 6.07 | 5.72 | 5.48 | 4.93 | 4.22 | 3.50 | 2.77 | 1669.8 | 4.6 |
| LATITUDE : | | 3.14 | 3.76 | 4.55 | 5.26 | 5.40 | 5.53 | 5.30 | 5.27 | 5.00 | 4.52 | 3.94 | 3.15 | 1668.1 | 4.6 |
| LATITUDE +15: | | 3.28 | 3.78 | 4.38 | 4.81 | 4.76 | 4.79 | 4.66 | 4.82 | 4.81 | 4.58 | 4.15 | 3.36 | 1587.1 | 4.3 |

| SITE ARRAY TILT | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL (KWH/SQ. M) | AVERAGE DAY (KWH/SQ. M) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RICHMOND VA | LATITUDE: 37 DEGREES 30 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.65 | 3.35 | 4.25 | 5.10 | 5.44 | 5.68 | 5.47 | 5.22 | 4.77 | 4.05 | 3.16 | 2.52 | 1572.6 | 4.3 |
| LATITUDE : | 2.93 | 3.54 | 4.29 | 4.90 | 5.04 | 5.18 | 5.07 | 5.01 | 4.83 | 4.32 | 3.53 | 2.85 | 1567.2 | 4.3 |
| LATITUDE +15: | 3.05 | 3.54 | 4.12 | 4.48 | 4.44 | 4.50 | 4.46 | 4.58 | 4.64 | 4.36 | 3.71 | 3.03 | 1488.6 | 4.1 |
| ROANOKE VA | LATITUDE: 37 DEGREES 19 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.78 | 3.44 | 4.35 | 5.15 | 5.45 | 5.71 | 5.54 | 5.28 | 4.81 | 4.25 | 3.31 | 2.64 | 1604.6 | 4.4 |
| LATITUDE : | 3.08 | 3.64 | 4.39 | 4.95 | 5.05 | 5.21 | 5.13 | 5.08 | 4.86 | 4.55 | 3.71 | 2.99 | 1601.9 | 4.4 |
| LATITUDE +15: | 3.22 | 3.64 | 4.22 | 4.52 | 4.45 | 4.52 | 4.51 | 4.64 | 4.67 | 4.60 | 3.90 | 3.18 | 1523.8 | 4.2 |
| BURLINGTON VT | LATITUDE: 44 DEGREES 28 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 1.78 | 2.46 | 3.45 | 4.30 | 4.89 | 5.24 | 5.36 | 4.94 | 4.21 | 3.17 | 1.71 | 1.54 | 1311.3 | 3.6 |
| LATITUDE : | 1.94 | 2.57 | 3.46 | 4.11 | 4.51 | 4.77 | 4.94 | 4.73 | 4.24 | 3.36 | 1.86 | 1.76 | 1286.8 | 3.5 |
| LATITUDE +15: | 2.00 | 2.55 | 3.30 | 3.74 | 3.97 | 4.13 | 4.33 | 4.30 | 4.06 | 3.37 | 1.92 | 1.87 | 1204.5 | 3.3 |
| OLYMPIA WA | LATITUDE: 46 DEGREES 58 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 1.39 | 2.04 | 3.14 | 4.21 | 5.10 | 5.14 | 6.00 | 5.28 | 4.51 | 2.80 | 1.67 | 1.27 | 1297.0 | 3.6 |
| LATITUDE : | 1.54 | 2.11 | 3.14 | 4.02 | 4.70 | 4.67 | 5.52 | 5.06 | 4.56 | 2.96 | 1.83 | 1.44 | 1266.6 | 3.5 |
| LATITUDE +15: | 1.60 | 2.08 | 2.99 | 3.65 | 4.12 | 4.05 | 4.83 | 4.60 | 4.37 | 2.97 | 1.89 | 1.53 | 1179.3 | 3.2 |
| SEATTLE-TACOMA WA | LATITUDE: 47 DEGREES 27 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 1.38 | 2.02 | 3.19 | 4.35 | 5.36 | 5.46 | 7.10 | 5.56 | 4.50 | 2.95 | 1.69 | 1.23 | 1366.3 | 3.7 |
| LATITUDE : | 1.52 | 2.10 | 3.19 | 4.16 | 4.93 | 4.96 | 6.51 | 5.32 | 4.55 | 3.13 | 1.86 | 1.39 | 1330.4 | 3.6 |
| LATITUDE +15: | 1.58 | 2.07 | 3.04 | 3.78 | 4.32 | 4.28 | 5.67 | 4.84 | 4.36 | 3.14 | 1.92 | 1.48 | 1234.3 | 3.4 |
| SPOKANE WA | LATITUDE: 47 DEGREES 38 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 1.54 | 2.65 | 4.05 | 5.10 | 6.03 | 6.34 | 7.47 | 6.81 | 5.88 | 4.03 | 2.15 | 1.38 | 1628.7 | 4.5 |
| LATITUDE : | 1.68 | 2.80 | 4.09 | 4.88 | 5.55 | 5.74 | 6.86 | 6.55 | 6.01 | 4.33 | 2.39 | 1.54 | 1596.9 | 4.4 |
| LATITUDE +15: | 1.73 | 2.79 | 3.92 | 4.44 | 4.85 | 4.94 | 5.96 | 5.96 | 5.80 | 4.39 | 2.50 | 1.61 | 1489.2 | 4.1 |
| WHIDBEY ISLAND WA | LATITUDE: 48 DEGREES 21 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 1.60 | 2.29 | 3.53 | 4.57 | 5.52 | 5.51 | 6.24 | 5.50 | 4.69 | 3.02 | 1.92 | 1.27 | 1392.0 | 3.8 |
| LATITUDE : | 1.79 | 2.40 | 3.55 | 4.36 | 5.07 | 5.00 | 5.73 | 5.27 | 4.75 | 3.21 | 2.13 | 1.41 | 1361.1 | 3.7 |
| LATITUDE +15: | 1.88 | 2.38 | 3.39 | 3.96 | 4.44 | 4.32 | 5.00 | 4.79 | 4.56 | 3.22 | 2.22 | 1.48 | 1267.9 | 3.5 |
| GREEN BAY WI | LATITUDE: 44 DEGREES 29 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.20 | 3.06 | 4.14 | 4.81 | 5.35 | 5.78 | 5.89 | 5.47 | 4.62 | 3.57 | 2.30 | 1.79 | 1491.8 | 4.1 |
| LATITUDE : | 2.43 | 3.24 | 4.18 | 4.60 | 4.94 | 5.25 | 5.42 | 5.25 | 4.67 | 3.81 | 2.55 | 2.02 | 1472.1 | 4.0 |
| LATITUDE +15: | 2.53 | 3.24 | 4.01 | 4.19 | 4.33 | 4.54 | 4.75 | 4.78 | 4.48 | 3.84 | 2.66 | 2.13 | 1384.0 | 3.8 |
| LA CROSSE WI | LATITUDE: 43 DEGREES 52 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.32 | 3.22 | 4.10 | 4.75 | 5.33 | 5.78 | 5.93 | 5.62 | 4.68 | 3.73 | 2.42 | 1.87 | 1514.7 | 4.1 |
| LATITUDE : | 2.58 | 3.41 | 4.14 | 4.55 | 4.92 | 5.25 | 5.46 | 5.39 | 4.74 | 3.99 | 2.69 | 2.10 | 1498.5 | 4.1 |
| LATITUDE +15: | 2.69 | 3.42 | 3.96 | 4.15 | 4.33 | 4.54 | 4.79 | 4.91 | 4.55 | 4.02 | 2.81 | 2.22 | 1412.3 | 3.9 |
| MADISON WI | LATITUDE: 43 DEGREES 8 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.48 | 3.37 | 4.21 | 4.64 | 5.41 | 5.90 | 6.01 | 5.73 | 4.89 | 3.92 | 2.42 | 1.94 | 1550.6 | 4.2 |
| LATITUDE : | 2.75 | 3.57 | 4.25 | 4.44 | 4.99 | 5.36 | 5.54 | 5.50 | 4.95 | 4.20 | 2.68 | 2.18 | 1534.5 | 4.2 |
| LATITUDE +15: | 2.87 | 3.58 | 4.07 | 4.04 | 4.38 | 4.63 | 4.85 | 5.01 | 4.75 | 4.24 | 2.80 | 2.30 | 1446.4 | 4.0 |
| MILWAUKEE WI | LATITUDE: 42 DEGREES 57 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.24 | 3.01 | 4.01 | 4.79 | 5.50 | 5.99 | 6.11 | 5.77 | 4.92 | 3.88 | 2.52 | 1.85 | 1540.7 | 4.2 |
| LATITUDE : | 2.47 | 3.18 | 4.04 | 4.59 | 5.08 | 5.45 | 5.63 | 5.55 | 4.99 | 4.16 | 2.80 | 2.08 | 1522.9 | 4.2 |
| LATITUDE +15: | 2.57 | 3.18 | 3.87 | 4.18 | 4.46 | 4.71 | 4.94 | 5.06 | 4.80 | 4.20 | 2.93 | 2.19 | 1433.8 | 3.9 |
| CHARLESTON WV | LATITUDE: 38 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.02 | 2.64 | 3.52 | 4.41 | 5.06 | 5.39 | 5.20 | 4.95 | 4.52 | 3.84 | 2.63 | 1.89 | 1402.6 | 3.8 |
| LATITUDE : | 2.20 | 2.75 | 3.53 | 4.23 | 4.69 | 4.92 | 4.81 | 4.75 | 4.56 | 4.09 | 2.91 | 2.10 | 1386.2 | 3.8 |
| LATITUDE +15: | 2.26 | 2.73 | 3.37 | 3.86 | 4.14 | 4.28 | 4.24 | 4.34 | 4.38 | 4.12 | 3.04 | 2.19 | 1307.2 | 3.6 |
| HUNTINGTON WV | LATITUDE: 38 DEGREES 22 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.16 | 2.87 | 3.74 | 4.72 | 5.28 | 5.59 | 5.46 | 5.17 | 4.65 | 3.98 | 2.75 | 2.04 | 1474.5 | 4.0 |
| LATITUDE : | 2.36 | 3.00 | 3.76 | 4.53 | 4.89 | 5.10 | 5.05 | 4.96 | 4.70 | 4.24 | 3.05 | 2.28 | 1459.7 | 4.0 |
| LATITUDE +15: | 2.44 | 2.99 | 3.60 | 4.14 | 4.31 | 4.43 | 4.45 | 4.53 | 4.51 | 4.28 | 3.19 | 2.40 | 1378.1 | 3.8 |
| CASPER WY | LATITUDE: 42 DEGREES 55 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.49 | 4.41 | 5.49 | 6.23 | 6.88 | 7.59 | 7.95 | 7.62 | 6.85 | 5.55 | 4.05 | 3.31 | 2114.3 | 5.8 |
| LATITUDE : | 3.95 | 4.74 | 5.60 | 5.99 | 6.34 | 6.86 | 7.30 | 7.36 | 7.04 | 6.04 | 4.63 | 3.84 | 2121.9 | 5.8 |
| LATITUDE +15: | 4.18 | 4.80 | 5.40 | 5.46 | 5.54 | 5.88 | 6.35 | 6.71 | 6.83 | 6.19 | 4.93 | 4.15 | 2021.2 | 5.5 |
| ROCK SPRINGS WY | LATITUDE: 41 DEGREES 36 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 3.63 | 4.65 | 5.78 | 6.53 | 7.31 | 7.80 | 7.96 | 7.60 | 7.10 | 5.83 | 4.24 | 3.50 | 2190.3 | 6.0 |
| LATITUDE : | 4.11 | 5.01 | 5.90 | 6.28 | 6.73 | 7.05 | 7.31 | 7.33 | 7.30 | 6.36 | 4.84 | 4.07 | 2200.7 | 6.0 |
| LATITUDE +15: | 4.35 | 5.08 | 5.70 | 5.73 | 5.87 | 6.03 | 6.35 | 6.69 | 7.08 | 6.52 | 5.16 | 4.39 | 2098.0 | 5.7 |
| SHERIDAN WY | LATITUDE: 44 DEGREES 46 MINUTES | | | | | | | | | | | | | |
| LATITUDE -15: | 2.65 | 3.41 | 4.58 | 5.17 | 5.88 | 6.55 | 7.31 | 6.90 | 5.91 | 4.61 | 3.14 | 2.46 | 1784.6 | 4.9 |
| LATITUDE : | 2.96 | 3.62 | 4.64 | 4.95 | 5.42 | 5.94 | 6.72 | 6.64 | 6.04 | 4.98 | 3.54 | 2.82 | 1775.2 | 4.9 |
| LATITUDE +15: | 3.11 | 3.64 | 4.46 | 4.51 | 4.75 | 5.11 | 5.85 | 6.05 | 5.83 | 5.07 | 3.74 | 3.01 | 1678.9 | 4.6 |

# Appendix B

# The National Electric Code

# DRAFT

# PHOTOVOLTAIC POWER SYSTEMS
# AND
# THE *NATIONAL ELECTRIC CODE*

## SUGGESTED PRACTICES

April 1991

A "FOR COMMENT" DRAFT

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DRAFT

## PURPOSE

This guide provides information on the *National Electric Code® (NEC)* and how it relates to photovoltaic (PV) systems. It is not intended to interpret, or replace the *NEC*. It merely paraphrases the NEC and aligns information contained in the NEC with PV subsystems. Any PV system designer, equipment manufacturer, or installer should have a thorough knowledge of the *NEC* and a full understanding of the engineering principles and hazards associated with photovoltaic power systems. This material is not intended to be a design guide nor an instruction manual for an untrained person. Furthermore, this guide is not intended to cover all aspects of the *NEC* or PV systems--it must be used in conjunction with the full text of the *National Electric Code*. This guide will be revised and updated as needed. Suggestions should be sent to the address on the front cover.

The *National Electric Code* including the 1990 *National Electric Code* is published and updated every three years by the National Fire Protection Association (NFPA), Batterymarch Park, Quincy, Massachusetts 02269. The *National Electric Code* and the term *NEC* are registered trademarks of the National Fire Protection Association and may not be used without their permission. Copies of the 1990 *National Electric Code* are available from the NFPA at the above address, most electrical supply distributors, and many bookstores.

In many locations, all electrical wiring including photovoltaic power systems must be accomplished by a licensed electrician and inspected by a designated local authority. Some municipalities have more stringent codes that supplement or replace the *NEC*. The local inspector has the final say on what is acceptable. In some areas, compliance with codes is not required.

## DISCLAIMER

**Neither the authors, the Southwest Region Experiment Station, the Southwest Technology Development Institute, New Mexico State University, Sandia National Laboratories, the U. S. Department of Energy, nor the National Fire Protection Association assume any liability resulting from the use of the information presented in this manual. This information is believed to be the best available at the time of publication and is believed to be technically accurate. Any application of this information and results obtained from the use of this information are solely the responsibility of the reader.**


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## APPLICABLE ARTICLES FROM THE *NATIONAL ELECTRIC CODE*

Although numerous portions of the *National Electric Code* apply to photovoltaic power systems, those listed below are of particular significance.

| Article | Contents |
|---|---|
| 90 | Introduction |
| 100 | Definition |
| 110 | Requirements |
| 200 | Grounded Conductors |
| 210 | Branch Circuits |
| 240 | Overcurrent Protection |
| 250 | Grounding |
| 300 | Wiring Methods |
| 310 | Conductors |
| 331 | Electrical Nonmetallic Tubing |
| 336 | Nonmetallic Sheathed Cable |
| 338 | Service Entrance Cable |
| 339 | Underground Feeders |
| 348 | Electrical Metallic Tubing |
| 384 | Switchboards and Panel Boards |
| 445 | Generators |
| 480 | Storage Batteries |
| 690 | PV Systems |
| 705 | Interconnected Electric Power Production Sources |
| 720 | Low-Voltage Systems |

# PHOTOVOLTAIC POWER SYSTEMS

# AND

# THE *NATIONAL ELECTRIC CODE*

## SUGGESTED PRACTICES

### OBJECTIVE

- SAFE, RELIABLE, DURABLE PHOTOVOLTAIC POWER SYSTEMS
- KNOWLEDGEABLE MANUFACTURERS, DEALERS, INSTALLERS, CONSUMERS, AND INSPECTORS

### METHOD

- WIDE DISSEMINATION OF THESE SUGGESTIONS
- TECHNICAL INTERCHANGE BETWEEN INTERESTED PARTIES

### INTRODUCTION

The National Fire Protection Association has acted as sponsor of the *National Electric Code (NEC)* since 1911. The original Code document was developed in 1897. With some exceptions, electrical power systems installed in the United States in this century have had to comply with a legally mandated local code or the *NEC*. This includes many photovoltaic (PV) power systems. In 1984, Article 690, which addresses safety standards for the installation of PV systems, was added to the Code. This article has been revised and expanded in the 1987 and 1990 editions.

Many of the PV systems in use and being installed today may not be in compliance with the *NEC* or other local codes. There are several contributing factors to this situation:

- The PV industry has a strong "grass roots," do-it-yourself faction that may not be fully aware of the dangers associated with low-voltage, dc, PV power systems.

- Some people in the PV community may believe that PV systems below 50 volts are not covered by the *NEC*.

- Some electrical inspectors have not had significant experience with direct-current portions of the code or PV power systems.

- The electrical equipment industries do not advertise or widely distribute equipment suitable for direct current (dc) use that meets *NEC* requirements.

- Popular publications are presenting information to the public that implies that PV systems are easily installed, modified, and maintained by untrained homeowners.

- Photovoltaic equipment manufacturers have been generally unable to afford the costs associated with testing and listing by national testing organizations like Underwriters Laboratories.

- Photovoltaic installers and dealers in many cases have not had significant experience in installing ac residential and commercial power systems.

Not all systems are unsafe. Some PV installers in the United States are licensed electrical contractors and are familiar with all sections of the *NEC*. These installer/contractors are installing reliable PV systems that meet the *National Electric Code* and minimize the hazards associated with electrical power systems. However, many PV installations may have numerous defects and may not meet the 1990 Code. Some of the more prominent problems are listed below.

- Improper ampacity of conductors
- Improper insulation on conductors
- Unsafe wiring methods
- No overcurrent protection on many conductors
- Inadequate number and placement of disconnects
- Improper application of equipment having Underwriters Laboratories listing
- No short-circuit current protection on battery systems
- Use of nonapproved components when approved components are available
- Improper system grounding
- Lack of equipment grounding
- Use of underrated components
- Unsafe use of batteries
- Use of ac components (fuses and switches) in dc applications

The Code may apply to many PV systems regardless of size or location. A single PV module may not present a hazard, and small systems in remote locations may not present many safety hazards because people are seldom in the area. On the other hand, two or three modules connected to a battery may be lethal if not installed and operated properly. A single deep-cycle storage battery (6 volts, 220 amp-hours) can discharge about 8,000 amps into a short-circuit. Systems with voltages of 50 volts or higher present shock hazards as do inductive surge currents on lower voltage systems. Storage batteries can be dangerous; hydrogen gas and acid residue from lead-acid batteries must be dealt with safely.

The problems are compounded because unlike ac equipment and systems there are few *UL*-listed components that can be easily "plugged" together to make a PV system. Connectors and devices do not have mating inputs or outputs, and the knowledge and understanding of what works with what is not second nature to the installer. The dc "cookbook" of knowledge does not yet exist.

To meet the objective of safe, reliable, durable photovoltaic power systems, the following suggestions are made:

- Dealer-installers of PV systems become familiar with the methods of wiring residential and commercial ac power systems.
- All PV installations be inspected, where required, by the local inspection authority in the same manner as other equivalent electrical systems.
- Photovoltaic equipment manufacturers build equipment to *UL* or other recognized standards and have equipment tested and approved when practical.
- Listed or recognized subcomponents be used in assembled equipment where formal testing and listing is not practical.
- Electrical equipment manufacturers produce, distribute, and advertise listed, reasonably-priced, dc-rated components.
- Electrical inspectors become familiar with dc and PV systems.
- The PV industry educate the public, modify advertising, and encourage all installations to comply with the *NEC* or other codes.
- All persons installing PV systems obtain and study the current *National Electric Code.*
- Existing PV installations be upgraded to comply with the *NEC* or modified to meet minimum safety standards.

## SUGGESTED PRACTICES

### Scope and Purpose of the *NEC*

Some local inspection authorities use regional electrical codes, but most jurisdictions use the *National Electric Code*–sometimes with slight modification. The *NEC* states that adherence to the recommendations made will reduce the hazards associated with electrical installations. The *NEC* also says these installations may not necessarily be efficient, convenient, or adequate for good service or future expansion of electrical use [90-1]. (Numbers in brackets refer to articles in the *NEC.)*

The *National Electric Code* addresses nearly all PV power installations, even those with voltages less than 50 volts. It covers stand-alone and grid-connected systems. It covers billboards, other remote applications, floating buildings, and recreational vehicles (RV) [90-2a, 690, 720]. The Code deals with any PV system that produces power and has external wiring or electrical components or contacts accessible to the untrained and unqualified person.

There are some exceptions. The *National Electric Code* does not cover installations in automobiles, railway cars, boats, or on utility company properties used for power generation [90-2b]. It also does not cover micropower systems used in watches, calculators, or self-contained electronic equipment that has no external electrical wiring or contacts.

Article 690 of the *NEC* specifically deals with PV systems, but many other sections of the *NEC* contain requirements for any electrical system including PV systems [90-2, 720]. When there is a conflict between Article 690 of the *NEC* and any other article, Article 690 takes precedence [690-3].

The *NEC* suggests, and most inspection officials require, that equipment identified, listed, labeled, or tested by a recognized national testing organization be used when available. Two national testing organizations are the *Underwriters Laboratories (UL)* and Factory Mutual Research (FM) [90-6,100,110-3]. *Underwriters Laboratories* and *UL* are registered trademarks of Underwriters Laboratories Inc., 1285 Walt Whitman Road, Melville, New York 11747.

Most building and electrical inspectors expect to see *UL* on electrical products used in electrical systems in the United States. This is a problem for the PV industry because obtaining *UL* approval is expensive, and the market is often small. Some manufacturers claim their product specifications exceed those required by the testing organizations, but inspectors readily admit to not having the expertise, time, or funding to validate these unlabeled items.

## THE PLAN

The suggested installation practices contained in this guide progress from the photovoltaic modules to the electrical outlets. For each component, *NEC* requirements are addressed and the appropriate Code articles are referenced in brackets. A sentence, phrase, or paragraph followed by a *NEC* reference refers to a requirement established by the *NEC*. The words "**will**," "**shall**," or "**must**" also refer to *NEC* requirements. Suggestions based on field experience with PV systems are worded as such and will use the word "should." The availability of approved components is noted, and alternatives are discussed.

Appendix A lists sources for dc rated and identified, listed, or labeled products, and reference to the products is made as they are discussed.

Appendix B presents diagrams for PV systems of varying sizes showing suggested connection and wiring methods.

## PHOTOVOLTAIC MODULES

Only two manufacturers, Siemens/ARCO (*UL*) and Solarex (FM), offer listed modules at the present time. Kyocera has redesigned its junction box to meet *UL* standards, and this module is being marketed in Europe. Introduction into the United States is planned in the future. Also, Kyocera and Hoxan are reviewing the *UL* standard to determine what will be required for *UL* labeling.

Methods of connecting wiring to the modules vary from manufacturer to manufacturer. The Code requires strain relief be provided for connecting wires. If the module has a closed weatherproof junction box, strain relief and moisture-tight clamps should be used in any knockouts provided for field wiring. Where the weather-resistant gaskets are a part of the junction box, the manufacturer's instructions must be followed to ensure proper strain relief and weatherproofing [*UL* Standard 1703]. Figure 1 shows various types of strain reliefs. The one on the left is a basic cable clamp for interior use with nonmetallic sheathed cable. The clamps in the center and on the right are watertight and can be used with either single or multiconductor cable--depending on the insert. The plastic unit on the right is made by Heyco (Appendix A).

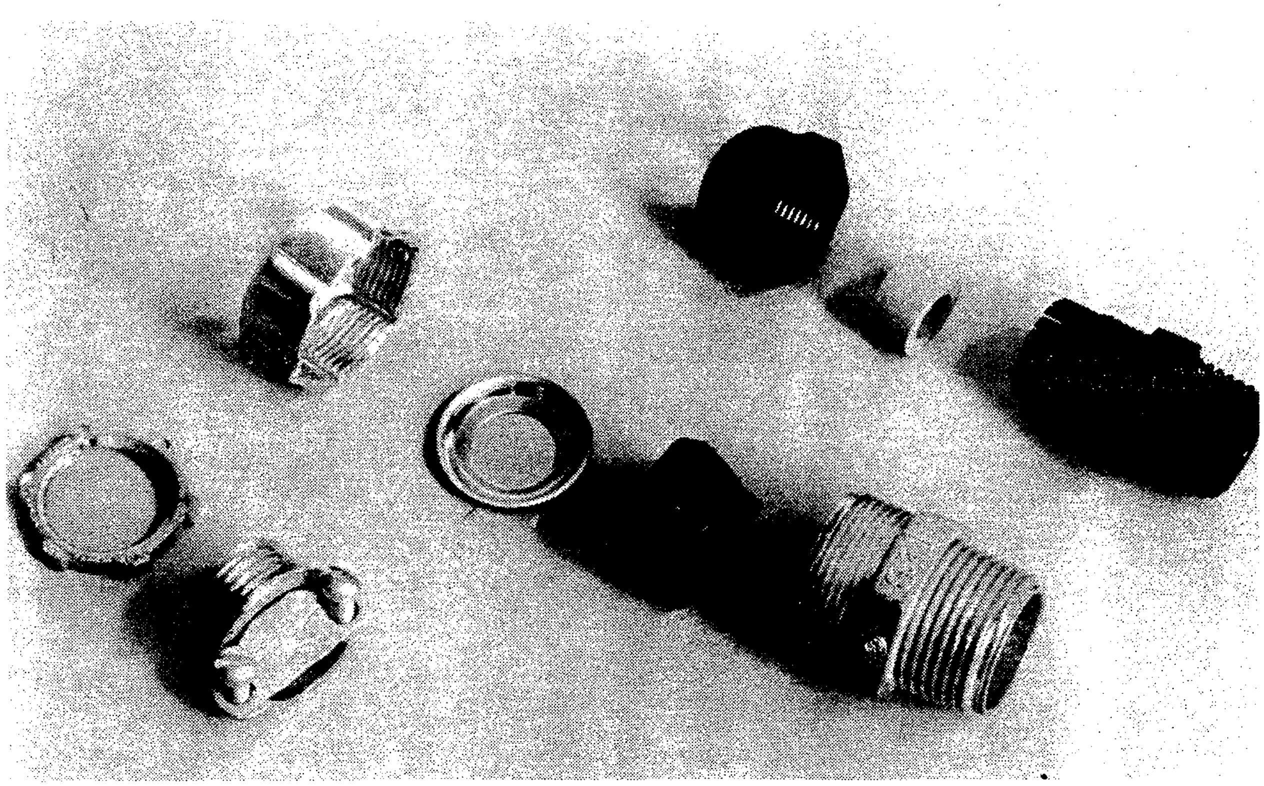


**Figure 1.** Strain Reliefs.

## Module Marking

Certain electrical information must appear on each module. If modules are not factory marked (required by the listing agency--*UL*), then they should be marked at the site to facilitate inspection and to allow the inspector to determine the requirements for conductor ampacity and rating of overcurrent devices. The information supplied by the manufacturer **will** include the following items:

- Polarity of output terminals or leads
- Maximum overcurrent device rating for module protection
- Rated open-circuit voltage
- Rated operating voltage
- Rated operating current
- Rated short-circuit current
- Rated maximum power
- Maximum permissible system voltage [690-51]

Figure 2 shows a typical label that appears on the back of a module.

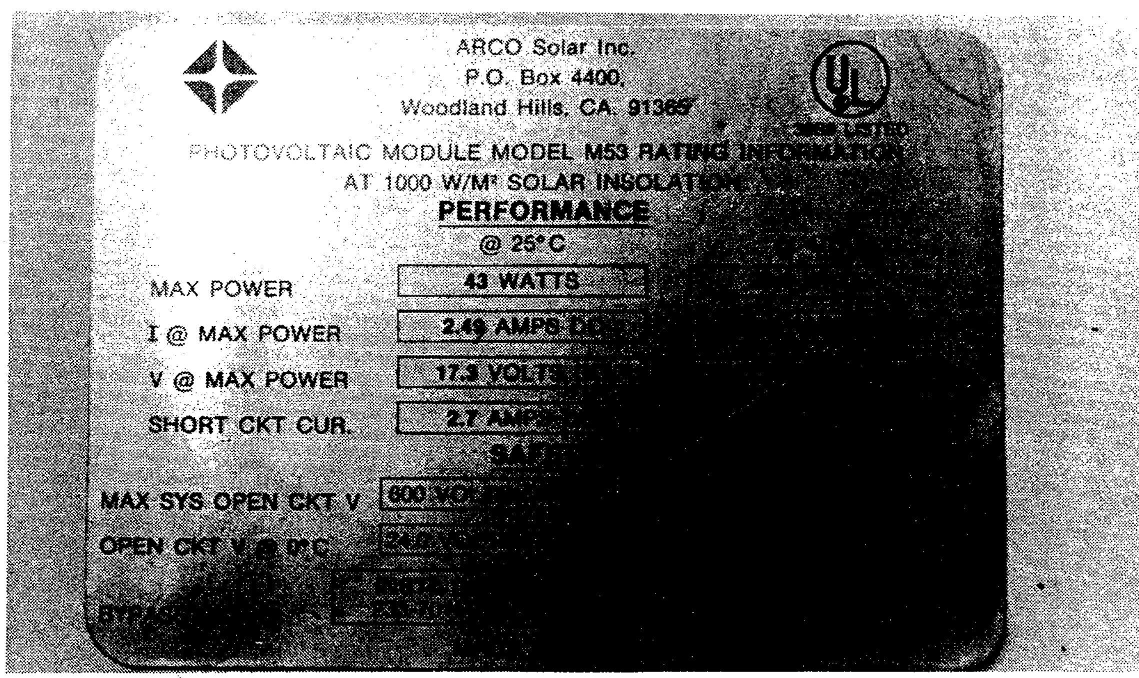



**Figure 2.** Label on Typical PV Module.

**Module Interconnections**

Copper conductors are recommended for almost all photovoltaic system wiring. Copper conductors have lower voltage drops and maximum resistance to corrosion. Aluminum or copper-clad aluminum wires can be used in certain applications but their use is not recommended--particularly in dwellings. All wire sizes presented in this guide refer to copper conductors.

The *NEC* requires No. 12 American Wire Gage (AWG) or larger conductors to be used with systems under 50 volts [720-4]. Single-conductor, type-UF (Underground Feeder) cable identified as sunlight resistant is permitted for module interconnect wiring [690-31b]. Stranded wire is suggested to ease servicing of the modules after installation [690-34]. Unfortunately, single-conductor, stranded, UF sunlight-resistant cable is not readily available. The limited amount that was available had a gray or red insulation rated at 60°C. This insulation was not suitable for long-term exposure to direct sunlight at temperatures likely to occur on roofs near PV modules. Such wire has shown signs of deterioration after four years of exposure.

A widely available and acceptable substitute is black, single-conductor cable identified as Underground Service Entrance Cable (USE). When made to the *UL* standard, it has a 90°C temperature rating and is sunlight resistant even though not commonly marked as such. It is acceptable to most electrical inspectors [Table 310-13 and 16].

Where No. 10 AWG meets ampacity considerations, it is a good compromise between ease of installation and minimizing the voltage drop in the array wiring. Where modules are connected in parallel, the ampacity of the conductors will have to be adjusted accordingly. Ampacity of conductors at any point must be at least 125 percent of the module (or array of parallel modules) rated short-circuit current at that point [690-8a, b1]. If flexible two-conductor cable is needed, electrical tray cable

(TC) is available, but must be supported in a specific manner as outlined in the *NEC* [318]. It is sunlight resistant and is generally marked as such. Although frequently used for module interconnections, SO, SOJ, and similar flexible, portable cables and cordage are not sunlight resistant and are not approved for fixed (nonportable) installations [400-7, 8].

Crimped ring terminals are recommended for use in the module junction box to ensure all strands of the conductor are connected to the screw terminal. If captive screws are used, then fork-type crimped terminals could be used, but no more than two should be used on any one screw. Crimping and soldering the ring or fork terminal to the wire is recommended--particularly in areas of high humidity.

Crimping tools designed for crimping smaller wires used in electronic components usually do not provide sufficient force to make long-lasting crimps on connectors for PV installations even though they may be sized for No. 12-10 AWG. Insulated terminals crimped with these light-duty crimpers frequently develop high resistance in a short time and may even fail as the wire pulls out of the terminal under light pressure. It is strongly suggested that only heavy-duty industrial-type crimpers be used for PV system wiring. Figure 3 shows four styles of crimpers. On the far left is a stripper/crimper used for electronics work that will crimp only insulated terminals. Second from the left is a stripper/crimper that can make crimps on both insulated and uninsulated terminals. The pen points to the dies used for uninsulated terminals. With some care, this crimper can be used to crimp uninsulated terminals on PV systems if the terminals are soldered after the crimp. The two crimpers on the right are heavy-duty industrial designs with ratcheting jaws and interchangeable dies that will provide the highest quality connections. They are usually available from electrical supply houses.

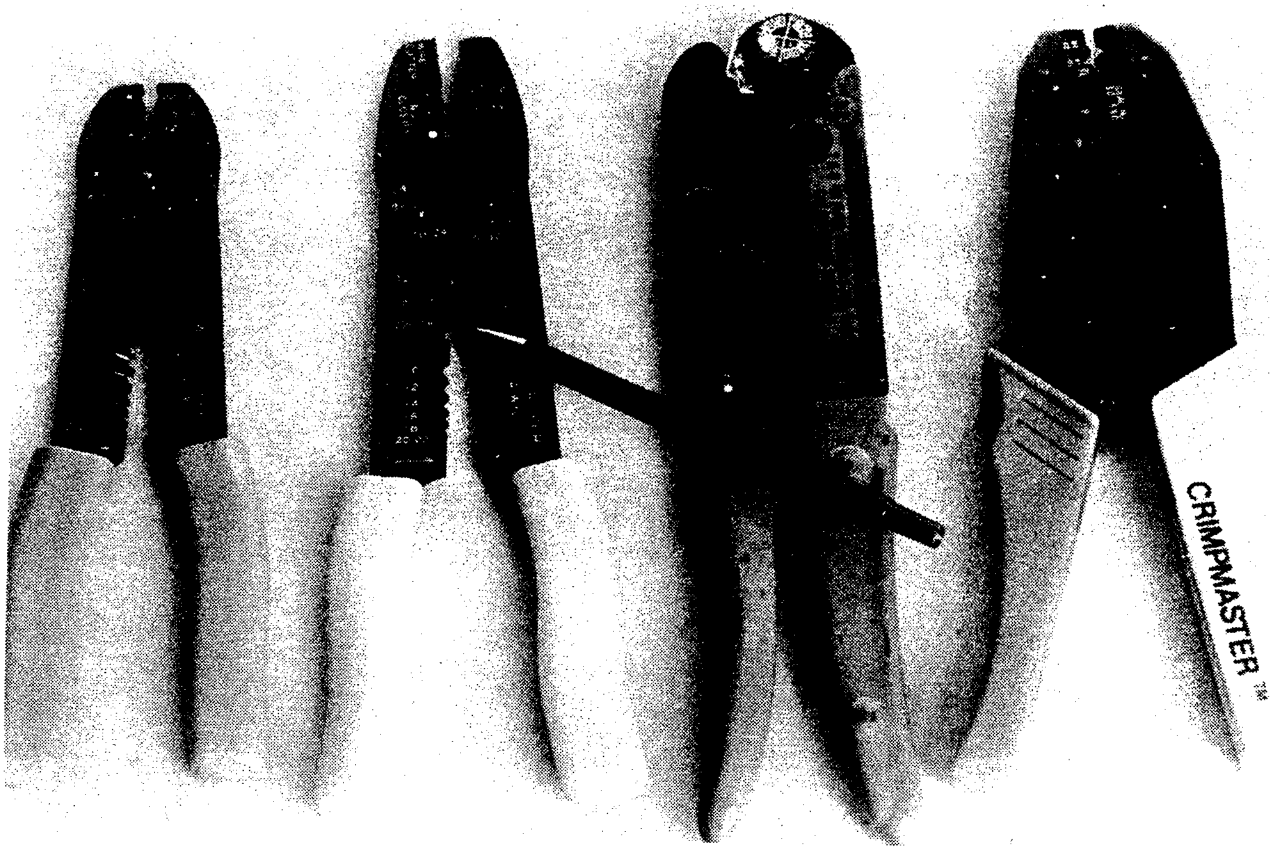



**Figure 3.** Terminal Crimpers.

Figure 4 shows some examples of insulated and uninsulated terminals. In general, uninsulated terminals are preferred (with insulation applied later if required), but care must be exercised to obtain the heavier, more reliable *UL*-listed terminals and not unlisted electronic or automotive grades. Again, an electrical supply house rather than an electronic or automotive parts store is the place to find the required items.

If the junction box provides clamping-type terminals, it is not necessary to use the crimped terminals. Although time consuming, the crimping and soldering technique should be considered to ensure the connections last as long as the modules themselves. Because of the relatively high cost of USE and TC cables and wire, they are usually connected to less expensive cable at the earliest possible opportunity. Other than module interconnections, all other PV system wiring must

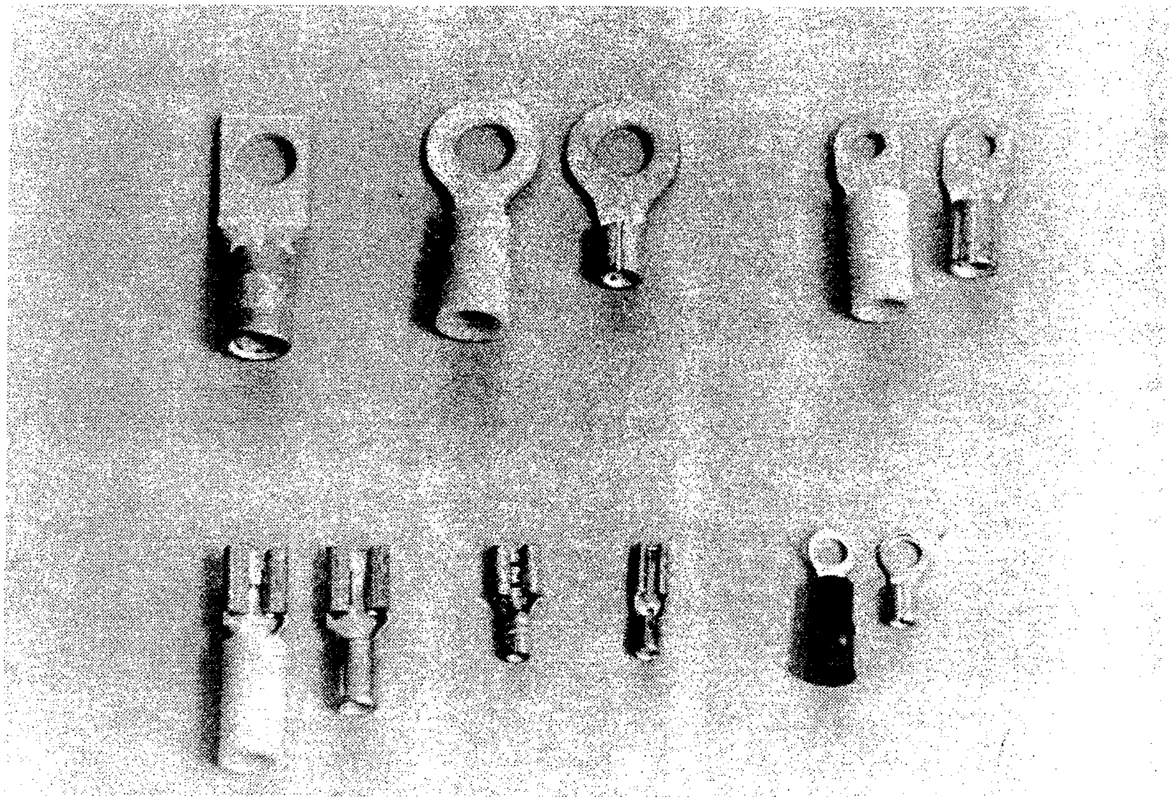


**Figure 4.** Insulated and Uninsulated Terminals.

be made using one of the methods included in the *NEC* [690-31, Chapter 3]. Single-conductor, exposed wiring is not permitted except with special permission [Chapter 3]. The most common methods used for PV systems are individual conductors in rigid metallic and nonmetallic conduit and nonmetallic sheathed cable.

Where individual conductors are used in conduit, they should be conductors with at least 90°C insulation such as THHN. The conduit can be either thick-wall or thin-wall electrical metallic tubing (EMT). If nonmetallic conduit is used, electrical (gray) PVC rather than plumbing (white) PVC tubing must be used [346, 347].

Two-conductor with ground, UF cable that is marked sunlight resistant is frequently used between the module interconnect wiring and the PV disconnect device. Black is the preferred color because of higher resistance to ultraviolet light, but the gray color seems durable because of the thicker insulation associated with the cable. Splices from the stranded wire to this wire must be protected in rainproof junction boxes such as NEMA style 3R. Cable clamps must also be used. Figure 5 shows a rainproof box with a pressure connector terminal strip installed for module wiring connections.

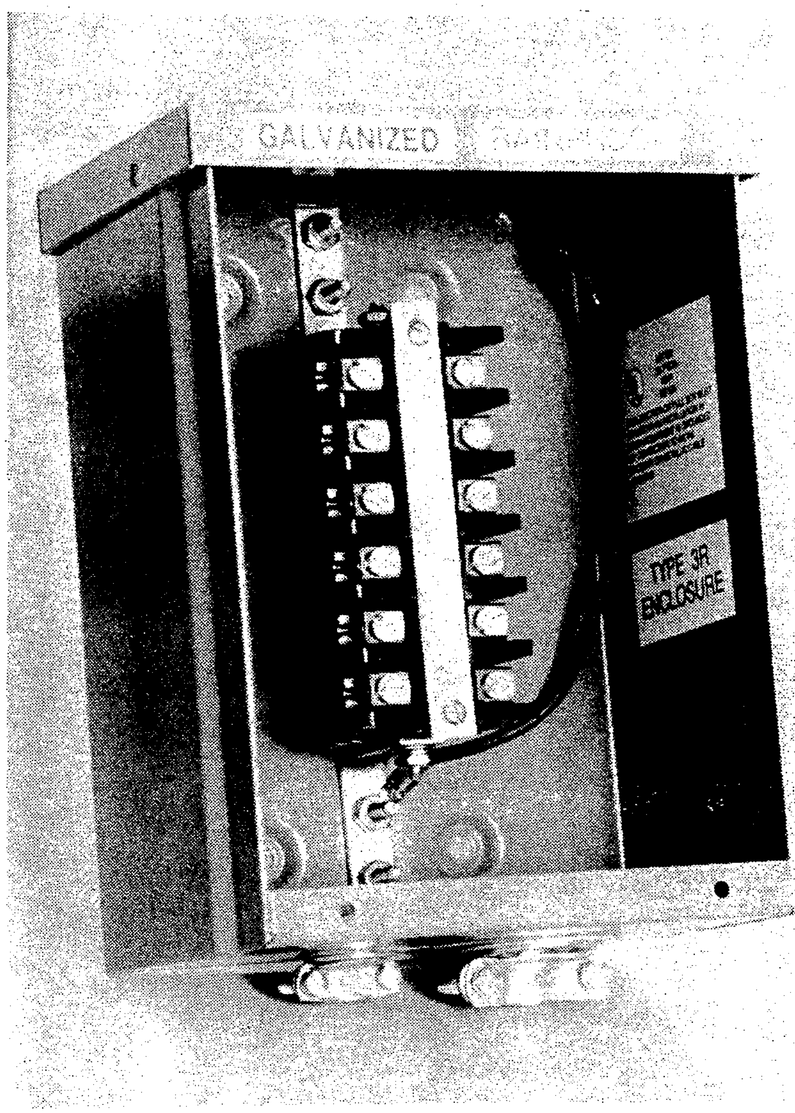



**Figure 5.** Rainproof Junction Box. Shown with Custom Terminal Strip for Module Connections.

the cable. Splices from the stranded wire to this wire must be protected in rainproof junction boxes such as NEMA style 3R. Cable clamps must also be used. Figure 5 shows a rainproof box with a pressure connector terminal strip installed for module wiring connections.

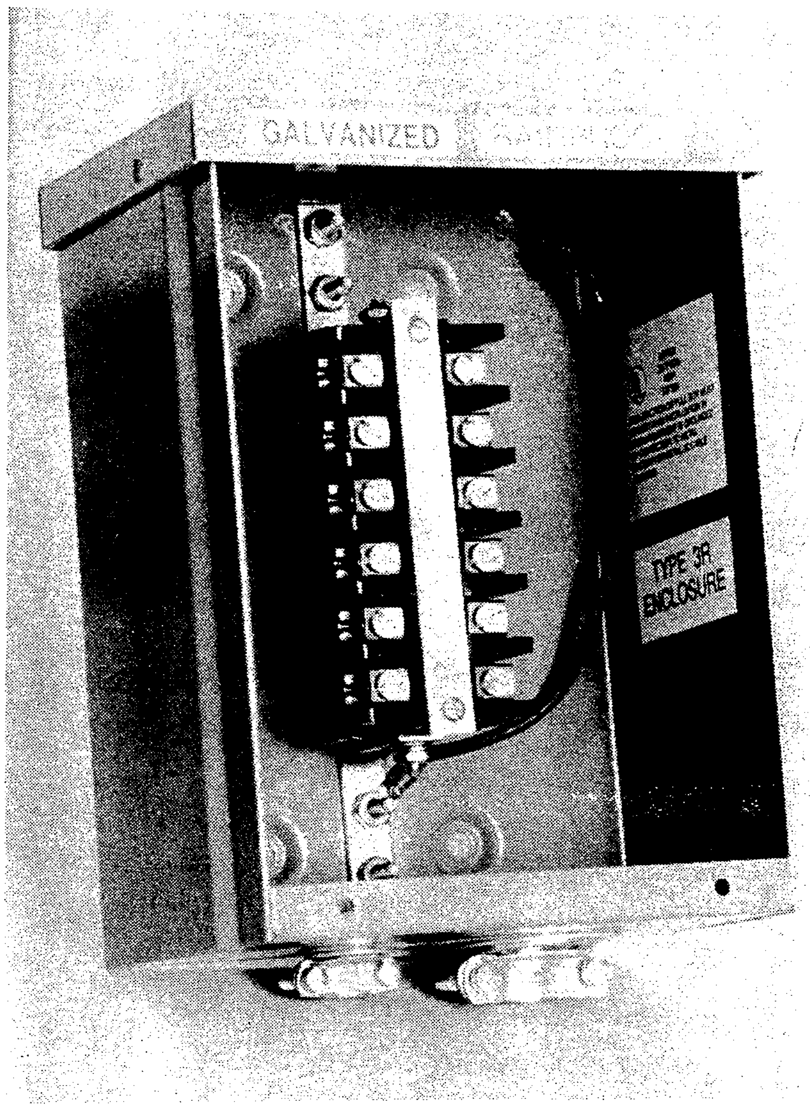



**Figure 5.** Rainproof Junction Box. Shown with Custom Terminal Strip for Module Connections.

Interior exposed cable runs can be made only with sheathed cable types such as NM, NMC, and UF. The cable should not be subjected to physical abuse. If abuse is possible, physical protection must be provided [300-4, 336 B, 339]. Single conductor cable (commonly used between batteries and inverters) **shall** not be used in exposed locations--except as module interconnect conductors [300-3a].

## WIRING

### Module Connectors

Concealed module connectors must be able to resist the environment, be polarized, and be able to handle the short-circuit current. They **shall** also be of a latching design with the terminals guarded. The grounding member **shall** make first and break last [690-32, 33]. The *UL* standard also requires that the connectors for positive and negative conductors **shall** not be interchangeable. Even if the connection is concealed, they **shall** be able to resist the environment.

### Module Connection Access

All junction boxes and other locations where module wiring connections are made **shall** be accessible. Removable modules and flexible wiring **will** allow accessibility [690-34]. This means modules should not be permanently fixed (welded) to mounting frames, and solid wire that could break when modules are moved to service the junction boxes should not be used.

### Splices

All splices **must** be made in approved junction boxes with an approved splicing method. There are, however, some *UL*-listed devices that can be used for taps on nonmetallic sheathed cable outside junction boxes. Conductors **must** be twisted firmly to make a good electrical and mechanical connection, then brazed, welded, or soldered, and then taped [110-14b]. Although solder has a higher resistivity than copper, a rosin-fluxed, soldered splice will have slightly lower electrical resistance, and potentially higher resistance to corrosion than an unsoldered splice. Mechanical splicing devices such as split bolt connectors or terminal strips are also acceptable. Crimped splicing terminals may also be used if heavy-duty crimpers are used.

If the highest reliability is needed, then ultrasonic welding should be used for splices. Also, properly used pressure connectors give high reliability. Fuse blocks, fused disconnects, and circuit breakers are available with these pressure connectors.

Twist-on wire connectors (approved for splicing wires) have not proved adequate when used on low-voltage (12-50 volts), high-current PV systems because of thermal stress and oxidation of the contacts.

Where several modules are connected in parallel, a terminal block or bus bar arrangement **must** be used so that one module can be disconnected without disconnecting the grounded (on grounded systems) conductor of other modules [690-4c]. On grounded systems, this indicates that the popular "Daisy Chain" method of connecting modules is not acceptable because removing one module in the chain will disconnect the grounded conductor for all of those modules further out the chain. This becomes more critical on larger systems where paralleled sets of long series strings of modules are used. Figure 6 shows unacceptable and acceptable methods.

Several different types of terminal blocks and strips are shown in Figure 7. The larger blocks are made by Marathon (Appendix A) and others.

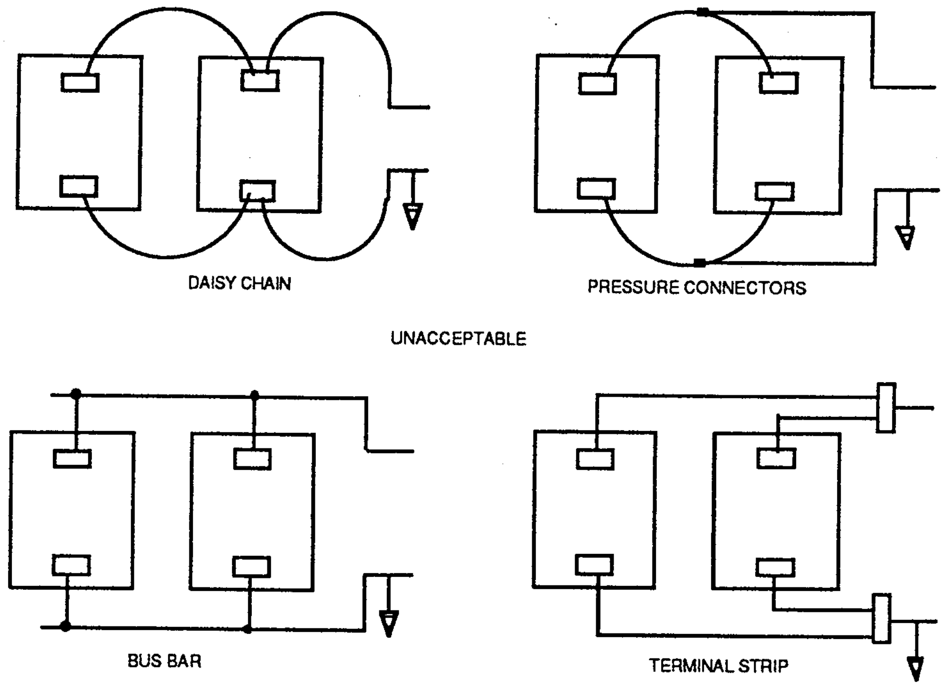



**Figure 6.** Module Interconnect Methods.

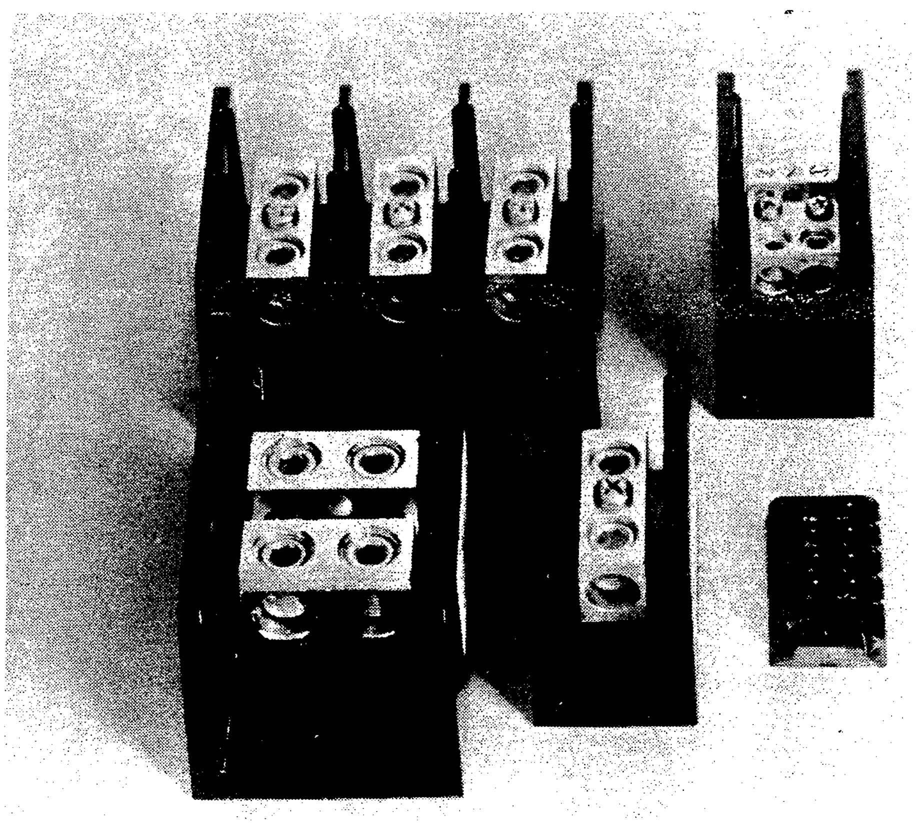


**Figure 7.** Power Splicing Blocks and Terminal Strips.

## Conductor Color Codes

The *NEC* established color codes for electrical power systems many years before either the automobile or electronics industries were started. PV systems are being installed in the arena covered by the *NEC* and therefore **must** comply with those standards that apply to both ac and dc power systems. In a system where one conductor is grounded, the insulation on all grounded conductors **must** be white or natural gray (not much UV light resistance) or be any color but green and marked with white plastic tape or paint at each end. Conductors used for module frame grounding and other exposed metal equipment grounding **must** be bare (no insulation) or have green or green with yellow-striped insulation or identification [200-6, 7; 210-5].

The *NEC* requirements specify that the grounded conductor be white. In most PV-powered systems that are grounded, the grounded conductor turns out to be the negative conductor. A prominent exception is the telephone system, which uses a positive ground. In a PV system where the array is center tapped, the center tap or neutral **must** be grounded [690-41] and this becomes the white conductor. There is no *NEC* requirement designating the color of the ungrounded conductor, but the convention in power wiring is that the first ungrounded conductor is colored black and the second ungrounded conductor is colored red. This suggests that in two-wire, negative-grounded PV systems the positive conductor be red or any color with a red marking but green or white and the negative grounded conductor be white. In a three-wire, center-tapped system, the positive conductor could be red, the grounded center tap conductor **must** be white and the negative conductor could be black.

## GROUND-FAULT PROTECTION AND ARRAY DISABLEMENT

### Ground-Faults

Article 690-5 of the *NEC* requires a ground-fault detection, interruption, and array disablement (GFID) system for fire protection if PV arrays are mounted on the roofs of dwellings. Ground-mounted arrays are not required to have this device. A group of devices to meet this requirement is under development but is not currently available. These particular devices will require that the system grounding conductor be routed through the device. To keep costs to a minimum, the device under development will most probably replace the PV disconnect switch and will serve multiple functions, such as for

- Manual PV disconnect switch
- Ground-fault detection
- Ground-fault interruption
- Array disablement
- Array wiring overcurrent protection

If a revised version of the *NEC* specifies equipment that is not available, the preceding edition of the code may be used with the approval of the inspecting authority. In this case, the 1987 *NEC* did not require a GFID device [90-4].

### Array Disablement

Article 690-18 requires that a mechanism be provided to disable portions of the array or the entire array. The term disable has several meanings, and the *NEC* is not clear on what is intended. The *NEC* Handbook does elaborate. Disable can be defined several ways:

- Prevent the PV system from producing any output
- Reduce the output voltage to zero
- Reduce the output current to zero

The output could be measured at either the PV source terminals or at the load terminals.

Fire fighters are reluctant to fight a fire in a high-voltage battery room because there is no way to turn off a battery bank unless you can somehow remove the electrolyte. In a similar manner, the only way a PV system can have zero output at the array terminals is by preventing light from illuminating the modules or by removing the terminals on the modules. The output voltage may be reduced to zero by shorting the PV module or array terminals. When this is done, short-circuit current will flow through the shorting conductor, which in a properly wired system with bypass diodes, does no harm. The output current may be reduced to zero by disconnecting the PV system from any load. The PV disconnect switch would accomplish this action, but open-circuit voltages would still be present on the array wiring and in the disconnect box.

During PV module installations, the individual PV modules can be covered to disable them. For a system in use, the PV disconnect switch is opened and the array is either short circuited or left open circuit depending on the circumstances. In practical terms, some provision should be made to disconnect portions of the array from other sections for servicing. As individual modules or sets of modules are serviced, they may be covered and/or isolated and shorted to reduce the potential for electrical shock.

Ground-fault detection, interruption, and array disablement devices might accomplish the following actions automatically:

- Sense ground-fault currents exceeding a specified value
- Interrupt or significantly reduce the fault currents
- Open the circuit between the array and the load
- Short the array output terminals

These actions would reduce the array voltages to nearly zero (minimizing human shock hazards and equipment damage) and would serve to force the fault currents away from the fault path and back into the normal conductors. For fault location and repair, the array shorting device would have to be opened.

## GROUNDING

The subject of grounding is one of the most confusing issues in electrical installations. A few definitions from Article 100 of the *NEC* address the situation.

| | |
|---|---|
| Grounded: | Connected to the earth. |
| Grounded Conductor: | A system conductor that normally carries current and is intentionally grounded. In PV systems, one conductor (normally the negative) of a two-conductor system or the center-tapped wire of a bipolar system is grounded. |
| Grounding Conductor: | A conductor not meant to carry current used to: (1) connect the exposed metal portions of equipment to the ground electrode system or the grounded conductor, or (2) connect the grounded conductor to the grounding electrode or grounding electrode system. |
| Equipment Grounding Conductor: | See Grounding Conductor 1. |
| Grounding Electrode Conductor: | See Grounding Conductor 2. |

### Grounding--System

For a two-wire PV system over 50 volts (open-circuit PV output voltage), one dc conductor **shall** be grounded. In a three-wire system, the neutral or center tap of the dc system **shall** be grounded [690-7, 41]. These requirements apply to both stand-alone and grid-tied systems. Such system grounding will enhance personnel safety and minimize the effects of lightning and other induced surges on equipment. Also, grounding of all PV systems will minimize radio frequency noise from dc-operated fluorescent lights and inverters.

The system grounding electrode conductor for the direct current portion of a PV system **shall** be connected to the PV source circuits as close to the modules as possible but still on the load side of the PV disconnect switch [690-42, 250-22]. In grid-connected systems in which the inverter output is grounded, the grounding point could be on the array side of the PV disconnect switch, and even with grounded conductor switching, most of the system would be grounded. In a stand-alone system, if the grounding point were on the PV side of the array disconnect switch and the grounded conductor were opened, most of the system including the battery and the load would be ungrounded. The *NEC* Handbook clarifies the issue somewhat by stating that one of the purposes of opening the grounded conductor with the PV disconnect switch is to purposely unground the array and open the ground path for ground faults. This implies that the grounding point **must** be on the load side of the PV disconnect switch.

In grid-tied systems, for which the inverter design allows a dc grounded system, it is suggested that the grounded conductor not be switched by the PV disconnect switch. In this case, the grounding point for the dc portion of the system would be near or at the inverter input, and the dc grounding conductor would be tied to the same ground rod as the ac grounding conductor. Inverters that do not allow for dc grounding of the array on systems over 50 volts do not meet the requirements of the *NEC*.

The direct-current system-grounding electrode conductor **shall** not be smaller than No. 8 AWG or the largest conductor supplied by the system [250-93]. This may present a problem in some installations in which the battery-to-inverter cables are AWG 1/0 or 2/0 or larger. The conductor from the battery to charge controller and then to the PV disconnect device may be as small as No. 10 or 12 AWG (depending on charging current), and this is where the system grounding conductor could be connected. According to the *NEC*, the larger conductor (i.e., 1/0) will have to be used for the system grounding electrode conductor, and in this example it would be connected to the much smaller wire between the PV disconnect device and the battery. Figure 8 illustrates this problem for a particular system (the conductor sizes are representative only). To be conservative, the larger wire size could be used as the grounded conductor from the attachment point for the grounding electrode conductor all the way to the battery.

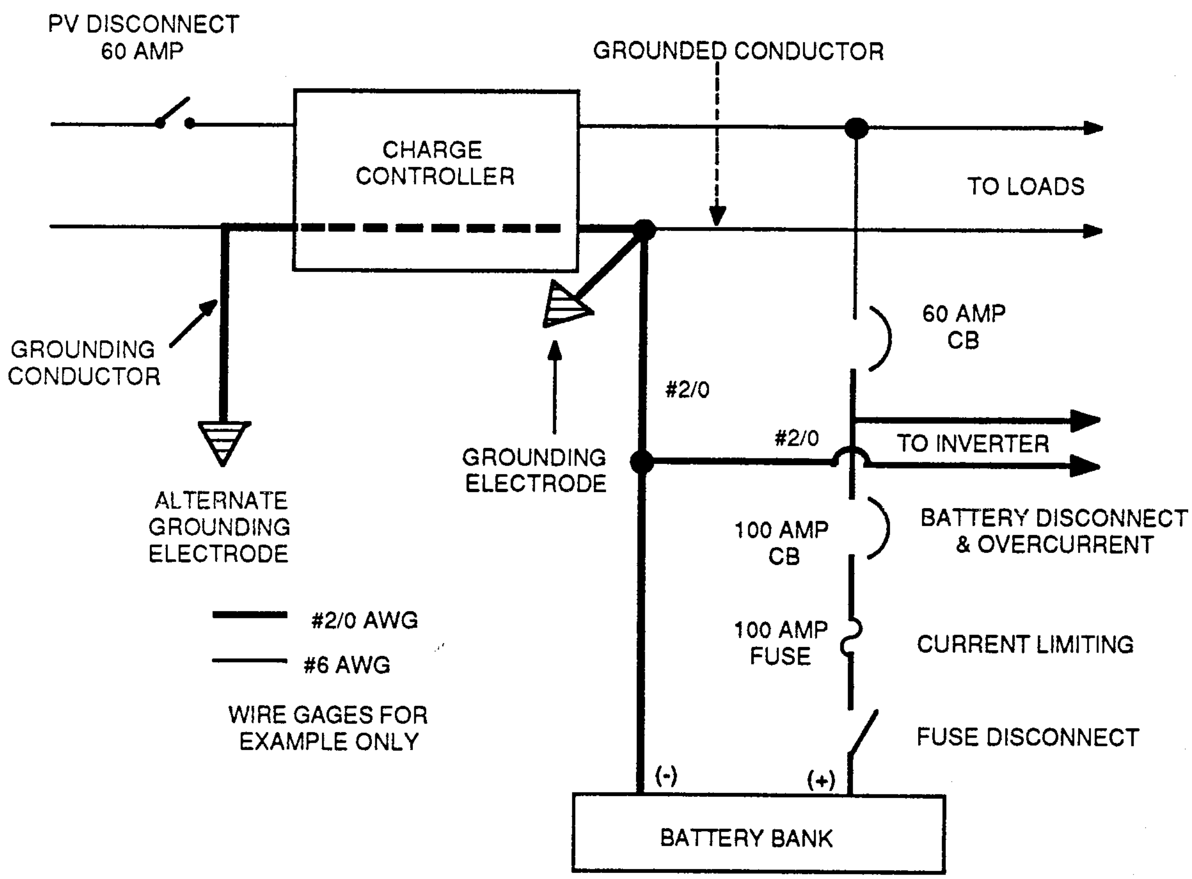



Figure 8. Typical System: Possible Grounding Conductor Locations.

Since the *NEC* does not provide a clear definition of where the PV output circuits end, the single grounding point may be on the battery side of the charge controller or even the negative terminal on the battery or the inverter. The negative dc input to the inverter is grounded in some designs, and this would be an appropriate place to connect the grounding electrode conductor and other equipment grounding conductors. Connection of the grounding electrode conductor to either the negative battery terminal or negative inverter terminal would avoid the "large wire/small wire" problem outlined above.

**It is imperative that there be no more than one grounding connection to the negative conductor of a PV system.** Failure to limit the connections will allow currents to flow in uninsulated conductors and will create unintentional multiple ground faults in the grounded conductor [250-21]. Also keep in mind that future ground-fault interrupter systems may require that this single grounding connection be made at a specific location.

Some inverter designs have the entire chassis used as part of the negative circuit. Also the same situation exists in certain radios--automobile and shortwave. These designs will not pass the current *UL* standards for consumer electrical equipment and will probably require modification in the future since they do not provide electrical isolation between the exterior metal surfaces and the current carrying conductors. Also they create the very real potential for multiple grounding conductor connections.

A few charge controllers break the negative lead internally, and others use a current shunt in the negative lead. It appears that breaking the negative lead will unground some part of the system on negative-grounded systems and thus violate the provisions of the code. This, of course, depends on the location of the grounding point, but in any case some part of the system becomes ungrounded when the controller opens the circuit. A current shunt installed in the negative lead of a charge controller or elsewhere in a properly designed system will have the same or greater ampacity as the negative conductor from the PV source circuits and poses no problems. Some telephone systems ground the positive conductor, and this may cause problems for the PV system. An isolated-ground, dc to dc converter may be used to power subsystems that have different grounding polarities from the main system. In the ac realm, an isolation transformer will serve the same purpose.

In larger utility-tied systems and some stand-alone systems, high impedance grounding systems might be used in lieu of or in addition to the required hard ground. The discussion and design of these systems are beyond the scope of this guide because they are very site specific.

### Grounding--Equipment

All noncurrent-carrying exposed metal parts of junction boxes, equipment, and appliances in the entire PV and dc load system **shall** be grounded [690-43, 250 E, 720-1 & 10]. All PV systems, regardless of voltage, **must** have an equipment grounding system for exposed metal surfaces (e.g., module frames and inverter cases). The grounding conductor **shall** be sized as required by Article 690-43 or 250-95. Generally this will mean a grounding conductor size equal to the size of the current-carrying conductors. If the array can provide short-circuit currents that are more than twice the rating of a particular overcurrent device, then grounding conductors **must** be used that are based on the rating of the overcurrent device [690-43, 250-95].

### Grounding Electrode

The dc system grounding electrode **shall** be common with or bonded to the ac grounding electrode (if any). It **shall** be located as close to the system grounding-conductor connection point as practical [690-44, 250-26c]. The system grounding conductor and the equipment grounding conductor **shall** be tied to the same ground electrode or ground electrode system. Even if the PV system is ungrounded (less than 50 volts), the equipment grounding conductor **must** be connected to a grounding electrode [250-50]. The grounding electrode **shall** be a manufactured device, 5/8 inch in diameter with at least 8 feet driven into the soil at an angle no larger than 45 degrees from the vertical [250-83]. Metal water pipes and other metallic structures as well as concrete encased electrodes may also be used in some circumstances [250-26c, 250-81, 250-83].

A bare-metal well casing makes a good grounding electrode. If it is distant from the PV array or the main disconnect, it should be part of a grounding electrode system. The central pipe to the well should not be used for grounding because it is sometimes removed for servicing.

For maximum protection against lightning-induced surges, it is suggested that a grounding electrode **system** be used with at least two grounding electrodes bonded together. One electrode would be the main system grounding electrode as described above. The other would be a supplemental grounding electrode located as close to the PV array as practical. The module frames and array frames would be connected directly to this electrode to provide as short a path as possible for lightning-induced surges to reach the earth. This electrode **must** be bonded with a conductor to the main system grounding electrode [250-81]. The size of the bonding or jumper cable **must** be related to the ampacity of the overcurrent device protecting the PV source circuits. This bonding jumper is an auxiliary to the module frame grounding that is required to be grounded with an equipment grounding conductor. Table 250-95 gives the requirements. Generally, this **must** be no smaller than No. 8 AWG to comply with bonding jumper requirements. Grounding conductors are allowed to be smaller than circuit conductors when the circuit conductors become very large. Article 250 of the *NEC* elaborates on these requirements.

**Do not** connect the negative conductor to the grounding electrode, the grounding conductor, or the frame at the modules. There should be one and only one point in the system where the grounding electrode conductor is attached to the system-grounded conductor. See Figure 9 for clarification. The wire sizes shown are for illustration only and will vary depending on system size. Chapter 3 of the *NEC* specifies the ampacity of various types and sizes of conductors.

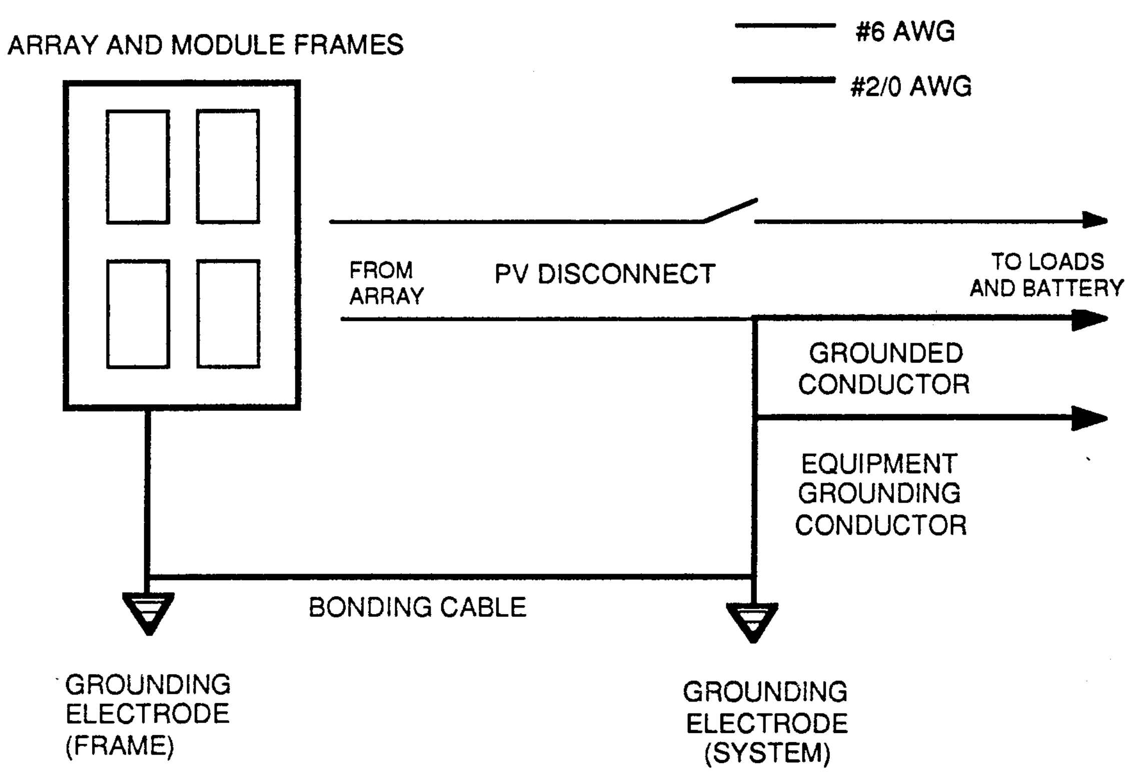



**Figure 9.** Example Grounding Electrode System.

## CONDUCTOR AMPACITY

Photovoltaic modules are limited in their ability to deliver current. Their short-circuit currents are nominally 10 to 15 percent higher than their operating currents. With reflective ground cover such as sand or snow and with reflections from clouds, PV output may reach 125 percent of rated output for short periods of time (minutes). Therefore, common overcurrent trip devices cannot be used to disconnect a PV array under shorted conditions.

Another problem for PV systems is that the conductors may operate at temperatures as high as 65°C when the modules are mounted close to a structure, there are no winds, and the ambient temperatures are high. Temperatures in module junction boxes frequently are in this range. This may require that the ampacity of the conductors be derated or corrected with factors given in *NEC* Table 310-16. For example, a No. 10 AWG USE single conductor cable used for module interconnections has a 90°C insulation and an ampacity of 40 amps in an ambient temperature of 26-30°C. When it is used in ambient temperatures of 61-70°C, the ampacity of this cable is reduced to 23.2 amps.

The ampacity of conductors in PV source circuits **shall** be at least 125 percent of the rated module or parallel-connected modules short-circuit current [690-8]. The ampacity of the PV output circuit conductors **shall** be at least 125 percent of the normal rated output current [690-8]. Rated operating current refers to the manufacturer's rating of peak power voltage and current at standard conditions of 1,000 watts per square meter of irradiance and a cell temperature of 25°C. Conservative design dictates using 125 percent of the parallel module short-circuit current, which will be higher than the normal rated output current. The ampacity of conductors to and from an inverter or power conditioning system **shall** be 125 percent of the rated operating current for that device [690-8]. In a similar manner, other conductors in the system should have an ampacity of 125 percent of the rated operating current to allow for long duration operation at full power. Operation when snow or cloud enhancement increases the PV output above normal may require additional ampacity.

A 1989 revision to the *UL* Standard 1703 for PV modules requires that the module marking and installation instructions be based on 150 percent of the 25°C ratings. Conservative design practices require oversizing wire and increasing the ratings of overcurrent devices on PV source and output circuits. The ampacity of conductors and the sizing of overcurrent devices is an area that demands careful attention by the PV system designer/installer. Temperatures and wiring methods **must** be addressed for each site.

**Stand-Alone Systems**

In stand-alone systems, inverters are frequently used to change the direct current (dc) from a battery bank to 120-volt or 240-volt, 60-Hertz (Hz) alternating current (ac). The conductors between the inverter and the battery **must** have properly rated overcurrent protection and disconnect mechanisms. These inverters frequently have short duration (tens of seconds) surge capabilities that are as high as four times their rated output. For example, a 2,500-watt inverter might be required to surge to 10,000 watts for 10 seconds when a motor load **must** be started. The *NEC* requires the ampacity of the conductors between the battery and the inverter to be sized by the rated 2,500 watt output of the inverter. For example, in a 24-volt system, a 2,500-watt inverter would draw 105 amps at full load and 420 amps for motor-starting surges. To minimize steady-state voltage drops, account for surge-induced voltage drops, and increase system efficiency, most well-designed systems have conductors several sizes larger than required by the *NEC*.

When the battery bank is tapped to provide multiple voltages (i.e., 12 and 24 volts from a 24-volt battery bank), the common negative conductor will carry the **sum** of all of the simultaneous load currents. The negative conductor **must** have an **ampacity at least equal to the sum** of all the amp ratings of the overcurrent devices protecting the positive conductors or have an ampacity equal to the sum of the ampacities of the positive conductors.

The *NEC* does not allow paralleling conductors for added ampacity, except that cables 1/0 AWG or larger may be paralleled under certain conditions [310-4]. DC-rated switchgear, overcurrent devices and conductors cost significantly more when rated to carry more than 100 amps. It is suggested that large PV arrays be broken down into subarrays, each having a short-circuit output of less than 80 amps. This will allow use of 100-amp-rated equipment (125 percent of 80 amps) on each source circuit.

## OVERCURRENT PROTECTION

The *NEC* requires that every ungrounded conductor be protected by an overcurrent device [240-20]. In a PV system with multiple sources of power (PV modules, batteries, battery chargers, generators, power conditioning systems, etc.), the overcurrent device **must** protect the conductor from overcurrent from any source connected to that conductor [690-9]. If the PV system is directly connected to the load without battery storage or other source of power, then no overcurrent protection is required if the conductors are sized at 125 percent of the short-circuit current [690-8].

When circuits are opened in dc systems, arcs can be sustained much longer than they are in ac systems. This presents additional burdens on overcurrent-protection devices rated for dc operation. Such devices **must** carry the rated load current and sense overcurrent situations as well as be able to safely interrupt dc currents. AC overcurrent devices have the same requirements, but the interrupt function is considerably easier.

**Ampere Rating**

The PV source circuits **shall** have overcurrent devices rated at least 125 percent of the parallel module short-circuit current. The PV output circuit overcurrent devices **shall** be rated at least 125 percent of the rated PV currents [690-8]. Since some installations have experienced the blowing of fuses for unknown reasons, conservative practice might call for increasing the rating of these overcurrent devices and the ampacity of the conductors they protect to 150 percent of the short-circuit current or more. This agrees with the recent *UL* requirements mentioned above. Time delay fuses or circuit breakers would minimize nuisance tripping or blowing. In all cases, dc-rated devices having the appropriate voltage rating **must** be used and adequate ventilation **must** be provided.

Both conductors from the PV array **shall** be protected with overcurrent devices when both positive and negative conductors of the PV output circuit are opened by the disconnect switch [Diagram 690-1]. This requirement also makes PV disconnects resemble service entrance disconnects. Since PV module outputs are current limited, these overcurrent devices are actually protecting the array wiring from battery or power conditioning system short circuits.

Often PV modules or series strings of modules are connected in parallel. As the conductor size used in the array wiring increases to accommodate the higher short-circuit currents of paralleled modules, each conductor size **must** be protected by an appropriately sized overcurrent device. This device **must** be placed nearest the source of the largest potential overcurrent for that conductor [240-21]. Figure 10 shows an example of array conductor overcurrent protection for a medium-size array broken into subarrays.

Either fuses or circuit breakers are acceptable for overcurrent devices provided they are rated for their intended uses--i.e., they have dc ratings when used in dc circuits, the ampacity is correct, and they can interrupt the necessary currents when

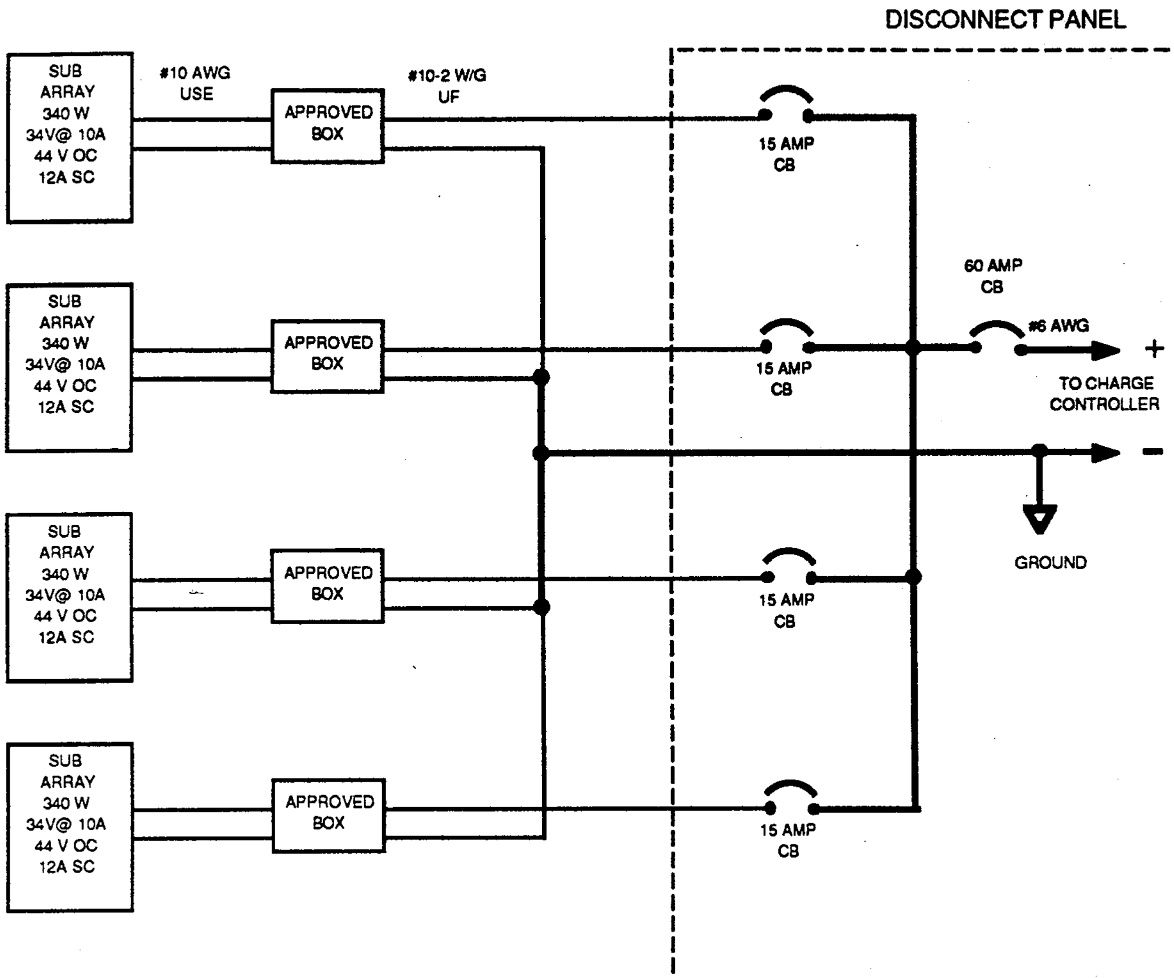



**Figure 10.** Typical Array Conductor Overcurrent Protection (with Optional Subarray Disconnects).

short-circuit currents occur [240 E, F, G]. Figure 11 shows dc-rated, *UL*-listed circuit breakers being used for PV source circuit disconnects. Circuit breakers are by Airpax (Appendix A).

Since PV systems may have transients--lightning and motor starting as well as others--inverse time circuit breakers (the standard type) or time-delay fuses should be used in most cases. In circuits where no transients are anticipated, fast-acting fuses can be used. They should be used if relays and other switchgear in dc systems are to be protected.

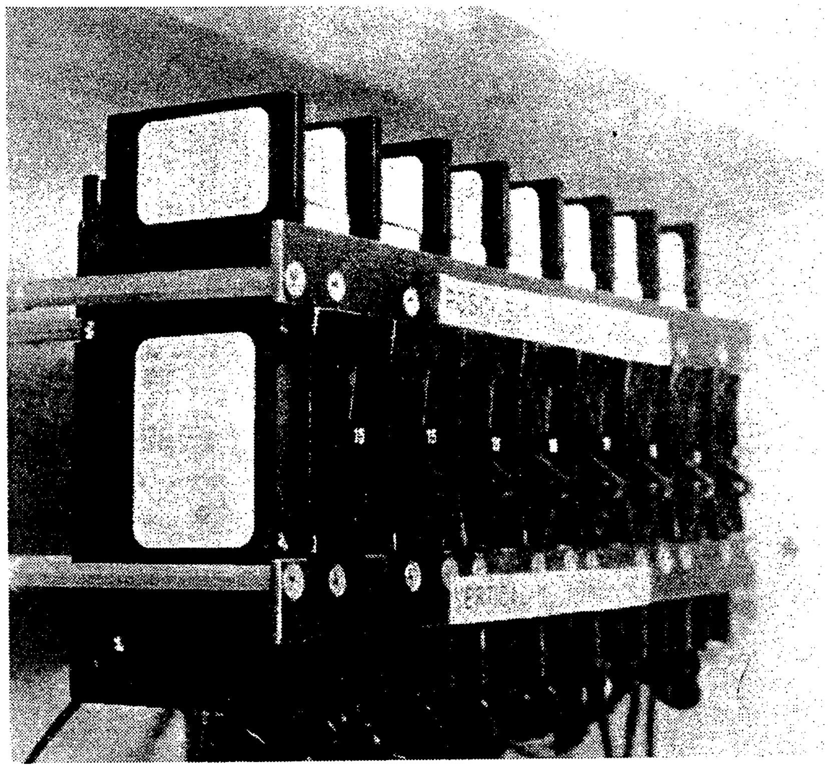


**Figure 11.** Approved Circuit Breakers.

**Branch Circuits**

Fuses used to protect dc or ac branch circuits **must** be tested and rated for that use. They **must** also be of different sizes and markings for each amperage and voltage group to prevent unintentional interchange. However, dc-rated fuses that meet the requirements of the *NEC* are difficult to find [240F]. Figure 12 shows *UL*-listed, dc-rated, time-delay fuses on the left that are acceptable for branch circuit use, which would include the battery fuse. Acceptable dc-rated, *UL*-recognized fast-acting supplementary fuses are shown on the right and can be used in the PV source circuits. The fuses shown are made by Littelfuse (Appendix A), and the fuse holders are by Marathon (Appendix A).

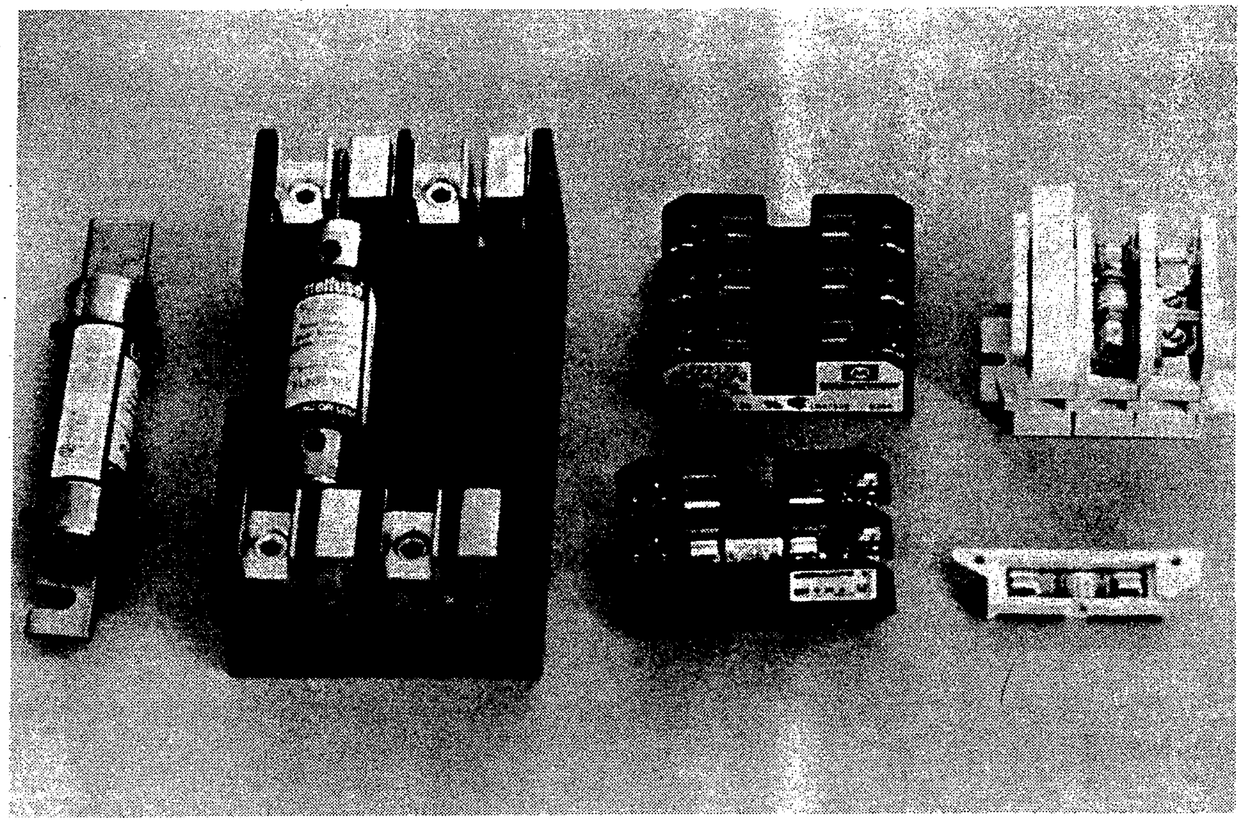


**Figure 12.** Listed and Recognized Fuses.

These particular requirements eliminate the use of glass, ceramic, and plastic automotive fuses as branch circuit overcurrent devices because they are neither tested nor rated for this application.

Automotive fuses have no dc rating by the fuse industry or the testing laboratories. When rated by the manufacturer, they have only a 32-volt maximum rating, which is less than the open-circuit voltage from a 24-volt PV array. Furthermore, these fuses have no rating for interrupt current, nor are they generally marked with all of the information required for branch circuit fuses. They are not considered supplemental fuses under the *UL* component recognition program and must not be used anywhere in the PV system. Figure 13 shows unacceptable automotive fuses on the left and recognized supplemental fuses on the right. Unfortunately, even the supplemental fuses frequently have no dc rating.

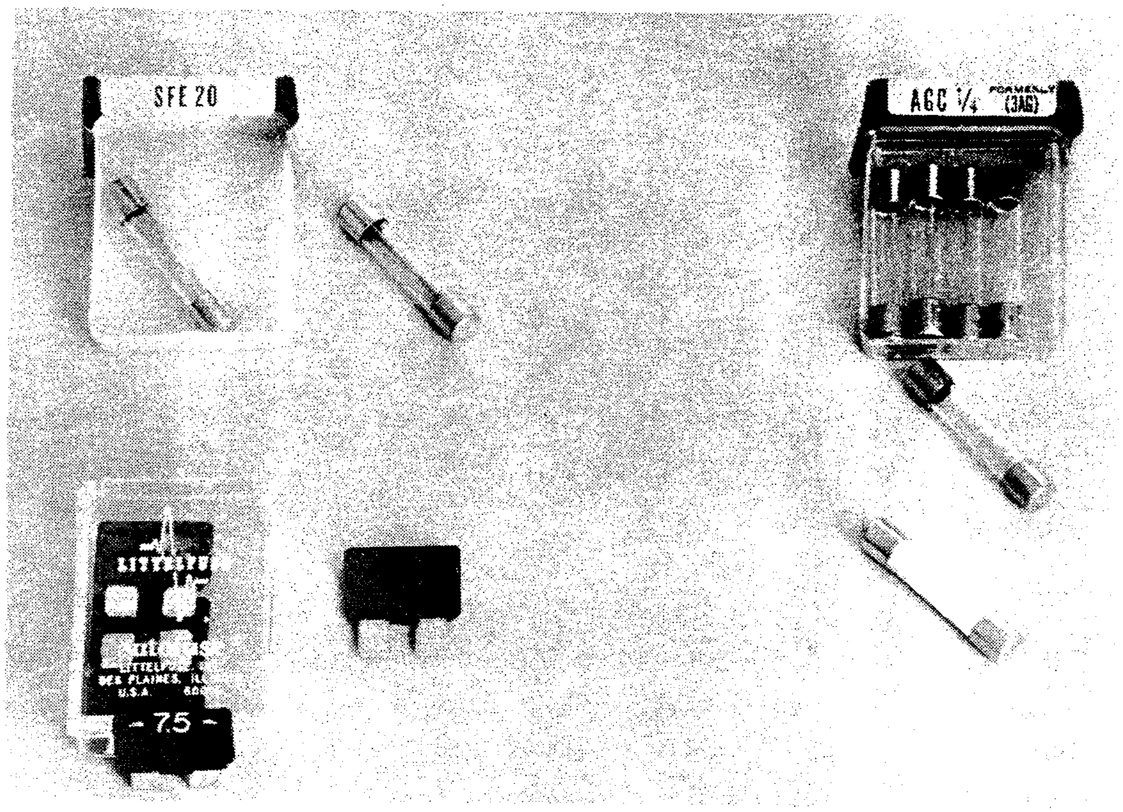



**Figure 13.** Acceptable and Nonacceptable Fuses.

Circuit breakers also have specific requirements when used in branch circuits, but they are generally available with the needed dc ratings [240 G]. Figure 14 shows examples of dc-rated, *UL*-recognized circuit breakers on the left. They may be used in the PV source circuits for disconnects and overcurrent protection. The larger units are dc-rated, *UL*-listed circuit breakers that can be used in dc load centers for branch circuit protection. The breakers shown are produced by Square D and Heinemann. Airpax also produces a dc *UL*-listed circuit breaker, and Potter Brumfield and others produce dc-rated, *UL*-recognized breakers.

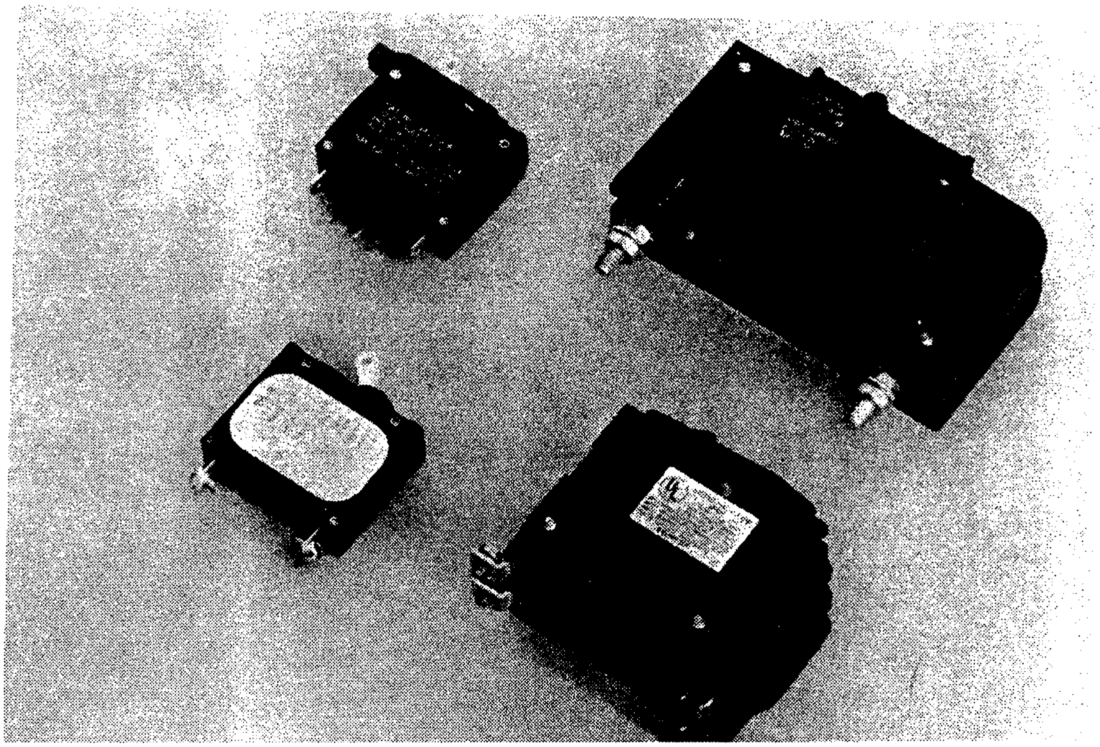


**Figure 14.** *UL*-Recognized and Listed Circuit Breakers.

**Ampere of Interrupt Current (AIC)--Short-Circuit Conditions**

Overcurrent devices--both fuses and circuit breakers--**must** be able to safely open circuits with short-circuit currents flowing in them. Since PV arrays are inherently current limited, high short-circuit currents are not a problem, and the normal ampacity of the conductors is sufficient. In stand-alone systems with storage batteries, however, the short-circuit problem is very severe. A single 220 amp-hour, 6-volt, deep-discharge, lead-acid battery may produce short-circuit currents as high as 8,000 amps for a fraction of a second and as much as 6,000 amps for a few seconds in a direct terminal-to-terminal short circuit. Such high currents are likely to create an arc in an underrated overcurrent device causing that device to burn or blow apart. Two paralleled batteries would generate twice as much current, and larger capacity batteries would be able to deliver proportionately more current into a short circuit.

In dc systems, particularly stand-alone systems with batteries, the interrupt capability of every overcurrent device is important. This interrupt capability is specified as amps of interrupt capability or AIC.

Most dc-rated, *UL*-listed, branch circuit breakers that can be used in PV systems have an AIC of 5,000 amps, however, Heinemann Electric makes one with an AIC of 25,000 amps (Appendix A). Some dc-rated, *UL*-recognized circuit breakers have an AIC of only 3,000 amps. DC-rated fuses normally have an AIC of a few thousand amps, up to 10,000 amps if they are of the current-limiting variety.

### Fusing of PV Source Circuits

The *NEC* allows supplementary fuses to be used in PV source circuits [690-9c]. A supplementary fuse is one that is designed for use inside a piece of equipment. These fuses supplement the main branch fuse and do not have to comply with all of the requirements of branch fuses. They should, however, be dc rated and able to handle the short-circuit currents they may be subjected to. Unfortunately, many supplemental fuses are not dc rated, and if they are, the AIC (when available) is usually less than 5,000 amps. The use of ac-rated supplementary fuses **is not** recommended for the dc circuits of PV systems.

### Current Limiting Fuses--Stand-Alone Systems

A current-limiting fuse or high AIC circuit breaker should be used in the positive conductor near the battery to limit the current that a battery bank can supply to a short-circuit and to reduce the short-circuit currents to levels that are within the AIC of downstream overcurrent devices. These fuses are available with *UL* ratings of 125 and 300 volts dc, currents of 0.1 to 600 amps, and a dc AIC of 20,000 amps. They are classed as RK5 or RK1 current-limiting fuses and should be mounted in class-R rejecting fuse holders or dc-rated, fused disconnects. For reasons mentioned previously, time delay fuses should be specified. One of these fuses and the associated disconnect switch should be used in **each** bank of batteries with a paralleled amp-hour capacity up to 1,000 amp-hours. Batteries with single cell amp-hour capacities higher than 1,000 amp-hours will require special design considerations because these batteries may be able to generate short-circuit currents in excess of the 20,000 AIC rating of the current-limiting fuse. When calculating short-circuit currents, the resistances of all connections, terminals, wire, fuse holders, circuit breakers, and switches **must** be considered. These resistances serve to reduce the magnitude of the available short-circuit currents at any particular point. The suggestion of one fuse per 1,000 amp-hours of battery size is only a general estimate, and the calculations are site specific. The fuses shown in Figure 12 are current limiting.

For systems less than 65 volts (open circuit), Heinemann Electric 25,000 AIC circuit breakers may be used (Appendix A). These circuit breakers are not current limiting even with the high interrupt rating so they cannot be used to protect other fuses or circuit breakers. An appropriate use would be in the conductor between the battery bank and the inverter. This single device would minimize voltage drop and provide the necessary disconnect and overcurrent features.

**Current-Limiting Fuses--Grid Connected Systems**

Normal electrical installation practice requires that service entrance equipment have fault-current protection devices that can interrupt the available short-circuit currents [230-208]. This requirement applies to the utility side of any power conditioning system in a PV installation.

### Dead Fuses

Whenever a fuse is used for an overcurrent device and is accessible to other than qualified persons, it **must** be in a circuit where all power can be removed from both sides of the fuse for servicing. It is not sufficient to reduce the current to zero before changing the fuse; there **must** be no voltage present on either end of the fuse prior to service. This may require the addition of switches on both sides of the fuse location--a complication that increases the voltage drop and reduces the reliability of the system [690-16, Diagram 690-1]. Because of this requirement and the complications it causes and the need for disconnects, it is recommended that a current-limiting fuse be used at the battery and that circuit breakers be used for all other overcurrent devices.

## DISCONNECTING MEANS

There are many considerations in configuring the disconnect switches for a PV system. The National Electric Code deals with safety first and other requirements last--if at all. The PV designer **must** also consider equipment damage from over voltage, performance options, equipment limitations, and cost.

A photovoltaic system is a power generation system, and a specific minimum number of disconnects are necessary to deal with that power. Untrained persons will be operating the systems, and the disconnect system **must** be designed to provide safe, reliable, and understandable operation.

Disconnects may range from nonexistent in a self-contained PV-powered light for a sidewalk to the space-shuttle-like control room in a large, multi-megwatt, utility-tied PV power station. Generally, local inspectors will not require disconnects on totally enclosed, self-contained PV systems like the sidewalk illumination system or a pre-wired attic ventilation fan. This would be particularly true if the entire assembly were *UL*-listed as a unit and there were no external contacts or user serviceable parts. However, as the complexity of the device increases and separate modules, batteries, and charge controllers having external contacts **must** be be wired together and possibly operated and serviced by unqualified persons, the situation changes.

**Photovoltaic Array Disconnects**

Article 690 requires all current-carrying conductors from the PV power source to have a disconnect provision. This includes the grounded conductor, if any [690-13, 14; 230 F]. If a grounded conductor is opened by the PV disconnect switch, all other conductors **must** open simultaneously. This requires a multipole switch. Diagram 690-1 and Article 690-13 indicate and imply that the negative conductor disconnect **must** be a switch and no further elaboration is given--even in the *NEC* Handbook. However, Article 690-17 does discuss using switches or circuit breakers for disconnects of the ungrounded conductors, and Article 230 F does say that ac service-entrance grounded conductors may be disconnected with a bolted connection. The *NEC* Handbook provides further insight when discussing array disablement where the system grounding conductor is attached to the load side of the PV disconnect switch. In this case, the switched grounded conductor is used to interrupt the ground fault path by ungrounding the array.

In normal operations (with no ground faults) on a system where the grounded conductor is opened by the PV disconnect switch, some part of the system becomes ungrounded, and this presents a safety problem. If the array were ungrounded, static voltages and inductive surges could soar on the conductors and cause conductor insulation breakdown and spark hazards. Ground faults are rare in Block V PV modules manufactured since 1985. For these reasons, it is suggested that the grounded conductor remain unswitched to stabilize the system voltage with respect to ground and enhance system safety rather than be configured to remove ground faults that rarely happen. A bolted disconnect **must**, however, be used to comply with the *NEC*. The local inspection authority may have specific requirements on this issue. Of course in an unground, 12- or 24-volt PV system, both positive and negative conductors **must** be switched.

### Equipment Disconnects

Each piece of equipment in the PV system **shall** have disconnect switches to disconnect it from all sources of power. The disconnects **shall** be circuit breakers or switches and **shall** comply with all of the provisions of Article 690-17. DC-rated switches and fuses are expensive and difficult to locate. The ready availability of moderately priced dc-rated circuit breakers with ratings up to 48 volts and 70 amps would seem to encourage their use in all 12- and 24-volt systems. When properly located and used within their approved ratings, circuit breakers can serve as both the disconnect and overcurrent device. In simple systems, one switch or circuit breaker disconnecting the PV array and another disconnecting the battery may be all that is required.

A 2,000-watt inverter on a 12-volt system can draw nearly 200 amps at full load. Disconnect switches **must** be rated to carry this load and be protected by current-limiting fuses, since the battery-to-inverter wiring is usually a very large gage wire to minimize voltage drops. Again a dc-rated, *UL*-listed circuit breaker may prove less costly than a switch with the same ratings.

### Battery Disconnect

When the battery is disconnected from the stand-alone system, either manually or through the action of a fuse or circuit breaker, care **must** be taken that the PV system not be allowed to remain connected to the load. Low-level loads will allow the PV array voltage to increase from the normal battery charging levels to the open-circuit voltage, which will shorten lamp life and possibly damage electronic components.

This potential problem can be avoided by using multipole circuit breaker or fuse disconnects as shown in Figure 15. This figure shows two ways of making the connection. Separate circuits, including disconnects and fuses between the charge controller and the battery and the battery and the load as shown in Figure 16, may be used if it is desired to operate the loads without the PV array being connected. If the design requires that the entire system shut down with a minimum number of switch actions, the switches and circuit breakers could be ganged multipole units.

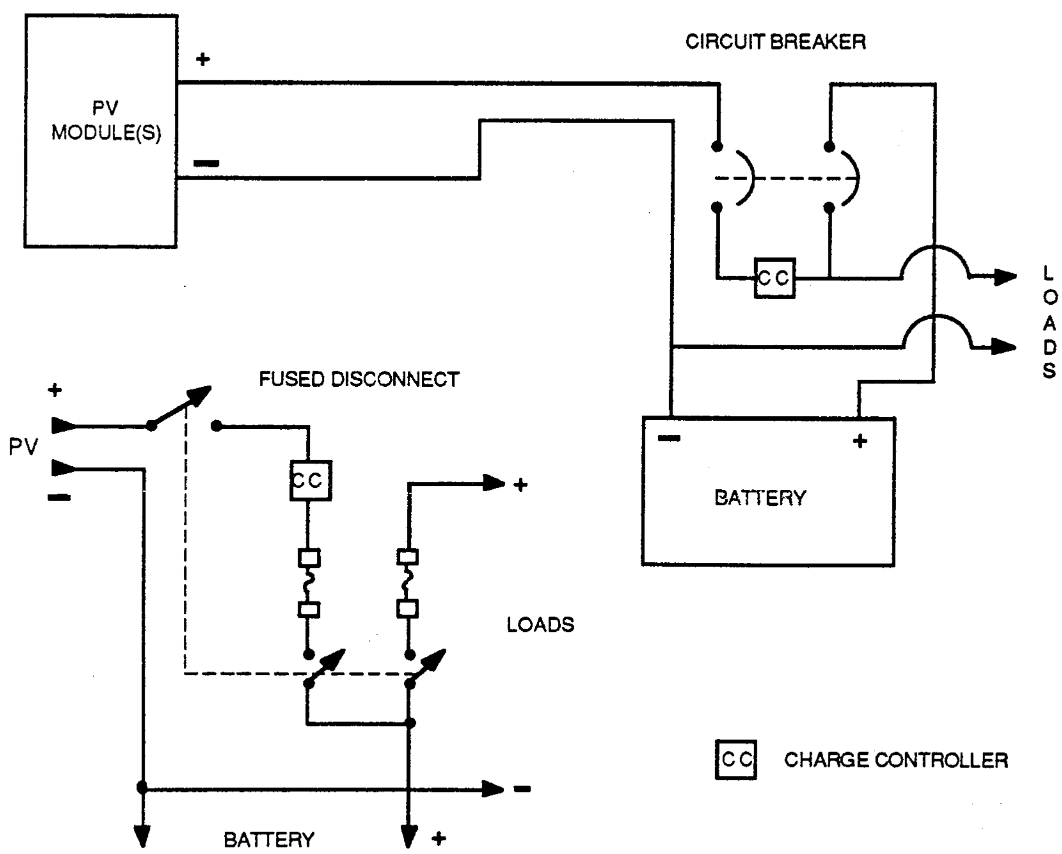



**Figure 15.** Small System Disconnects.

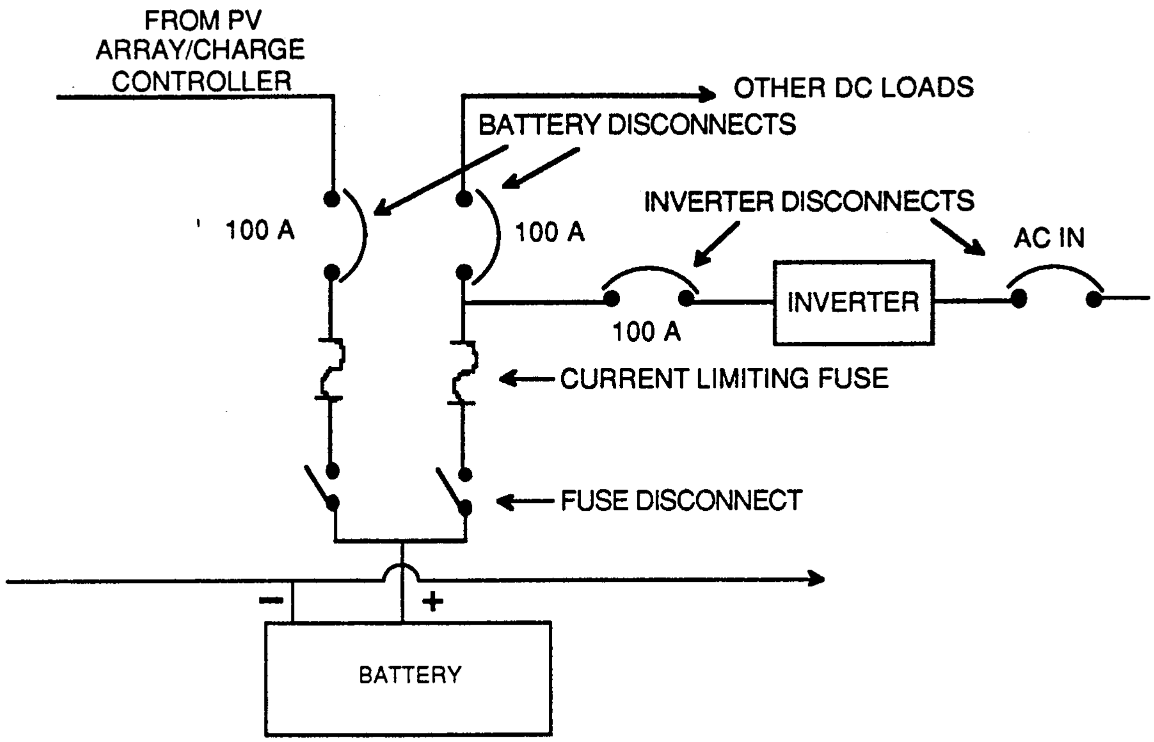



**Figure 16.** Separate Battery Disconnects.

### Charge Controller Disconnects

Some charge controllers are fussy about the sequence in which they are connected and disconnected from the system. Most charge controllers do not respond well to being connected to the PV array and not being connected to the battery. The sensed battery voltage (or lack thereof) would tend to rapidly cycle between the array open-circuit voltage and zero as the controller tried to regulate the nonexistent charge process. This problem will be particularly acute in self-contained charge controllers with no external battery sensing.

Again, the multipole switch or circuit breaker can be used to disconnect not only the battery from the charge controller, but the charge controller from the array. Probably the safest method for self-contained charge controllers is to have the PV disconnect switch disconnect both the input and the output of the charge controller from the system. Larger systems with separate charge control electronics and switching elements will require a case-by-case analysis--at least until the controller manufacturers make their products more tolerant. Figure 17 shows two methods of disconnecting the charge controller.

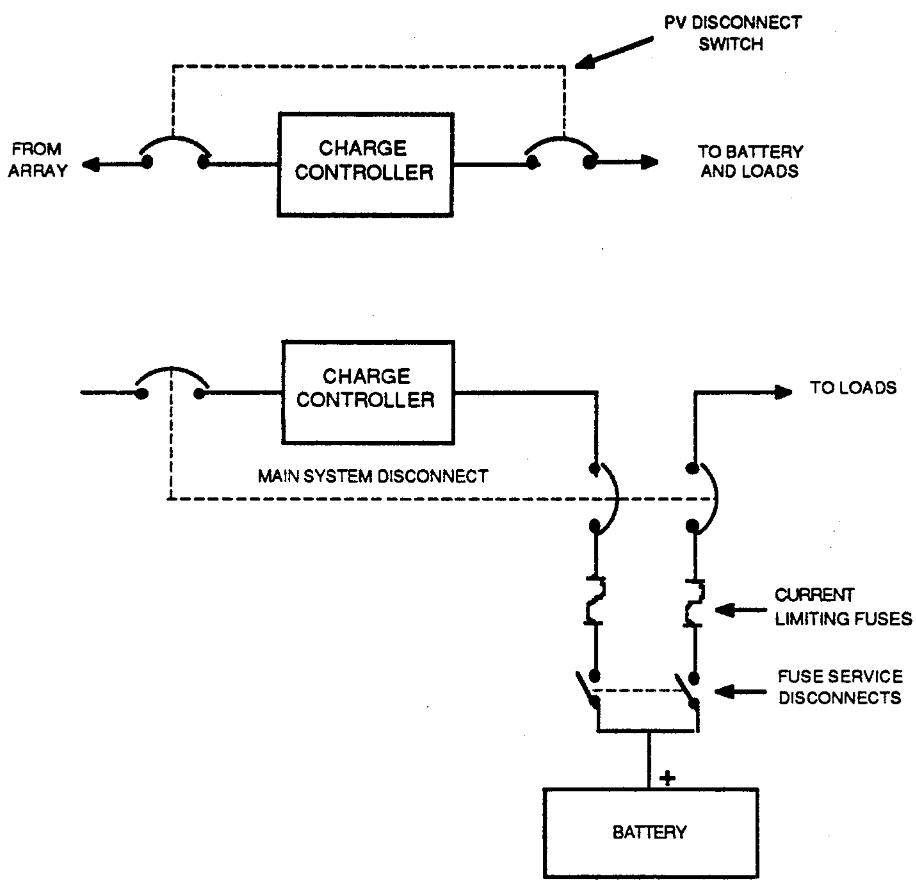



**Figure 17.** Charge Controller Disconnects.

## Multiple Power Sources

When multiple sources of power are involved, the disconnect switches **shall** be grouped and identified [230-72, 690-15]. No more than six motions of the hand **will** be required to operate all of the disconnect switches required to remove all power from the system [230-71]. These disconnects include those for the PV output, the battery system, any generator, and any other source of power. Multipole disconnects or handle ties should be used to keep the number of motions to six or fewer.

## PANEL BOARDS, ENCLOSURES, AND BOXES

Disconnect and overcurrent devices **shall** be mounted in approved enclosures, panel boards, or boxes [240-30]. Wiring between these enclosures **must** be by an *NEC*-approved method [690-13a]. Appropriate cable clamps, strain-relief methods, or conduit **shall** be used. All openings not used **shall** be closed with the same or similar material to that of the enclosure [370-8]. Metal enclosures **must** be bonded to the grounding conductor [370-4]. Use of wood or other flammable materials is discouraged. Conductors from different systems such as utility power, gas generator, hydro, or wind **shall** not be placed in the same enclosure, box, conduit, etc., as PV conductors unless the enclosure is partitioned [690-4b].

When designing a PV distribution system or panel board, an approved NEMA style box and approved disconnect devices and overcurrent devices should be used. The requirements for internal configuration of *NEC* Articles 370, 373, and 384 **must** be followed. Dead front-panel boards with no exposed current-carrying conductors, terminals, or contacts are generally required.

## BATTERIES

Battery storage in stand-alone PV systems poses several safety hazards. In general, *NEC* Articles 480 and 690-71, 72, 73 should be followed. Several hazards are present:

- Hydrogen gas generation from charging lead-acid batteries
- High short-circuit currents
- Acid or caustic electrolyte
- Electric shock potential in higher voltage systems

### Hydrogen Gas

When flooded, non-sealed, lead-acid batteries are charged at high rates or when the terminal voltage reaches about 2.4 volts per cell, the batteries produce hydrogen gas. Even sealed batteries may vent hydrogen gas under certain conditions. This gas, if confined and not properly vented, poses an explosive hazard if exposed to a spark from a charge controller relay or switch or battery-servicing tool. The amount of gas generated is a function of the battery temperature, the voltage, the charging current, and the battery bank size. Hydrogen is a light, small-molecule gas that is easily dissipated. Small battery banks (i.e., 1-8 220-amp-hour, 6-volt batteries) placed in a large room or a well-ventilated area do not pose a significant hazard. Larger numbers of batteries in smaller or tightly enclosed areas require venting. Venting manifolds may be attached to each cell and routed to an exterior location. A catalytic recombiner cap may be attached to each cell to recombine some of the hydrogen with oxygen in the air to produce water. If these combiner caps are used, they will require periodic maintenance. The batteries may be installed in a sealed box, (nearly impossible with hydrogen) and the box vented with a pipe to the outside in a safe location. It is rarely necessary to use power venting [480-8].

Certain charge controllers are designed to minimize the generation of hydrogen gas, but lead-acid batteries need periodic overcharging to equalize the cells. This produces gassing that should be dissipated.

In **no case** should charge controllers, switches, relays, or other devices capable of producing an electric spark be mounted in a battery enclosure or directly over a battery bank. Care **must** be exercised when routing conduit from a sealed battery box to a disconnect. Hydrogen gas may travel in the conduit to the arcing contacts of the switch.

### High Short-Circuit Currents

Batteries are capable of generating tens of thousands of amps of current when shorted. A short circuit in a conductor not protected by overcurrent devices can melt wrenches or other tools, battery terminals and cables, and spray molten metal around the room. Exposed battery terminals and cable connections **must** be protected from accidental contact with metal objects. Live parts of batteries **must** be guarded. Battery voltages **must** be less than 50 volts in dwellings unless certain protective criteria are met [690-71]. This generally means that the batteries should be accessible only to a qualified person. A locked room, battery box, or other container and some method to prevent access by the untrained person should minimize the hazards from short circuits and electric shock. The danger may be reduced if insulated caps or tape are placed on each terminal and an insulated wrench is used for servicing, but in these circumstances, corrosion may go unnoticed on the terminals. The *NEC* requires certain spacings around battery enclosures and boxes to allow for unrestricted servicing. This is generally about three feet [110-16].

### Acid or Caustic Electrolyte

A thin film of electrolyte can accumulate on the tops of the battery and on nearby surfaces. This material can cause flesh burns. It is also a conductor and in higher voltage battery banks poses a shock hazard. It should be removed periodically with an appropriate neutralizing solution. For lead-acid batteries, a dilute solution of baking soda and water works well. A mild vinegar solution works on nickel-cadmium batteries.

Charge controllers are available that minimize the dispersion of the electrolyte at the same time they minimize battery gassing. They do this by keeping the battery voltage from climbing into the vigorous gassing region where the high volume of gas causes electrolyte to bubble out of the cells.

Battery servicing hazards can be minimized by using protective clothing including face masks, gloves, and rubber aprons. Self-contained eyewash stations and neutralizing solution would be beneficial additions to any battery room. Water should be used to wash acid or alkaline electrolyte from the skin and eyes.

### Electric Shock Potential

Storage batteries in dwellings **must** operate at less than 50 volts unless live parts are protected during routine servicing [690-71]. It is recommended that live parts of any battery bank should be guarded [690-71b(2)].

## GENERATORS

Other electrical power generators such as wind, hydro, and gasoline/propane/diesel **must** comply with the requirements of the *NEC*. These requirements are specified in the following *NEC* articles:

| | |
|---|---|
| Article 230 | Services |
| Article 250 | Grounding |
| Article 445 | Generators |
| Article 700 | Emergency Systems |
| Article 701 | Legally Required Standby Systems |
| Article 702 | Optional Standby Systems |
| Article 705 | Interconnected Power Production Sources |

When multiple sources of ac power are to be connected to the PV system, they **must** be connected with an appropriately rated and approved transfer switch. AC generators frequently are rated to supply larger amounts of power than that supplied by the PV/battery/inverter. The transfer switch **must** be able to safely accommodate this additional power.

## CHARGE CONTROLLERS

A charge controller or self-regulating system **shall** be used in a stand-alone system with battery storage. The mechanism for adjusting state of charge **shall** be accessible only to qualified persons [690-72].

Presently, there are no charge controllers on the market that have been tested by *UL* or other recognized testing organizations. Some are scheduled to be tested in the near future.

Any charge controller should be mounted in a listed enclosure with provisions for ventilation. Surface mounting of devices with external terminals readily accessible to the unqualified person will not be accepted by the inspection authority. Dead-front panels with no exposed contacts are generally required for safety. A typical charge controller such as shown in Figure 18 should be mounted in a *UL*-listed enclosure so that none of the terminals are exposed.


**Figure 18.** Typical Charge Controller.

## DISTRIBUTION SYSTEMS

The *National Electric Code* was formulated when there were abundant supplies of relatively cheap energy. As the code was expanded to include other power systems such as PV, many sections were not modified to reflect the recent push toward efficient use of electricity in the home. Stand-alone PV systems **may** be required to have services with 60- to 100-amp capacities to meet the code [230-79]. DC receptacles and lighting circuits **may** have to be as numerous as their ac counterparts [220, 422]. In a small one- to four-module system on a remote cabin or small home, these requirements are overstated, since the power source may be able to supply only a few hundred watts of power.

The local inspection authority has the final say on what is, or is not, required and what is, or is not, safe. Reasoned conversations may result in a liberal interpretation of the code. For a new dwelling, it seems appropriate to install a complete ac electrical system as required by the *NEC*. This will meet the requirements of the inspection authority, the mortgage company, and the insurance industry. Then the PV system and its dc distribution system can be added. If an inverter is used, it can be connected to the ac service entrance. DC branch circuits and outlets can be added where needed, and everyone will be happy. If or when grid power becomes available, it can be integrated into the system with minimum difficulty. If the building is sold at a later date, it will comply with the *NEC* and will have been inspected.

Square D has received a direct current (dc), *UL* listing for its standard QO residential **branch** circuit breakers. They can be used up to 48 volts (PV open-circuit voltage) and 70 amps dc. The AIC is 5,000 amps, so a current-limiting fuse (RK5 type) **must** be used when they are connected on a battery system. The Square D QOM **main** breakers (used at the top of the load center) **do not** have this listing, so the load center **must** be obtained with main lugs and no main breakers (Appendix A).

In a small PV system, a two-pole Square D QO breaker could be used as the PV disconnect (one pole) and the battery disconnect (one pole). Also, a fused disconnect could be used in this configuration. This would give a little more flexibility since the fuses could have different current ratings. Figure 15 on page 41 shows both systems with only a single branch circuit.

In a system with several branch circuits, the Square D load center can be used. A standard, off-the-shelf Square D residential load center without a main breaker can be used for a dc distribution panel in 12- and 24-volt dc systems. The main disconnect would have to be a QO breaker "back fed" and connected in one of the normal branch circuit locations. Since the load center has two separate circuits, (one for each phase) they will have to be tied together to use the entire load center. Figure 19 illustrates this use of the Square D load center.

Another possibility is to use one of the phase circuits to combine separate PV source circuits, then go out of the load center through a breaker for the PV disconnect switch to the charge controller. Finally the conductors would be routed back to the other phase circuit in the load center for branch circuit distribution. Several options exist in using one and two-pole breakers for disconnects. Figure 20 demonstrates this system.

### Interior Wiring and Receptacles

The interior wiring used in a PV system **must** comply with the *NEC*. Exposed single conductors are not permitted--they **must** be installed in conduit. Wires carrying the same current (i.e., positive and negative battery currents) **must** be installed in the same conduit or cable to prevent increased circuit inductances that would pose additional electrical stresses on disconnect and overcurrent devices [300-3(b)]. Nonmetallic sheathed cable may be used and it should be installed in the same manner as cable for ac branch circuits [300, 690-31a]. The bare grounding conductor in such cable **must** not be used to carry current and cannot be used as a common negative conductor for combination 12/24-volt systems [336-25].

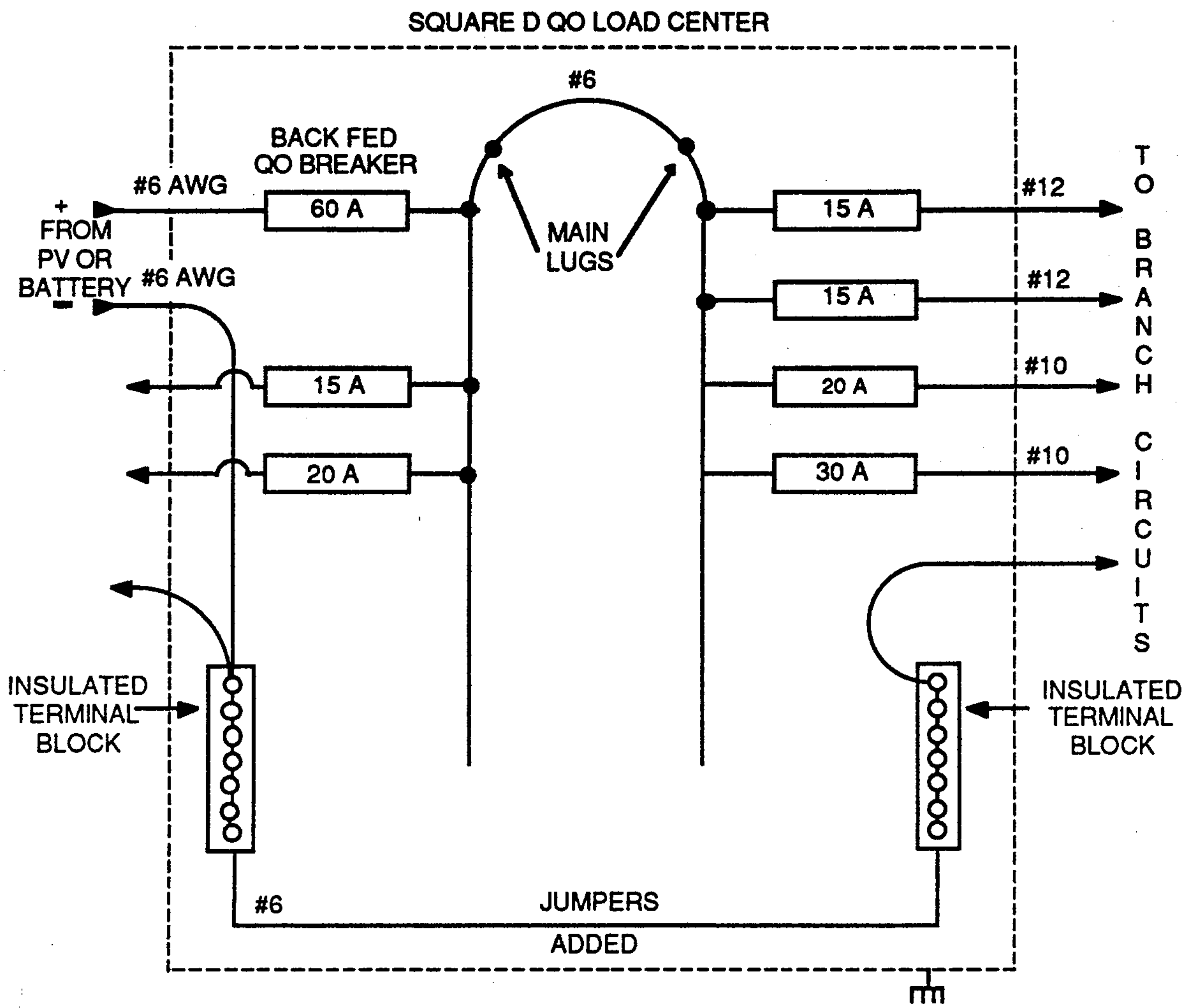



**Figure 19.** DC Load Center.

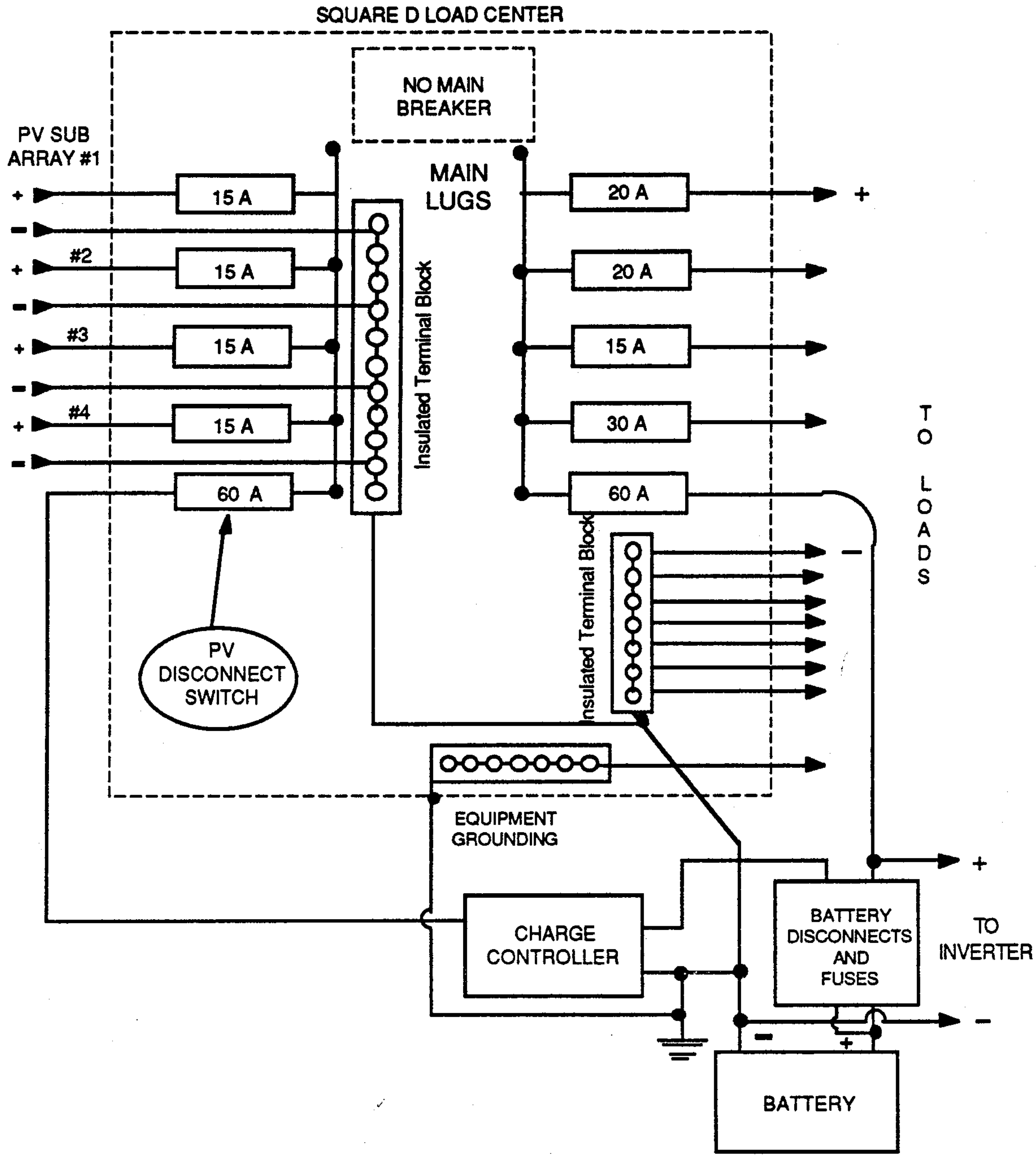



**Figure 20.** DC Combining Box and Load Center.

The receptacles used for dc **must** be different than those used for any other service in the system [210-7f, 551-20f]. The receptacles should have a rating of not less than 15 amps and **must** be of the three-prong grounding type [210-7a, 720-6]. These requirements can be met in most locations by using the three-conductor 15-, 20-, or 30-amp 240-volt ac NEMA style 6-15, 6-20, 6-30 receptacles for the 12-volt dc outlets. If 24-volt dc is also used, the NEMA 125-volt locking connectors, style L5-15 or L5-20, are commonly available. The NEMA FSL-1 is a locking 30-amp 28-volt dc connector, but its availability cannot be determined. Numerous different styles of approved receptacles are available that meet this requirement. Cigarette lighter sockets and plugs frequently found on "PV" and "RV" appliances **do not** meet the requirements of the *National Electric Code.*

It is not permissible to use the third or grounding conductor of a three-conductor plug or receptacle to carry common negative return currents on a combined 12/24-volt system. This terminal **must** be used for equipment grounding and may not carry current except in fault conditions [210-7].

## Smoke Detectors

Many building codes require smoke and fire detectors to be wired directly into the ac power wiring of the dwelling. With a system that has no inverter, two solutions might be offered to the inspector. The first is to use the 9-volt or other primary-cell, battery-powered detector. The second is to use a voltage regulator to drop the PV system voltage to the 9-volt or other level required by the detector. The regulator **must** be able to withstand the PV open-circuit voltage and supply the current required by the detector alarm.

On inverter systems, the detector on some units may trigger the inverter into an "on" state, unnecessarily wasting power. In other units, the alarm may not draw enough current to turn the inverter on and thereby produce a reduced volume alarm or in some cases no alarm at all. Small dedicated power inverters might be used, but this seems a waste of power and reliability when the dc detectors are available.

### Ground-Fault Circuit Interrupters

Some ac ground-fault circuit interrupters (GFCI) do not operate reliably on the output of some non sine wave inverters. If the GFCI does not function when tested, insure that the neutral (white-grounded) conductor of the inverter output is solidly grounded and connected to the grounding (green or bare) conductor of the inverter in the required manner. If this does not result in the GFCI testing properly, other options are possible. A direct measurement of an intentional ground fault may indicate that slightly more than the 5 milliamp internal test current is required to trip the GFCI. The inspector may accept this. Some inverters will work with a ferro resonant transformer to produce a waveform more satisfactory for use with GFCIs, but the no-load power consumption may be high enough to warrant a manual demand switch. A sine wave inverter could be used to power those circuits requiring GFCI protection.

### Interior Switches

Switches rated for ac only **shall** not be used in dc circuits [380-14]. AC-DC general-use snap switches are available on special order from most electrical supply houses and they are similar in appearance to normal "quiet switches." *UL*-listed electronic switches with the proper dc voltage and current ratings might also be used, but the nonstandard appearance may require that the *UL*-listing specifications be provided to the inspectors.

There have been some failures of dc-rated snap switches when used as PV array and battery disconnect switches. If these switches are used on 12- and 24-volt systems and are not activated frequently, they may build up internal oxidation or corrosion and not function properly. Switches in these locations **must** be activated under load periodically to keep them clean.

## SYSTEM LABELS AND WARNINGS

### Photovoltaic Power Source

A permanent label **shall** be applied near the PV disconnect switch that contains the following information: [690-52]

- Operating Current (System maximum power current)
- Operating Voltage (System maximum power voltage)
- Open-Circuit Voltage
- Short-Circuit Current

### Multiple Power Systems

Systems with multiple sources of power such as PV, gas generator, wind, hydro, etc., **shall** have diagrams and markings showing the interconnections [705-10].

### Switch or Circuit Breaker

If a switch or circuit breaker might have its terminals energized in the open position, a label should be placed near it indicating: [690-17]

- WARNING - ELECTRIC SHOCK HAZARD - DO NOT TOUCH - TERMINALS ENERGIZED IN OPEN POSITION

### General

Each piece of equipment that might be opened by unqualified persons should be marked with warning signs:

- WARNING - ELECTRIC SHOCK HAZARD - DANGEROUS VOLTAGES AND CURRENTS - NO USER SERVICEABLE PARTS INSIDE - CONTACT QUALIFIED SERVICE PERSONNEL FOR ASSISTANCE

Each battery container, box, or room should also have warning signs:

- WARNING - ELECTRIC SHOCK HAZARD - DANGEROUS VOLTAGES AND CURRENTS - EXPLOSIVE GAS - NO SPARKS OR FLAMES - NO SMOKING - ACID BURNS - WEAR PROTECTIVE CLOTHING WHEN SERVICING

# APPENDIX A

## Sources of Equipment Meeting the Requirements of

## The *National Electric Code®*

These sources represent a partial list; other sources may exist.

### CONDUCTORS

Standard multiconductor cable such as 10-2 with ground nonmetallic sheathed cable (NM and NMC); underground feeder (UF); larger sizes (6 AWG) single conductor cable; stranded, underground, service-entrance cable (USE); uninsulated grounding conductors; and numerous styles of high-temperature wire for panel wiring can be obtained from electrical supply distributors and building supply stores.

Stranded 10- and 12-gauge USE single conductor cable can be obtained from various wire distributors, including:

Paige Electric Corp.
1071 Hudson Street
P.O. Box 368
Union, New Jersey 07083
(800) 327-2443

Anixter Bros.
2201 Main Street
Evanston, Illinois 60202
Call (800) 323-8166 for the nearest distributor

## MISCELLANEOUS HARDWARE

Stainless steel nuts, bolts and screws, and other hardware; insulated and uninsulated crimp-on terminals, battery terminals, copper lugs for heavy cable, battery cable, weather-resistant cable ties, heat shrink tubing and more.

Chesapeake Marine Fasteners
1805 George Avenue
P.O. Box 6521
Annapolis, Maryland 21401
(800) 526-0658

Dealers price sheet available

Watertight strain reliefs are needed for older ARCO modules and the current production Solarex modules as well as others. The single-conductor versions are hard to find, and the metal types are very expensive. The company listed below makes in plastic those that fit the standard 1/2" electrical knockout (7/8" diameter). Ask for a catalog and information on product 3224 ( for AWG 10) or 3231 (for larger wire). The company also makes UV-resistant black cable ties and copper, heavy-duty lugs, as well as other products that might be useful.

Heyco Molded Products, Inc.
Box 160
Kenilworth, New Jersey 07033
(800) 526-4182 or (201) 245-0033

## DC-RATED FUSES

Battery current-limiting and branch circuit fuses: 0.1-600 amp at 125 and 300 volts dc (125-volt fuse is less expensive)

Use 15, 20, 30 amps and higher rated fuses for branch circuit overcurrent protection depending on conductor ampacity and load. Use larger sizes (100 amp and up) for current-limiting and overcurrent protection on battery outputs.

Littelfuse
Power Fuse Division
800 E. Northwest Highway
Des Plaines, Illinois 60016

Technical Questions to:
Wes Carlson or Holly Ost
(708) 824-1188
1-800-TEC FUSE

**Fuses (Littelfuse Brand)**

Use the following fuses for battery circuit and branch circuit overcurrent protection and current limiting. If transients are anticipated in PV circuits, use these fuses in those locations too.

FLN-R 125 volt dc, RK5 Time delay, current-limiting fuse .1-600 amp

FLS-R 300 volt dc, RK5 Time delay, current-limiting fuse .1-600 amp

Use the following fuses for PV source circuit protection if you anticipate no problems with transients. They may also be used inside control panels to protect relays and other equipment.

KLK-D Fast-acting, current-limiting midget fuse .1-30 amp

Fuse Holders **(Also See Fused Disconnects)**

For FLN-R and FLS-R, use LR-series fuse blocks matching the voltage rating and current rating of the selected fuse (Littlefuse Types).

For midget fuses use L60030M (Littlefuse) series with the number of poles and lugs desired. NOTE: Other fuse manufacturers make fuses with similar ratings and test them for dc use--but they presently do not have *UL* listing.

Marathon Special Projects also makes suitable fuse holders. Ask for information and distributors of Class R and Class M (midget fuse holders). The company also makes power-distribution blocks for control panels.

Marathon Special Products
P.O. Box 468
Bowling Green, Ohio 43402
(419) 352-8441

**Fused Disconnects (Also See Circuit Breakers)**

Since fuses **must** not have power applied to either end for servicing, a combination switch and fuse can be mounted in a single enclosure to meet some if not all of the requirements.

Siemens I-T-E
Siemens Energy & Automation, Inc.
3333 State Bridge Rd.
Alpharetta, Georgia 30201

Call 404-751-2000 for nearest regional sales office that can direct you to a stocking distributor

Indoor fused switches, 250-volt dc--JN and JF series

Outdoor fused switches, 250-volt dc--NR and FR series

Square D Company
Palatine, Illinois

Contact your nearest Square D electrical supply distributor

Indoor fused switches
250-volt-dc--H22x, H32x, and H42x series
600-volt-dc--H26xx and H36xx series

Outdoor fused switches
250-volt-dc--H22xR, H32xR, and H42xR series
600-volt-dc--H26xR and H36xR series

## CIRCUIT BREAKERS

Square D Company
Palatine, Illinois

Contact the nearest Square D electrical distributor

Square D QO circuit breakers (these are the common ac residential breakers). *UL*-listed at 5000 AIC at 48 volts dc; 1 and 2 pole, 10-70 amps; 3 pole, 10-60 amps

Square D FA circuit breakers; 125- and 250-volt dc ratings, multiple currents

Enclosures for QO breakers

2 and 3 pole units
Indoor QO21xxBN, QO3100BN
Rainproof QO21xxBNRB, QO3100BNRB

Load Centers

Any of the load centers for QO breakers without main breakers may be used--ask for main lugs instead.

Heinemann Electric Company
P.O. Box 6800
Lawrenceville, New Jersey 08648-0800
(609) 882-4800

Call for nearest source and catalog

Applications engineering available

Full line of dc-rated, *UL*-listed and recognized circuit breakers, but they **must** be mounted in custom-built enclosures. (You punch the metal).

CD-CE-CF 5000 AIC at 125-volt dc, 15-110 amp

25,000 AIC available on special order. Ask for polyester case, spun rivets and *UL*-listed units.

GH 10,000 AIC at 250-volts dc, 15-100 amp

GJ 10000 AIC at 250-volts dc, 100-250 amps and others

Airpax Corporation
P.O. Box 520
Cambridge, Maryland
(301) 228-4600

Call for nearest source and catalog. Applications engineering available.

Full line of dc-rated, *UL*-listed and recognized circuit breakers, but they **must** be mounted in custom-built enclosures.

ENCLOSURES AND JUNCTION BOXES

Indoor and outdoor (rainproof) general-purpose enclosures and junction boxes are available at most electrical supply houses. These devices usually have knockouts for cable entrances, and the distributor will stock the necessary bushings and/or cable clamps. Interior component mounting panels are available for some enclosures, as are enclosures with hinged doors. For visual access to the interior, NEMA 4x enclosures are available that are made of clear, transparent plastic.

## APPENDIX B

### Examples of Various PV Systems

These examples show some of the ways PV systems might be connected to meet the requirements of the *National Electric Code*. The examples are presented for reference only and may require modification to meet site-specific and local jurisdiction requirements.

Figure B-1 shows a self-contained assembly with no external connections or user access to the electrical conductors. Such a unit might be an attic ventilation fan or a circulating pump on a domestic hot water system and might have *UL* certification as a unit. No disconnect switches or overcurrent devices would be required in a properly designed unit, although an on-off switch might be desired. This unit would also not have any exposed metal surfaces that might come in contact with internal live parts and therefore would not require a grounding conductor.

A system with external connections and wiring for a direct-drive load may or may not require disconnects and overcurrent protection. It depends on the design and the accessibility of live contacts.

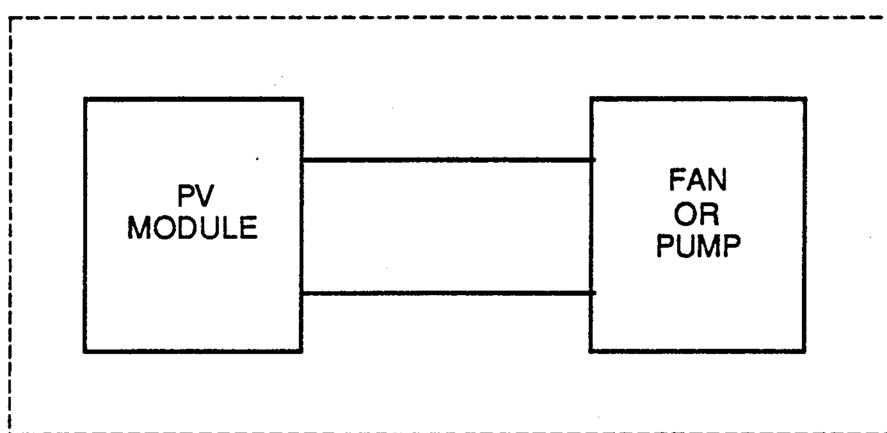



**Figure B-1.** Totally Self-Contained System.

It would be possible to design connectors that had no exposed live contacts for such a system, and the code-required disconnects could be managed by unplugging the connectors. If all components and conductors were sized to handle 125-150 percent of the PV short-circuit current, overcurrent devices might not be required. Such a system might look like Figure B-2.

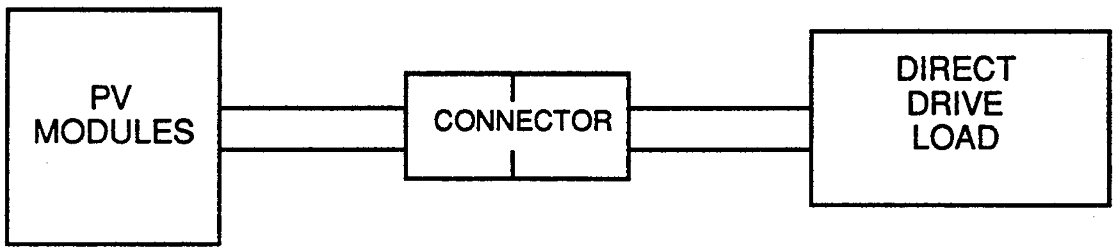



**Figure B-2.** Direct-Drive System--No Live Contacts.

As the system becomes more complex with battery storage, additional articles of the *NEC* will apply. Multiple component systems with modules, charge controllers, and batteries imply that external wiring will be needed and service will be required periodically. The *NEC* dictates the disconnects and various other protective devices. Figure B-3 illustrates some of the safety and performance requirements for a small stand-alone system.

In Figure B-3, the conductors are sized for the needed ampacity and to minimize voltage drop. The length of the wire and its resistance are calculated to keep potential short-circuit currents to a level that does not exceed the AIC of the circuit breakers. The battery bank will also be on the small side and most likely will be a sealed maintenance-free unit, further lowering the available short-circuit currents. Each circuit breaker might be replaced by a fuse and a switch, if care were

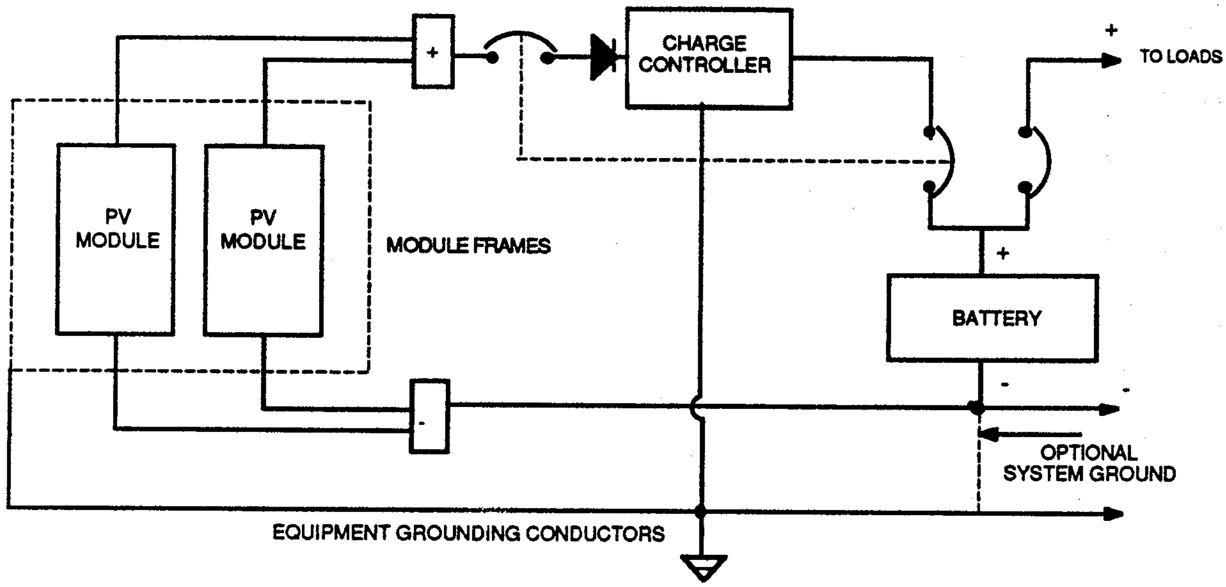



**Figure B-3.** Small System.

taken to insure that fuses could be serviced only when dead on both ends. Some charge controller designs may alleviate the need for the blocking diode. Note the method of connecting modules in parallel so one can be disconnected without disturbing the grounded conductor (if the system is grounded) of the other. Equipment grounds and three wire cables are needed to each load.

In medium-size systems where multiple strings of modules are connected in parallel, attention should be given to blocking and bypass diodes. Modules may or may not have internal bypass diodes to overcome problems caused by shaded cells, and the manufacturer's recommendations should be followed in this area. Blocking diodes not only prevent batteries from discharging into the array at night, but prevent parallel strings of modules from forcing current into shaded strings. Figure B-4 illustrates disconnects, overcurrent protection, short-circuit protection and diodes for a 1,500-watt stand-alone system. In very large arrays, blocking diodes might also be used at both ends of strings to prevent ground-fault currents from circulating.

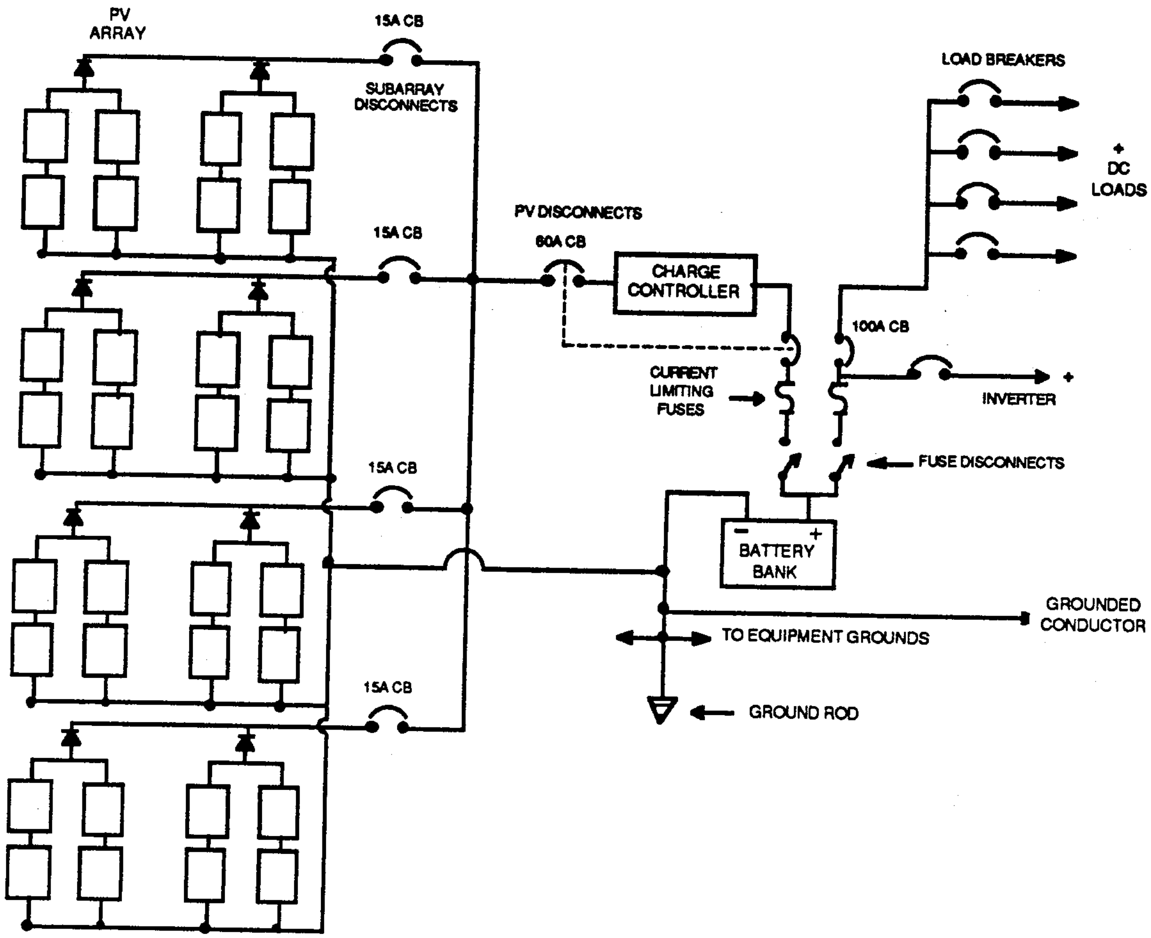



**Figure B-4.** Medium-Size Stand-Alone System.

Figure B-5 shows the use of blocking diodes on each end of long high-voltage strings of modules to prevent reverse biasing of the entire string when shaded. Normally only one diode would be used, but the use of one at each end of the string will serve to minimize the possibility of circulating ground fault currents should they occur in high-voltage arrays.

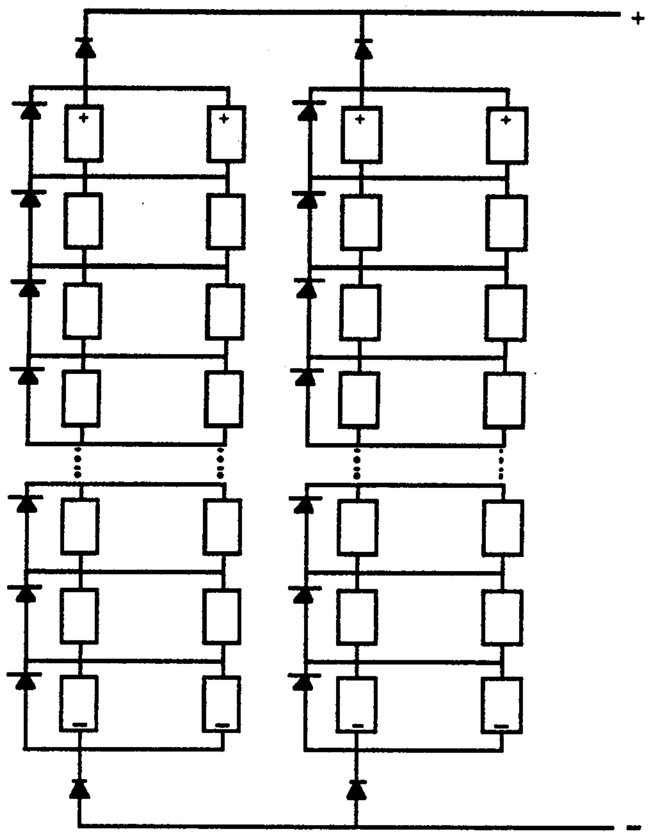



**Figure B-5.** Blocking and Bypass Diodes on Large Systems.

The cost of and the power lost in the blocking diodes **must** be weighed against the potential for damage if they are omitted. Bypass diodes protect individual modules or sets of parallel modules from the effects of shading.

On systems larger than about 2 kW and systems with array voltages greater than about 200 volts, careful attention **must** be given to system grounding, ground fault protection, and system disconnects. Tradeoffs **must** be made between cost, safety, component and system reliability, and component availability. These tradeoffs can only be made on a site by site basis and need to be made by an engineer experienced in dc power systems.

# Appendix C

# Gardner Project

# Information

Date: July 5, 1992

TO:
Publisher
Electric Power Research Institute
3412 Hillveiw Avenue
Palo Alto, California 94304

FROM:
Mehmet H. Duymazlar
10 Sudbury Drive
Nashua, New Hampshire 03062
(603) 891-2469

Dear Publisher,

I am writing to you to ask permission to reproduce some tables and figures from one of EPRI publications. Shira McWaters and I are students working on our IQP (Interactive Qualifying Project) at Worcester Polytechnic Institute. We are writing a report, for homeowners to understand photovoltaics and how to design a system for themselves, this report will also incorporate two chapters on the New England Electric Systems' solar photovoltaics project in Gardner, Massachusetts. This report will not be published, it will be completed for a grade and in part of qualification to graduate.

The report that we would like to reproduce the tables and figures for is

EPRI G-S 7227
Project 1607-15
Final Report
July 1991

This report was prepared by Ascension Technology, INC. of Lincoln Center, Massachusetts.

The figures, tables and there respective pages that would like to be reproduce are as follows:

In Body of report,
Figure 1-1 Three residential PV system metering options
Figure 1-2 Example of cumulative energy for three metering methods
Figure 2-2 Wiring and physical layout of the Gardner arrays
Figure 2-10 Hourly PV generation and NEES system load on August 10, 1988
Figure 2-12 Monthly energy production in 1988 for all 30 Gardner PV systems

In Appendix of the report,
Table 2-1 Information on the NEES Gardner PV demonstration project
Table 2-2 Gardner PV modules and array characteristics
Table 2-3 Gardner power conditioner characteristics

Thank You
Sincerely Yours,
Mehmet H. Duymazlar

Mehmet H. Duymazlar
Student, WPI

**Table 2-1**

INFORMATION ON THE NEES GARDNER PV DEMONSTRATION PROJECT

| | |
|---|---|
| **Project Data** | |
| Number of Residential PV Systems: | 30 |
| Site: | Gardner, MA |
| Latitude: | 42.6° North |
| Longitude: | 71.9° West |
| Elevation: | 1,000 ft. |
| First System Turn-on: | October 1985 |
| Final System Turn-on: | September 1986 |
| **Instrumentation (as of 1/90)** | |
| Interval Demand Meter (AC output of all 30 PV systems) | GE TMR82 |
| Ratcheted kWh Meter (Outgoing energy from all 30 residences) | |
| **Organizations Involved** | |
| Project Sponsor | New England Electric System (Westborough, MA) |
| PV System Designers | Mass. Institute of Technology (Cambridge, MA) |
| PV System Construction | Solar Design Associates (Harvard, MA) |
| Host Utility Company | Massachusetts Electric Company (Westborough, MA) |
| Hardware Suppliers | |
| PV Modules | Mobil Solar Energy Corporation (Billerica, MA) |
| Power Conditioners | American Power Conversion (Burlington, MA) |
| Balance of Systems | Ascension Technology, Inc. (Lincoln Center, MA) |

Prepared By Edward C. Kern Jr., Ph.D. and Miles C. Russell,
Ascension Technology, Inc. For EPRI.

**Table 2-2**

GARDNER PV MODULE AND ARRAY CHARACTERISTICS

| | |
|---|---|
| **PV Module Physical Data** | |
| Manufacturer | Mobil Solar Energy Corporation |
| Model Number | RA-180 |
| Date of Manufacture | 1985/86 |
| Frame Type | Perimeter aluminum, painted |
| Module Width | 47.875 inches |
| Module Length | 71 inches |
| Frame Thickness | 2 inches |
| Weight | 75 lbs |
| Solar Cell Technology | EFG ribbon silicon |
| Solar Cell Shape, Size | Rectangle, 2-in x 4-in |
| Number of Solar Cells | 432 |
| Series | 108 |
| Parallel | 4 |
| **PV Module Specifications*** | |
| Rating Conditions | 1,000 W/m$^2$ irradiance<br>25 C cell temperature |
| Open-circuit Voltage | 62.1 Volts DC |
| Max-power Voltage | 50.0 Volts DC |
| Max-power Current | 4.4 Amps DC |
| Short-circuit Current | 4.9 Amps DC |
| Rated Power | 220 Watts DC |
| Fill Factor | 0.72 |
| **PV Array Physical Data** | |
| Number of PV Modules | 10 |
| Series | 5 |
| Parallel | 2 |
| Mounting Method | Standoff, over asphalt shingles |
| PV Array Width | 21 feet |
| PV Array Slope Height | 12 feet |
| Tilt Angle | 18.5° to 28° |
| Azimuth Orientation | 170° to 245° True (180° = due South) |

* Values obtained from manufacturer's literature

Prepared By Edward C. Kern Jr.,Ph.D. and Miles C. Russell,
Ascension Technology,Inc. For EPRI.

**Table 2-3**

GARDNER POWER CONDITIONER CHARACTERISTICS

| | | |
|---|---|---|
| **Power Conditioner Physical Data** | | |
| Manufacturer: | American Power Conversion | Omnion |
| Now Installed: | 29 units | 1 unit |
| Model Number: | Sunsine™ UI-2000C | Series 2200 |
| Manufacture Date: | 1985/86 | 1989 |
| Height: | 17 inches | 16 inches |
| Width: | 13 inches | 12 inches |
| Depth: | 10.3 inches | 9 inches |
| Weight: | 97 lbs | 42 lbs |
| Mounting Method: | Wall mount | Wall mount |
| Mounting Location: | Basement or garage, typ. | Garage |
| **Power Conditioner Ratings** | | |
| DC Input Power | 2,000 W DC | 2,200 W DC |
| Nominal Input Voltage | 215 Volts DC | ±225 Volts DC |
| PV Array Voltage Control | Max Power Track | Max Power Track |
| Tracking Range | 209 - 270 V DC | ±200 - 250 V DC |
| AC Output Power | 1,800 Watts AC | 2,000 Watts AC |
| AC Output Current | 7.5 A (max.) | 16.7 A (max.) |
| AC Output Voltage | 240 Volts AC | 120 Volts AC |

Prepared By Edward C. Kern Jr.,Ph.D. and Miles C. Russell,
Ascension Technology,Inc. For EPRI.

# Ra180

Mobil Solar's large-area, high power Ra180 solar photovoltaic module simplifies installation and increases reliability and efficiency in medium to large sized photovoltaic (solar electric) systems. Rated at 220 watts and available in 12, 24, 36 and 48 volt configurations, the Ra180 module offers exceptional flexibility in system design. Mobil Solar has designed easy and economical methods for both roof integration (in new construction) and stand-off mounting. A solid, deep blue Ra180 array is an attractive element in residential architecture, and the module is equally well-suited for large-scale commercial and utility applications because of its high efficiency, reliability and low installation costs.

## MODULE FEATURES

- 220 watts peak power at 12, 24, 36 or 48 volts (nominal);
- 432 silicon ribbon solar cells in one module;
- Standard module is unframed for roof integration in new construction;
- Attractive, durable aluminum frame available for stand-off or rack mounting;
- Junction boxes protect electrical connections and simplify installation and maintenance;
- Bypass diode protection in junction box for 24, 36 and 48 volt modules;
- AMP Solarlok® harnesses available (optional) for quick and flawless wiring.

## DESIGN FEATURES

The Ra180 module minimizes the expense of installing your photovoltaic array, while enhancing the design flexibility and performance of the system.

### Economical Installation

The high power of the Ra180 module simplifies the installation of a photovoltaic array. Because an array requires fewer Ra180 modules than lower-power modules, the physical installation and electrical connection time are shortened significantly.

In addition, this decrease in the number of individual modules greatly reduces other balance-of-system costs (frame, support structure, wiring and hardware).

### Efficient and Reliable Performance

An array of Ra180 modules requires fewer external electrical connections than an array of lower power modules. The Ra180 module enhances the reliability of the photovoltaic array because the fewer interconnections minimize any potential connector deterioration. In particular, the high-voltage Ra180s (which have lower current) greatly reduce the potential power losses ($I^2R$) and improve efficiency.

For example, a typical utility interactive system with a 2.2kW array requires only ten 36 volt Ra180 modules (five modules in a series string). In contrast, an array of the same power consisting of 12 volt, 36 watt modules would require a total of 60 modules (15 in a series string). The additional external connections (six times as many) of the latter array result in lower efficiency and reliability. In large-scale systems, the advantage of the high power Ra180 module is even more marked.

### Flexible System Design

The Ra180 module increases the flexibility in designing a photovoltaic system with maximum efficiency and reliability. For instance, in systems that require a DC to AC inverter, modules are wired in series/parallel combinations to provide an optimum voltage and current for the inverter. Because the Ra180 has four available voltages, there are more options for wiring a system to match a particular inverter's requirements.

## MOUNTING METHODS

The Ra180 module can be mounted conveniently and economically whether you are constructing a new building with roof-integrated modules, adding a solar electric array to the roof of an existing building, or installing an array on the ground.

### Roof Integration

The Ra180 module is ideal for roof-integrated mounting in new construction. The size of the module, approximately 4′ by 6′, enables it to be mounted directly onto roof trusses or rafters spaced 24 or 48 inches on-center. The modules then become the roof surface. The savings in roofing materials can offset substantially all of the labor cost of installing the photovoltaic array.

This mounting method uses unframed Ra180 modules and requires no support structure for the array other than the roof rafters of the building. Weatherproof battens between modules provide a permanent seal from rain, ice and snow.

Roof-integrated modules are accessible from the back for ease of wiring, inspection and maintenance. In addition, the back of the array can be passively cooled from the building's interior, reducing the temperature of the module's solar cells and thus maintaining their efficiency and electrical output.

### Stand-off Mounting

An array of Ra180 modules can be mounted on the roof of an existing building more economically than an equivalent system using smaller, lower power modules. The large size of the Ra180 modules reduces the amount of required supporting material and roof penetrations, while Mobil Solar's convenient stand-off mounting system minimizes costly installation time and labor. For example, four workers can mount and wire a stand-off system of ten Ra180 modules in about two hours.

For stand-off mounting, Ra180 modules are framed and then attached to the roof by means of roof jacks. This mounting method requires no additional support structure, and is designed to withstand wind speeds of up to 120 mph.

The frame on the Ra180 is made of durable aluminum with a handsome flat black finish for trouble-free service in all environments. The roof jacks are made of black galvanized steel and are electrically isolated from the aluminum frame to prevent corrosion.

### Large-Area Array Mounting

Ra180 arrays can also be mounted on the ground or on flat surfaces. A custom mounting structure can be designed for individually framed Ra180 modules.

## MODULE CONSTRUCTION

Mobil Solar modules perform reliably in extreme environments and adverse weather conditions, with a life expectancy of twenty years or more. The front of the module is tempered, low-iron glass that provides excellent light transmission as well as protection from the environment. The back of the module is a multi-layered weather barrier of Tedlar® film, metal foil and polyester. In the middle, the solar cells are cushioned and sealed between layers of ethylene vinyl acetate (EVA).

Mobil Solar's silicon ribbon solar cells provide a reliable and stable electrical output, even after years in direct sunlight. Modules are constructed with redundant electrical interconnections between solar cells for increased reliability.

## QUALITY GUARANTEE

All Ra180 modules undergo strict quality control throughout the manufacturing process. Each finished module is carefully inspected and tested to assure that you receive a superior product.

Mobil Solar guarantees power output of each module for a period of 5 years from the date of shipment. Complete details of Mobil Solar's Limited Warranty are available upon request.

## Ra180
## ELECTRICAL CHARACTERISTICS

| Ra180 Module (Vno) | Peak Power (Pm) | Peak Voltage (Vm) | Peak Current (Im) | Open Circuit Voltage (Voc) | Short Circuit Current (Isc) | Series × Parallel Cells (432) |
|---|---|---|---|---|---|---|
| **12 Volt** | 220W | 16.5V | 13.3A | 20.7V | 14.7A | 36 × 12 |
| **24 Volt** | 220W | 33.3V | 6.6A | 41.4V | 7.4A | 72 × 6 |
| **36 Volt** | 220W | 50.0V | 4.4A | 62.1V | 4.9A | 108 × 4 |
| **48 Volt** | 220W | 66.5V | 3.3A | 82.8V | 3.7A | 144 × 3 |

**Values obtained at Standard Test Conditions:**
Cell Temperature = 25 °C  Air Mass = 1.5  Insolation = $1000 W/m^2$

**Temperature Coefficients:** Isc = 1.2mA/ °C/Cell(Parallel)
Voc = −2.18mV/ °C/Cell(Series)

## Ra180
## MECHANICAL CHARACTERISTICS

| | Unframed | | Framed | |
|---|---|---|---|---|
| **Width** | 47.4″ | (1.20m) | 47.9″ | (1.22m) |
| **Length** | 70.5″ | (1.79m) | 71.0″ | (1.80m) |
| **Thickness*** | 2.0″ | (0.05m) | 2.0″ | (0.05m) |
| **Weight** | 65lb | (29.5kg) | 72lb | (32.7kg) |

* with Junction Box

The information contained in this data sheet concerns products that are subject to change. Mobil Solar Energy Corporation reserves the right to make changes to the products referred to herein and does not assume any liability arising out of the application or use of the products described herein.

**For Further Information:**

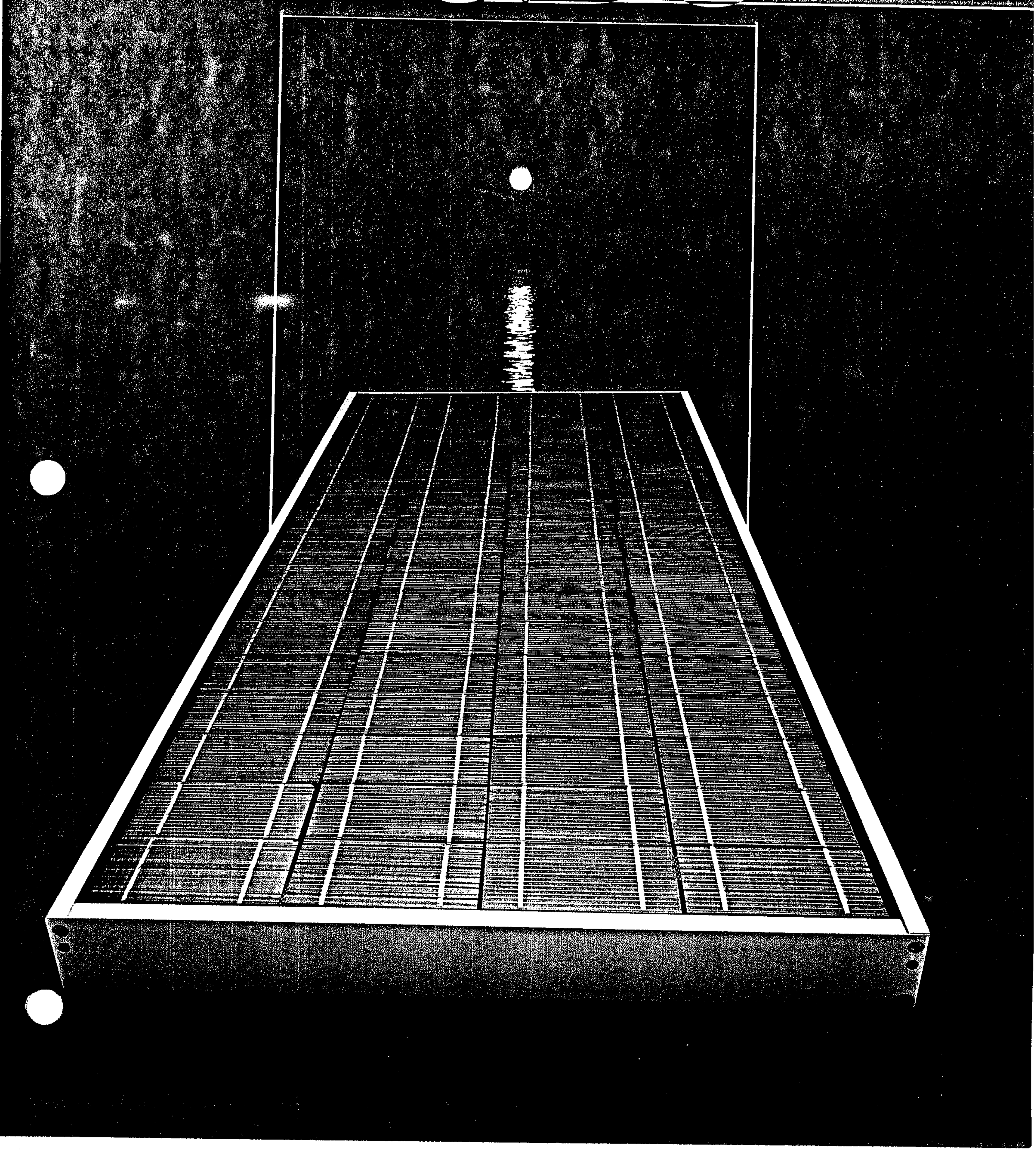
# Mobil Solar Energy Corporation

Subsidiary of Mobil Oil Corporation
*16 Hickory Drive, Waltham, Massachusetts 02254 U.S.A (617) 890-1180 Telex: 951272 MOBILSOLAR WHA*



Printed in U.S.A. (2/86) 1k

# Ra30



The Ra30 is the latest Mobil Solar Energy Corporation (MSEC) high performance, ribbon photovoltaic (PV) module. Employing solar cells manufactured by Mobil Solar's Edge-defined, Film-fed Growth (EFG) technology, MSEC has established state-of-the-art PV modules.

The rectangular solar cells produced by this technology allow the highest packing density for maximum power output per unit area, adding to the aesthetically superior appearance of the deep blue color. Designed to exceed JPL (Jet Propulsion Laboratory) Block V performance criteria, the Ra30 is of rugged, maintenance-free construction. Convenient module size allows easy one-person installation.

## MODULE FEATURES *(See FIGURE 1)*

- Typical electrical performance:

| | |
|---|---|
| Peak power (watts) | 30.0 |
| Open circuit voltage (volts) | 18.9 |
| Peak power voltage (volts) | 15.5 |
| Short circuit current (amps) | 2.2 |
| Peak power current (amps) | 1.9 |

- 12-volt (nominal) configuration (6-volt module available on special order)
- Dimensions - inches (millimeters)
  (Thickness X Width X Length)
  unframed: 1.0* (25.4) X 16.0 (406.4) X 35.5 (901.7)
  framed: 2.0 (50.8) X 16.2 (411.5) X 35.7 (906.8)
  *1" thickness includes termination studs
- Weight - lbs. (kilograms)
  unframed: 8.4 (3.8)
  framed: 9.0 (4.1)
- Designed to withstand wind loading of up to 50 psf (125 mph)
- Two parallel strings of 36 series connected cells (72 cells total)
- Ground continuity; less than 1 ohm between all metallic surfaces
- Module leakage current; less than 50µA at 3000 Vdc.

## APPLICATIONS *(See FIGURE 2)*

Mobil Solar's ribbon photovoltaic modules are presently being used in a wide variety of applications, from stand-alone remote systems to grid-connected residences. Typical applications include:

- Remote Communications
- Cathodic Protection
- Water Pumping
- Desalination
- Remote Lighting
- Remote Home Electrification
- Grid-Connected Residences
- Navigational Aids



**Figure 1: Ra30 Module**

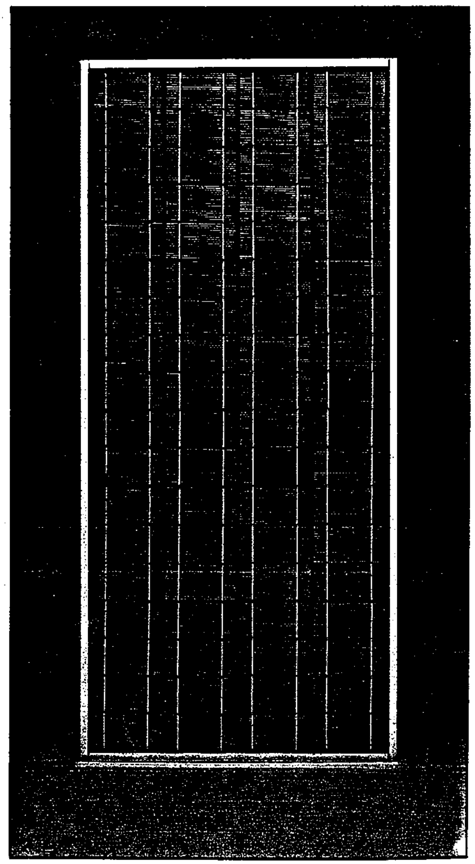


**Figure 2: Remote Lighting: One Ra30 Module Powers a 12 Volt, 18 Watt Fluorescent Light**

## UNSURPASSED MODULE CONSTRUCTION *(See FIGURE 3)*

### Cells

The cell is the basic module building block. Mobil Solar's proprietary cell processing and metallization technology assures a permanent ohmic bond between the ribbon cell and the cell-to-cell interconnecting material. Within the module, electrically matched silicon solar cells are interconnected with multiple bus bar contacts for increased circuit reliability. Redundant electrical paths within cell strings reduce the possibility of power loss resulting from the unlikely event of cell cracking.

The cell grid pattern, designed by computer, is optimized for low resistance and minimum cell shading. An anti-reflection coating enhances light absorption (and, hence, power generation). Ribbon cells convert both direct and diffuse light efficiently, producing power even on cloudy days (proportionate to sunlight intensity).

MSEC ribbon cells are highly resistant to degradation with a metallization system highly tolerant of corrosive environments, moisture, humidity and air. Cells are protected by sandwiching layers of tempered glass, polymeric encapsulant, a weather barrier of polyester, metal foil and Tedlar® back surface which provides an expected useful life in excess of 20 years.

### Glass

The front surface of the Ra30 module is tempered, low-iron glass. This surface provides for both optimum transmission of light and protection of cells from physical impact and adverse weather conditions.

In most environments it has been shown that glass possesses self-cleaning properties, easily cleaned by rain and wind. In all but extreme cases, snow will melt and slide from the module surface within a few hours.

### Laminating Encapsulant

Beneath the glass, the solar cells are permanently sealed between layers of ethylene vinyl acetate (EVA). The EVA has been specially formulated for the PV industry with the addition of UV stabilizers, anti-oxidants and cross linkage agents which maintain the thermo-setting properties of this plastic in a variety of harsh environments. EVA cushions the cells from thermal stress, and produces a superior optical coupling between cells and the glass.

"Ra" modules are laminated in the world's largest, microprocessor-controlled photovoltaic module lamination chambers. State-of-the-art technology is continually being applied in all phases of module production.

### Module Backskin

Layers of polyester, aluminum foil and Tedlar® provide the finishing protection to the Ra30. The polyester, a thermo-setting plastic, acts as an electrical insulator between the solar cells and the metal foil layer. Like the foil used to protect food products containing no preservatives, (packages of peanuts, for instance) the metal foil layer provides a positive moisture barrier. The final Tedlar® layer was selected for its proven weatherability. Tedlar® is scratch resistant and has been proven in such applications as aircraft interiors, automobile trim and home siding.

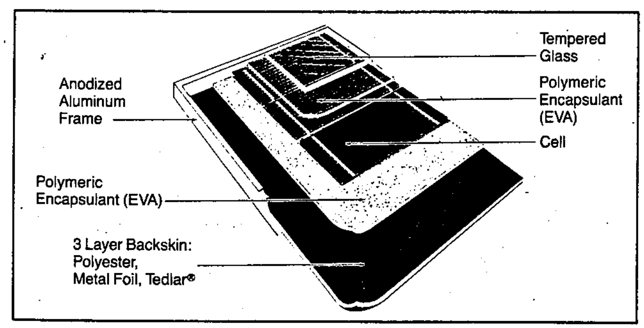



**Figure 3: Ra30 Module Cross Section**

## Frame

The Ra30 module frame is a strong, four-piece, eight-screw assembly constructed of anodized aluminum, designed for long, trouble-free service in all environments. This frame has been carefully designed to provide the necessary structural support for the module and provides an inexpensive "mating" with a variety of array support structures.

Module frames are electrically connected to the foil barrier within the module, thus reducing the likelihood of a possible shock hazard situation in a high voltage system.

As optional equipment, Mobil Solar has available a variety of arraying structures allowing any number of Ra30 modules (from 2 to 10) to be assembled together into a "panel" or "array". Along with these structures, mounting hardware is available to complete your system installation.

## Electrical Terminations

Wiring the module is accomplished by connecting wires to the positive and negative threaded posts on the back of the Ra30. The threaded module termination posts are made of tin-plated brass, protected by an industrial plastic sleeve; screws in the termination posts are stainless steel. These posts are highly resistant to corrosion. This termination was selected for its versatility and compatibility with numerous types of connectors.

## Junction Box

To protect electrical connections from extreme environments, a junction box (J-Box) is factory installed on each Ra30 module. (Modules without junction boxes are available on special order only). Constructed of Xenoy, the J-Box is impact resistant and will not shrink or deform under high temperature (90°C) conditions as required by JPL Block V specifications. This junction box has been designed for easy wiring access. It is securely fastened to the back side of the module, over the threaded termination studs. *(See FIGURE 4)* The cover to the box, secured to the box with a gasket and four corner screws, is easily removed for access to the termination studs.

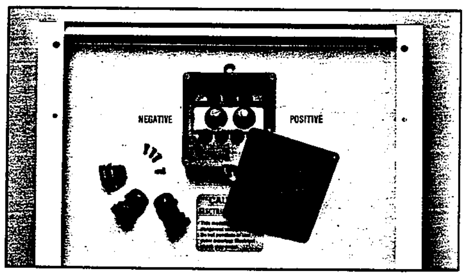
The junction box was designed to accommodate optional bypass diodes and the attachment of output wires via the standard HEYCO® fitting or optional connector. *(See MODULE OPTIONS)*

## Wiring and Connectors

Each Ra30 module is supplied with a pair of HEYCO® strain relief fittings allowing a variety of wire sizes to be connected directly to the screws in the threaded termination studs. *(See FIGURE 4)* Wiring requires no special tooling. These fittings allow liquid-tight strain relief and are suitable for both series and parallel connections.

Optional AMP® SOLARLOK receptacles are available on special order. *(See MODULE OPTIONS)*

**Figure 4: The Ra30 is Supplied with Electrical Stud Terminations, Junction Box, Two Heyco Fittings and One Plug**




# ELECTRICAL CHARACTERISTICS

**Figure 5: Electrical Outputs at Standard Test and Normal Operating Conditions**

| Condition Air Mass 1.5 | $I_{SC}$ Typ (A) | $I_M$ @ $V_{NO}$ Typ (A) | $I_M$ @ $V_{NO}$ (V) | $V_{OC}$ Typ (V) | $P_M$ (W) Min | $P_M$ (W) Typ |
|---|---|---|---|---|---|---|
| (Standard Test) $T_C$ = 25°C, 1000W/m² | 2.2 | 1.94 | 15.5 | 18.9 | 27.0 | 30.0 |
| (Normal Operating) $T_A$ = 20°C, $T_C$ = 46°C, 800W/m² | 1.8 | 1.60 | 13.5 | 17.0 | 19.3 | 21.4 |

Temperature Coefficients
TC $I_{SC}$ = 1.60 mA/°C/Cell (Parallel)
TC $V_{OC}$ = −2.18 mV/°C/Cell (Series)

$I_{SC}$ = Short Circuit Current, Amps DC
$V_{OC}$ = Open Circuit Voltage, Volts DC
$V_{NO}$ = Nominal Operating Voltage, Volts DC, is the Reference Voltage Level at which the Modules are Designed to Provide Maximum Power Output at Specified Operating Conditions.
$I_M$ = Current, Amps DC, Measured at $V_{NO}$
$P_M$ = Rated Power, Watts, Measured at $V_{NO}$
$T_A$ = Ambient Temperature, °C
$T_C$ = Cell Temperature, °C

This document contains information on a new product. Mechanical & electrical information is subject to change without notice.



## I-V Curves

*I-V Curves* (current-voltage) characterize the performance of the Ra30 module under various conditions of sunlight and temperature to aid the system designer in calculating the performance of the module under a wide range of conditions encountered in the field. These curves also show that modules have been designed to properly charge batteries under worst case temperature conditions.

I-V curves relate the module's current to operating voltage. This is important for system sizing since a certain current at a given voltage is required to satisfy system requirements.

*Figure 6* shows the effect of insolation (sunlight intensity) on module performance. The current decreases in proportion to the insolation, but the peak power voltage and open circuit voltage change very little. This is an important factor to consider in the sizing of battery charging systems.

The module voltage will remain high enough to charge the battery even when the insolation level is low.

There is a "best" operating voltage which provides the most power under a given set of sunlight and temperature conditions. This occurs at the "peak power point" or "knee" of the I-V curve. MSEC has taken great care in the design of the Ra30 module to make sure the peak power point falls at the optimum voltage for charging a 12 volt lead acid battery.

*Figure 7* illustrates the effect that temperature has on solar modules. Notice that the current of the module increases by 0.1% for each degree Celsius increase in temperature. The voltage decreases by 0.4%/°C as temperature increases. This effect must be considered when computing the expected performance of a module under temperature conditions that differ from its rating conditions.

**Figure 6: Ra30-12 Characteristics vs. Sunlight Intensity**

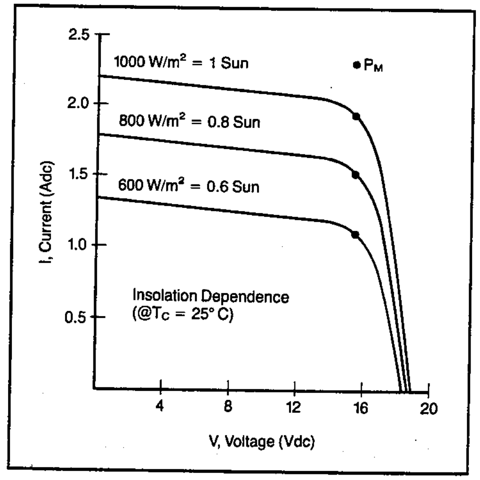
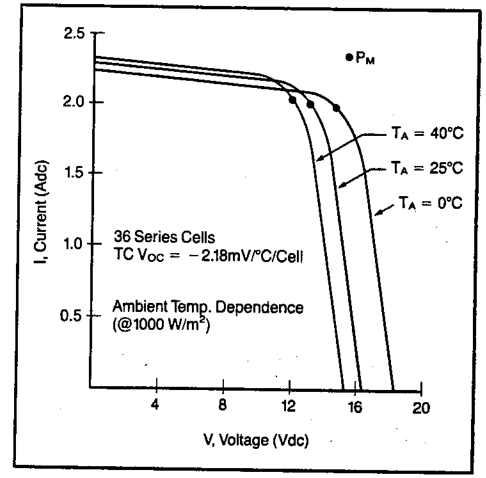



**Figure 7: Ra30-12 Characteristics vs. Temperature**



## MECHANICAL CHARACTERISTICS*

Figure 8:
Front View

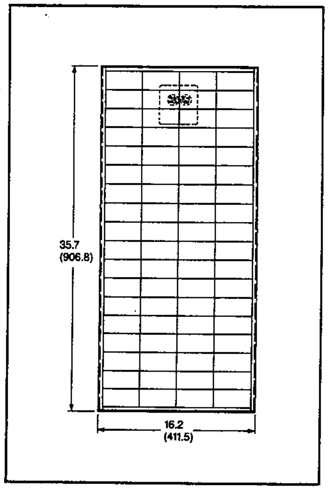



Figure 9:
Back view

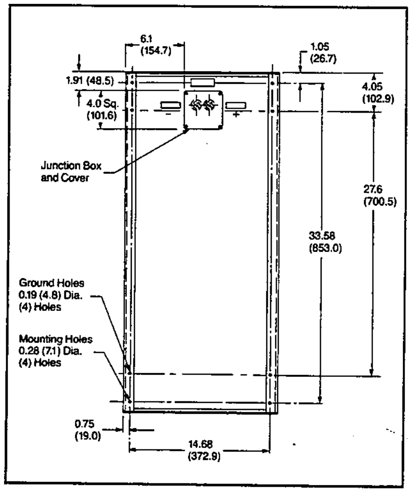
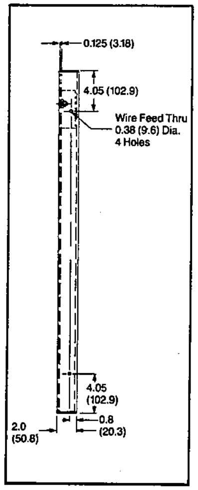



Figure 10:
Side view




***All dimensions in inches (millimeters)**

## MODULE OPTIONS

### AMP® Connectors

The AMP® SOLARLOK quick disconnect is available from MSEC by special order. This wiring design allows quick installation and because the receptacles are polarized, the possibility of incorrect wiring is all but eliminated.

SOLARLOK connectors offer water-tight cable strain relief and are suitable for both parallel and series connections.

The user must anticipate cable harness lengths needed between modules prior to field installation; special tools are required for on-site connections. Harnesses are supplied with AWG 12 or 14 UF cable.

### Bypass Diodes

Bypass diodes are recommended for high voltage systems to minimize potential system current losses should one or several modules become shaded in some fashion. Because their usefulness is limited to high voltage applications, diodes are not supplied as a standard item by MSEC.

If bypass diodes are desired, MSEC recommends Motorola diode, part MR 750 (6A, 50V, plastic case, axial leads) or equivalent.

## HOW TO ORDER A Ra30 MODULE

When ordering a 12 volt (nominal) Ra30 module, the notation, *Ra30-12* should be used. Affix one or two of the following suffixes to *Ra30-12* when ordering a module with options.

| | Suffix | Option Ordered |
|---|---|---|
| Ra30-12 | | |
| | -R* | Module with +/− SOLARLOK connectors |
| | -D | Factory installed bypass diode |

*EXAMPLE:* Ra30-12-R-D defines a Ra30, 12 volt module, complete with optional SOLARLOK receptacles and factory installed bypass diode.

*With SOLARLOK receptacles, cable length of the mating harness must be specified.

## QUALITY ASSURANCE

All Mobil Solar modules are subjected to strict quality control throughout the manufacturing process. Before leaving the factory, each finished module is carefully inspected to assure delivery of a superior product.

MSEC's *Limited Warranty* guarantees power output of each module for a period of five (5) years from the date of shipment. (See MSEC's full warranty for details.)

## THE FAMILY OF "Ra" MODULES

The Ra30 is only one in the family of "Ra" modules supplied by Mobil Solar Energy Corporation. *(See FIGURE 11)*

The Ra7 and Ra15 modules, supplying 7 and 15 watts peak, respectively, offer the flexibility to use superior Mobil Solar products for smaller systems. The Ra180, supplying 180 watts peak, is the largest photovoltaic module available. Designed in conjunction with leading solar architects, this module is well suited to roof-integrated, residential systems.

Data sheets for other Mobil Solar products are available upon request.

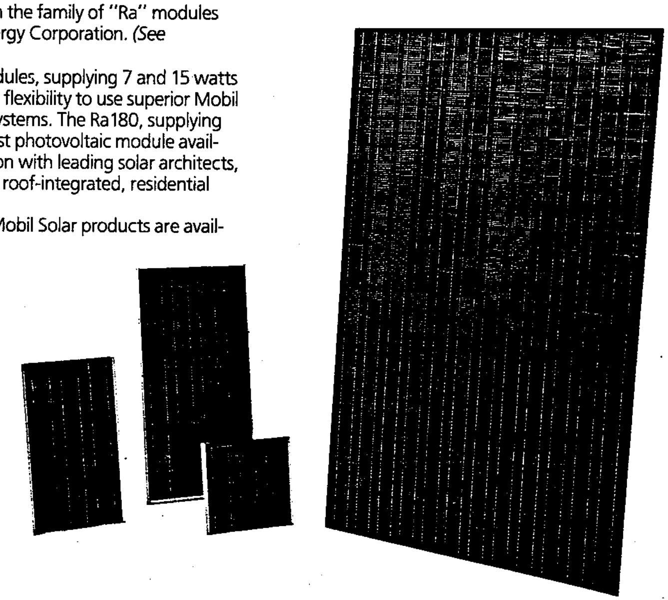


**Figure 11: The Family of "Ra" Modules Includes (Left to Right) The Ra15, Ra30, Ra7 and Ra180**

# SUPPORT Ra30 Structures

Mobil Solar Energy Corporation offers a full range of attractive, durable support structures for mounting the Ra30 module. Two categories of support structures are available, each with a range of tilt angles. The *Variable Tilt Support Structure (VTSS)* is available for mounting one or two modules. The *Single Row and Double Row Support Structures (SR30/DR30)* accept three to ten modules in a panel. These support structures, like Mobil Solar's modules, are strong, weatherproof, lightweight, low cost, and easy to install.

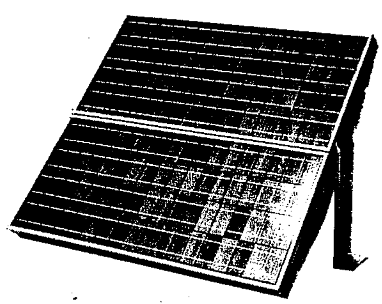
## Variable Tilt Support Structures
### for One and Two Modules

The *Variable Tilt Support Structure I and II* hold one and two Ra30 modules respectively. They can be easily mounted on a roof, wall, pole or prepared ground footing using a two-point mounting method (see Figure 1). Mounting feet can be secured to the brackets at pre-drilled points allowing for tilt angles of 0°, 15°, 30° and 45° from the horizontal. All necessary assembly hardware and flashing are supplied. Durable structure members are constructed of clear anodized aluminum with stainless steel fastening hardware.

The *VTSSI* weighs 1.1 kg (3.4 lb) and the *VTSSII* weighs 2.9 kg (6.4 lb) excluding modules. Mounting space required is:

| | Width | Length |
|---|---|---|
| VTSSI | 411.5mm (16.2") | 1021.1mm (40.2") |
| VTSSII | 863.4mm (34") | 1021.1mm (40.2") |

**FIGURE 1: A *VTSSII* Support Structure**



## Single Row and Double Row Support Structures
### for Three to Ten Modules

The *SR30/DR30* support structures provide a simple, versatile method for mounting three to ten Ra30 modules in a single or double row arrangement. Panels of three, four and five modules are mounted side-by-side using a *SR30* mount (see Figure 2). Panels of six to ten modules are usually constructed in a double row, using a *DR30* mount. Panels of seven and nine modules can be constructed with a vacant module position without affecting the rigidity of the structure.

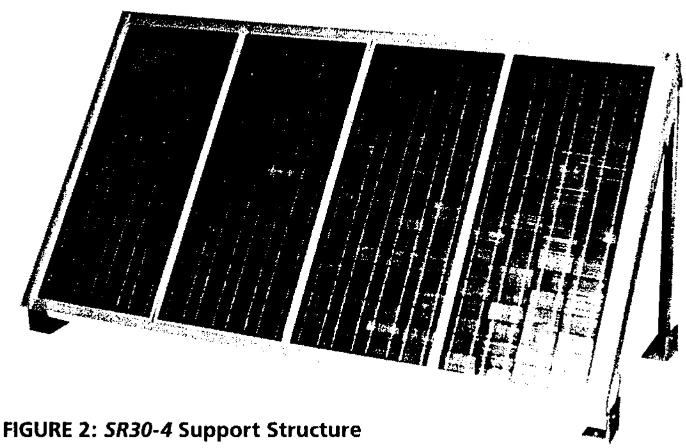


**FIGURE 2: *SR30-4* Support Structure**

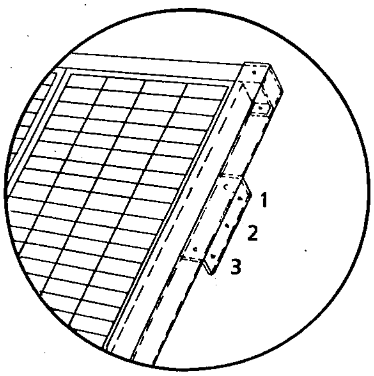
Alternatively, panels of six to ten modules can also be mounted in two adjacent single row support structures if this enhances the aesthetics or efficiency of the solar array in a given application.

Installations requiring more than ten Ra30 modules can use several support structures.

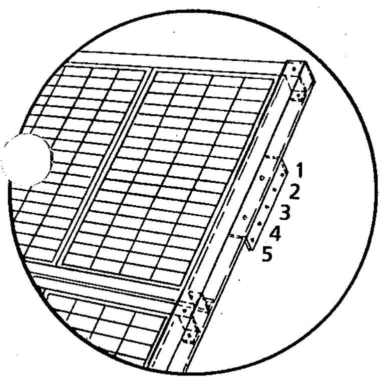
## SR30/DR30 Tilt Ranges

The *SR30/DR30* offers tilt angles from 15° to 65° from the horizontal. Tilt angle is primarily determined by the length of the supporting rear leg. Several leg lengths are available for each structure. A selected leg length can be attached to the back bracket at one of several positions, allowing a range of tilt angles from each leg length. Figure 3 shows the predrilled holes on the back brackets. Figure 4 gives the range of tilt angles available from each leg length.

**FIGURE 3: Back Bracket Detail**




Single Row Panel




Double Row Panel

## Mechanical Characteristics

The *SR30/DR30* support structures use a four-point mount. The bottom of the panel is secured by steel feet and the top by aluminum support legs that attach to the brackets.

The ⅛ inch thick frame and 3⁄16 inch thick brackets and legs are constructed of Type 6063-T6 aluminum for lightweight durability. The steel feet are electroplated with zinc to ensure corrosion-resistance.

All stainless steel fastening hardware is provided according to these same rigorous standards.

The support structures are built to withstand sustained wind velocities in excess of 200 km/h (125 mph) or 50 psf. For the mounting footprints and weight of the *SR30/DR30* structures, refer to page 3.

## Easy to Install

The *SR30/DR30* support structures can be installed with common hand tools and are supplied with all necessary hardware for assembly. Installation instructions are provided with each support structure. Hardware to secure the feet to the foundation must be obtained locally.

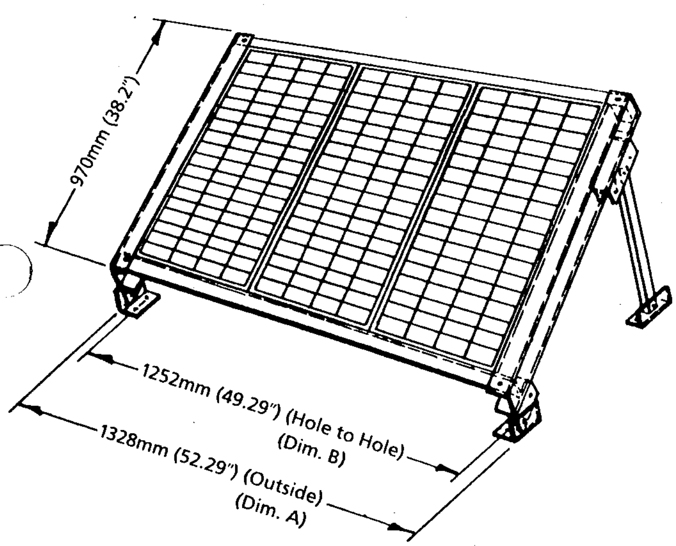
**Figure 4: Leg Lengths and Tilt Angles**

| PANEL CONFIGURATION | BACK BRACKET MOUNTING POSITION 1 | 2 | 3 | 4 | 5 | LEG CODE | LEG LENGTH |
|---|---|---|---|---|---|---|---|
| | TILT ANGLES | | | | | | |
| (SR) SINGLE ROW (3-5 MODULES) | 15° | 20° | — | | | A | 305 mm (12″) |
| | 25° | 30° | 35° | | | B | 456 mm (18″) |
| | 40° | 45° | 50° | | | C | 610 mm (24″) |
| | 55° | 60° | 65° | | | D | 762 mm (30″) |
| (DR) DOUBLE ROW (6-10 MODULES) | 16° | 18° | — | — | — | B | 456 mm (18″) |
| | 20° | 23° | 25° | — | — | C | 610 mm (24″) |
| | 25° | 28° | 30° | 33° | — | D | 762 mm (30″) |
| | 35° | 39° | 42° | 45° | 48° | E | 1067 mm (42″) |
| | 49° | 52° | 55° | 58° | 61° | F | 1334 mm (52.5″) |

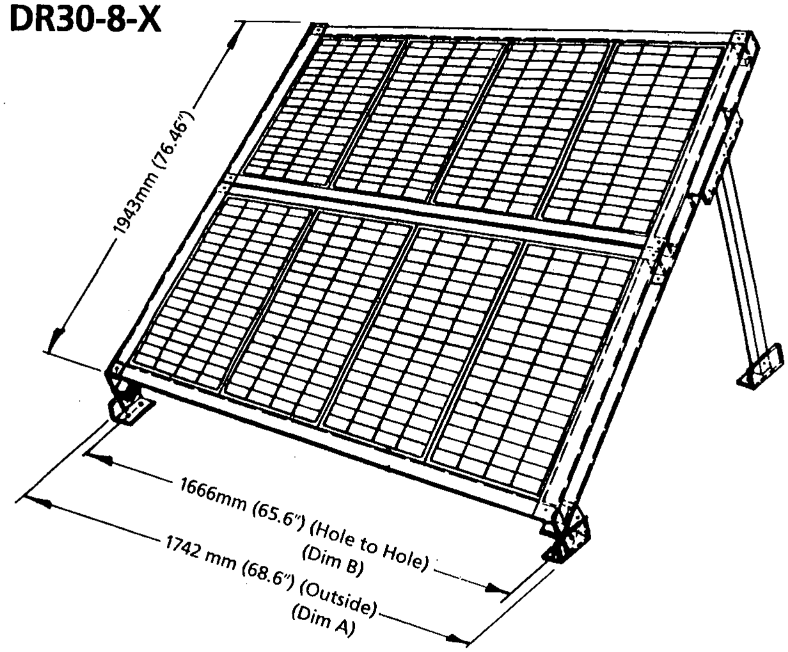
# SR/DR Sizes & Weights

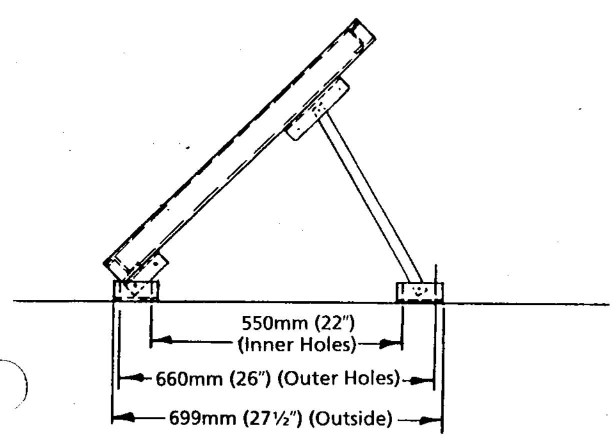
| | SR30-3-X | SR30-4-X | SR30-5-X | DR30-6-X | DR30-7 (or 8) -X | DR30-9 (or 10) -X |
|---|---|---|---|---|---|---|
| **Module Capacity** | 3 (Shown Below) | 4 | 5 | 6 | 7 or 8 (Shown Below) | 9 or 10 |
| **Completed Array:** | | | | | | |
| Length | 970mm (38.2") | 970mm (38.2") | 970mm (38.2") | 1,943mm (76.5") | 1,943mm (76.5") | 1,943mm (76.5") |
| Width | 1,316mm (51.8") | 1,730mm (68.1") | 2,144mm (84.4") | 1,316mm (51.8") | 1,730mm (68.1") | 2,144mm (84.4") |
| Depth | 65mm ( 2.5") | 64mm ( 2.5") | 64mm ( 2.5") | 64mm ( 2.5") | 64mm ( 2.5") | 64mm ( 2.5") |
| **Mounting Footprint** Side-to-Side Outside Dim. A | 1,328mm (52.3") | 1,742mm (68.6") | 2,156mm (84.9") | 1,328mm (52.3") | 1,742mm (68.6") | 2,157mm (84.9") |
| Mounting Hole Dim. B | 1,252mm (49.3") | 1,666mm (65.6") | 2,080mm (81.9") | 1,252mm (49.3") | 1,666mm (65.6") | 2,080mm (81.9") |
| **Weight** (Excluding modules; including hardware for 45° tilt angle) | 12.3kg (27.0 lbs) | 13.2kg (29.0 lbs) | 14.1kg (31.0 lbs) | 17.7kg (39 lbs) | 18.6kg (41 lbs) | 19.6kg (43 lbs) |

## SR30-3-X

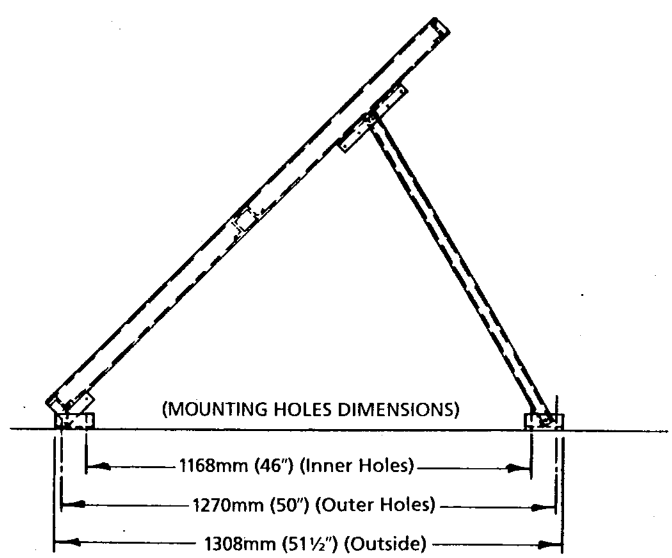



## DR30-8-X



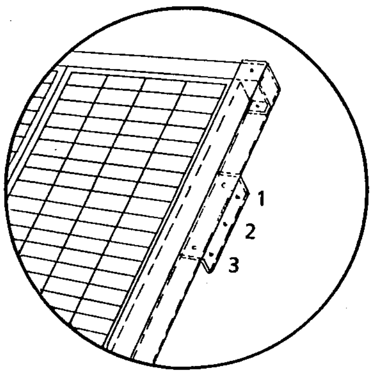

(MOUNTING HOLES DIMENSIONS)



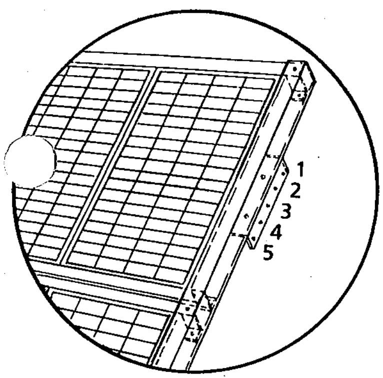
## SR30/DR30 Tilt Ranges

The *SR30/DR30* offers tilt angles from 15° to 65° from the horizontal. Tilt angle is primarily determined by the length of the supporting rear leg. Several leg lengths are available for each structure. A selected leg length can be attached to the back bracket at one of several positions, allowing a range of tilt angles from each leg length. Figure 3 shows the predrilled holes on the back brackets. Figure 4 gives the range of tilt angles available from each leg length.

**FIGURE 3: Back Bracket Detail**




Single Row Panel




Double Row Panel

## Mechanical Characteristics

The *SR30/DR30* support structures use a four-point mount. The bottom of the panel is secured by steel feet and the top by aluminum support legs that attach to the brackets.

The ⅛ inch thick frame and 3⁄16 inch thick brackets and legs are constructed of Type 6063-T6 aluminum for lightweight durability. The steel feet are electroplated with zinc to ensure corrosion-resistance.

All stainless steel fastening hardware is provided according to these same rigorous standards.

The support structures are built to withstand sustained wind velocities in excess of 200 km/h (125 mph) or 50 psf. For the mounting footprints and weight of the *SR30/DR30* structures, refer to page 3.

## Easy to Install

The *SR30/DR30* support structures can be installed with common hand tools and are supplied with all necessary hardware for assembly. Installation instructions are provided with each support structure. Hardware to secure the feet to the foundation must be obtained locally.

**Figure 4: Leg Lengths and Tilt Angles**

| PANEL CONFIGURATION | BACK BRACKET MOUNTING POSITION 1 | 2 | 3 | 4 | 5 | LEG CODE | LEG LENGTH |
|---|---|---|---|---|---|---|---|
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| | 25° | 30° | 35° | | | B | 456 mm (18″) |
| | 40° | 45° | 50° | | | C | 610 mm (24″) |
| | 55° | 60° | 65° | | | D | 762 mm (30″) |
| (DR) DOUBLE ROW (6-10 MODULES) | 16° | 18° | — | — | — | B | 456 mm (18″) |
| | 20° | 23° | 25° | — | — | C | 610 mm (24″) |
| | 25° | 28° | 30° | 33° | — | D | 762 mm (30″) |
| | 35° | 39° | 42° | 45° | 48° | E | 1067 mm (42″) |
| | 49° | 52° | 55° | 58° | 61° | F | 1334 mm (52.5″) |

# NEW ENGLAND ELECTRIC'S RESIDENTIAL AND COMMERCIAL PHOTOVOLTAIC INSTALLATIONS

John J. Bzura, Ph.D.
Senior Engineer

New England Power Service Company
Westborough, Massachusetts 01582
(508) 366-9011 April 12,1990

## 1 OVERVIEW OF THE PROJECT

The New England Electric System is conducting a unique photovoltaic (PV) systems research and demonstration project in two of its subsidiaries: the Massachusetts Electric Company (MECo), and the Narragansett Electric Company (NECo), located in Rhode Island. This is a four-year project with multiple objectives, namely: (1) gather information about the performance, reliability and cost effectiveness of residential and commercial state-of-the-art photovoltaic systems installed at 38 customer locations; (2) record the variation in production of electricity during the year, particularly during peak load periods; (3) showcase PV system components made in Massachusetts, and (4),for the residential project, study the effects that a cluster of PV generating systems has on a single distribution feeder.

All of the PV system components were manufactured in Massachusetts. Mobil Solar Energy Corporation (MSEC), of Billerica, was chosen to supply the PV modules and to serve as general contractor. The construction coordinator was Solar Design Associates, located in Harvard. Residential inverters were made by the American Power Conversion Corporation of Burlington. Acheval Wind Electronics Corporation of Dracut made the inverters for the commercial and institutional buildings.

## 2 RESIDENTIAL INSTALLATIONS

### 2.1 General Description of Residential PV Systems

A PV array covering a total of 240 square feet of roof has been installed on each of 30 houses with southern exposures on two neighboring streets in Gardner, Massachusetts. This city is located about 50 miles west of Boston. All 30 residences receive electricity from the same substation, and 28 of 30 are located on one phase of a distribution feeder.

If the energy provided by the PV system is greater than site energy needs at any given time, the excess energy flows back through the meter to the distribution system. The meter rotates backward as a result of

Presented at the New England Environmental Exposition in Boston, Massachusetts

this reverse power flow. Consequently, the customer gets full credit for all excess energy.

Most of the homes are of the ranch type, with basements. The average roof pitch is 23 degrees. Average area is approximately 1,100 square feet and the mode regarding number of rooms is 5. No homes have central air conditioning but 6 of the 30 have window-mounted A/C units. Baseboard electric heat is used in 11 of these residences.

At the conclusion of the research phase of this project, ownership of the PV systems will be transferred to the participating home owners.

### 2.2 Photovoltaic Arrays

The cells used in New England Electric's photovoltaic research project are composed of thin crystalline silicon sheets, 2 inches by 4 inches. Approximately 11% of the radiant energy reaching cells under peak conditions is converted into dc power. The cells are encapsulated under glass on large aluminum panels, 4 feet by 6 feet (1.22 m by 1.83 m), that can be mounted on special brackets attached directly to roofs with lag bolts. These modules produce 50 Vdc and 4.4 amps dc under standard test conditions, or 220 watts per module. Standard test conditions are defined as insolation of 1,000 watts per square meter, cell temperature of 25 degrees C and air mass = 1.5.

Every home has 10 modules located in two rows of five modules each. The modules in each row are connected in series, thereby making up what is called a "string", to produce power at approximately 250 Vdc. Positive, negative and ground conductors for both strings are led into a roof-mounted feedthrough assembly and then down to the basement or garage into a "string combiner".

### 2.3 String Combiners

These devices contain surge protection components (metal oxide varistors, also called movistors), string isolation switches, blocking diodes and a grounding resistor network. The movistors will absorb voltage surges if lightning strikes nearby, but can not provide any protection from a direct lightning strike on the PV system. The string isolation switches provide a convenient way to remove dc power from the inverter for test or service purposes.

The resistor network ties one side of each string to ground through a high resistance (100,000 ohms), which limits the current flow to a small value if part of the string should become shorted to ground. This network also provides connections to test jacks on the front of the string combiner. Using these test points, it is possible to quickly determine whether any part of the array is grounded.

If one PV cell or module in a string should develop a short circuit, this would create a problem for the other string in the array. Blocking diodes in the string combiner prevent current flow from a normally operating string to a string with a shorted PV cell or module, thereby eliminating this problem. The strings are tied together in parallel (hence the name combiner) after the blocking diodes, to present single positive and negative conductors to the inverter.

## 2.4 Inverters

The residential inverters use forced commutation to provide 240 Vac output power, and are completely automatic in that the owner does nothing after turning it on. The units disconnect from the house service panel wiring immediately upon loss of utility power, start automatically as soon as sufficient light hits the array, and shut down when insolation falls to an impractical level. Further, this model has a maximum power tracking feature that always optimizes the product of array voltage and current, thereby maximizing output power. There are panel lights indicating standby status, startup mode, normal operating mode, and array ready mode. These provide the owner with very helpful information on the status of the PV system. Perhaps the best feature from the owner's perspective is the power output indicator. This consists of 10 LEDs (Light Emitting Diodes) stacked vertically in a "bar graph" configuration, such that an LED is lit (starting at the bottom LED) for each 10% increment of maximum power. Home owners have indicated they like to watch this indicator on sunny days when all 10 LEDs are lit, which confirms they are getting full power from their system. Inverter efficiency is approximately 92% over the range of 38% to 100% of full power.

## 2.5 Daily energy production

From the electric utility perspective, a major attribute of PV systems is their ability to contribute capacity during summer peak periods. Figure 1 compares the NEES hourly load profile to the average hourly PV production profile on a day with clear skies in August of 1987. The residential PV systems reach their peak output shortly after the System reaches its peak load. Approximately 60% of the total daily PV system output is supplied during the peak period, if this period is defined as the time when load is equal to or greater than 95% of the maximum load reached in the day. On an hourly basis, the PV systems provide an average of 1.2 kW of demand reduction during the peak period.

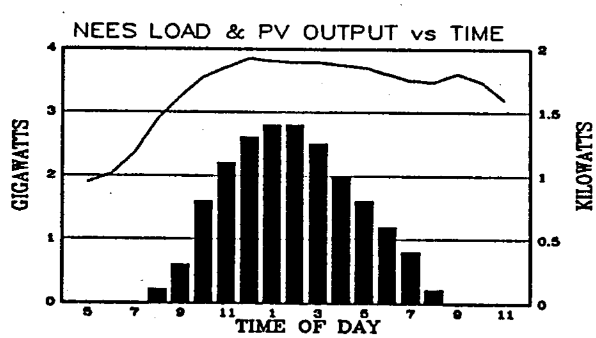



Figure 1

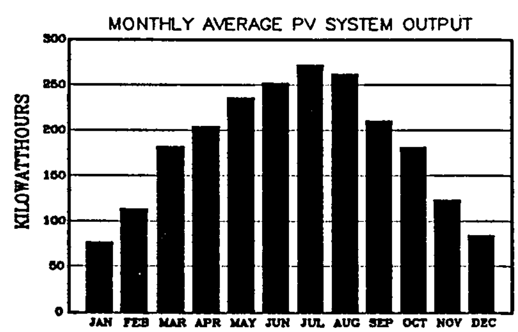



Figure 2

## 2.6 Monthly energy production

The average monthly output of residential PV systems varies from about 70 kWh in a midwinter month to approximately 270 kWh in a midsummer month. Figure 2 shows the average monthly energy production observed in Gardner from January through December, using two years of data.

It is worth noting that the January, February and December values shown are more subject to change than data in other months, because of the unpredictable action of snow. Wet snow freezing to arrays will stay on them much longer than dry snow, which tends to blow off or melt more readily in sunshine. For the two years of data analyzed, average annual energy production was 2,212 kWh.

### 2.7 Seasonal energy production.

For present purposes let the seasons be defined as shown below. The monthly average energy production for each home in each season appears below also.

| SEASON | MONTHS IN SEASON | AVERAGE MONTHLY OUTPUT |
|---|---|---|
| Winter | December, January, February | 93 kWh |
| Spring | March, April, May | 213 kWh |
| Summer | June, July, August | 261 kWh |
| Fall | September, October, November | 171 kWh |

## 3 OVERVIEW OF COMMERCIAL INSTALLATIONS

PV arrays have been installed on eight commercial or institutional buildings. The five located in Gardner are on city hall, the town library, a restaurant, a furniture store and the local community college. Maximum generating capacity per site ranges from 1.8 to 7.3 kilowatts of direct current power. The remaining three sites are in Rhode Island, on two police stations and an office building. These locations, with electric service provided by The Narragansett Electric Company, have maximum dc power levels of 3.4, 4.8 and 5.5 kilowatts.

Each PV system is connected to the building power service panel through a 3-phase inverter, separate circuit breakers and an isolation transformer. Since the buildings all use energy at a rate considerably higher than the PV system capacity there have been no cases of reverse power flow. All energy is used on site, thereby displacing energy that would have been purchased from MECo or NECo.

Electronic load-profile recording meters are used at all sites to monitor ac power produced in 15-minute intervals. In some cases the meter is on the building side of the isolation transformer; the alternative location is directly on the output of the inverter. Meters located on the building side of the transformer measure both gross PV system output and the losses of the transformer.

Ownership of these PV systems will be transferred to individual site owners when the project is completed.

### 3.1 C/I PV System Components

The cells comprising commercial PV arrays are also 2 inches by 4 inches in size, but two module sizes were employed: 4 feet by 6 feet (identical to the residential modules) and 16 inches X 36 inches (.41 m by .91 m). The smaller modules produce approximately 30 watts at 19 Vdc.

In contrast to the residential systems, many of the C/I systems consist of arrays mounted on structural steel frameworks. These roof-mounted frameworks are tied in to the building structural steel.

All framework arrays have modules inclined 45 degrees from vertical. Two sites use roof mounting brackets identical to the residential system brackets, but applied to the backs of skylights inclined 40 and 45 degrees from vertical. One site uses the brackets on a roof pitched at 14 degrees from horizontal. This site contributes most strongly to reducing NEES summer peak loads because the sun is nearly perpendicular to the array in June.

The string combiners for each commercial/institutional (C/I) site were custom-built, reflecting the variations in number of strings per site. PV systems were designed with 3, 4, 6 and 8 strings in order to achieve the desired dc input voltage per string (186 to 240 Vdc) to the inverter.

The 3-phase line-commutated inverters used at the C/I sites have indicator lights for normal power transfer, ac power on, and any fault in the inverter input or output circuits. In addition, a three-scale meter can be used for voltage, current and power readings. This meter provides several useful troubleshooting functions for the array and string combiner as well as the inverter. There are system monitoring circuits and LEDs inside that provide indications of unusual dc or ac conditions (under-voltage, phase fault, etc.) if they should occur.

Operation of this inverter is also totally automatic. The unit begins power production at 120/208 Vac as soon as insolation reaches a threshold level, disconnects from the array immediately if ac power is lost, and shuts down when insolation drops below the threshold.

### 3.2 Comments On Commercial Energy Production

No sites have operated continuously since array installation, for several reasons. The primary reason is that key system components were either relocated or upgraded in capacity at almost every site. Second, additional equipment in the form of isolating switches and circuit breakers was installed at every site. A third source of delay was the complexity of matching array, string combiner, inverter, transformer, and unusual building voltages in some cases. As a result, data on energy production at these sites are limited.

### 3.3 Typical C/I PV System Energy Production

The next table shows seasonal energy output for a typical Massachusetts PV installation and a typical Rhode Island PV installation; both arrays are inclined at 45 degrees and are approximately south-facing. The data shown represent kWh produced per peak kW of capacity during 1988-1989.

| SEASON --> | WINTER | SPRING | SUMMER | FALL | TOTAL |
|---|---|---|---|---|---|
| MASSACHUSETTS | 69 | 99 | 106 | 91 | 365 |
| RHODE ISLAND | 66 | 100 | 96 | 90 | 352 |

## 4 ADVANTAGES OF PV SYSTEMS

### 4.1 Background

The type of power generating plant most similar to a PV generating system is called a peaking unit, because the peaking unit only produces power during peak load periods of the day. For present purposes assume a utility is summer peaking, and that the peak period runs from 12:00 noon to 5:00 p.m. This time span will encompass most of the output of a PV system in New England, as discussed previously, so that comparison of a PV generating system with a peaking power plant is most appropriate. Just to complete the picture, there are two other types of power plants: cycling and base-load. The cycling plant will operate for more hours of the day, starting earlier and shutting down later than a PV plant. The base-load plant operates 24 hours per day, every day, except for maintenance.

### 4.2 Advantages re Energy Source

A major advantage, if not the main advantage, of PV systems is the energy source. Everyone knows that using the sun's electromagnetic energy results in the equivalent of free fuel for a PV power plant, but there are other advantages worth mentioning. Consider a combination peaking plant that includes a PV system and a backup oil-fired turbine generator, and compare this to a pure oil-fired peaking plant. The advantages of the combination plant include (1) reduced oil consumption, with attendant reduced costs [of all types] required to find, process and transport the oil, (2) reduced oil storage tank capacity, (3) reduced land for tank siting and (4) reduced emissions of all types. Some of these advantages are discussed in more detail below.

### 4.3 Advantages re Emissions

Operation of a PV system will not result in emissions of $CO_2$, noise, the combustion by-products of typical fossil-fired peaking generating plants, heated water or heated air. On the other hand, a pumped-storage facility is also a source of peaking energy and it has all of the advantages cited above for a PV system. One has to look further back at the source of energy for the pumped-storage plant for a thorough comparison. The most common energy sources are base-load coal, oil or nuclear power plants. When one considers the emissions of these types of power plants, the PV system has a definite advantage of minimal emissions.

### 4.4 Advantages re Siting

One of the advantages of PV systems is that they can usually be located at the location where electricity is needed. Having a source of energy at the site where energy is used results in elimination of the losses developed in a conventional power system with power plants located at a distance from the customer's property. Specifically, the PV system can eliminate the losses associated with transmission transformers, transmission lines, distribution transformers and distribution lines during peak periods. It is not appropriate to claim elimination of the need for transmission and distribution lines, because they are required to provide service when the PV system is not generating power.

### 4.5 Advantage re Summer Peak Period

Previous discussion (Section 2.5) emphasized the fact that PV systems can usually provide energy during a utility's weekday summer peak period. The additional point worth noting here is that peaking plants are traditionally the most expensive type of power plant to operate. This means that the output of a peaking plant can displace a utility's most costly energy, thereby enhancing the economics of PV systems.

### 4.6 Advantages re Maintenance

A PV system has zero moving parts and far fewer complex electronic circuits than a conventional peaking power plant. For this reason, the operation and maintenance (O & M) costs of a PV plant should be significantly lower than a conventional peaking power plant and the reliability should be improved also.

## 5 DISADVANTAGES OF PV SYSTEMS

### 5.1 Disadvantage re Uncertain Output

A major drawback to PV systems from a utility operating perspective is the uncertain capacity at any given daylight hour. The situation is worst in the Northeast, where frequent cloudy periods, plus days with heavy overcast, rain or snow make estimating the capacity of a PV system difficult at best. This is in marked contrast to conventional peaking plants, which are almost always available at full capacity for as long as needed.

### 5.2 Disadvantage re Economics

Another major disadvantage of PV systems is cost. Current commercial PV system components cannot produce energy in the range of 4 to 12 cents per kWh, which spans most utility residential rates. Some PV module manufacturers are estimating that multimegawatt-scale power plants using their products could produce energy at the upper end of this price range, but the estimates rest upon many assumptions that cannot be proven at present. It is nevertheless encouraging that the cost of PV energy will indeed come down as module efficiency increases and manufacturing costs decline due to ongoing research. Section 6 summarizes PV research at present in the U. S.

### 5.3 Disadvantage re Winter Peak Hours

If a utility is winter peaking, that peak is very likely to occur either in the evening as streetlights and other loads come on (the usual time for New England Electric is 6:00 p.m.) or in the coldest part of the night. Needless to say, PV systems without energy storage capability would not be able to help reduce winter peak loads. Energy storage itself is so costly, no matter what the means (pumped storage, batteries or compressed air), that PV systems should not be regarded as contributing to capacity during winter peak periods.

### 5.4 Disadvantage re Siting

Considering roof-mounted residential PV systems first, any home with the ridge line oriented approximately north-south will be at a technical and economic disadvantage to homes where the ridge line runs approximately east-west. The latter homes, with half of the roof surface oriented in a generally southerly direction, will be able to get maximum energy production from a single array. A home with the ridge line running north-south will experience the difficulty of accommodating two arrays with different energy outputs during most of a day.

### 5.5 Miscellaneous Disadvantages

Considering that many homes have shade or ornamental trees nearby, the shading resulting from the trees will reduce daily energy output. In most cases the economics of PV systems will become less favorable to home owners, and in some cases a PV system may simply not be cost-effective. This limits the potential number of PV systems that can be installed. Other limiting factors include personal preferences re appearance (some people in Gardner found the proposed roof-mounted panels aesthetically unappealing) and roofing materials (e.g., slate) or geometry not conducive to simple installation of PV systems.

## 6 PV RESEARCH ACTIVITY IN THE U. S.

There is a wide range of research on PV cells in the U.S., which can be categorized into two major types of PV cell materials: [A] **thin-film**, which includes both amorphous and crystalline materials in layers on the order of 1 micrometer (about 40 millionths of an inch) thick, and [B] **crystalline**, the term generally used for both single-crystal and poly-crystalline cells in wafers around 200 micrometers thick (.008 inch). Another type of PV system uses a concentrating lens to apply high-intensity light to a specialized small-area cell; this system will be discussed separately.

### 6.1 Thin-film Cells

This category of PV cells has the active material deposited in a thin film on a thick substrate that provides mechanical strength. It is the most exotic branch of PV cell research, including such compounds as cadmium telluride, copper indium diselenide and gallium antimonide - but the element receiving primary attention is silicon. Some of these unusual materials offer high efficiency, up to 37% for the combination of gallium arsenide and gallium antimonide, but production costs are prohibitive for anything but space missions. Amorphous silicon, however, can be put on substrates of glass or other materials relatively inexpensively. Its disadvantage is a low efficiency at the start of operation (now claimed to be around 6%) that declines with exposure to the sun. Other thin film technologies do not seem to suffer this degradation in performance, but their costs are higher than that of amorphous silicon. There are many manufacturers working in this field. A partial list includes ARCO Solar Corp., the Utility Power Group, Chronar Corp., Sovonics, Photon Energy and Energy Conversion Devices.

### 6.2 Crystalline Cells

The most common material for single-crystal cells, also known as ribbon cells, wafer cells or dendritic-web cells, is silicon. Major manufacturers include Mobil Solar Energy Corp., Westinghouse Electric Corp. and ARCO Solar Energy Corp. Commercial-sized modules of these cells have efficiencies in the range of 11 to 14% at present. The manufacturers are working to increase cell efficiency as well as reduce manufacturing costs. Single-crystal cells have the virtue of maintaining efficiency through decades of operation.

In the second cell category, polycrystalline, the dominant material of interest is also silicon. As the name implies, a PV cell of this type of material consists of many small single-crystal areas. Cells can be made from a polycrystalline film on a substrate (an Astro Power product) or polycrystalline material alone (a Solarex approach); the efficiency range is 8 to 13% at present. Energy conversion efficiency appears to be stable over time for this type of PV cell. The goals of manufacturers are higher cell efficiencies and reduced cost per watt.

### 6.3 Cells Using Concentrators

The efficiency of a PV cell is a function of its size, at present. Under laboratory conditions, i.e. carefully controlled environments, cells with small areas (on the order of 1 square cm) demonstrate higher efficiency than cells with areas of hundreds of square centimeters manufactured in high-volume production lines. Accordingly, one approach is to make the most efficient cell possible in a small size and then use an inexpensive lens to concentrate the light falling on a large area onto the cell. The Entech Corporation has provided cells of this type to PVUSA, the major utility PV research and demonstration project discussed next. Another firm working in this field is Acrian, Inc. This company is working to adapt semiconductor manufacturing techniques to PV cell production.

## 6.4 PVUSA

The acronym is based upon PhotoVoltaics for Utility Scale Applications, and represents a cooperative research, development and demonstration project. Funding has been provided by the federal government, the Electric Power Research Institute (EPRI) and individual utilities. A site near Davis, California, has been established for long-term testing of PV systems. Work at the site is managed by personnel from Pacific Gas & Electric Company, the major utility sponsor. In addition to testing utility scalable systems, which are generally state-of-the-art commercialized PV components, PVUSA has devoted an area to testing emerging PV technologies. Almost all of the companies noted above in Sections 6.2 to 6.4 have products under test at PVUSA.

# 7 CONCLUSIONS

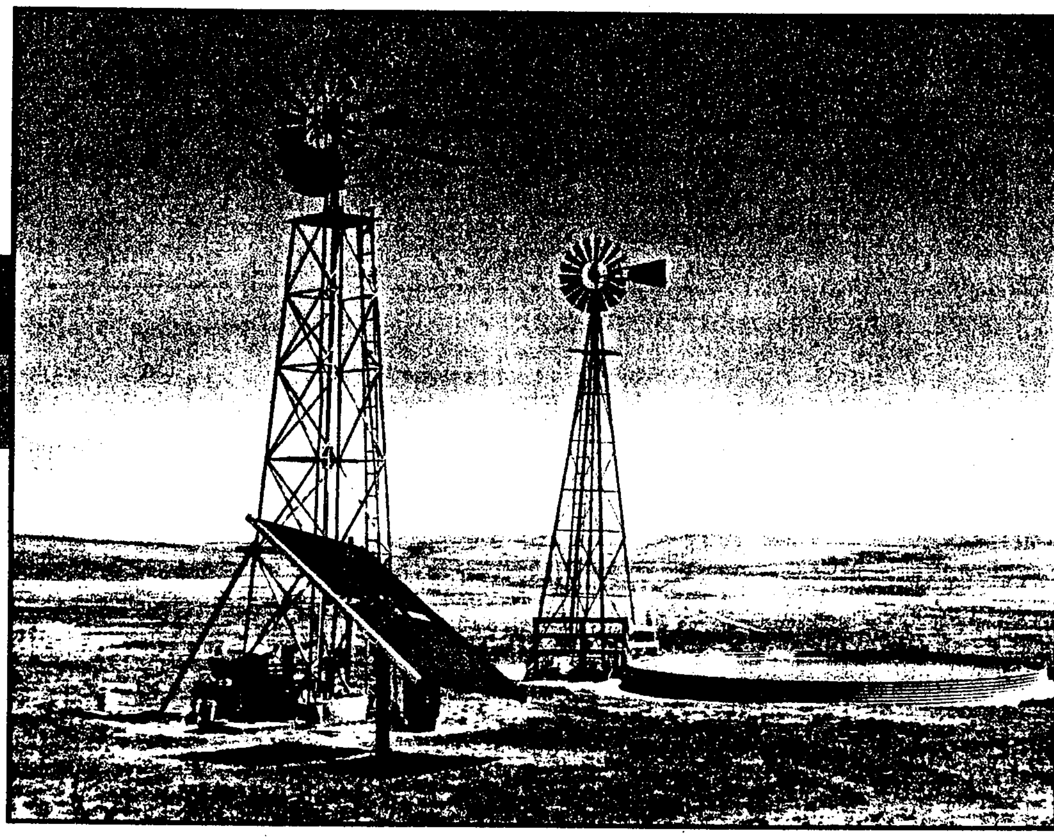
The primary question under discussion at this session of the conference is whether PV systems are ready now for widespread use. My response would be that the time of widespread use is closer now than it ever has been, certainly within the next decade. More encouragingly, there are probably specific applications for PV systems that are cost effective now. EPRI has funded a research project (RP 1975-06) to identify as many utility "first use" applications of PV systems as possible, in an effort to expand the market for photovoltaic systems.

Having installed PV systems on 30 homes and 8 commercial buildings, New England Electric has made a significant contribution to PV development both in New England and the United States. The Company has demonstrated that residential PV systems can be (A) installed and removed easily, (B) operated safely and reliably, from both utility and home owner perspectives, and (C) useful contributors to reducing residential loads during summer peak hours. Further, the project has been a showcase for the regional PV industry since all components were manufactured in Massachusetts.

As a result of this project the Company has been able to increase customer awareness of PV systems and better answer the many inquiries we receive on PV technology. Articles in magazines and regional newspapers, plus radio and TV interviews have all helped to make New Englanders more informed on this valuable potential option for electricity supply. Other utilities have also benefitted, through the EPRI-sponsored research and report on the interaction of multiple PV systems with a utility power distribution system.

In conclusion, this research and demonstration project has provided an affirmative answer to a question of great significance to utilities: can large numbers of PV systems be accommodated safely in present utility power distribution systems, and without adversely affecting the quality of power delivered to all customers? This alone makes the project worthwhile; all the other benefits resulting from the project should be sufficient to encourage other utilities to launch their own photovoltaic R&D projects.

# PHOTOVOLTAICS:
## New Opportunities for Utilities



***Perspectives from:***

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# Residential Photovoltaics:

## The New England Experience Builds Confidence in PV

***A residential project in Gardner, Massachusetts demonstrates the effects of dispersed rooftop systems on a single distribution feeder. The results are impressive.***

**by John J. Bzura**
Principal Engineer,
New England Power Service Company

The New England Electric System (NEES) is conducting a unique photovoltaic systems research and demonstration project in two of its subsidiaries: the Massachusetts Electric Company (MECo) and the Narragansett Electric Company (NECo), which is located in Rhode Island.

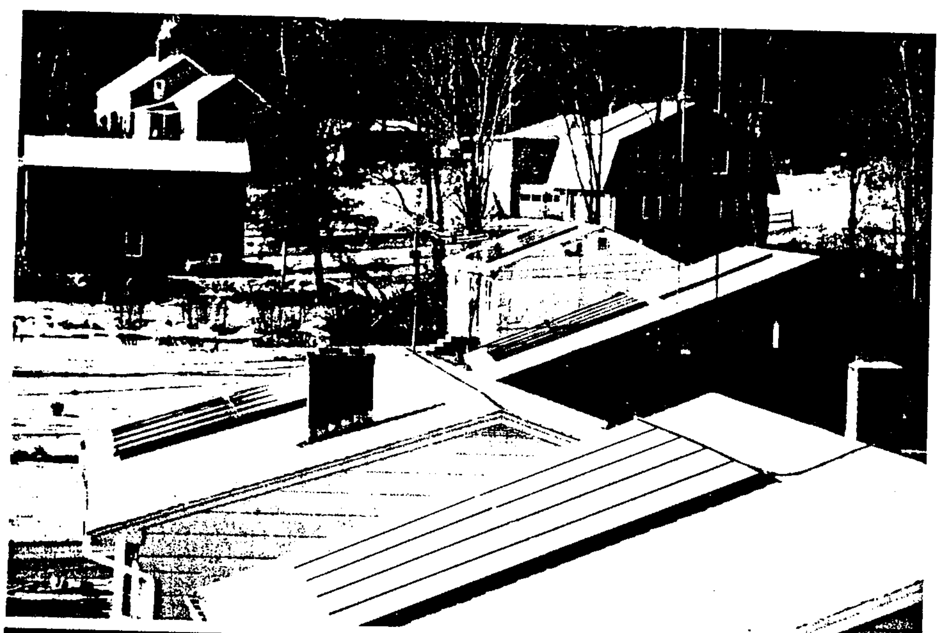


***Figure 1-1.*** *PV arrays, each covering 240 square feet of a roof, were installed on each of 30 houses on two neighboring streets in Gardner, Massachusetts. All 30 residences receive electricity from the same substation and are located on one phase of a distribution feeder.*

This six-year project has gathered information about the performance, reliability, and cost-effectiveness of residential and commercial photovoltaic systems installed at 38 customer locations. In doing so, we have also recorded variations in electric energy production over long spans of time and have studied the effects of a cluster of PV residential systems on a single distribution feeder. The latter study, conducted by New England Power Service Company (NEPSCo) with funding from the Electric Power Research Institute (EPRI), has focused on three areas of greatest potential concern in terms of PV applications: the effects of brief power outages and voltage transients due to lightning and other causes on PV systems and the distribution system; the harmonic performance of inverters and their effect on household appliances, other inverters, and the distribution system; the system effects of fast and slow changes in sunlight, such as those caused by cloud movements.

PV arrays, each covering 240 square feet ($ft^2$) of a roof, were installed on each of 30 houses with southern exposures on two neighboring streets in Gardner, Massachusetts, about 50 miles west of Boston. All 30 residences receive electricity from the same substation and are located on one phase of a distribution feeder. If the energy provided by the PV system is greater than the energy needed at the site at any given time, the excess energy flows back through the meter to the distribution system. The meter rotates backward as a result of this reverse power flow. Consequently, the customer gets full credit for all of this excess energy.

Most of the homes are 1100-$ft^2$ ranches, with an average roof pitch of 23 degrees. No homes have central air conditioning, but 6 of the 30 have window-mounted air-conditioning units. Baseboard electric heat is used in 11 residences. When the study is completed, ownership of the PV systems will be transferred to the homeowners.

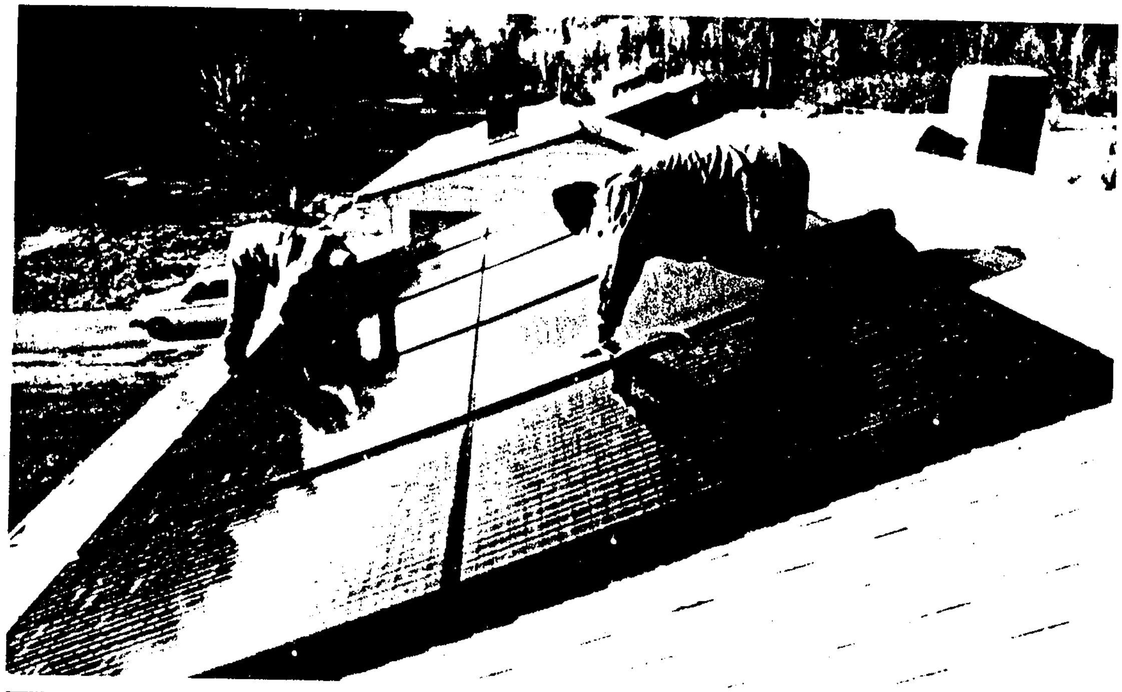


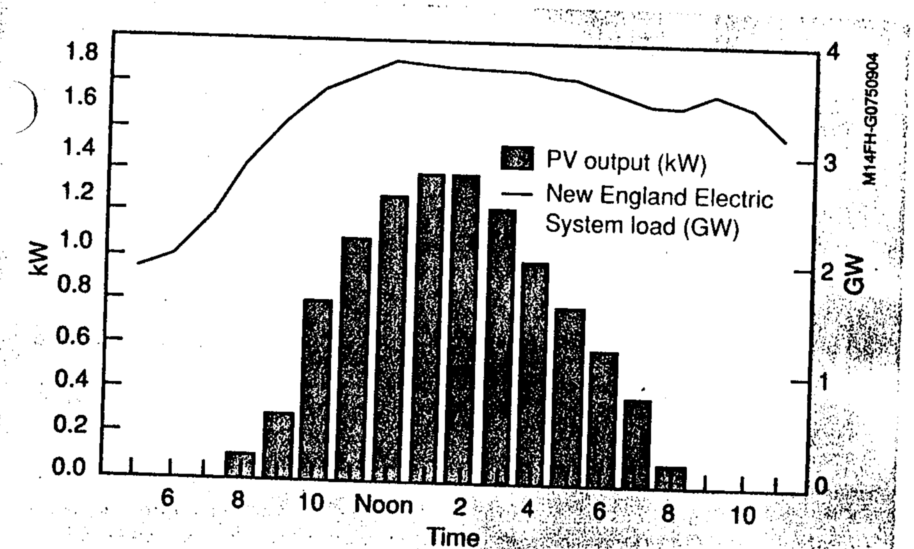
*Figure 1-2. The Gardner study has earned a high degree of confidence in PV's system reliability and interaction with the distribution system. Although 53% of the residential systems have operated on a single feeder, there have been no apparent adverse effects.*

***The PV systems.*** The arrays are made of cells of thin crystalline silicon. Measuring 2 inches by 4 inches, these cells were manufactured in Massachusetts by Mobil Solar Energy Corporation. Approximately 11% of the radiant energy reaching the cells under peak conditions is converted into direct-current (dc) power. The cells are encapsulated in 4-ft by 6-ft aluminum modules that can be bolted to the roof. Modules produce 50 volts dc (Vdc) and 4.4 amps dc in bright sunlight at temperatures of 25°C, which amounts to 220 watts per module.

The modules in each row of five are connected in series, making up what is called a "string," to produce power at approximately 250 Vdc. Positive, negative, and ground conductors for both strings are led from the roof down to the basement or garage into a "string combiner," containing surge protection components (metal oxide varistors), string isolation switches, blocking diodes, and a grounding resistor network. The varistors will absorb voltage surges if lightning strikes nearby, but they cannot provide any protection from a direct lightning strike on the PV system.

Completely automatic inverters provide 240 volts alternating-current (Vac) output power. The units disconnect from the house service panel immediately upon loss of utility power, start automatically as soon as sufficient light hits the array, and shut down when insolation falls to an impractical level. The model also has a power-maximizing feature that always optimizes the product of the array's voltage and current. Ten light emitting diodes stacked in a "bar graph" configuration give the customer a reading of power output.

From the electric utility perspective, a major attribute of PV systems is their ability to contribute capacity during summer peak periods. Figure 1-3 (page 4) compares the New England Electric System hourly load profile to the average hourly PV production profile on a day with clear skies. The residential PV systems reach their peak output shortly after the New England System reaches its peak load. Approximately



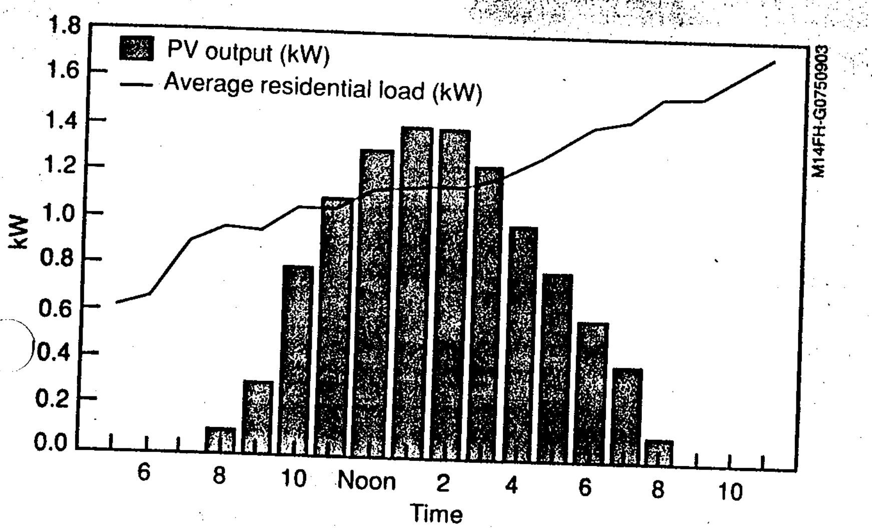




*Figure 1-3. This comparison of hourly system load profile to average hourly PV electricity production on a typical clear day shows an attractive complement. Approximately 60% of the total daily PV output is supplied during the peak period — an hourly average of 1.2 kW of demand reduction during the hours when load is equal to or greater than 95% of the maximum reached in the day.*

*Figure 1-4. A comparison of a residential load profile on a typical clear day and the corresponding average PV system profile shows that the PV system supplies all of the home's energy needs on a diversified basis during the hours from 11:00 a.m. to 3:00 p.m. The word diversified is important because each Gardner PV system is incapable of meeting any house demand in excess of 2 kW.*

60% of the total daily output from the PV systems is supplied during the peak period, defined as the time when load is equal to or greater than 95% of the maximum load reached during the day. On an hourly basis, the PV systems provide an average demand reduction of 1.2 kW during the peak period.

***PV power output.*** A question frequently asked is, "How much of the home's energy needs can be supplied by the PV system?" The answer is, "None to more than enough, depending on the time of day and the season." Summer is the optimal season for these roof-mounted arrays, because their average tilt angle is 23 degrees from horizontal. Figure 1-4 shows the residential load profile on a typical clear day and the corresponding average PV system profile. From 11:00 a.m. through 3:00 p.m., the PV system supplies all of the house's energy needs on a diversified basis. The word "diversified" is important, because each PV system is incapable of meeting any house demand in excess of 2 kW. It is only because the distribution system acts like a battery, in the energy storage sense, that one phase of the feeder can be considered to be powered by the PV systems on it.

The 30 homes on phase B of the feeder can in fact supply enough energy for 25 other homes without PV systems from noon to 2:00 p.m. on clear summer days. Since each home uses about 500 kWh per month, and the PV system produces about 270 kWh per month under good conditions, customers have seen reductions of about 50% in their summer monthly electricity bills.

Figure 1-5 shows the fluctuations in PV production in relation to variations in cloud cover. An index of 0 corresponds to clear skies; days with total cloud cover result in PV production that is, on the average, about 5% of maximum capability. Daily fluctuations in average PV system output point up the inherently uncertain capacity value of PV systems in the New England climate.

During a three-year span, the typical annual energy production of these systems was 2200 kWh. The average monthly output of residential PV systems varies from about 50 kWh in a midwinter month to approximately 270 kWh in a midsummer month. Figure 1-6 shows the average monthly energy production recorded in Gardner from January through December, using three years of data. Winter values are subject to wide variations caused by snow conditions;

wet snow covers arrays much longer than dry snow, which tends to blow off r melt more readily in sunshine.

It must be noted that the Gardner residences are not oriented to provide maximum solar efficiency. Most are oriented approximately south-southwest at 198 degrees plus or minus 6 degrees. Despite the wide differences in orientation between some houses that face southeast and some that face southwest, average energy production did not vary by more than 1% during the summer, the most productive season.

PV arrays were also installed on five commercial or institutional buildings in Gardner and at three institutional sites in Rhode Island. The array and power-conditioning configurations were different from those used in the residential study. Since all of these use energy at a considerably higher rate than the PV system capacity, there have been no cases of reverse power flow.

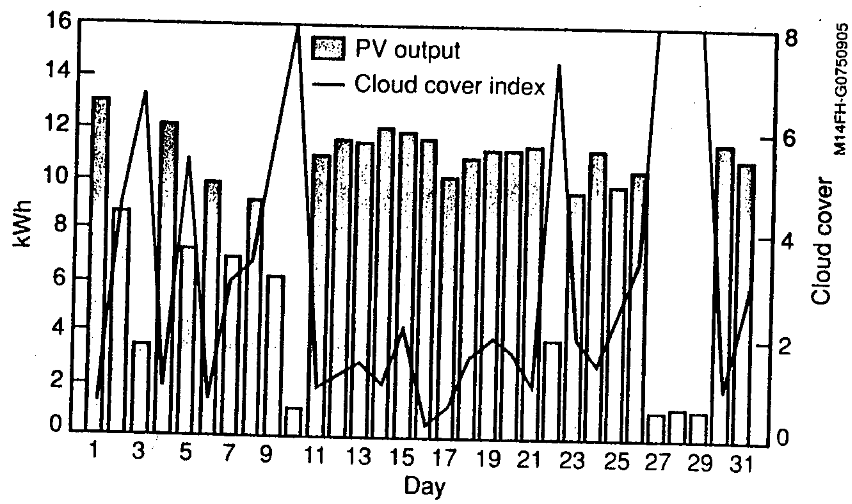
***Conclusions.*** This research has given us a high degree of confidence in photovoltaics, in terms of system reliability d interaction with the distribution system. Although a high concentration (53%) of the residential systems has been operating on a single feeder, there have been no apparent adverse effects on the feeder or on the residences served. The total harmonic distortion generated by the inverters is less than the background level observed before the PV systems began operating.

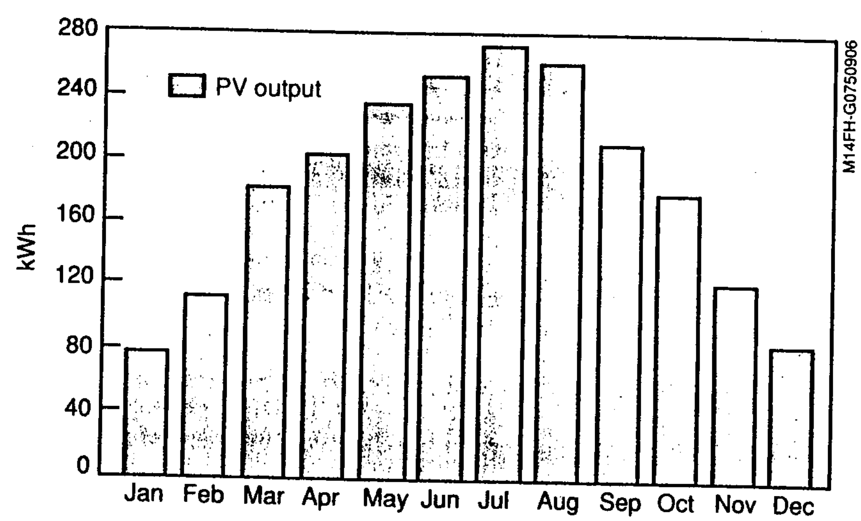
Customers' acceptance of the systems, in regard to their appearance, operation, and output, has been excellent. The project has also shown that systems can be readily assembled, quickly installed by local roofers and electricians, and easily operated by homeowners.

Moreover, operating both residential and commercial PV systems has brought important benefits to us as a utility. A project like this demonstrates a willingness to explore a source of energy well-liked by the public, with many environmental benefits. Lectures for schools and service groups are just one of the public relations activities that emerged from the project, and the local media have shown a willingness to provide publicity because of strong public interest. And, of course, the knowledge we have gained about impacts of photovoltaics on the distribution system is invaluable. It helps to make a utility ready for the widespread installation of PV systems in the next century. ❖

***Figure 1-5.*** *Fluctuations in PV production during the month of August relate to variations in cloud cover. An index of 0 corresponds to clear skies. Days with total cloud cover result in PV production that is, on average, about 5% of maximum capacity.*

***Figure 1-6.*** *Average monthly energy production observed in Gardner, using three years of data. Gardner residences are not oriented to provide maximum solar efficiency; most are oriented at 198 degrees plus or minus 6 degrees, approximately south-southwest.*



# THE NEW ENGLAND ELECTRIC PHOTOVOLTAIC SYSTEMS RESEARCH AND DEMONSTRATION PROJECT

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Westborough, Massachusetts

## ABSTRACT

Photovoltaic systems have been designed, installed and operated at 30 residences and 8 commercial or institutional sites. All residential systems are rated at 2.2 kW of dc power under standard test conditions (STC) and produce ac power at 240 volts. The commercial/institutional (C/I) systems range from 1.8 to 7.3 kW of dc power at STC; three-phase power is produced at 120/208 volts. The photovoltaic (PV) modules in all systems are crystalline silicon with an efficiency of 11%. Residential inverters are forced-commutated; C/I inverters are line commutated. The residential arrays and 3 of the 8 C/I arrays are attached to brackets mounted directly on roof surfaces. Frameworks of structural steel or aluminum are used to mount the remaining systems, and the tilt angle is 45 degrees for these systems.

The prime purpose of the residential project was to examine the interaction of a high concentration (53% of the residences served) of independent PV systems with a single distribution feeder. Other purposes included collecting data on PV system performance in New England and showcasing the PV system components, all of which were manufactured by companies in the New England Electric service area.

Energy production for the residential systems has averaged 2,195 kWh per year over two years. Maximum production occurs in July (270 kWh); minimum production occurs in January. The reliability of all components is now excellent. No adverse effects have been observed on the distribution system in terms of operations or safety as a result of installing the PV systems.

The commercial/institutional systems were completed in February of 1989. Installation was more complex for these systems, and the operating environment is generally more severe. Nevertheless, data collected to date indicate reliable performance of all components.

KEYWORDS

Photovoltaic systems, PV systems, residential PV systems, commercial PV systems, line-connected PV, interactive PV

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## INTRODUCTION

The New England Electric System is conducting a unique photovoltaic (PV) systems research and demonstration project in two of its subsidiaries: the Massachusetts Electric Company (MECo), and the Narragansett Electric Company (NECo), located in Rhode Island. This is a four-year project with multiple objectives, namely: (1) gather information about the performance, reliability and cost effectiveness of residential and commercial state-of-the-art photovoltaic systems installed at 38 customer locations; (2) record the variation in production of electricity during the year, particularly during peak load periods; (3) showcase PV system components made in Massachusetts, and (4), for the residential project, study the effects that a cluster of PV generating systems has on a single distribution feeder.

The Electric Power Research Institute (EPRI) has provided funding to another New England Electric subsidiary, New England Power Service Company (NEPSCo), to fund objective 4 above. NEPSCo in turn awarded subcontracts in three areas. Electric Research and Management, Inc. studied the effects of brief power outages and voltage transients due to lightning and other causes on the PV systems and their subsequent interaction with the distribution system. Worcester Polytechnic Institute examined the harmonic performance of inverters and their effect on household appliances, other inverters, and the distribution system. Ascension Technology, Inc. had the task of studying the effects of fast and slow changes in sunlight, such as those caused by cloud movements, on the system.

The Demand Planning Department of NEPSCo has overall responsibility for day-to-day operations and monitoring of energy production at all PV sites. The NEPSCo Electrical Engineering Department was responsible for the overall coordination of the feeder monitoring experiment in Gardner and for evaluating the impact of such an installation on the planning of power distribution systems in the future.

All of the PV system components were manufactured in Massachusetts. Mobil Solar Energy Corporation (MSEC), of Billerica, was chosen to supply the PV modules and to serve as general contractor. The construction coordinator was Solar Design Associates, located in Harvard. Residential inverters were made by the American Power Conversion Corporation of Burlington. Acheval Wind Electronics Corporation of Dracut made the inverters for the commercial and institutional buildings.

## GENERAL COMMENTS ON RESIDENTIAL SYSTEMS

A PV array covering a total of 240 square feet of roof has been installed on each of 30 houses with southern exposures on two neighboring streets in Gardner, Massachusetts. This city is located about 50 miles west of Boston. All 30 residences receive electricity from the same substation, and 28 of 30 are located on one phase of a distribution feeder.

If the energy provided by the PV system is greater than site energy needs at any given time, the excess energy flows back through the meter to the distribution system. The meter rotates backward as a result of this reverse power flow. Consequently, the customer gets full credit for all of this excess energy.

Most of the homes are of the ranch type, with basements. The average roof pitch is 23 degrees. Average area is approximately 1,100 square feet and the mode regarding number of rooms is 5. No homes have central air conditioning but 6 of the 30 have window-mounted A/C units. Baseboard electric heat is used in 11 of these residences.

At the conclusion of the research phase of this project, ownership of the PV systems will be transferred to the participating home owners.

## RESIDENTIAL PV SYSTEM COMPONENTS

### Photovoltaic Arrays

The cells used in New England Electric's photovoltaic research project are composed of thin crystalline silicon sheets, 2 inches by 4 inches. Approximately 11% of the radiant energy reaching cells under peak conditions is converted into dc power. The cells are encapsulated under glass on large aluminum modules, 4 feet by 6 feet (1.22 m by 1.83 m), that can be mounted on special brackets attached directly to roofs with lag bolts. These modules produce 50 Vdc and 4.4 amps dc under standard test conditions, or 220 watts per module. Standard test conditions are defined as insolation of 1,000 watts per square meter, cell temperature of 25 degrees C and air mass = 1.5.

Every home has 10 modules located in two rows of five modules each. The modules in each row are connected in series, thereby making up what is called a "string", to produce power at approximately 250 Vdc. Positive, negative and ground conductors for both strings are led into a roof-mounted feedthrough assembly and then down to the basement or garage into a "string combiner".

### String Combiners

These devices contain surge protection components (metal oxide varistors, also called movistors), string isolation switches, blocking diodes and a grounding resistor network. The movistors will absorb voltage surges if lightning strikes nearby, but can not provide any protection from a direct lightning strike on the PV system. The string isolation switches provide a convenient way to remove dc power from the inverter for test or service purposes.

The resistor network ties one side of each string to ground through a high resistance (100,000 ohms), which limits the current flow to a small value if part of the string should become shorted to ground. This network also provides connections to test jacks on the front of the string combiner. Using these test points, it is possible to quickly determine whether any part of the array is grounded.

If one PV cell or module in a string should develop a short circuit, this would create a problem for the other string in the array. Blocking diodes in the string combiner prevent current flow from a normally operating string to a string with a shorted PV cell or module, thereby eliminating this problem. The strings are tied together in parallel (hence the name combiner) after the blocking diodes, to present single positive and negative conductors to the inverter.

### Inverters

The residential inverters use forced commutation to provide 240 Vac output power, and are completely automatic in that the owner does nothing after turning it on. The units disconnect from the house service panel wiring immediately upon loss of utility power, start automatically as soon as sufficient light hits the array, and shut down when insolation falls to an impractical level. Further, this model has a maximum power tracking feature that always optimizes the product of array voltage and current, thereby maximizing output power. There are panel lights indicating standby status, startup mode, normal operating mode, and array ready mode. These provide the owner with very helpful information on the status of the PV system. Perhaps the best feature from the owner's perspective is the power output indicator. This consists of 10 LEDs stacked vertically in a "bar graph" configuration, such that an LED is lit (starting at the bottom LED) for each 10% increment of maximum power. Home owners have indicated they like to watch this indicator on sunny days when all 10 LEDs are lit, which confirms they are getting full power from their system. Inverter efficiency is approximately 92% over the range of 38% to 100% of full power.

## ANALYSIS OF RESIDENTIAL ENERGY PRODUCTION

Within this paper, the analysis of data collected from the NEES Photovoltaic Project focuses on four specific topics: the correlation between hourly PV production and System daily load profile; the potential impact of PV production on residential customer load, the relationship between PV energy production and cloud cover, and the monthly variation in energy output.

### Hourly PV Output versus NEE System Load Profile

From the electric utility perspective, a major attribute of PV systems is their ability to contribute capacity during summer peak periods. Figure 1 compares the NEES hourly load profile to the average hourly PV production profile on a day with clear skies in August of 1987. The residential PV systems reach their peak output shortly after the System reaches its peak load. Approximately 60% of the total daily PV system output is supplied during the peak period, if this period is defined as the time when load is equal to or greater than 95% of the maximum load reached in the day. On an hourly basis, the PV systems provide an average of 1.2 kW of demand reduction during the peak period.

NEES LOAD & PV OUTPUT vs. TIME

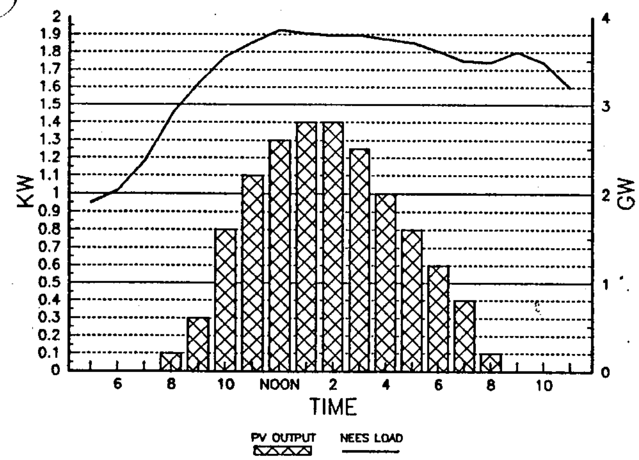


Figure 1

### Hourly PV Output versus Residential Load Profile

A question frequently asked concerning these residential systems is "How much of the home's energy needs can be supplied by the PV system?". The answer is zero to more than enough, depending on the time of day and the season. Summer is the optimal season for these roof-mounted arrays because their average tilt angle is 23 degrees from horizontal. Figure 2 shows the residential load profile on a typical clear day and the corresponding average PV system profile. During the hours from 11:00 a.m. through 3:00 p.m. the PV system supplies all of the house energy needs on a diversified basis. The word diversified is important, because each PV system is incapable of meeting any house demand in excess of 2 kW. It is only because the distribution system acts like a battery, in the energy storage sense, that one phase of the feeder can be considered to be powered by the PV systems on it.

AVERAGE RES. LOAD & PV OUTPUT vs TIME

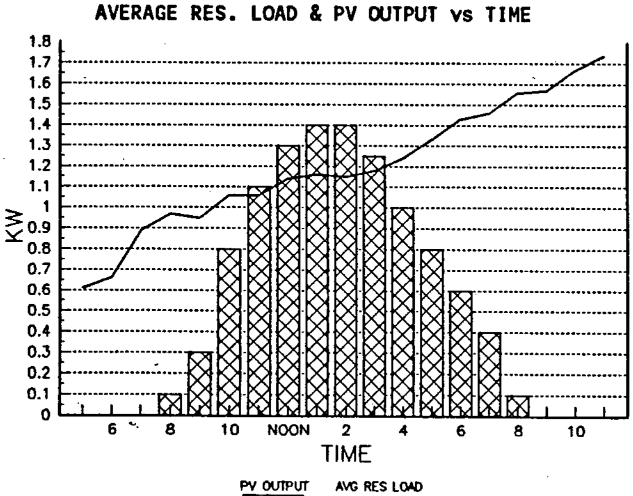


Figure 2

The 28 homes on phase B of the feeder can in fact supply enough energy for 25 other homes without PV systems in the hours from noon to 2:00 p.m. on clear days in summer. Since each home uses about 500 kWh per month, and the PV system produces about 270 kWh per month under good conditions, customers have seen reductions on the order of 50% in their summer monthly electricity bills.

### Output versus Cloud Cover

A third area of interest concerning PV systems is the sensitivity of PV production to varying levels of cloud cover. Figure 3 shows the fluctuations in PV production in relation to variations in cloud cover. In this graph a cloud cover index of 0 corresponds to clear skies, and 8 represents complete overcast. Days with total cloud cover result in PV production that is, on average, about 5% of maximum observed production capability.

CLOUD COVER & PV OUTPUT: AUGUST

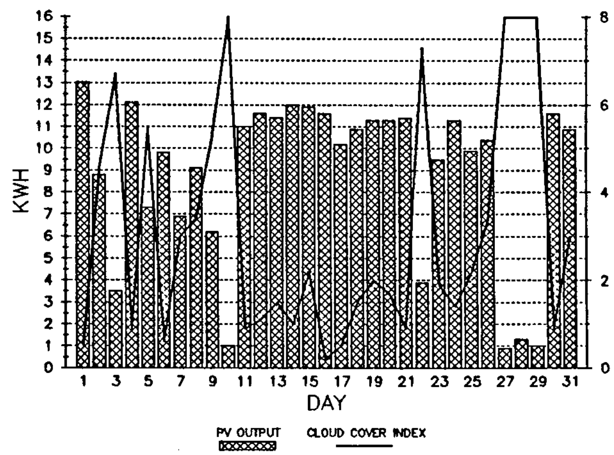


Figure 3

August of 1987 was a near-ideal month in terms of clear skies. The daily fluctuations in average PV system output in other summer months point up the inherently uncertain capacity value of PV systems in the New England climate. It would perhaps be a worthwhile measure of expected PV capacity to calculate a monthly effective capacity. This effective capacity could be the product of peak capacity under ideal field conditions times a derating factor based upon the observed average daily levels of insolation at a particular location.

### Monthly and Annual PV Output

The average monthly output of residential PV systems varies from about 50 kWh in a midwinter month to approximately 270 kWh in a midsummer month. Figure 4 shows the average monthly energy production observed in Gardner from January through December, using two years of data. It is worth noting that the January, February and December values shown are more subject to change than data in other months, because of the unpredictable action of snow. Wet snow freezing to arrays will stay on them much longer than dry snow, which tends to blow off or melt more readily in sunshine.

For the two years of data analyzed, average annual energy production was 2,195 kWh.

MONTHLY AVERAGE PV SYSTEM OUTPUT

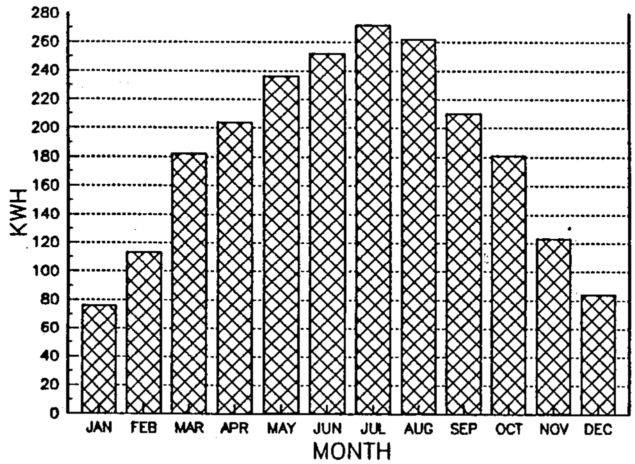


Figure 4

Output versus Orientation

The Gardner residences are oriented in a range from 39 degrees east of true south ( house "SE" ) to 54 degrees west of true south ( house "SW" ). None of the homes face true south with the closest being 3 degrees west of true south ( house "S" ). Most of the houses, 20 to be exact, are oriented at 198 degrees + or - 6 degrees, which is approximately south-southwest (SSW); these houses comprise the Main Group, abbreviated as MG.

For present purposes, let the seasons be defined as follows: Winter - January, February, and March; Spring - April, May, and June; Summer - July, August, and September; Fall - October, November, and December. Despite the wide difference in orientation between house SE and house SW, almost 90 degrees, average energy production did not vary by more than 1% between these two houses and MG houses during summer, the most productive season. Differences are more pronounced in other seasons, as shown below.

HOUSE ENERGY OUTPUT DIFFERENCE vs MAIN GROUP

| TYPE | WINTER | SPRING | SUMMER | FALL |
|---|---|---|---|---|
| SE | - 24% | - 5% | 0% | - 19% |
| S | - 15% | 0% | 0% | - 5% |
| SW | - 23% | - 2% | 0% | - 12% |

The final comment on orientation is that differences in winter and fall, as defined here, can vary depending on snow conditions.

Analysis of Harmonics and Transients

The EPRI-funded research in these areas has been completed and a final report is scheduled for late 1989. Interim information on current and voltage harmonics on the distribution system is presented in Reference 1. The effects of cloud movements on PV generation at the Gardner residential site, focusing on slow transients (tens of seconds) in PV system output, are described in Reference 2.

GENERAL COMMENTS ON COMMERCIAL SYSTEMS

PV arrays have been installed on eight commercial or institutional buildings. The five located in Gardner are on city hall, the town library, a restaurant, a furniture store and the local community college. Maximum generating capacity per site ranges from 1.8 to 7.3 kilowatts of direct current power. The remaining three sites are in Rhode Island, on two police stations and an office building. These locations, with electric service provided by The Narragansett Electric Company, have maximum dc power levels of 3.4, 4.8 and 5.5 kilowatts.

Each PV system is connected to the building power service panel through a 3-phase inverter, separate circuit breakers and an isolation transformer. Since the buildings all use energy at a rate considerably higher than the PV system capacity there have been no cases of reverse power flow. All energy is used on site, thereby displacing energy that would have been purchased from MECo or NECo.

Electronic load-profile recording meters are used at all sites to monitor ac power produced in 15-minute intervals. In some cases the meter is on the building side of the isolation transformer; the alternative location is directly on the output of the inverter. Meters located on the building side of the transformer measure both gross PV system output and the losses of the transformer.

Ownership of these PV systems will be transferred to individual site owners when the project is completed.

COMMERCIAL PV SYSTEM COMPONENTS

Photovoltaic Arrays

The cells comprising commercial PV arrays are also 2 inches by 4 inches in size, but two module sizes were employed: 4 feet by 6 feet (identical to the residential modules) and 16 inches X 36 inches (.41 m by .91 m). The smaller modules produce approximately 30 watts at 19 Vdc.

In contrast to the residential systems, many of the commercial/institutional PV systems consist of arrays mounted on structural steel frameworks. These roof-mounted frameworks are tied in to the building structural steel.

All framework arrays have modules inclined 45 degrees from vertical. Two sites use roof mounting brackets identical to the residential system brackets, but applied to the backs of skylights inclined 40 and 45 degrees from vertical. One site uses the brackets on a roof pitched at 14 degrees from horizontal. This site contributes most strongly to reducing NEES summer peak loads because the sun is nearly perpendicular to the array in June. The systems at approximately 45 degrees produce maximum energy in spring and fall.

String Combiners

The string combiners for each commercial/institutional (C/I) site were custom-built, reflecting the variations in number of strings per site. PV systems were designed with 3, 4, 6 and 8 strings in order to achieve the desired dc input voltage per string (186 to 240 Vdc) to the inverter.

Inverters

The 3-phase line-commutated inverters used at the C/I sites have indicator lights for normal power transfer, ac power on, and any fault in the inverter input or output circuits. In addition, a three-scale meter can be used for voltage, current and power readings. This meter provides several useful troubleshooting functions for the array and string combiner as well as the inverter. There are system monitoring circuits and LEDs inside that provide indications of unusual dc or ac conditions (undervoltage, phase fault, etc.) if they should occur.

Operation of this inverter is also totally automatic. The unit begins power production at 120/208 Vac as soon as insolation reaches a threshold level, disconnects from the array immediately if ac power is lost, and shuts down when insolation drops below the threshold.

COMMENTS ON COMMERCIAL ENERGY PRODUCTION

No sites have operated continuously since array installation, for several reasons. The primary reason is that key system components were either relocated or upgraded in capacity at almost every site. Second, additional equipment in the form of isolating switches and circuit breakers was installed at every site. A third source of delay was the complexity of matching array, string combiner, inverter, transformer, and unusual building voltages in some cases. As a result, data on energy production at these sites are limited. The detailed characteristics and more complete output analysis of the commercial/institutional PV systems will be the subject of a future publication.

SUMMARY

The Company has installed 30 residential PV generation systems on two streets served by one distribution feeder in Gardner, Massachusetts. These systems, rated at 2.2 peak kW under standard test conditions, have operated for approximately two years. Energy production varies from around 50 kWh in a winter month to 270 kWh in a summer month. Much of the energy production in summer occurs during NEES peak hours, so that the PV systems provide a load management benefit (reduced residential demand) in addition to the kWh conservation benefit.

Detailed studies have been done on the effects of electrical transients (described in Reference 1) and the subject of 60 Hz harmonics (described in Reference 2). A comprehensive report on the interaction of these residential PV systems and a distribution feeder will be published by EPRI in the latter part of 1989.

The reliability of all residential system elements has been excellent. The only component modifications involved upgrades of combiner diodes to improve thermal capacity and improvements in the array ground wire connectors to minimize corrosion.

All of the commercial/institutional PV sites were accepted by NEES in February of 1989, but intermittent operation of most sites has occurred since early 1988. Power levels have exceeded expectations at several sites under particular weather conditions. Energy production at these sites will be monitored until September of 1990.

CONCLUSIONS

A high concentration (53%) of residential PV generating systems has been operated on a distribution feeder for two years with no apparent adverse effects on the feeder or residences served by the feeder. Total harmonic distortion generated by the inverters is less than the background level found prior to PV system operation (Ref. 1) Customer acceptance of the systems, regarding appearance, operation and output, has been excellent. The project has shown that state-of-the-art PV electrical generating systems for residential applications can be readily assembled, installed quickly (less than half a day) by local roofers and electricians, and easily operated by home owners. As costs decline for the modules, inverters and string combiners, the economics of PV systems should become favorable to home owners within 10 to 15 years.

Regarding design and installation of PV systems on commercial or institutional buildings, the major factor is whether or not modules can be attached to a roof or skylight directly via brackets. Cost and complexity rise significantly if a separate frame must be used to mount the PV modules. The frame and array must be able to withstand the maximum probable wind at the site, which requires anchoring to the building structural framework. It is the penetrations of the roof required for this connection between array and building framework that require particular care to avoid leaks. The other additional cost factor, which is relatively minor, is that the string combiner will probably need to be custom-made for the site. Inverters providing three-phase output are readily available.

Finally, installation and operation of either type of PV system can produce important benefits to a utility. Such a project demonstrates willingness to explore an alternative source of energy well-liked by the public, with many environmental benefits. Lectures on the project can be given to local schools, public service groups, governmental agencies and technical organizations. Brochures can be developed, providing quick and positive responses to individual calls to utilities asking about their PV activities. Local newspapers and television stations are very likely to provide publicity because of strong public interest.

From a technical perspective, perhaps the most valuable benefit to a utility is the knowledge that will be gained on the performance of PV systems in its service area. Large-scale projects, such as the one described here, offer the potential of helping a utility to be ready for widespread installation of PV systems in the next century.


## ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance of William R. Blake, Scott G. Hutchins and Timothy M. Stout in taking field measurements of PV system parameters, participant communications, data processing, graph development and suggestions for certain aspects of this paper.


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## BIOGRAPHY

JOHN J. BZURA (M-1980, SM-1989) was born in Albany, Georgia on September 14, 1944. He received the B.S., M.E.E. and Ph.D. degrees from Cornell University, Ithaca, New York in 1966, 1967 and 1971 respectively, all in electrical engineering. In 1974, an M.B.A. degree was granted by Syracuse University, Syracuse, New York.

Dr. Bzura joined Arthur D. Little, Inc., Cambridge, Massachusetts, in 1974 where he performed technical and economic analysis of energy systems. He is currently a Senior Engineer in the Load Management Group of the Demand Planning Department at the New England Power Service Company.

He is a member of the IEEE Power Engineering Society and the Demand-Side Management Subcommittee (formerly the Load Management Subcommittee).

# PERFORMANCE OF GRID-CONNECTED PHOTOVOLTAIC SYSTEMS ON RESIDENCES AND COMMERCIAL BUILDINGS IN NEW ENGLAND

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ABSTRACT

Grid-connected photovoltaic systems, also referred to as utility-connected or line-connected, have been operated at 30 residences and 8 commercial or institutional sites since 1986. All residential arrays are rated at 2.2 kW of dc power under standard test conditions (STC) and produce ac power at 240 volts. The commercial and institutional (C&I) systems range from 1.8 to 7.3 kW of dc power at STC; three-phase power is produced at 120/208 volts. The photovoltaic (PV) modules in all systems are crystalline silicon with an efficiency of 11%. Residential inverters are forced-commutated; C&I inverters are line commutated.

A previous paper [1] discussed the design and installation of these systems, with initial analysis of energy production. The focus of this paper is a detailed examination of energy production, including a discussion of the capacity value of PV systems in New England. Reverse energy flow, from the customer to the utility, has been monitored and analyzed. The phenomenon is more frequent and more extensive than expected.

KEYWORDS

Photovoltaic systems, PV systems, residential PV systems, commercial PV systems, line-connected PV, interactive PV, capacity value of PV systems, reverse energy flow

## INTRODUCTION

The New England Electric System is conducting a unique photovoltaic (PV) systems research and demonstration project in two of its subsidiaries: the Massachusetts Electric Company (MECo), and the Narragansett Electric Company (NECo), located in Rhode Island. This is a six-year project with multiple objectives, namely: (1) gather information about the performance, reliability and cost effectiveness of residential and commercial state-of-the-art photovoltaic systems installed at 38 customer locations; (2) record the variation in production of electricity during the year, particularly during peak load periods; (3) showcase PV system components made in Massachusetts, and (4), for the residential project, study the effects that a cluster of PV generating systems has on a single distribution feeder. The Electric Power Research Institute (EPRI) has provided funding to another New England Electric subsidiary, New England Power Service Company (NEPSCo), to fund objective 4. The results of this study are discussed in Reference 2.

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The Demand Planning Department of NEPSCo has overall responsibility for day-to-day operations and monitoring of energy production at all PV sites. It is the demand-reduction potential of PV generating systems during summer peak-load periods that is of primary interest to this department.

## I RESIDENTIAL PV SYSTEMS

A PV array producing 2.2 kW of dc power under standard test conditions has been installed on each of 30 houses with southern exposures on two neighboring streets in Gardner, Massachusetts, which is located about 50 miles west of Boston. If the energy provided by the PV system is greater than site energy needs at any given time, the excess energy flows back through the meter to the distribution system. The meter rotates backward as a result of this reverse energy flow. Consequently, the customer gets full credit for all of this excess energy.

Most of the homes are of the ranch type, with basements. The average roof pitch is 23 degrees and the average area is approximately 1,100 square feet. No homes have central air conditioning but 6 of the 30 have window-mounted A/C units. Baseboard electric heat is used in 11 of these residences.

The cells used in these arrays are crystalline silicon sheets with an average efficiency of 11%. Large modules were specified, 4 feet by 6 feet (1.22 m by 1.83 m), to simplify installation. Every home has 10 modules located in two rows of five modules each.

The residential inverters use forced commutation to provide 240 Vac output power, and are completely automatic in that the owner does nothing after turning it on initially. The units disconnect from the house service panel wiring immediately upon loss of utility power, start automatically as soon as sufficient light hits the array, and shut down when insolation falls to an impractical level. Further, this model has a maximum power operating feature that always optimizes the product of array voltage and current, thereby maximizing output power. One drawback is that these inverters have an input power limitation of 1.9 kW. Inverter efficiency is approximately 92% over the power range of 38% to 100%.

## ANALYSIS OF PV ENERGY PRODUCTION

Within this paper, the analysis of data collected from the NEES Photovoltaic Project focuses on two specific topics: the correlation between hourly PV energy production and New England Electric System ("System") load profile in summer peak load periods, and the impact of PV energy production on residential customer load as seen from the distribution system. Correlation will be discussed first. From the New England Electric perspective, a major attribute of PV systems is their ability to contribute capacity during summer peak periods. The summer System peak load has occurred in either June, July, August or September in the last ten years.

Although the peak hour usually occurs in the period from noon to 4:00 p.m., the period from 10:00 a.m. to 4:00 p.m. will be analyzed here because that corresponds to the summer peak hours of the Narragansett Electric Company residential time-of-use rate A-30.

For the purposes of this paper, peak load period is defined as the time from 10:00 a.m. to 4:00 p.m. Eastern Daylight Savings Time. The analysis will focus on days when the peak load period average demand (abbreviated as PPD) is greater than 90% of the maximum PPD recorded in a summer. The reasoning behind this approach is that these peak load periods correspond to the time when peaking power plants (typically driven by combustion turbines or diesel engines) are needed most. Another utility may substitute a different percentage limit, say 85%, if that reflects their generating mix; the point here is to present an analytic procedure.

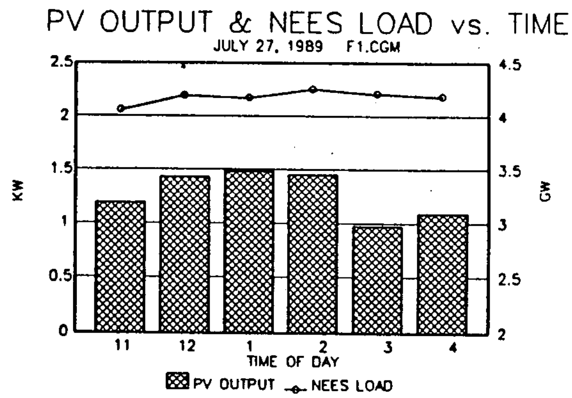
Table 1 shows the highest summer PPDs in New England Electric service territory in 1989. It is worth noting that the summer peak hour demand of 4,248 MW did occur in the first PPD listed, at 2:00 p.m. The NEES load values are normalized to the maximum peak load period average demand of 4,179 MW. In the third column of Table 1, normalized energy production from a typical residential PV site is tabulated. The normalizing basis is the product of [A] the maximum observed hourly capacity in any summer month (1.8 kW), times [B] the peak load period duration (6 hours), resulting in 10.8 kWh.

The timing of PV energy shown in Table 1, column 3, corresponds exactly to the timing of System peak load periods shown in column 2. For example, the first entry in each column corresponds to the hours from 10:00 a.m. to 4:00 p.m. on July 27, 1989.

TABLE 1: NEES LOAD VERSUS PV OUTPUT, 1989

| Periods of Maximum 1989 NEES Load (25,074 MWh base) | | Normalized PV Output (10.8 kWh base) |
|---|---|---|
| Date | Value | Value |
| 7-27 | 1.00 | 0.70 |
| 7-26 | 0.97 | 0.73 |
| 9-11 | 0.94 | 0.35 |
| 8-04 | 0.93 | 0.34 |
| 8-16 | 0.93 | 0.64 |
| 8-07 | 0.93 | 0.55 |
| 7-25 | 0.93 | 0.75 |
| 6-27 | 0.91 | 0.76 |
| 7-28 | 0.91 | 0.49 |

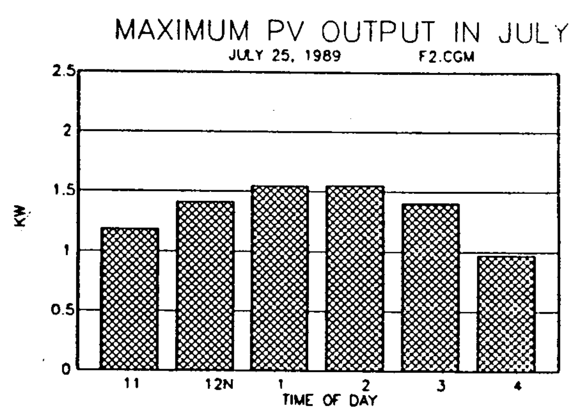
The exact contribution of a typical residential PV system in each hour of the summer's highest peak period, 10:00 a.m. to 4:00 p.m. on July 27, 1989, is shown in Figure 1 along with hourly NEES loads. Absolute maximum PV system output during the summer, for comparison, is 1.8 kW.




note: maximum PV output in summer is 1.8 kW

FIGURE 1

It is worth mentioning that the maximum observed hourly output of a residential PV system in summer, 1.8 kW, can be considered a high number to use for a normalization factor. On NEES peak load days such as those listed above the temperature is always relatively high (in excess of 85 degrees F [29 degrees C]) and the PV array does not function as efficiently as it would in cooler temperatures. For example, the highest hourly PV system output during all of the PPDs shown in Table 1 was 1.58 kW. Further, this peak output only occurs between noon and 2:00 p.m.; output is rising or falling in other hours of the day, as one would expect for a non-tracking array. Figure 2 illustrates these points. The data represent the best residential PV system performance in July during peak period hours. Total energy produced was 8.1 kWh on this day (July 25). From the viewpoint of using the maximum possible output of a generator during a given time period as a base or normalizing factor, 8.1 kWh would be more realistic than the 10.8 kWh figure used above. It has the disadvantage of making more allowance for the variable nature of PV-produced energy and thereby becoming less similar to the traditional procedure for calculating a capacity factor.




note: maximum PV output in summer is 1.8 kW

FIGURE 2

NEES load and PV system output data also exist for summer months in 1988; Table 2 summarizes these findings. The average PV system output for all PPDs in excess of 90% in the years 1988-1989 is 63%, which corresponds to an hourly average power of 1.1 kW. It is evident from Table 1 that the average power can be much less on certain days, e.g., September 11; this point will be addressed shortly.

TABLE 2: NEES LOAD VERSUS PV OUTPUT, 1988

| Periods of Maximum 1988 NEES Load (24,628 MWh base) | | Normalized PV Output (10.8 kWh base) |
|---|---|---|
| Date | Value | Value |
| 8-11 | 1.00 | 0.54 |
| 8-12 | 0.99 | 0.72 |
| 8-15 | 0.99 | 0.53 |
| 8-10 | 0.98 | 0.69 |
| 8-03 | 0.98 | 0.78 |
| 8-05 | 0.98 | 0.42 |
| 8-04 | 0.98 | 0.79 |
| 7-11 | 0.96 | 0.57 |
| 8-09 | 0.96 | 0.75 |
| 8-02 | 0.96 | 0.74 |
| 6-16 | 0.93 | 0.75 |
| 6-15 | 0.93 | 0.80 |
| 7-18 | 0.91 | 0.76 |

VALUE OF CAPACITY AND FORECASTS OF CAPACITY

A first approach to capacity evaluation might be to use a loss-of-load-probability (LOLP) calculation, based on maximum seasonal hourly load. Pacific Gas & Electric Company has performed this type of analysis [3, 4] for PV systems. New England Electric is a member of the New England Power Pool (NEPOOL), however, and NEE does not evaluate capacity using the LOLP technique. Fortunately the Demand Planning Department of NEPSCo has developed the Screening Tool, a computer program to evaluate the capacity value and energy value of conservation-oriented equipment and practices. This program was developed with the Power Supply Department and the Distribution Engineering Department of NEPSCo. It incorporates on-peak impacts of a device in each month of the year and appropriate weights to produce a total capacity benefit. Distribution loss factors and costs are employed to produce primary and secondary distribution system capacity benefits. Using the previous data for a typical residential PV system, the net present value of the capacity benefit is $1,560 and the energy credit (based upon 2,200 kWh/yr) is $1,360. For comparison, a conventional generator producing 1.1 kW each hour of the year would have a capacity benefit of $3,740 and an energy credit of $6,010. These credits apply uniquely to New England Electric, of course, with its current supply mix and T&D system configuration.

From a system dispatcher's perspective it is important to know the probable capacity value of any generation resource at any time in the near future. Based on historical PV capacity data such as these, it would be a relatively simple matter to have a person forecast estimated PV energy production 24 hours in advance. The procedure would require someone with minimal meteorological training to examine satellite photographs of cloud cover in the region of interest, plus forecasts of wind velocity and direction, and estimate the approximate degree of cloud cover each hour.
These data can be readily transformed into estimates of PV energy production each hour. The obvious extremes of heavy overcast or clear skies permit forecasts of PV output with near-certain accuracy.

REVERSE ENERGY FLOW

One of the most significant features of this research and demonstration project is that reverse energy flow, defined as from the customer to the utility, can occur during many daylight hours. Almost all (29 of 30) of the residential participants have a separate ratcheted watthour meter in series with the billing watthour meter. When a local surplus exists, resulting from PV system output greater than in-house load, energy flows back out to the distribution feeder and rotates the billing meter backward. The ratcheted "B" meter (for Back flow) also turns in a surplus condition. When local load is in excess of PV system output, the billing meter turns forward (its normal direction) and the B meter does not turn at all.

Previous requests to participants to write down B meter readings on a preprinted postpaid postcard once a week met with minimal success. As a result a NEPSCo retiree was hired to read these meters once a week at a regularly scheduled time. Table 3 shows the average weekly reverse energy flow from June through September. It was known that residential PV systems were producing about 260 kWh per month in summer, but the amount of energy exported by each house was not known prior to this work. The data displayed here show that the average daily reverse energy flow was approximately 2.83 kWh during the summer months. Several homes have zero values because a pool pump is running constantly; they were included because such homes are part of any broad-based sample of homes which may install a PV generating system. Excluding these homes, all participants show at least a few kWh of reverse energy flow each week. The maximum values also deserve comment. These are typically small homes with retirees or few people home during the day. The amount of reverse energy flow in these cases is more than 50% of the PV-produced energy

TABLE 3: VARIATION IN REVERSE ENERGY FLOW

| WEEKLY REVERSE ENERGY FLOW, IN KWH | | | |
|---|---|---|---|
| Month | Mean | Minimum | Maximum |
| June | 24 | 0 | 41 |
| July | 20 | 0 | 41 |
| Aug. | 17 | 0 | 39 |
| Sept. | 18 | 0 | 35 |

A PV generating system with a nominal peak capacity of 2 kW may seem to be a low-power system for an average residence; in fact, a 2-kW system can supply more than enough energy for several hours per day. The data in Table 3 are likely to be of interest to utility personnel working on determining the distribution system capacity credit of load-sited PV generating systems.

## II COMMERCIAL AND INSTITUTIONAL (C&I) PV SYSTEMS

These systems were described in Reference 1. General information for each site is shown in Table 4; orientation data are based upon true north. Energy data for a typical year are shown in Table 5. Data for the GCH site were adjusted to compensate for metering and inverter problems. In contrast to the residential PV system inverters, the C&I inverters do not have a maximum power operating mode. The dc voltage operating point was set manually to a value representative of typical summer voltage and current.

For this reason each C&I site is capable of producing more energy than that shown in Table 5. Consideration is being given to installing a newly-designed power optimization circuit board in each inverter.

TABLE 4: GENERAL DATA FOR C&I PV SITES

| City & State | Type of Building | Code | Tilt Angle (deg) | Orien-tation (deg) |
|---|---|---|---|---|
| Gardner MA | Library | GL | 45 | 168 |
| Gardner MA | City Hall | GCH | 45 | 180 |
| Gardner MA | College | GCC | 45 | 180 |
| Gardner MA | Restaurant | GBK | 30 | 150 |
| Gardner MA | Store | GSF | 45 | 180 |
| E. Providence RI | Police Station | EPPS | 45 | 212 |
| Cranston RI | Office Bldg | COB | 45 | 200 |
| Warwick RI | Police Station | WPS | 14 | 165 |

TABLE 5: ENERGY PRODUCTION DATA FOR C&I PV SITES

| Code | Peak Power | Output (kWh/yr) | Peak Month | Peak Month Output |
|---|---|---|---|---|
| GL | 2.4 kW | 2,600 | AUG | 280 kWh |
| GCH | 4.2 kW | 4,500a | AUG | 490a kWh |
| GCC | 7.3 kW | 8,000 | AUG | 850 kWh |
| GBK | 1.8 kW | 1,700 | AUG | 200 kWh |
| GSF | 3.9 kW | 4,100 | AUG | 410 kWh |
| EPPS | 3.4 kW | 3,700 | MAR | 390 kWh |
| COB | 4.8 kW | 5,000 | MAR | 530 kWh |
| WPS | 5.5 kW | 5,200 | MAY | 680 kWh |

## SUMMARY AND CONCLUSIONS

Data have been presented on the customer demand reduction potential of roof-mounted residential PV systems. It has been shown that these systems can contribute, on average, 63% of their normalized capacity (1.8 kW) during 6-hour peak load periods. The range of output is 34% to 80% during these periods.

Reverse energy flow (customer to utility) from residential PV systems has been analyzed. The data indicate non-zero reverse energy flow for almost all participants in summer, and high amounts (approximately 50%) for one group of participants.

The C&I PV systems generally operate in a more hostile electrical environment. In consequence, they have required more attention to maintain operating status and metering accuracy. The arrays themselves have required only three trouble calls (total) in three years, proving the viability of the array design and installation procedures employed and the reliability of the PV panels.


## ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance of Sarah G. Dagher, Scott G. Hutchins and Jay J. Silva in data collection and data processing for this paper.


## REFERENCES


[1] J. J. Bzura, "The New England Electric Photovoltaic Systems Research and Demonstration Project", IEEE Transactions on Energy Conversion, June 1990, pp. 284-289.

[2] "Photovoltaic Generation Effects on Distribution Feeders", EPRI Report EL-6754 in 3 volumes, March 1990, Electric Power Research Institute, Palo Alto, California.

[3] D. S. Shugar, "Photovoltaics in the Distribution System: an Evaluation of System and Distributed Benefits", 21st IEEE Photovoltaic Specialist Conference Proceedings, May 1990.

[4] T. E. Hoff, "Calculating Photovoltaics' Value: A Utility Perspective", IEEE Transactions on Energy Conversion, September 1988, pp. 491-495.


## BIOGRAPHY

JOHN J. BZURA (M-1980, SM-1989) was born in Albany, Georgia on September 14, 1944. He received the B.S., M.E.E. and Ph.D. degrees from Cornell University, Ithaca, New York in 1966, 1967 and 1971 respectively, all in electrical engineering. In 1974, an M.B.A. degree was granted by Syracuse University, Syracuse, New York.

Dr. Bzura was employed by Arthur D. Little, Inc., Cambridge, Massachusetts, from 1974 to 1983, where he performed technical and economic analysis of energy systems. He joined the New England Power Service Company in 1983, and is currently Principal Engineer in the Load Management Group of the Demand Planning Department.

He is a member of the IEEE Power Engineering Society, the Demand-Side Management Subcommittee (formerly the Load Management Subcommittee) and the Photovoltaic Working Group of the Energy Development Subcommittee.

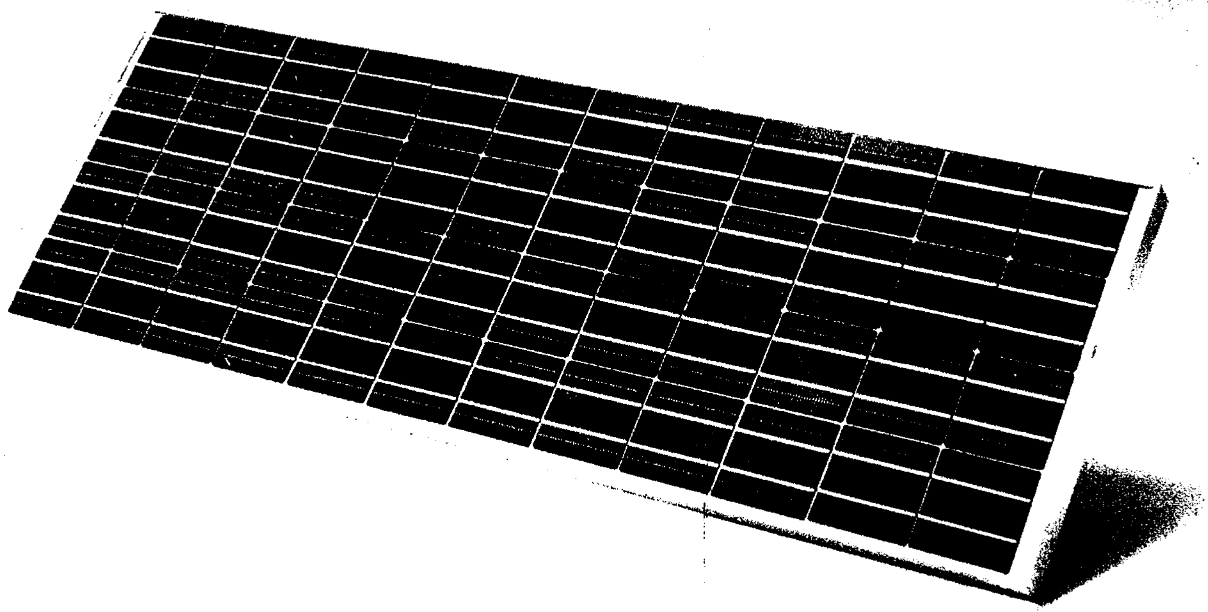
# Appendix D

# Miscellaneous

# Information

solec

# SUP-60 Solar Electric Utility Module



The SOLEC Utility Module is a new generation of PV modules that utilizes the series-parallel concept and offers the highest current output of any module currently on the market.

SOLEC's Utility Module with its unique series parallel block interconnection has the highest reliability in any power or utility application. The Utility module reduces mismatch in any size panel and array because the solar cells are closely matched in each series string of 12 cells. Four of these strings are connected in parallel to provide four-series parallel blocks for greater system reliability and performance.

The Super Module, like SOLEC's other standard modules, is designed to exceed all JPL Block V requirements. We use tempered low-iron glass as the front surface to provide for maximum transmission of light and impact resistance. The cells are laminated to the glass with layers of ethylene vinyl acetate (EVA).

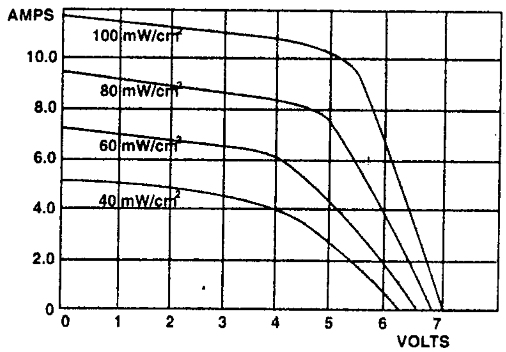
The Module back surface is white Tedlar ™, a substance which is not only an effective moisture barrier but also an excellent reflective surface. To give structural integrity to the module, a frame is added to the laminate and sealed with a special polyurethane polymer to provide rigid mechanical construction and effective moisture barriers for a maintenance-free operation.

The frame is made of extruded 6063-T6 anodized aluminum alloy. The module junction box is UV resistant and weather-proof with a moisture-tight wire strain reliever.

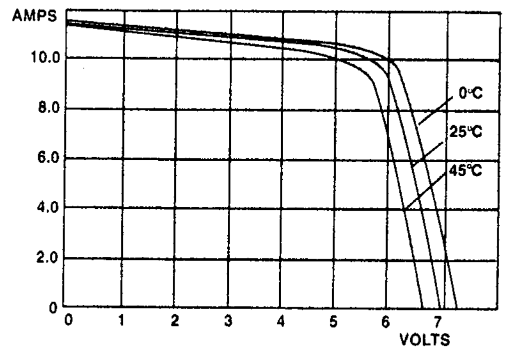

**SUNNYSIDE SOLAR, INC.**
N.E. Photoelectric Power Co.
R.D. 4 Box 808 Green River Road
Brattleboro, Vermont 05301
802 - 257-1482


"Bringing the Sun Down to Earth."

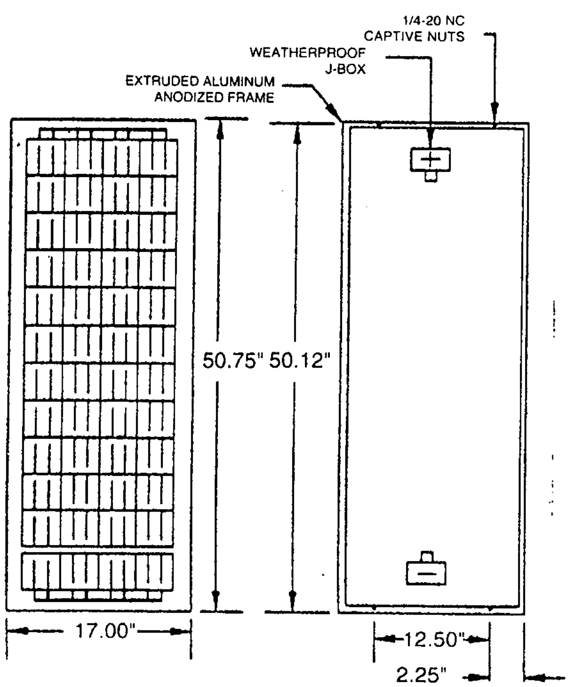
Since 1976




This graph demonstrates the effect on power output of varying light intensities at a cell temperature of 25°C.




This graph demonstrates how peak power and voltage are affected by changes in cell temperature.




## Electrical Characteristics

SUP-60 electrical characteristics at solar intensity of 100mW/cm² and a cell temperature of 25°C (77°F).

| | |
|---|---|
| Power (peak) | 60 Watts |
| Voltage (peak) | 5.64 Volts |
| Current (peak) | 11.00 Amps |
| Voltage (open circuit) | 7.00 Volts |
| Current (short circuit) | 13.4 Amps |

| | |
|---|---|
| Cell size: | 4 in (101.6 mm) square |
| Circuit: | 4 parallel strings of 12 cells in series |

## Physical Dimensions

| | | |
|---|---|---|
| Length | 50.75 inch | 1289 mm |
| Width | 17.00 inch | 425 mm |
| Thickness | 1.5 inch | 38 mm |
| Weight | 16.0 lbs | 7.27 kg |

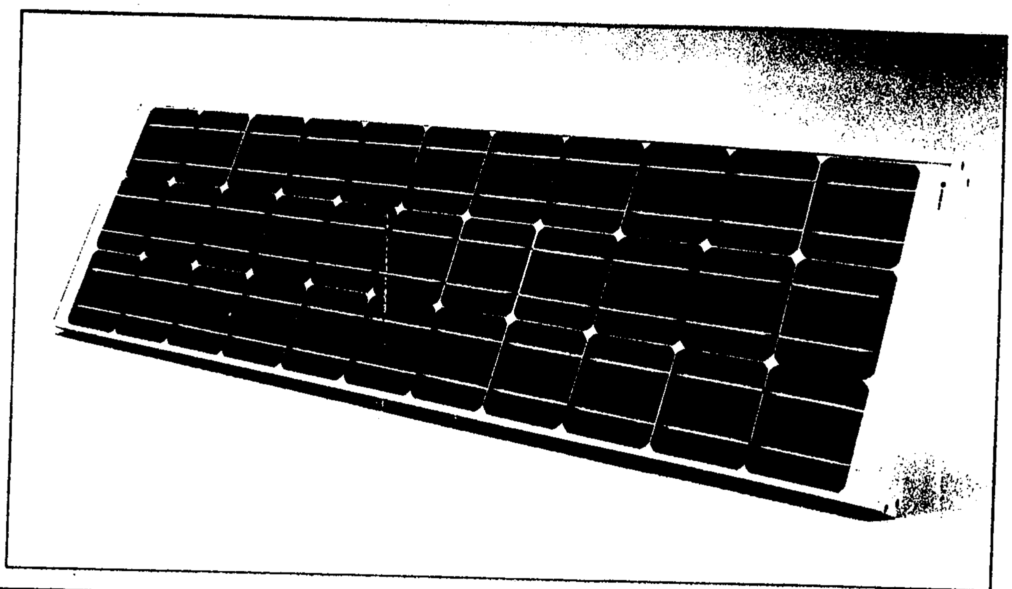
NOTE: Specifications given are examples of standard production modules and are subject to change without notice.

* The electrical characteristics represent nominal output. Actual production units may show a distribution of +/- 10%.


solec

**Solec International, Inc.**
12533 Chadron Avenue, Hawthorne, California 90250
TEL (310) 970-0065 • FAX (310) 970-1065

# M75 High Efficiency Solar Electric Module



**47 Watts*** UL Listed **10 Yr.** Limited Warranty* on Power Output

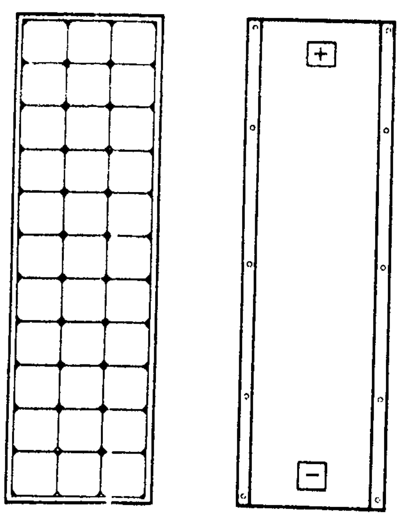
The ARCO Solar® M75 is a 47-watt photovoltaic module made with 33 high efficiency single-crystal silicon square cells. By using single-crystal silicon cells, the M75 can produce power in as little as five percent of full sun, resulting in power being produced from early to late in the day. Multiple redundant connections on the front and back of each cell help assure module circuit reliability.

M75 maintains the quality, features and construction that have established ARCO Solar modules as an industry standard. It is an efficient, reliable and durable power module, suitable for a wide variety of applications.

The M75 utilizes our highest standard of glass front, metal side rail construction, enabling it to withstand some of the world's harshest environments and continue to perform efficiently. Cells are protected from dirt, moisture and impact by a special low-iron, anti-reflective tempered glass front. The solar circuit is laminated between the glass front and a durable, multi-layered polymer backsheet using EVA for superior moisture resistance.

Two self-locking, environmentally-sealed junction covers on each M75 module, one for positive and one for negative termination, are designed for easy wiring access. Each junction cover contains a wired-in bypass diode to reduce potential power loss from cell or array shading.

The M75 is Listed by Underwriters Laboratories (UL), an independent, not-for-profit organization testing for public safety and comes with a 10-year limited warranty on power output.




## Power Specifications*

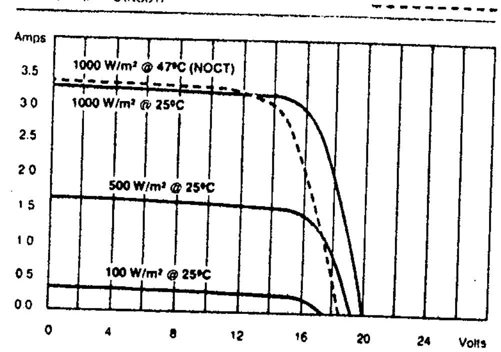
| Model | M75 |
|---|---|
| Rated Power | 47.0 Watts |
| Current (typical at load) | 2.94 Amps |
| Voltage (typical at load) | 16.0 Volts |
| Short Circuit Current (typical) | 3.27 Amps |
| Open Circuit Voltage (typical) | 19.9 Volts |

## Physical Characteristics

| | |
|---|---|
| Length | 48 in/1219 mm |
| Width | 13 in/330 mm |
| Depth | 1.4 in/36 mm |
| Weight | 11.6 lb/5.2 kg |

*Power specifications are at standard test conditions of: 1000 W/M², 25°C cell temperature and spectrum of 1.5 air mass.

## Performance Characteristics




The IV curve (current vs. voltage) above demonstrates typical power response to various light levels at 25°C cell temperature, and at the NOCT (Normal Cell Operating Temperature), 47°C.

ARCO Solar, Inc.
...ry of AtlanticRichfieldCompany
P.O. Box 6032, Camarillo, CA 93010

* These charts are for estimating purposes only, specifications are subject to change without notice
Complete warranty and installation information is included in module package or is available from ARCO Solar or your dealer prior to purchase
Modules marked with an (X) on the back will have different power ratings

**Available From:**

SUNNYSIDE SOLAR
N.E. PHOTOELECTRIC POWER CO.
RD 4 BOX 808 GREEN RIVER ROAD
W. BRATTLEBORO, VT 05301
802 - 257-1482

# ARCO Solar

**Model [illegible]5**
**Photo[illegible]aic Module**

ARCO Solar single crystal modules represent the optimum in solar electric generators. They combine the time proven reliability of modules from the world's leading manufacturer with innovations and advances that continue the ARCO Solar tradition of industry leadership.

Through the use of larger solar cells and special processing, ARCO Solar Modules now feature higher current (amperage) ouputs and increased area efficiencies. This means more useable power every day. Improved junction covers with self locking lids provide for easy array wiring and environmental protection.

ARCO Solar tests modules to meet or exceed government standards, as well as even more rigorous ARCO Solar quality and performance requirements. The module's test performance and our years of experience providing dependable power in locations throughout the world assure you that ARCO Solar modules can meet your solar power needs today.

**Module Characteristics:**

- Electrically-matched, single-crystal silicon solar cells for efficient conversion of both direct and diffuse light.
- Cells chemically textured and coated for anti-reflection enhancment.
- Fault tolerant, multiple redundant contacts on each cell for greater circuit reliability.
- Circuit laminated between layers of ethylene vinyl acetate (EVA) for moisture resistance, UV stability, and electrical isolation.
- Tough, multi-layered polymer backsheet for resistance to abrasion, tears and punctures.
- Interlocking, rugged, lightweight anodized aluminum frame (black frame optional).
- Two junction covers with self-locking lids for safety and environmental protection.
- Junction covers are designed for easy field wiring. Wired-in bypass diodes reduce potential loss of power from partial array shading.
- Module leakage current of less than 50 µA at 3000 VDC electrical voltage isolation.
- External grounding screw for electrical safety.
- Normal operating cell temperature (NOCT) 47 °C.
- Laboratory tested for wide range of operating conditions (−40 °C to + 90 °C, 0 to 100% humidity).
- Ground continuity of less than 1 ohm for all metallic surfaces.
- Ten-year limited warranty on power output.
- UL Listed.
- Minimum power upon final factory inspection is within 5% of rated power.

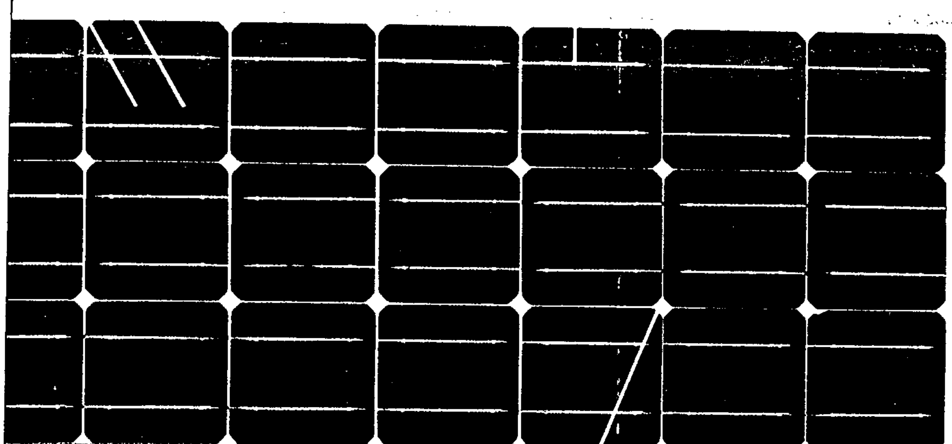
**Module Features:**

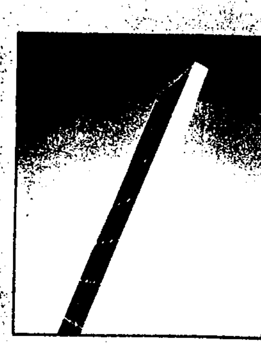
High efficiency single crystal solar cells. Each specially processed cell is anti-reflective coated. All cells within a module are electrically matched.

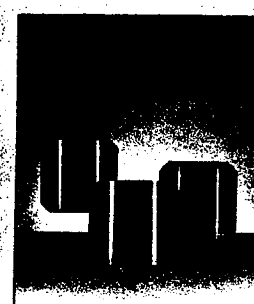
Multiple redundant contacts on the front & back of each cell provide a high degree of fault tolerance and circuit reliability.

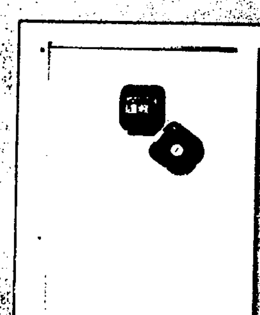
Tempered glass front provides strength and superior light transmission through an anti-reflective coating.

Rugged side rails are designed for exceptional structural strength. The lightweight, aluminum rails have multiple mounting holes strategically located for easy module installation.









ARCO Solar modules may be combined in series and/or parallel to meet nearly any power requirement.

Large area single crystal silicon cells provide the highest light to energy conversion efficiency available from ARCO Solar.

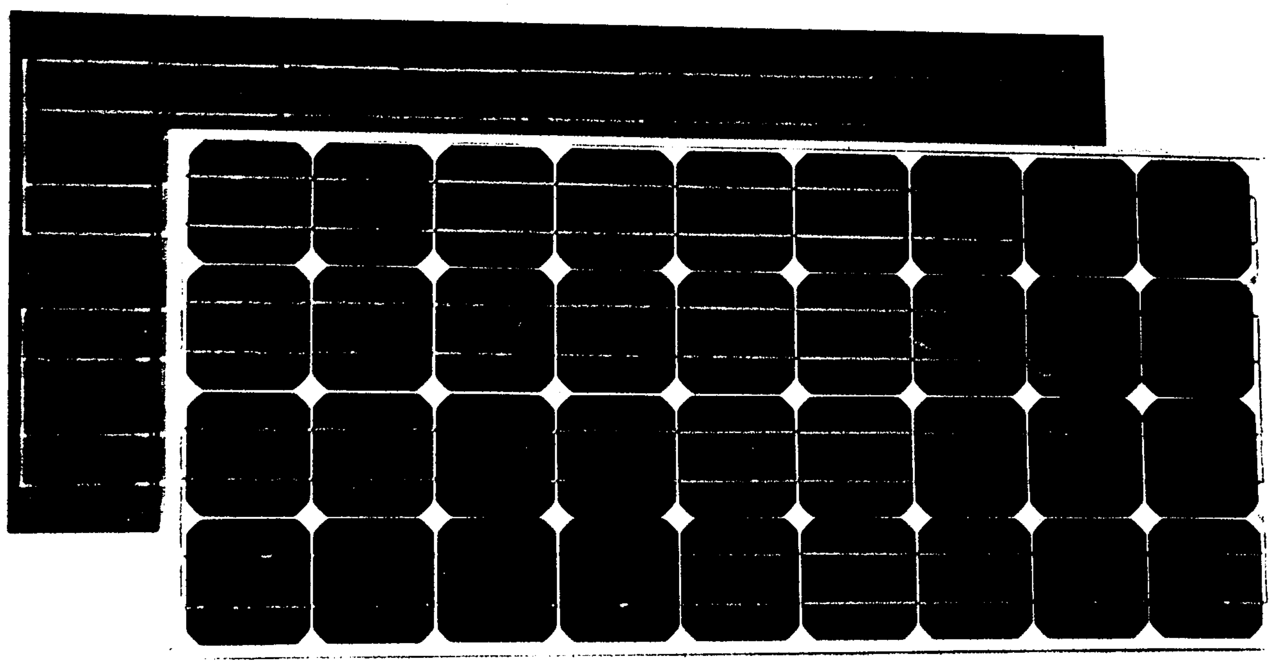
Multi-layered polymeric backing is used for environmental protection and enhanced heat dissipating properties.

Circuit is laminated between layers of ethylene vinyl acetate (EVA) for moisture resistance, UV stability and electrical isolation.

Junction covers with self-locking lids are engineered for easy wiring access.

# HOXAN
AMERICA INC.

## H-4810
**Photovoltaic Module**



## THE HOXAN H-4810

The **H-4810** is a premium quality photovoltaic module used in applications requiring reliable high power output such as remote telecommunications sites, outdoor lighting, remote environmental monitoring devices, water pumping and other remote electric power needs.

Specially processed single crystal silicon cells give the **H-4810WT** extremely high energy conversion efficiency. Options include white or black Tedlar backsheets with matching anodized aluminum frames and a choice of junction box designs. The **H-4810** has a 10-year limited warranty on power output (see warranty certificate for details).

## MODULE FEATURES

**1)** Thirty-six single crystal silicon cells wired in series maintain charging voltage in high ambient temperatures and low or diffuse sunlight conditions.
**2)** Special cell processing and a patented anti-reflective coating assure consistent cell quality for maximum power output.
**3)** Laminated EVA module construction and butyl rubber edge sealing resist moisture penetration.
**4)** Anodized aluminum frame resists corrosion.
**5)** Weather-proof Tedlar back sheet.
**6)** Standard AES junction box designed for simple module interconnection using conduit or wire only.

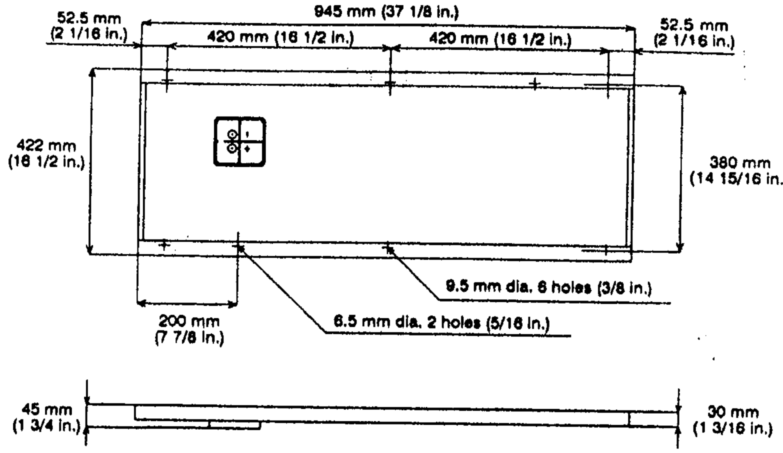
## QUALITY AND DURABILITY

Thousands of **H-4810** modules are functioning successfully in many applications worldwide in the most difficult environmental conditions. The **H-4810** has also passed rigorous laboratory tests for weather resistance and electrical isolation, including:
1) Thermal cycling (- 40°C to +90°C)
2) Thermal shock
3) Impact testing (227g ball dropped from 1 meter)
4) Wind loading to 135 MPH
5) Electrical isolation (less than 50mA at 3000VDC)
6) Corrosion resistance (5% salt fog at 35°C)
7) Humidity/freeze cycling

Test specifications are available on request.

## Mechanical Specifications

| | |
|---|---|
| Length: | 945 mm (37 1/8 in.) |
| Width: | 422 mm (16 1/2 in.) |
| Thickness: | 30 mm (1 3/16 in.) Frame only |
| | 45 mm (1 3/4 in.) With junction box |
| Weight: | 6.1 kg (13.4 lb.) |
| Front Cover: | Low iron tempered glass |
| Encapsulant: | Ethylene Vinyl Acetate |
| Solar Cells: | 100 x 100 mm square cells; 36 in series |
| Edge Sealant: | Butyl rubber |
| Frame: | Anodized structural aluminum |
| Electrical Isolation: | 3000 VDC, 10 microA (typ.) |




## Module Selector

| Module Selector | Color Selector | | Electrical Connections |
|---|---|---|---|
| | Back Sheet | Frame | |
| H-4810WT | White | Clear Anodized | Terminal Junction Box |
| H-4810WP | White | Clear Anodized | Pig-Tail Junction Wire |
| H-4810BT | Black | Black Anodized | Terminal Junction Box |
| H-4810BP | Black | Black Anodized | Pig-Tail Junction Wire |

## Electrical Specifications

### Standard Test Conditions 25°C

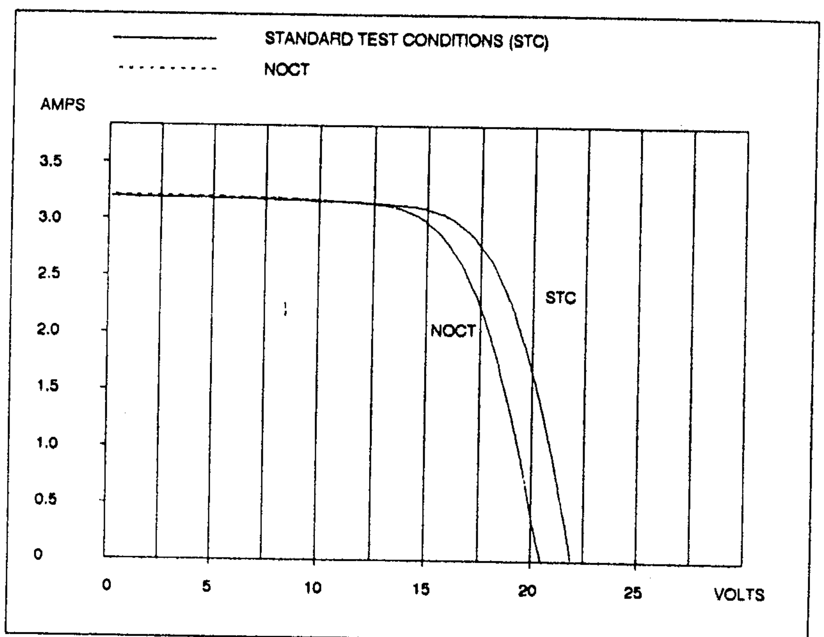
| | |
|---|---|
| Short Curcuit Current Isc | 3.2 Amps |
| Open Circuit Voltage Voc | 21.3 Volts |
| Current at Peak Power Point Im | 2.8 Amps |
| Voltage at Peak Power Point Vm | 17.0 Volts |
| Power Output (peak) | 48.0 Watts |

### Normal Operating Conditions 48°C

| | |
|---|---|
| Short Circuit Current Isc | 3.2 Amps |
| Open Circuit Voltage Voc | 19.8 Volts |
| Current at Peak Power Point Im | 2.8 Amps |
| Voltage at Peak Power Point Vm | 15.8 Volts |
| Power Output (peak) | 44.7 Watts |

The H-4810 is covered by a ten-year limited warranty on power output. (See warranty certificate for details)

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE




Standard test conditions: Insolation 1kW/M², Air Mass 1.5, Temperature 25°C.

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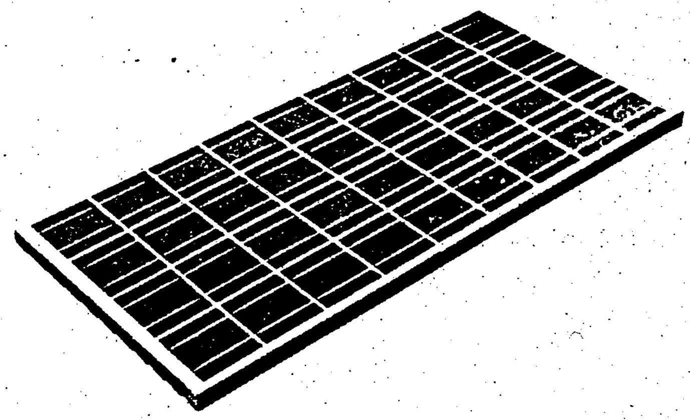
4810-5-90

KYOCERA

# LA361K51

## HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

TYPICAL OUTPUT 51.0 Wp



## HIGHLIGHTS OF KYOCERA PHOTOVOLTAIC MODULES

Kyocera's advanced cell processing technology and automated production facilities have produced a highly efficient multicrystal solar modules.
The conversion efficiency of the Kyocera solar cell is over 14%.
These cells are encapsulated between a tempered glass cover and an EVA pottant with PVF and aluminum foil back sheet to provide maximum protection from the severest environmental conditions.
The entire laminate is installed in an anodized aluminum frame to provide structural strength and ease of installation.

## APPLICATIONS

- Microwave/Radio repeater stations
- Electrification of villages in remote areas
- Medical facilities in rural areas
- Power source for summer vacation homes
- Emergency communication systems
- Water quality and environmental data monitoring systems
- Navigation lighthouses, and ocean buoys
- Pumping systems for irrigation, rural water supplies and livestock watering
- Aviation obstruction lights
- Cathodic protection systems
- Desalination systems
- Recreational vehicles
- Railroad signals
- Sailboat charging systems

## SPECIFICATIONS

### ■ Electrical Specifications

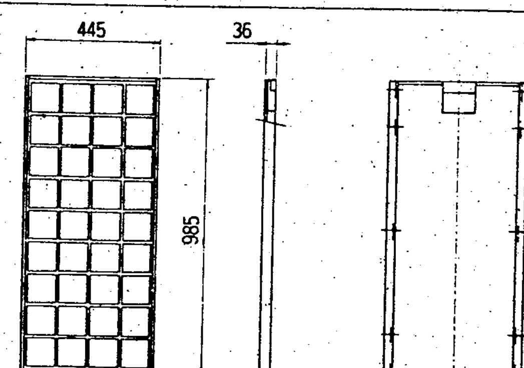
| MODEL | LA361K51 |
|---|---|
| Output | 51.0Watts |
| Optimum Voltage | 16.9Volts |
| Optimum Current | 3.02Amps |
| Open Circuit Voltage | 21.2Volts |
| Short-Circuit Current | 3.25Amps |
| Length | 985 mm (38.8 in.) |
| Width | 445 mm (17.5 in.) |
| Depth | 36 mm (1.4 in.) |
| Weight | 5.9 kg (13.0 lbs.) |

Note. The electrical specifications are under test conditions of Irradiance of 100 mW/cm$^2$, spectrum of 1.5 air mass and cell temperature of 25°C

Kyocera reserves the right to modify these specifications without notice
Custom made laminates and modules are also available upon request

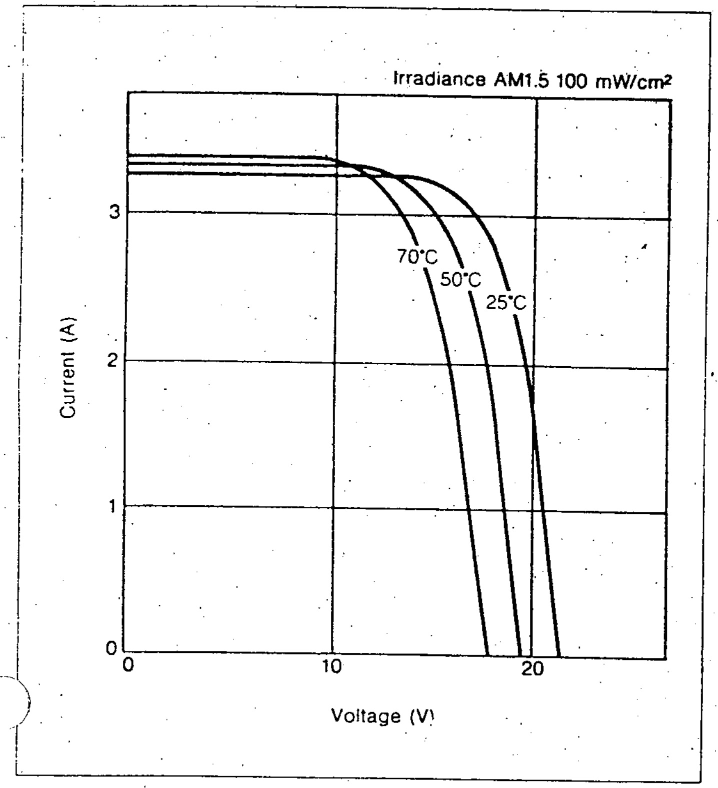
### ■ Physical Specifications

(Unit mm)

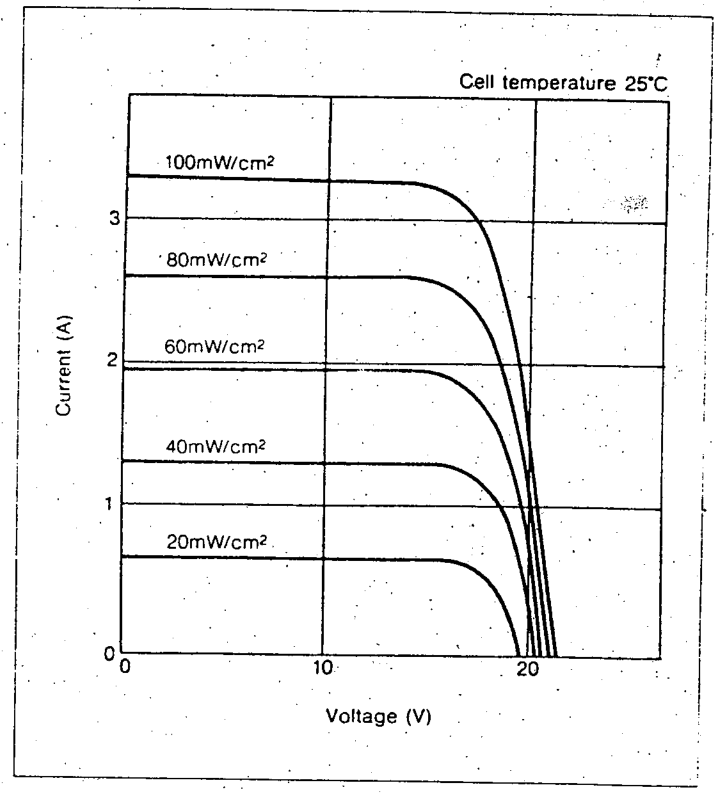


## ELECTRICAL CHARACTERISTICS

Voltage-Current characteristics of Solar Module LA361K51 at various cell temperatures




Current-Voltage characteristics of Solar Module LA361K51 at various irradiance levels




## QUALITY ASSURANCE

Kyocera multicrystal photovoltaic modules exceed government specifications for the following tests.

- Thermal cycling test
- Thermal shock test
- Thermal/Freezing and high humidity cycling test
- Electrical isolation test
- Hail impact test
- Mechanical, wind and twist loading test
- Salt mist test
- Light and water-exposure test
- Field exposure test

KYOCERA
PHOTOVOLTAIC POWER
MODULE
12 YEAR LIMITED
WARRANTY

FREE replacement module if unit loses over 10% of its rated power output over a 12 year period.

# CC-60C/CC-120C Charge Controller

The name means reliability
HELIOTROPE GENERAL
3733 Kenora Dr.
Spring Valley, CA 91977
Telephone (619) 460-3930

## Hi Reliability "Series Type" Charge Controller

### GENERAL

The CC-60C is a breakthrough POWER MOS FET design, 45 Amp photovoltaic "series" type battery charge controller without a relay. The 45 Amp can be increased to 60 Amp by installing the FAN-60, or mounting on a flat metal surface. Also available is a 120 Amp model, the CC-120C. The CC-60C series is field selectable for either 12 or 24 volts and a separate model is available for 48 volt application; specify CC-60C-48V or CC120C-48V.

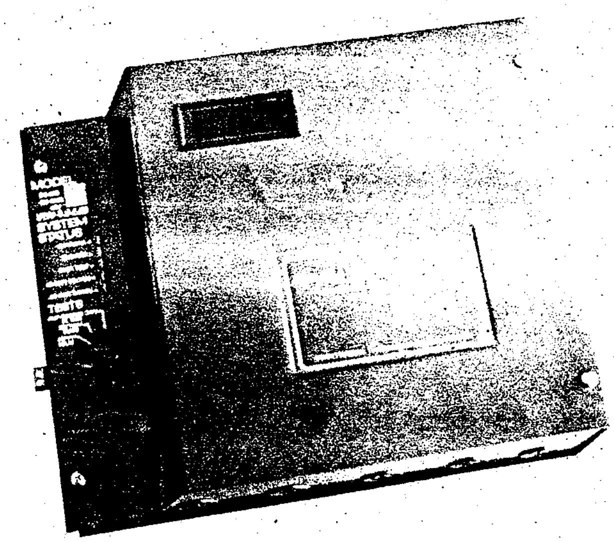
An LCD digital readout is incorporated into the front cover and is used in conjunction with the knob on the controller allowing readings of "Array Voltage," "Battery Voltage," and "Charging Current." A two point test output jack also allows for remote measurement with a voltmeter.

### CONTROL STRATEGY

The "series" type design of charge controller without a relay is accomplished with the use of POWER MOS FETS. Because the life of the MOS FET is not decreased by frequent on/off switching as with a relay a different charging strategy can be employed. When the full state of charge in the battery is reached with a relay type controller the incoming current shuts off the charging sequence and the battery voltage immediately drops. With the PWM Taper Charge (Pulse Width Modulation) the state of charge voltage is maintained by frequently switching on and off the photovoltaic current source. This PWM type charge assures that the battery is kept at the fullest possible charge. After the preset voltage is maintained a float (trickle) charge is effected to offset the losses expected in an inactive system.

Heretofore "series" type charge controllers have utilized relays to turn on and off the charging sequence of the photovoltaic array to the batteries. Relay reliability is severely affected by the frequent switching of high DC current loads. Because of relay life concerns the relay "series" type of charge controller do not bring batteries to their fully charged state of charge as with the Pulse Width Modulated (PWM) type charge controller. With the continued price reduction of POWER MOS FET components, a FET charge controller is now price competitive with the relay type.

Unique to the CC-60C is an overtemp shutdown indicator light. When the charging rate exceeds the heat dissipation capabilities of the unit, the unit stops the charging sequence.



When this happens there is no further heat build-up (as in shunt types) and cooling occurs allowing the unit to turn back on. The indicator light shows when this overtemp situation exists and addition of cooling via heat sink or fan will prevent this stopping of the charge sequence. Protection of all the electronic components due to overheat is accomplished which is impossible with shunt-type controllers. The CC-60C delivers maximum reliability by eliminating the relay and positively prevents overheating. Expansion of a system from 45 to 60 Amps is easily field accomplished by the addition of the fan and/or heat sinking.

Fuse protection is not necessary to protect the charge controller.

### FEATURES

This breakthrough POWER MOS FET design, the CC-60C, includes the following features:

- Field selectable 12 or 24 Volt
- 60 Amp Shottky type blocking diode
- Sixteen different battery charged voltage levels are field selectable from 13.5 to 16.5 in .2 Volt increments (x2 for 24V)

## FEATURES (Cont'd.)

- Low battery voltage warning light with optional remote plug-in audible warning. This low battery voltage threshold is field selectable at 10.5 or 11.0 Volts.
- Battery Temperature Compensation with optional low cost sensor
- External battery voltage sensor wiring connection for greater accuracy sensing. If not used the battery voltage is sensed through the battery lead terminals in the charge controller.
- Terminals for optional ACCU-SLOPE™ manufactured by Heliotrope General. The ACCU-SLOPE™ displays instantaneous Amp charging and daily accumulated Amp hours delivered by the PV array
- Pulse Width Modulated (PWM) charging occurs when full battery state of charge voltage is approached. This feature guarantees that the batteries are fully charged when PV power is available
- Float charge continues after the selected state of charge voltage has been reached
- Indicator light for charging, charged, low battery voltage warning, overtemp shut down, and low voltage disconnect. The Low Voltage Disconnect is applicable only when the optional LVD-60 board is installed
- 250MCM lug size for PV and battery connections
- Reverse polarity connection protected
- Protected against accidental short to ground while user is wiring any of the options
- All inputs and outputs are EMI, RFI and surge protected
- Size — 11" x 9" x 3.75"

## LOW VOLTAGE DISCONNECT OPTION

The CC-60C charge controllers may be converted to include a load control unit by the addition of the LVD-60, Low Voltage Disconnect (LVD) printed circuit board. The LVD is designed to protect the battery bank from harmful and permanent battery discharge by disconnecting the load from the battery when a preselected voltage is reached. The LVD is capable of passing 30 Amps of current and operating 12 or 24 volt systems. Eight different voltage levels from 10.5 to 11.5 are field selectable with DIP switch. The LVD can also be used as a dry contact closure or can operate a larger external relay with a 12VDC coil. The LVD may be overridden by shorting together two pins of a connector on the printed circuit board. The LVD is easily field installed with four nuts and screw connection of two wires to power the LVD indicator.

## ACCU-SLOPE™ OPTION

The ACCU-SLOPE™ is a wall or panel mounted instrument that records the current Amp charging rate and a cumulative Amp-hour meter. Depressing the reset button zeros the cumulative Amp-hour meter. The ACCU-SLOPE™ easily hooks up to the CC-60C charge controller with a four wire connector to a terminal strip. A separate descriptive data sheet is available on the ACCU-SLOPE™.

## ORDERING INFORMATION

| | |
|---|---|
| CC-60C | Charge controller, 60 Amp maximum |
| CC-120C | Charge controller, 120 Amp maximum |
| FAN-60 | Fan option to increase 45 Amps to 60 Amps on the CC-60; standard in CC-120 |
| LVD-60 | Low Voltage Disconnect. Add-on printed circuit board for LVD feature |
| ACCU-SLOPE | Photovoltaic Array Monitor. Monitor instantaneous array output and accumulative Amp hours. (for both 60 and 120 models) |
| SAS-10 | Sensor to add temperature compensation feature. |

## QUALITY CONTROL AND WARRANTY

Extreme emphasis is placed on quality control at Heliotrope General. There are a number of quality control steps in the manufacturing of every controller, from verification of component specifications from outside sources, to numerous in-process inspections and then final inspection of control before it is finally packaged for shipment.

As a direct result of this quality control emphasis, all controls carry a ten year limited warranty. During the first year replacement of defective merchandise with a tested replacement will be made at no charge. For years 2 through 5 replacement will be made for a service fee not to exceed 25% of the current list price and for years 6 through 10 the fee will not exceed 50% of the current list price. Ask for a copy of the warranty for full details.

INDEPENDENT POWER & LIGHT
Alternative Energy Specialists
RR 1, Box 3054 Hyde Park, VT. 05655
(802) 888-7194

Battery Specifications **Surrette**

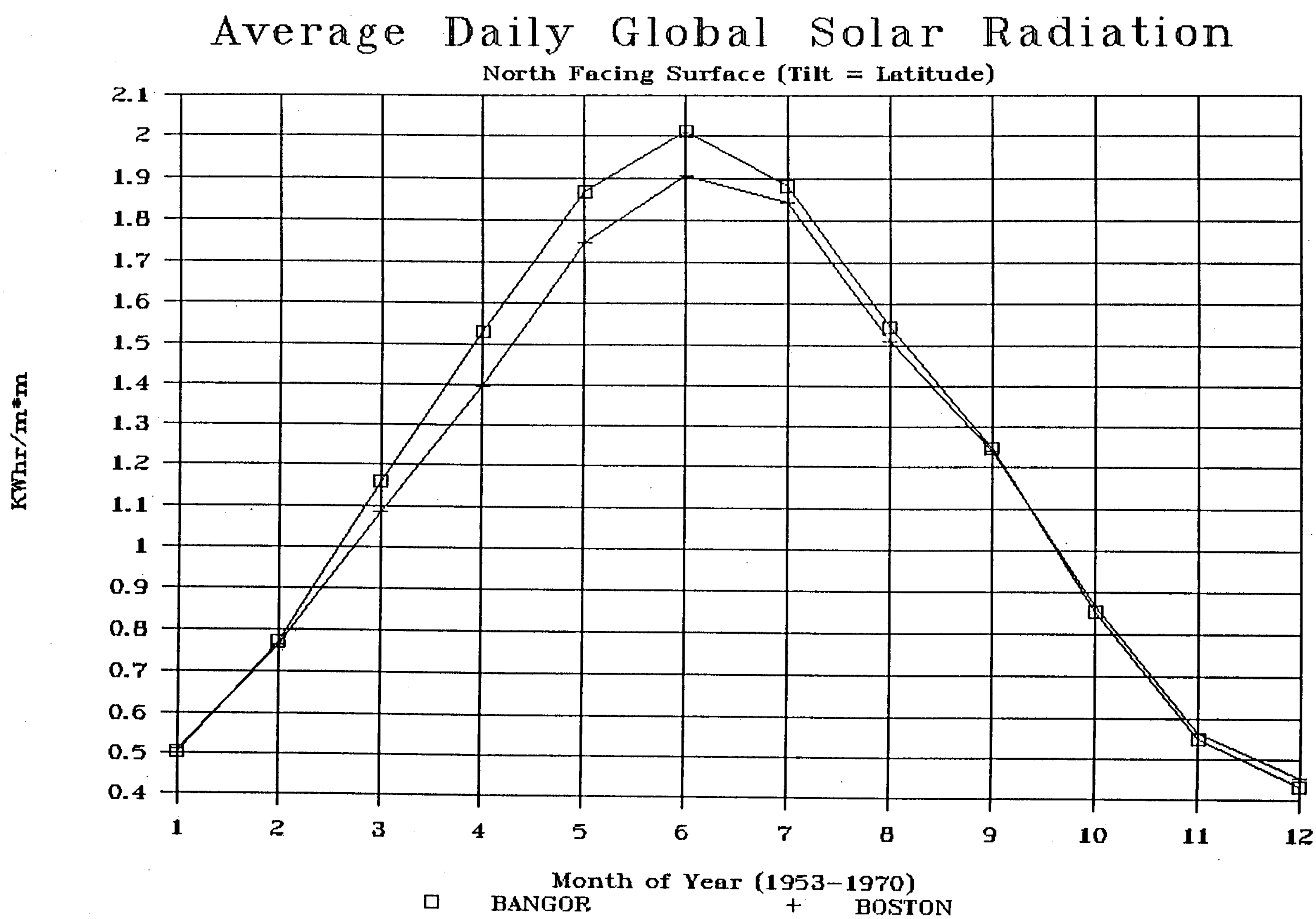
# ALTERNATIVE ENERGY BATTERIES

| Type | Assembly | Volts | BCI Group Size | Catalog Number | Electrical Performance: AMP Hours @ 20HR Rate | Electrical Performance: Reserve Capacity (minutes) | Electrical Performance: Cold Cranking Amps | Dimensions (Inches overall): Length | Dimensions (Inches overall): Width | Dimensions (Inches overall): Height | Weight (Pounds): Wet | Weight (Pounds): Dry | Quarts of Acid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXTRA HEAVY DUTY DEEP-CYCLING FOR PHOTOVOLTAIC AND WINDPOWER SYSTEMS | | | | | | | | | | | | | |
| **HG-1** | A | 6 | 1 | 409 | **105** | 160 | 485 | 9.1 | 7.0 | 8.9 | 40 | 30 | 4.5 |
| **XH-2** | A | 6 | 2 | 317 | **130** | 215 | 520 | 10.1 | 6.9 | 9.1 | 50 | 40 | 5.0 |
| **XH-3** | A | 6 | 3 | 309 | **149** | 270 | 775 | 11.8 | 7.1 | 9.4 | 58 | 48 | 5.5 |
| **HR-4** | A | 6 | 4 | 405 | **165** | 310 | 720 | 13.0 | 7.1 | 9.4 | 65 | 52 | 6.0 |
| **HR-5D** | B | 6 | 5D | 411 | **182** | 330 | 835 | 13.4 | 7.1 | 9.4 | 70 | 55 | 6.5 |
| **HR-7D** | B | 6 | 7D | 407 | **221** | 430 | 920 | 16.2 | 7.1 | 9.4 | 80 | 64 | 7.0 |
| **EHG-208** | C | 6 | GC2 | 415 | **208** | 345 | 727 | 10.3 | 7.1 | 10.3 | 72 | 57 | 5.8 |
| **EIG-225** | C | 6 | GC2H | 417 | **225** | 350 | 575 | 10.3 | 7.1 | 11.3 | 77 | 60 | 6.5 |
| **EIG-262** | C | 6 | SP | 419 | **262** | 395 | 785 | 11.7 | 7.0 | 11.3 | 90 | 70 | 7.5 |
| **NS-305** | B | 6 | SP | 435 | **305** | 458 | 900 | 12.9 | 7.0 | 14.3 | 115 | 86 | 8.8 |
| **CH-375** | B | 6 | SP | 421 | **335** | 460 | 890 | 11.7 | 7.0 | 16.8 | 122 | 98 | 10.5 |
| **6NS-29** | DH | 6 | SP | 423 | **490** | 780 | 1580 | 20.2 | 9.1 | 16.4 | 230 | 156 | 20.0 |
| **8HR-19** | DH | 8 | SP | 455 | **160** | 280 | 695 | 18.4 | 7.4 | 9.5 | 97 | 77 | 8.0 |
| **8HHG-175** | DH | 8 | SP | 441 | **175** | 263 | 650 | 21.4 | 7.5 | 10.8 | 110 | 82 | 9.0 |
| **8HHG-21** | DH | 8 | SP | 443 | **200** | 310 | 850 | 21.4 | 7.5 | 10.8 | 122 | 94 | 9.0 |
| **8HR-27** | DH | 8 | SP | 456 | **220** | 380 | 980 | 27.5 | 7.5 | 10.5 | 144 | 107 | 13.5 |
| **8M-23** | DH | 8 | SP | 444 | **225** | 360 | 900 | 27.5 | 7.5 | 10.5 | 146 | 109 | 14.0 |
| **8HHG-25** | DH | 8 | SP | 445 | **240** | 384 | 1032 | 24.4 | 7.5 | 10.8 | 141 | 113 | 11.0 |
| **8HHG-29** | DH | 8 | SP | 446 | **290** | 465 | 1190 | 27.5 | 7.5 | 10.5 | 165 | 130 | 12.0 |
| **8HHG-31** | DH | 8 | SP | 447 | **300** | 495 | 1320 | 26.9 | 8.4 | 10.8 | 183 | 145 | 15.0 |
| **8HHG-37** | DH | 8 | SP | 449 | **358** | 598 | 1575 | 26.9 | 10.0 | 10.8 | 220 | 197 | 17.0 |
| **8NS-17** | DH | 8 | SP | 501 | **285** | 450 | 910 | 27.9 | 6.3 | 17.9 | 220 | 190 | 13.0 |
| **8CH-17** | DH | 8 | SP | 502 | **355** | 565 | 1050 | 27.9 | 6.3 | 17.9 | 240 | 210 | 13.0 |
| **8NS-23** | FH | 8 | SP | 511 | **385** | 610 | 1240 | 28.3 | 7.5 | 17.5 | 250 | 213 | 18.0 |
| **8CH-23** | FH | 8 | SP | 513 | **470** | 750 | 1460 | 28.3 | 7.5 | 17.5 | 280 | 244 | 16.0 |
| **8NS-33** | FH | 8 | SP | 521 | **565** | 905 | 1850 | 28.3 | 10.5 | 16.4 | 359 | 304 | 26.0 |
| **8CH-33** | FH | 8 | SP | 523 | **681** | 1090 | 2090 | 28.3 | 10.5 | 16.4 | 400 | 353 | 23.0 |
| **T-12-120** | BH | 12 | SP | 414 | **120** | 210 | 610 | 13.5 | 7.0 | 11.3 | 84 | 66 | 9.0 |
| **12XH-130** | B | 12 | 18 | 314 | **130** | 215 | 520 | 20.4 | 7.5 | 9.6 | 108 | 85 | 10.0 |
| **T-12-140** | B | 12 | 16TF | 425 | **140** | 210 | 535 | 16.0 | 7.1 | 11.1 | 98 | 82 | 9.0 |
| **12XH-19** | BH | 12 | 4D | 303 | **165** | 285 | 775 | 20.3 | 8.8 | 9.8 | 135 | 108 | 12.0 |
| **12XH-21** | BH | 12 | 6D | 305 | **193** | 310 | 825 | 20.3 | 9.9 | 9.8 | 148 | 113 | 13.0 |
| **12XH-25** | BH | 12 | 8D | 307 | **230** | 385 | 900 | 20.3 | 11.0 | 9.8 | 159 | 126 | 14.0 |
| **HR-8D** | BH | 12 | 8D | 427 | **221** | 430 | 920 | 20.3 | 11.0 | 9.8 | 160 | 127 | 14.0 |

**NOTES TO SPECIFICATIONS**

1 **ASSEMBLY** Letter indicates terminals available and whether handles are included:

**A** AUTO posts standard. Option: COMBINATION post and stud terminals.
**B** AUTO posts standard. Option: COMBINATION post and stud terminals or MARINE "flag" terminals.
**C** COMBINATION post and stud terminals standard.
**D** MARINE "flag" terminals standard.
**E** Specify AUTO posts or stainless steel STUD posts.
**H** Handles included.



Average Daily Global Solar Radiation
North Facing Surface (Tilt = Latitude)
KWhr/m*m
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
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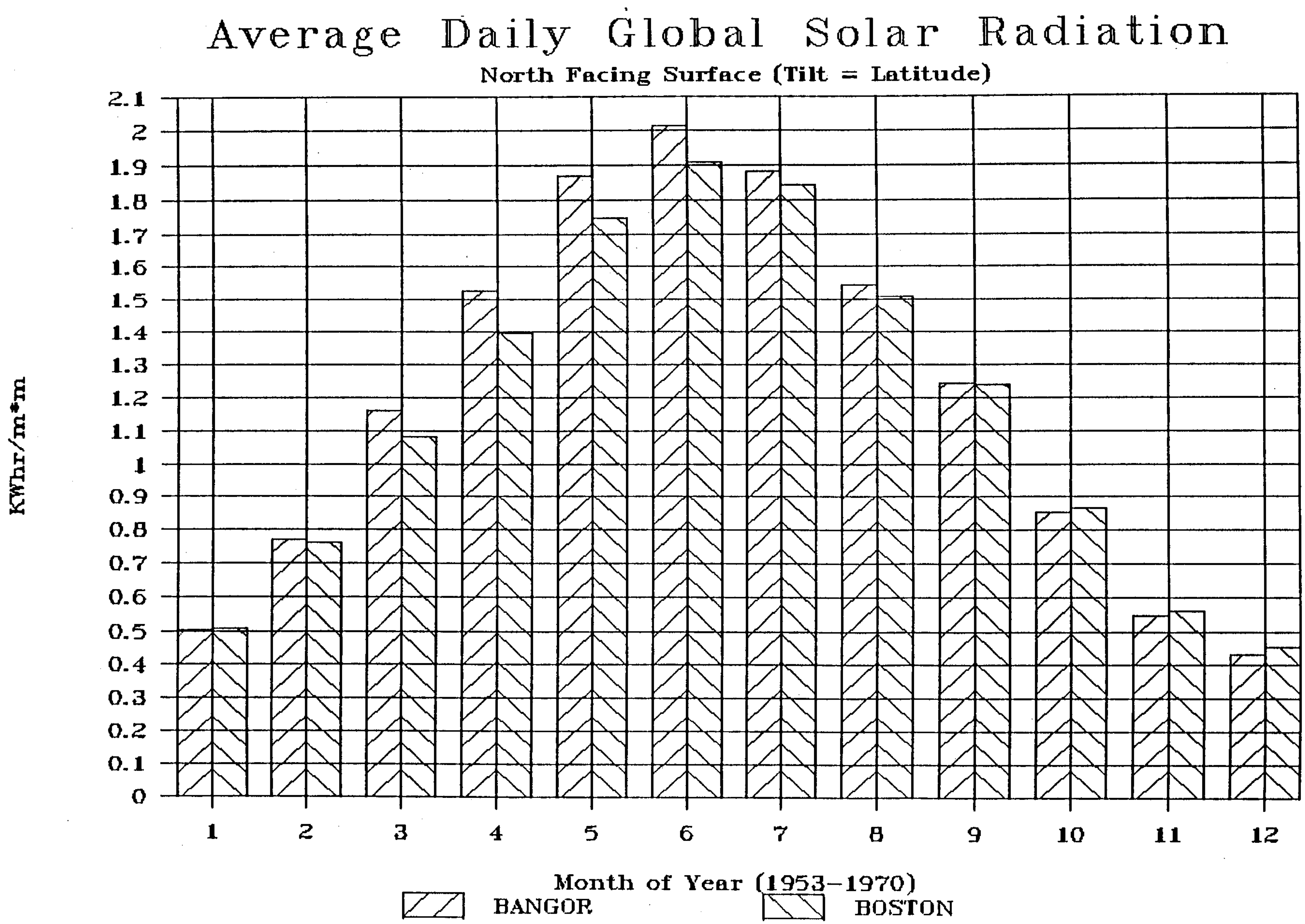
11
12
Month of Year (1953-1970)
BANGOR
+ BOSTON


Average Daily Global Solar Radiation
North Facing Surface (Tilt = Latitude)
KWhr/m*m
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2
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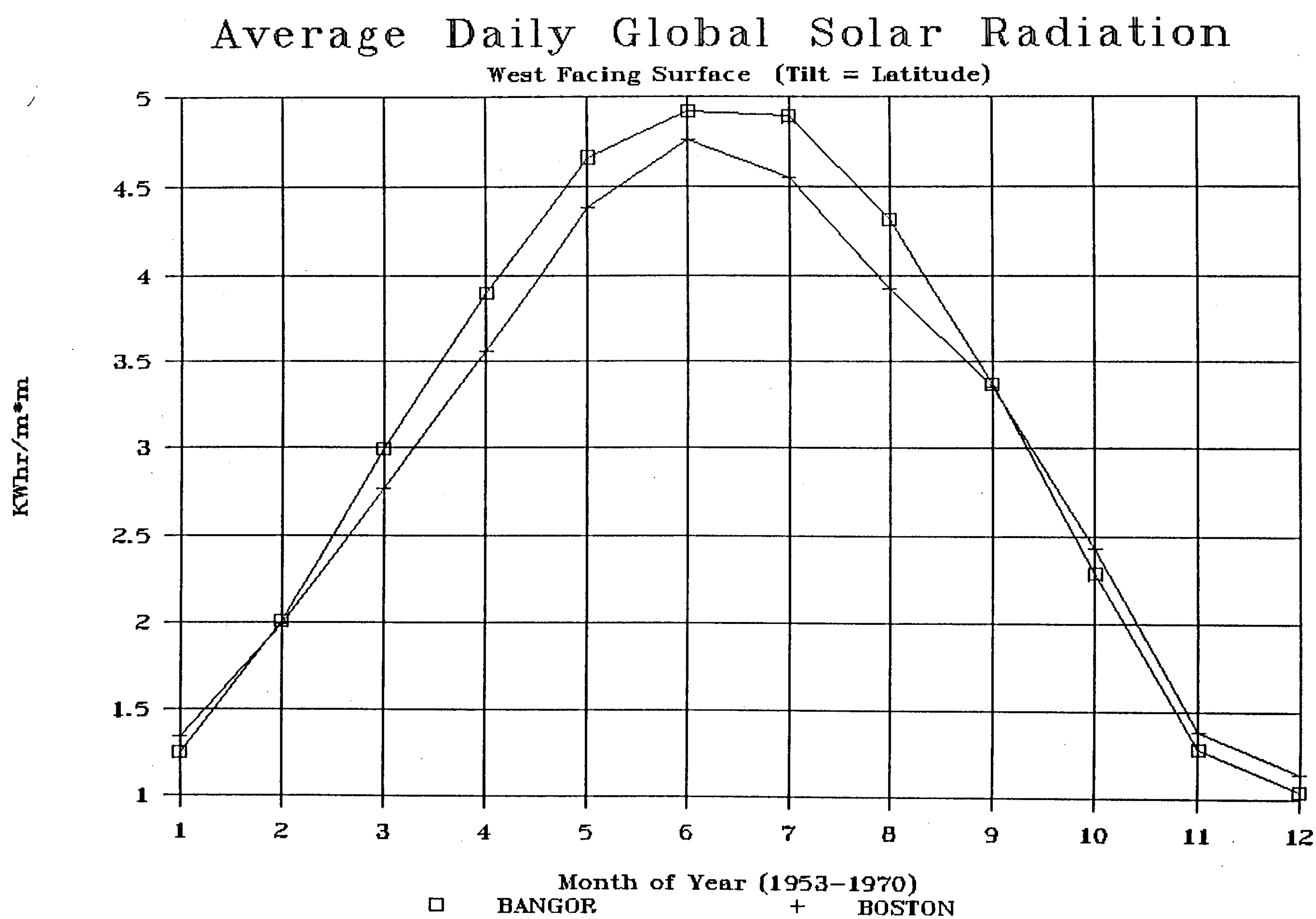
Month of Year (1953-1970)
BANGOR
BOSTON


Average Daily Global Solar Radiation
West Facing Surface (Tilt = Latitude)
KWhr/m*m
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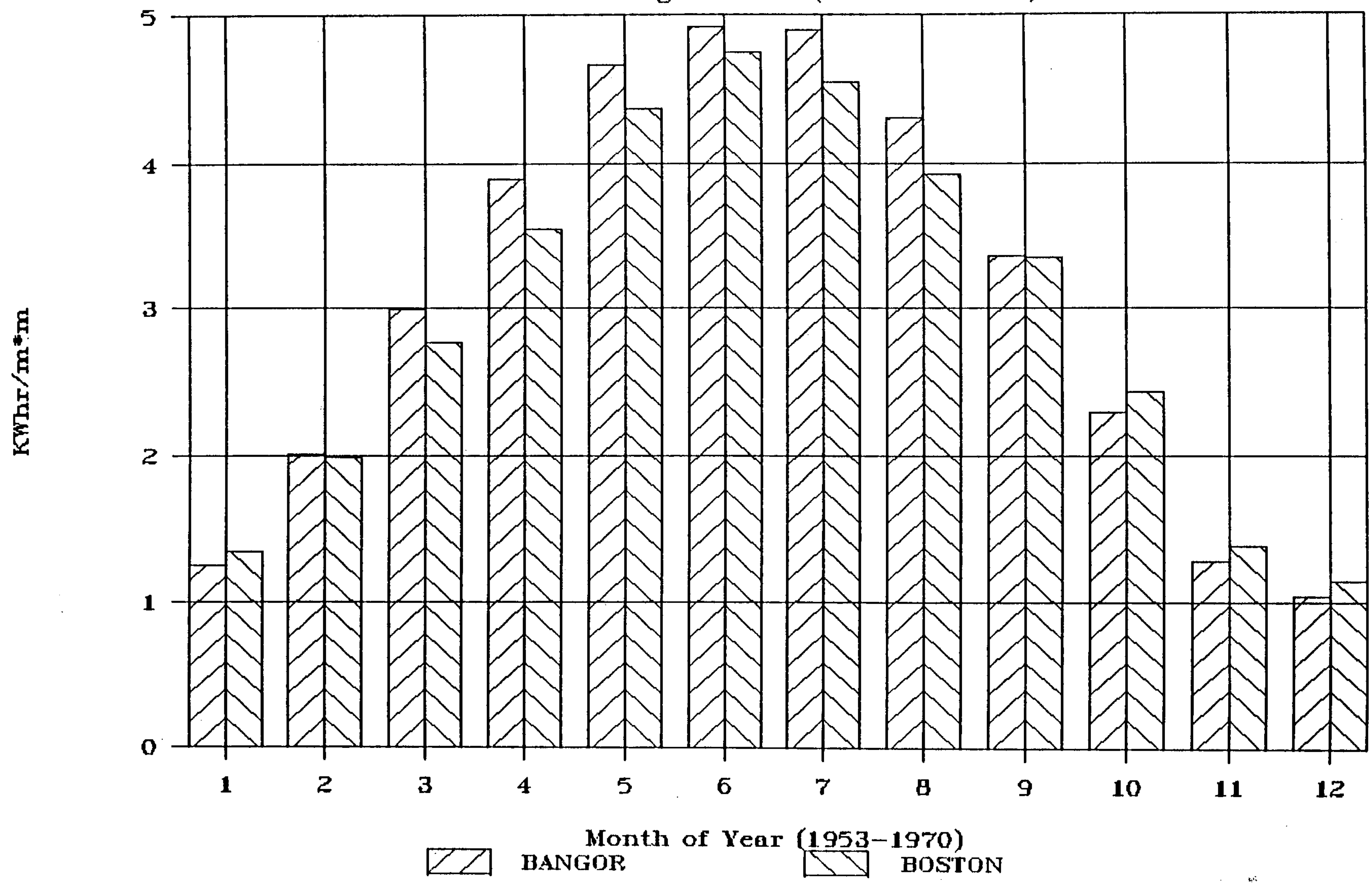
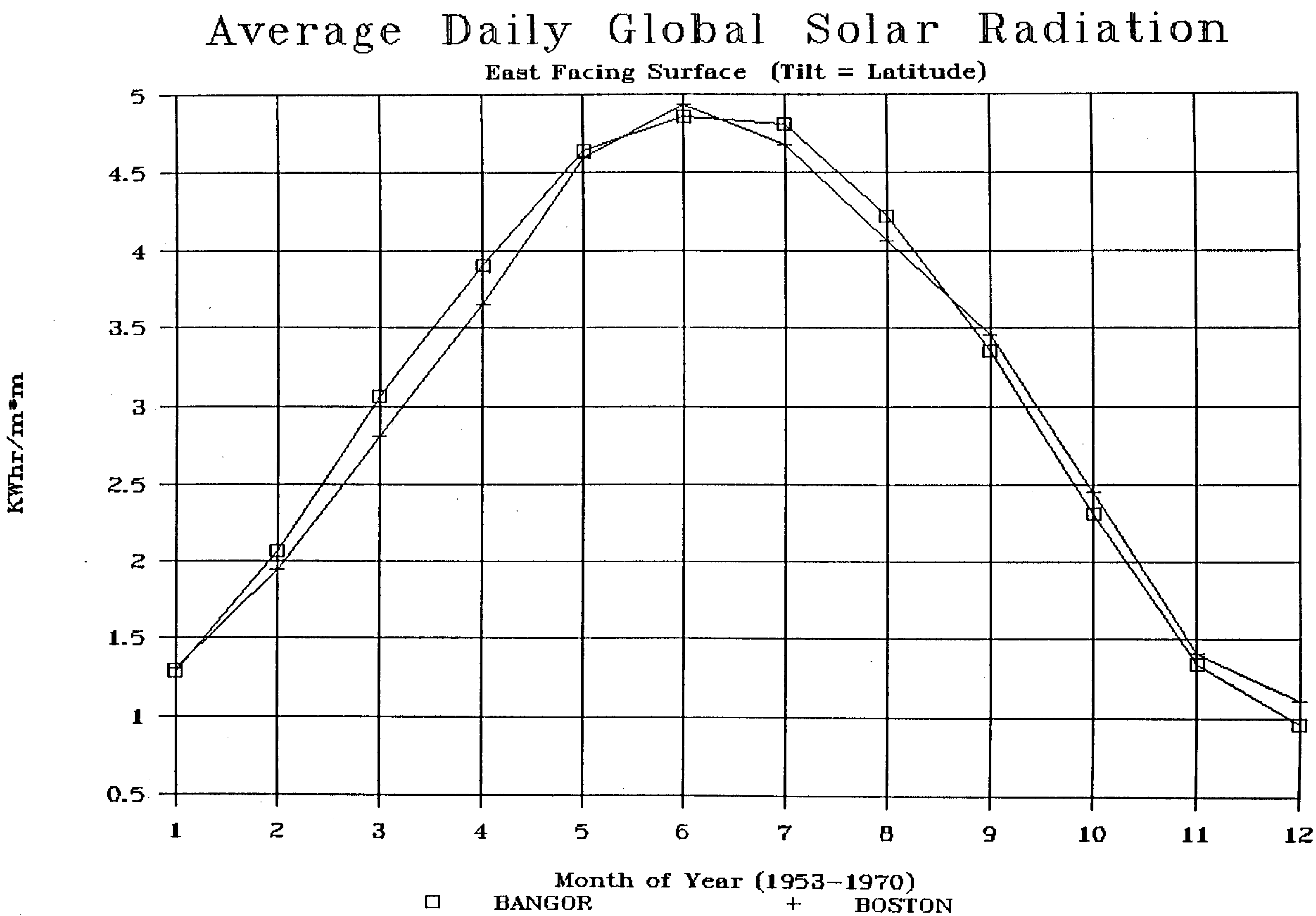
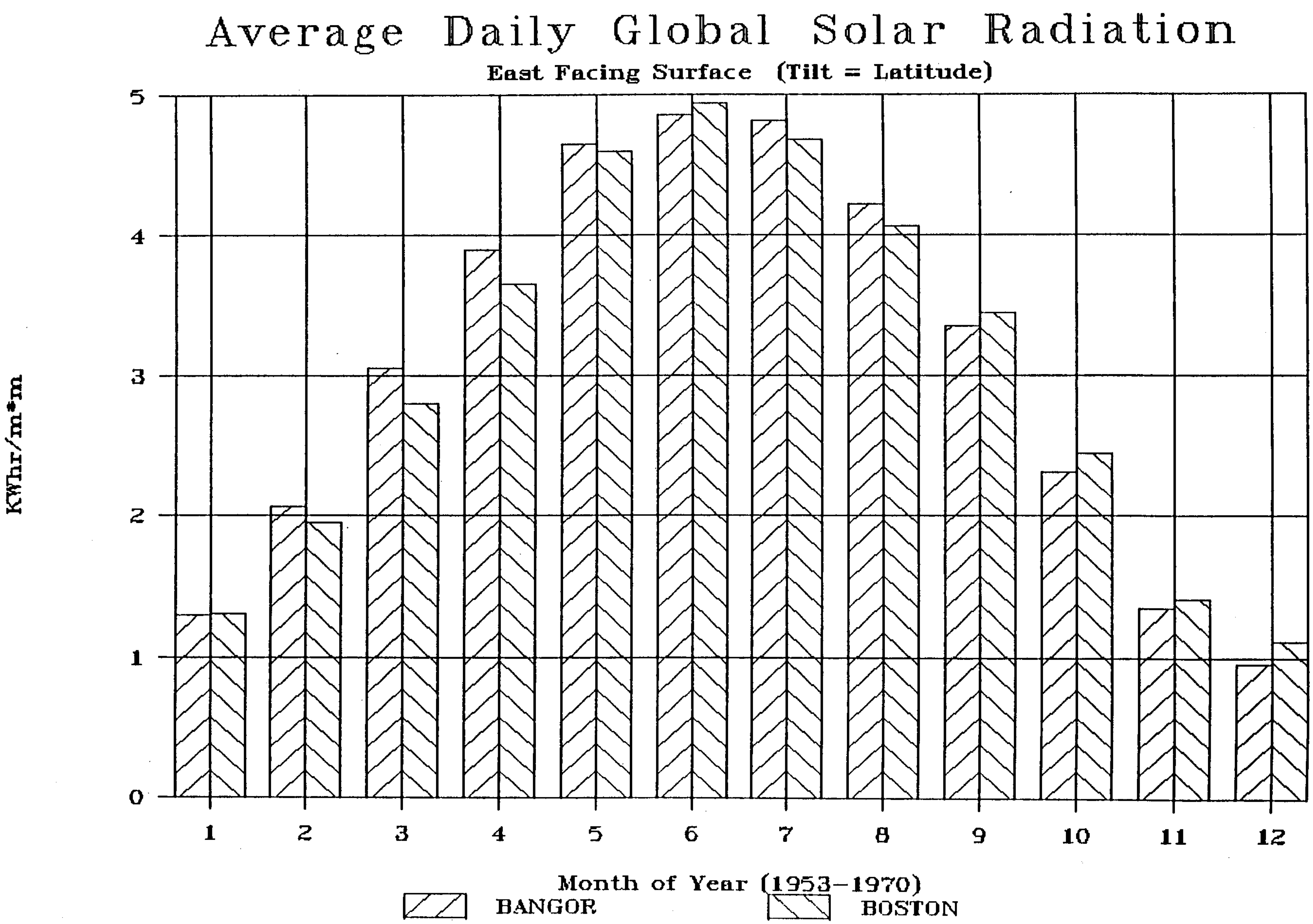
4.5
4
3.5
3
2.5
2
1.5
1
1 2 3 4 5 6 7 8 9 10 11 12
Month of Year (1953–1970)
BANGOR
BOSTON

# Average Daily Global Solar Radiation

West Facing Surface (Tilt = Latitude)




Average Daily Global Solar Radiation
East Facing Surface (Tilt = Latitude)
KWhr/m*m
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1 2 3 4 5 6 7 8 9 10 11 12
Month of Year (1953–1970)
□ BANGOR
+ BOSTON


Average Daily Global Solar Radiation
East Facing Surface (Tilt = Latitude)
KWhr/m*m
0
1
2
3
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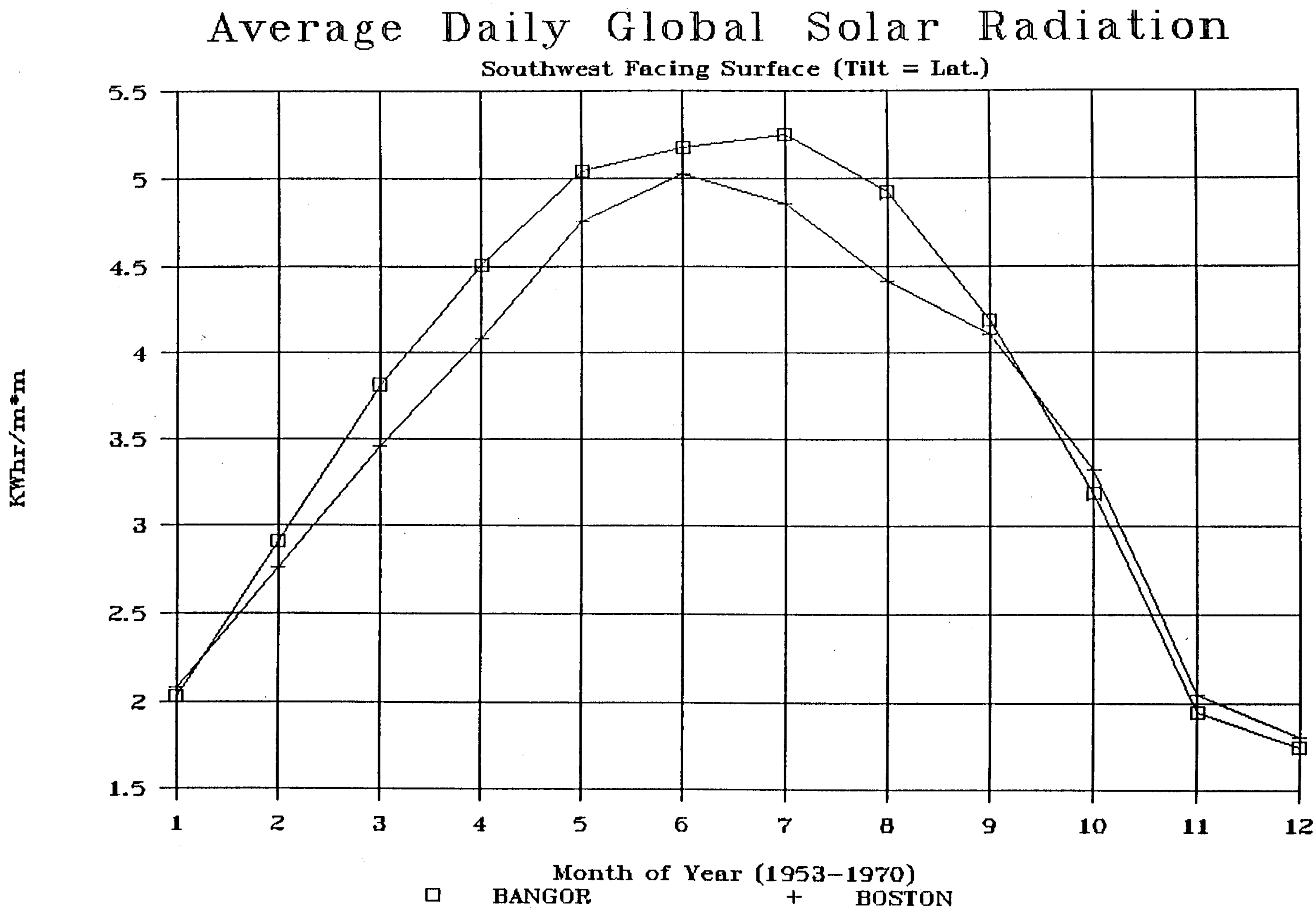
Month of Year (1953-1970)
BANGOR
BOSTON


Average Daily Global Solar Radiation
Southwest Facing Surface (Tilt = Lat.)
KWhr/m*m
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5
4.5
4
3.5
3
2.5
2
1.5
1
2
3
4
5
6
7
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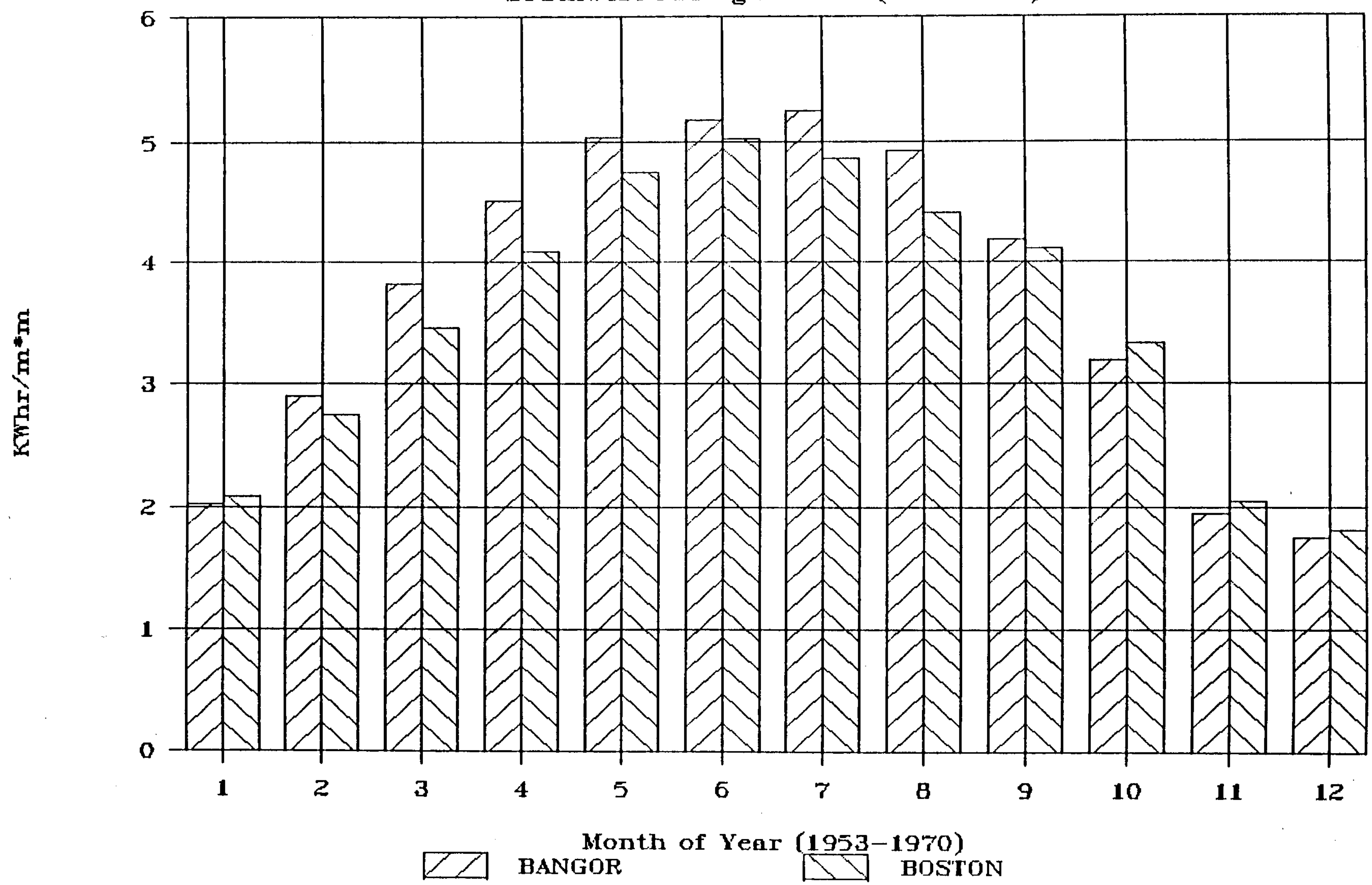
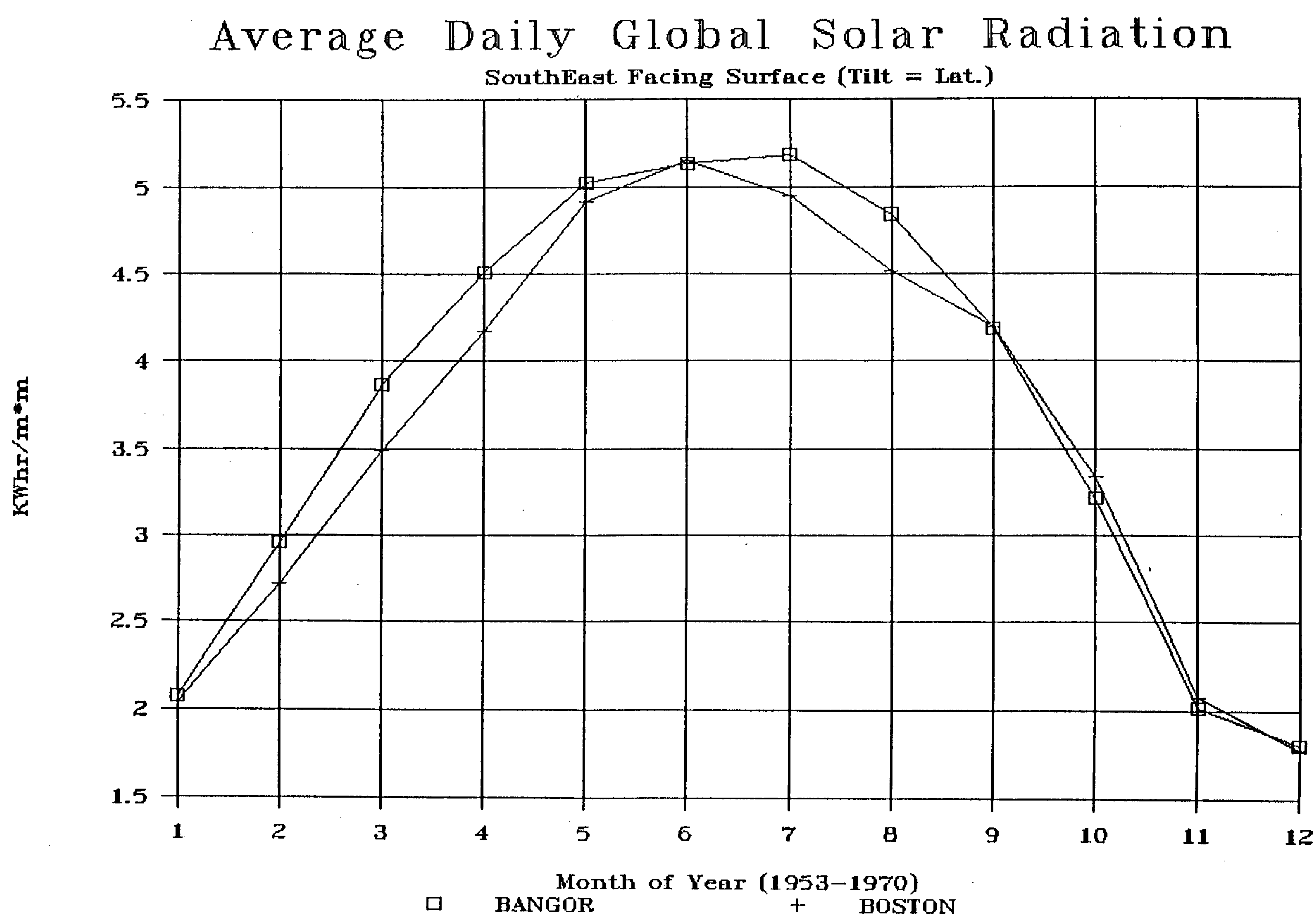
10
11
12
Month of Year (1953-1970)
□ BANGOR
+ BOSTON

## Average Daily Global Solar Radiation

Southwest Facing Surface (Tilt = Lat.)




Average Daily Global Solar Radiation
SouthEast Facing Surface (Tilt = Lat.)
KWhr/m*m
5.5
5
4.5
4
3.5
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2.5
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1.5
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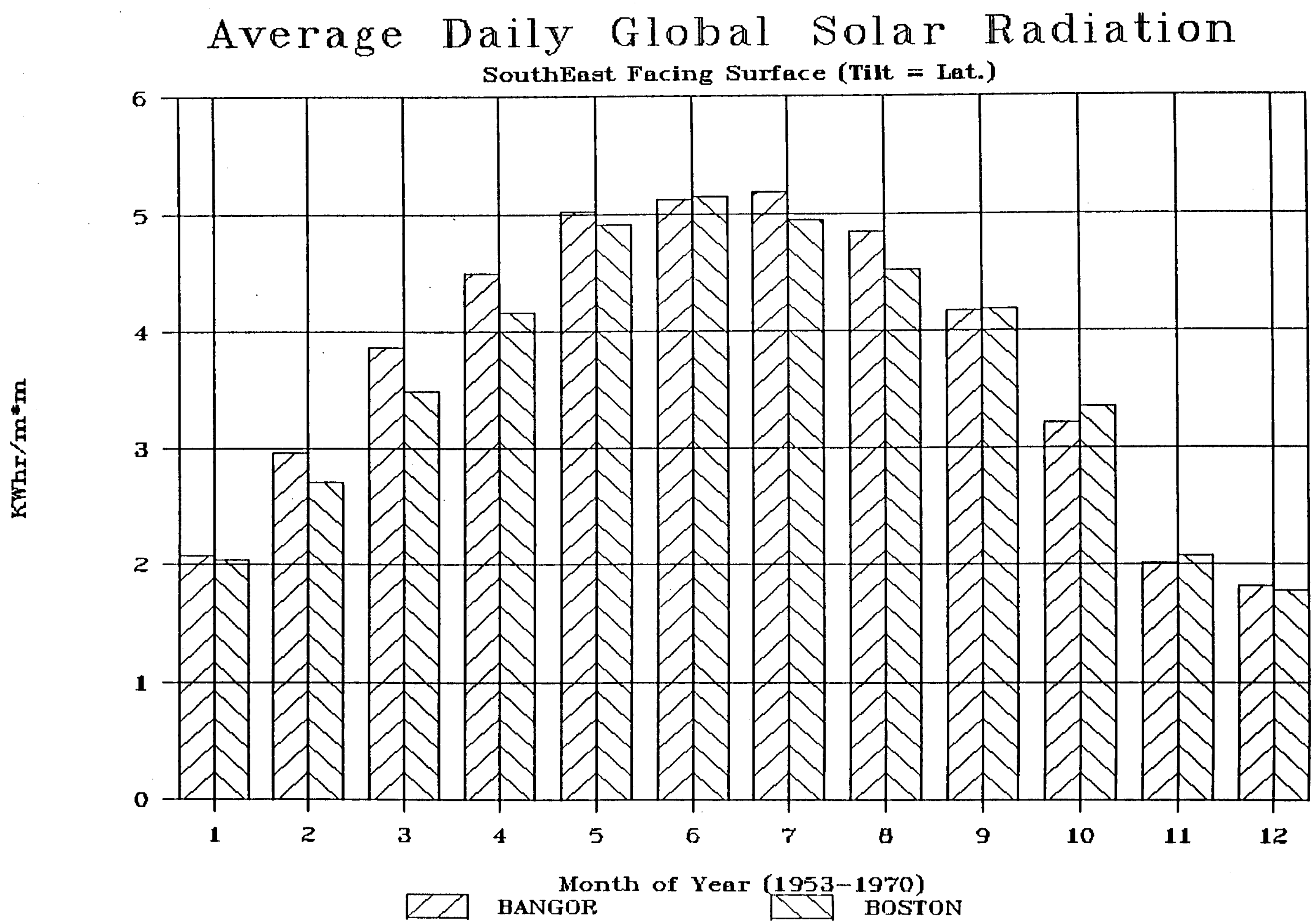
12
Month of Year (1953-1970)
□ BANGOR
+ BOSTON



Average Daily Global Solar Radiation
SouthEast Facing Surface (Tilt = Lat.)
KWhr/m*m
0
1
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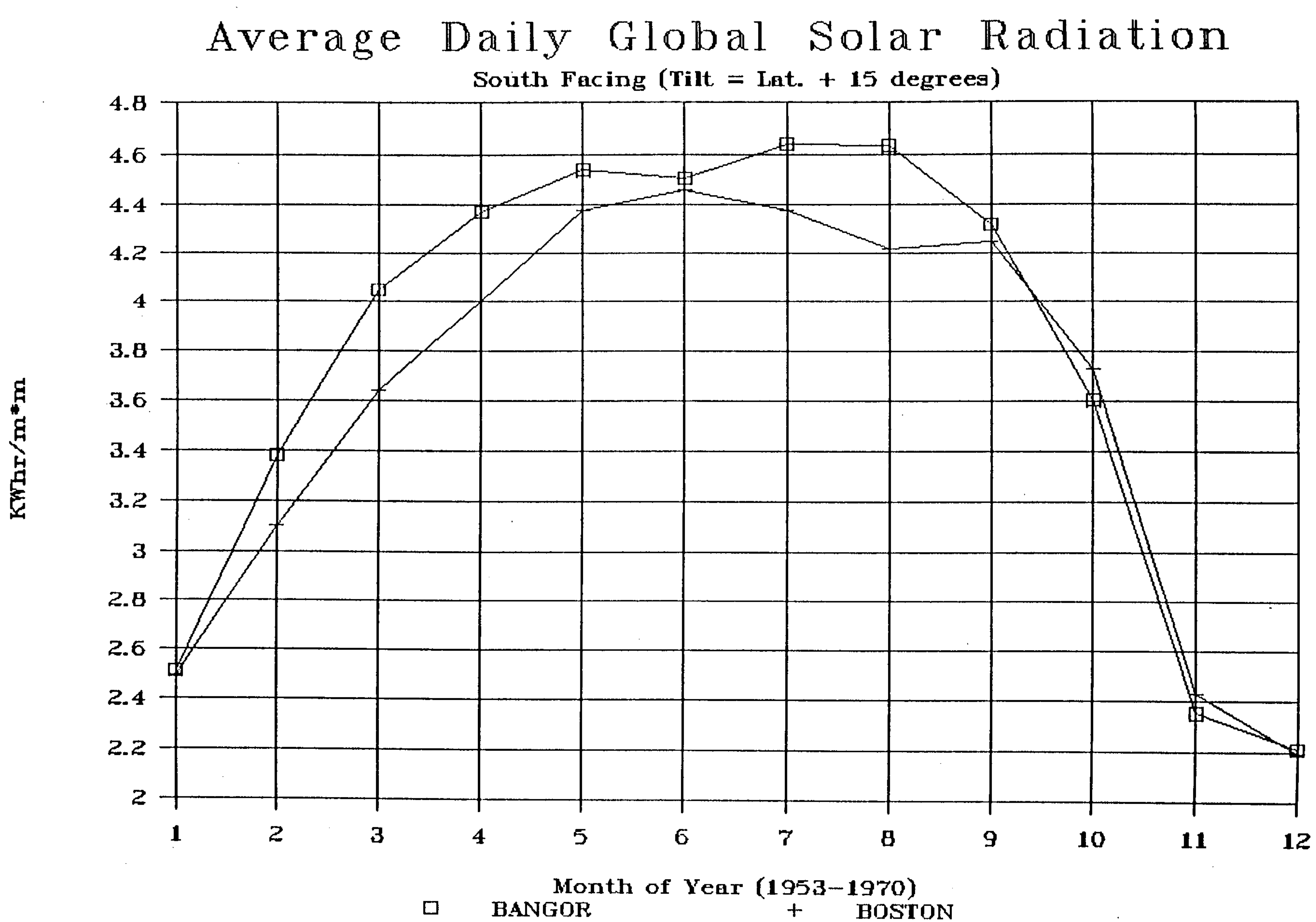
Month of Year (1953-1970)
BANGOR
BOSTON


Average Daily Global Solar Radiation
South Facing (Tilt = Lat. + 15 degrees)
KWhr/m*m
4.8
4.6
4.4
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3.6
3.4
3.2
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2.8
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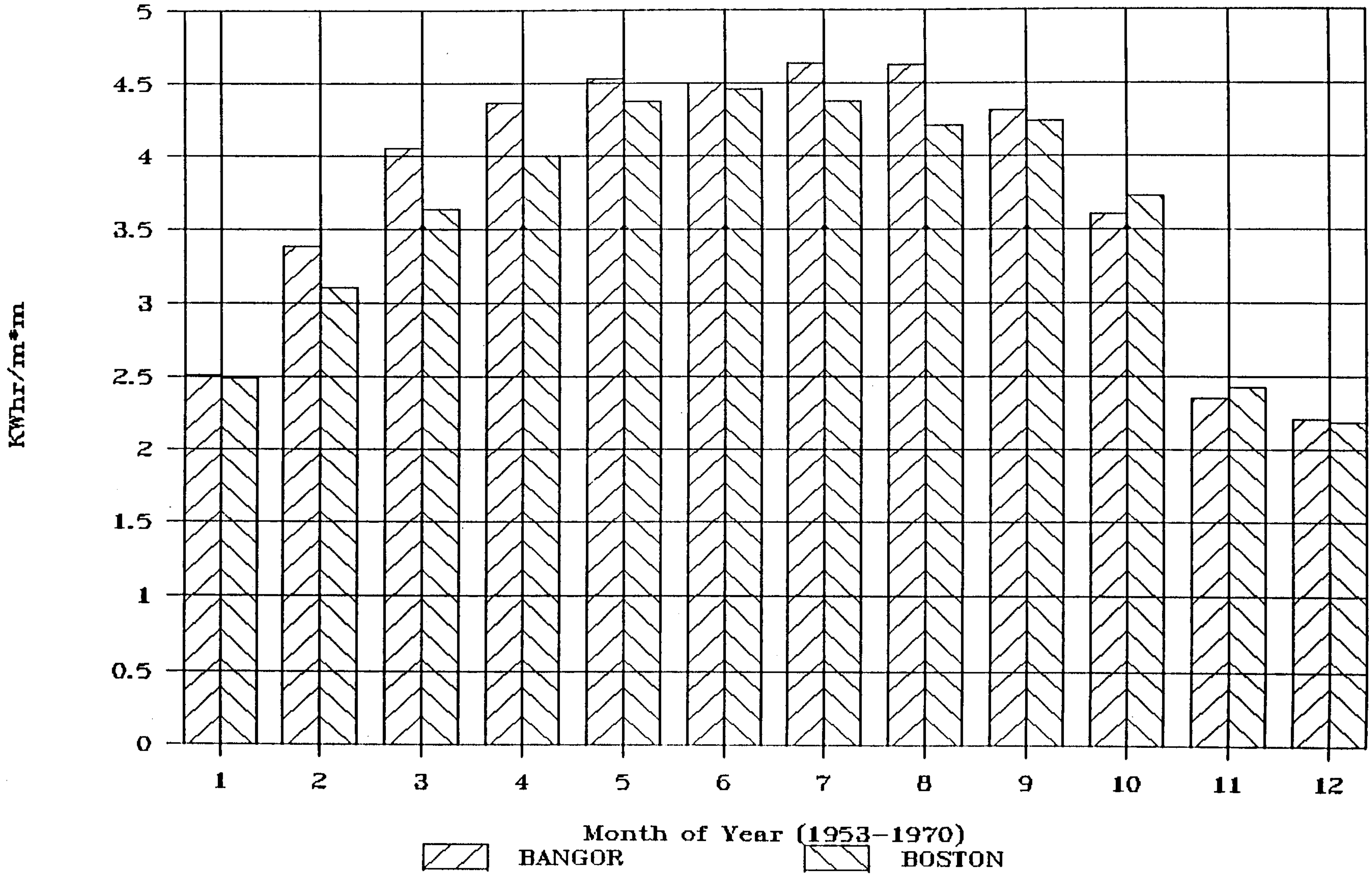
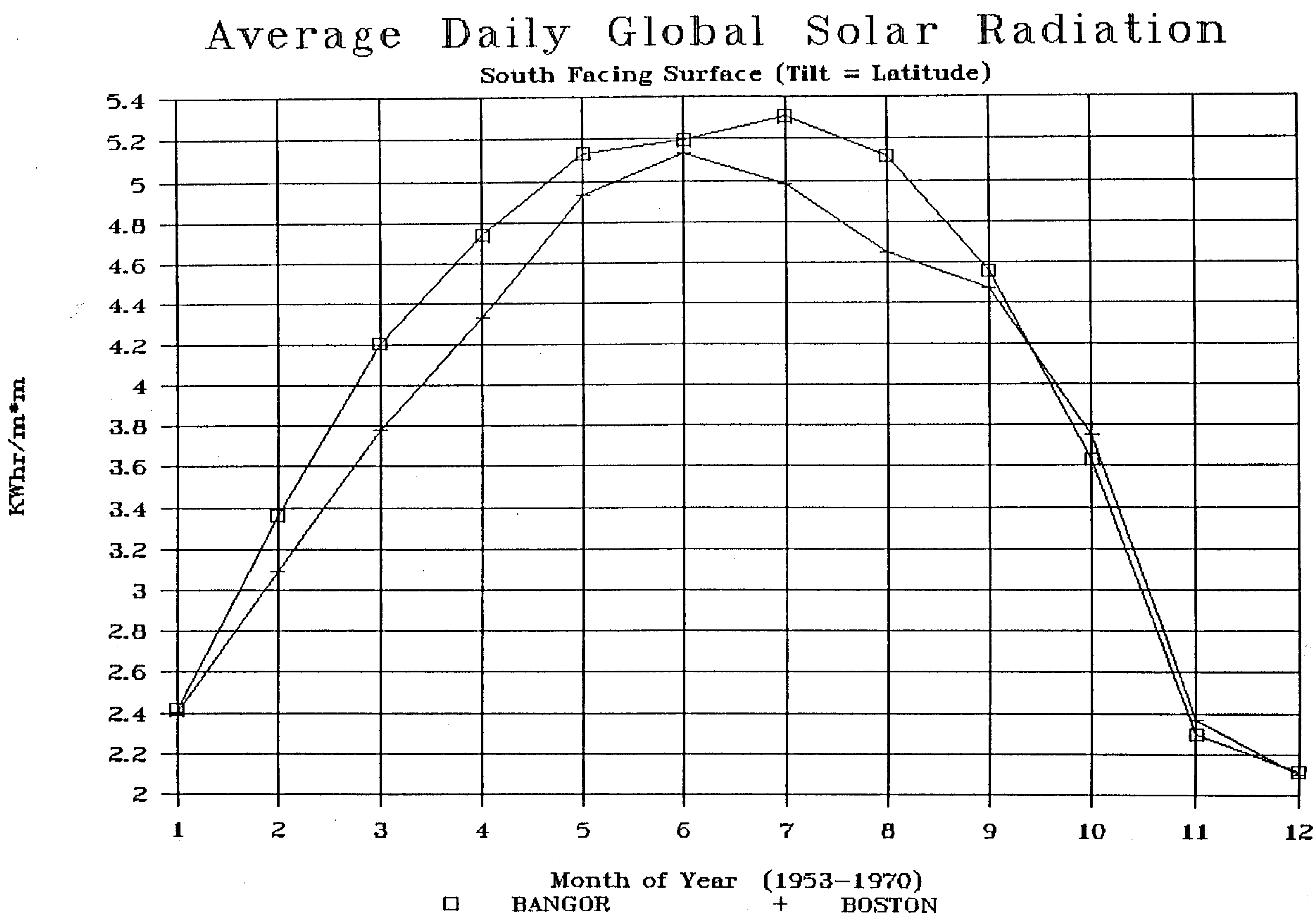
Month of Year (1953–1970)
□ BANGOR
+ BOSTON

# Average Daily Global Solar Radiation

South Facing (Tilt = Lat. + 15 degrees)




Average Daily Global Solar Radiation
South Facing Surface (Tilt = Latitude)
KWhr/m*m
5.4
5.2
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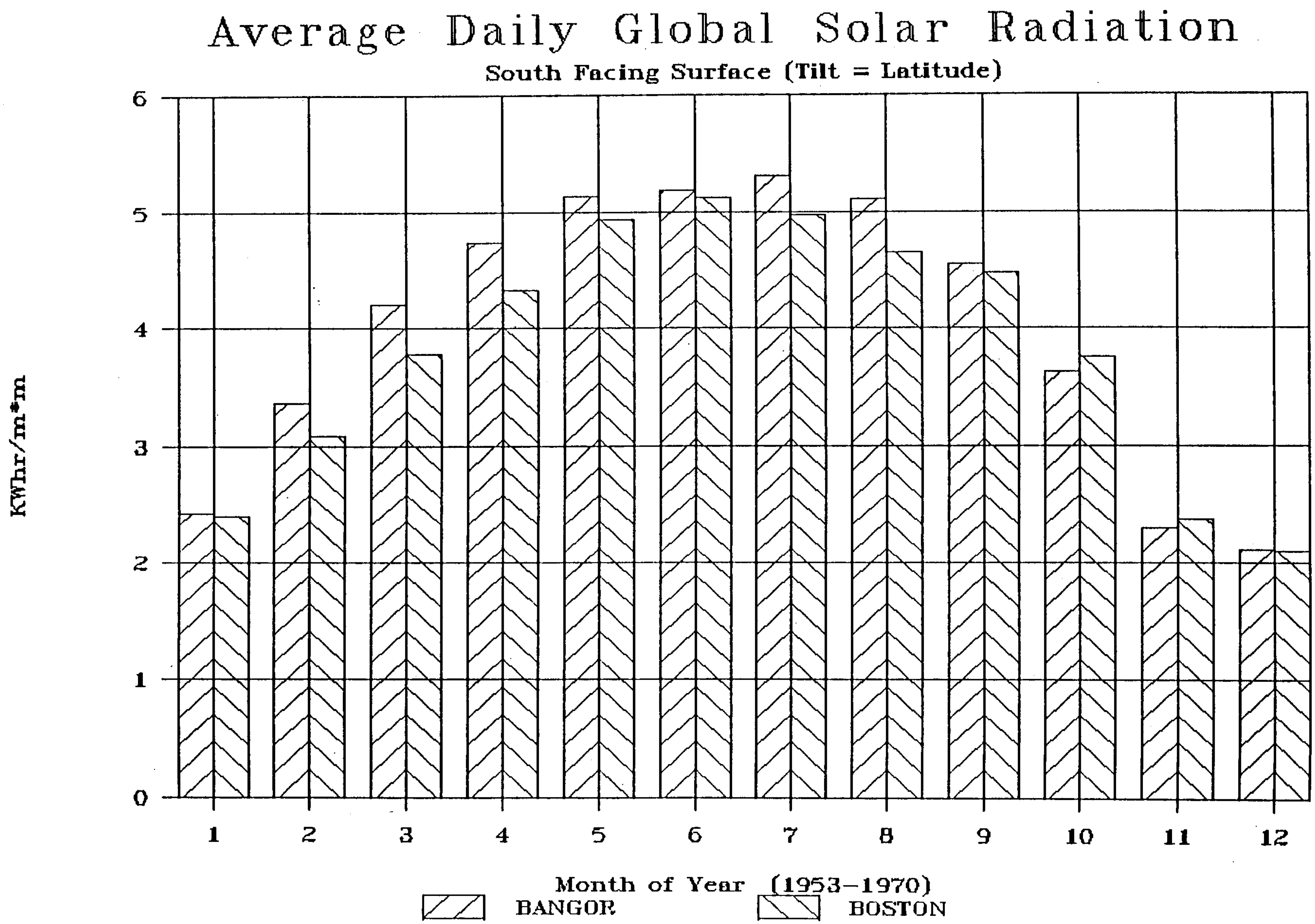
Month of Year (1953-1970)
□ BANGOR
+ BOSTON


Average Daily Global Solar Radiation
South Facing Surface (Tilt = Latitude)
KWhr/m*m
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Month of Year (1953–1970)
BANGOR
BOSTON