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DESIGN AND FABRICATION OF A PROTOTYPE SYSTEM FOR A
PHOTOVOLTAIC RESIDENCE IN THE NORTHEAST

MASTER

AUGUST 1982

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Solarex Corporation, Mueller Associates
and Price & Partners Architects

Prepared for MIT Lincoln Laboratory
Under Purchase Order No. BX-568

MIT Lincoln Laboratory
Lexington, Massachusetts 02173-0073

Prepared for
The U.S. Department of Energy
Under Contract No. DE-AC02-76ET20279

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Abstract

This MIT Lincoln Laboratory/DOE funded project consisted of the design, fabrication, and testing of a photovoltaic residence which is suitable for construction in the Northeast. A full-size residence was designed which included energy-conserving and passive features, and the energy performance of the residence was completed for a 5-kW PV array in a standoff configuration. Actual construction consisted of the roof structure and a building enclosure large enough to contain the PCU, test equipment, and load-simulation equipment. The PV array consists of 78 Solarex Powerline series modules along with a line tie inverter supplied by Abacus Controls, Inc. All test equipment, etc. was supplied by MIT Lincoln Laboratory.

NORTHEAST PHOTOVOLTAIC RESIDENCE

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Introduction

The purpose of this contract effort was to design and fabricate a prototype system for a photovoltaic (PV) residence in the Northeast. The system was to be appropriate for use in new construction of single-family detached housing. The prototype system comprises a full-size array as would be used in a lived-in residence; the balance-of-system (BOS) components; the roofing on which the array was installed; and an enclosure to house the BOS, instrumentation and load duplicating equipment. Heating, ventilating, air conditioning and lighting equipment were also supplied for this enclosure but not powered by the PV array.

The six tasks required for completion of the contract were as follows:

1. Preliminary design of a PV residence, including the PV system
2. Estimation of the energy performance of the PV residence
3. Detailed design of a Prototype System
4. Fabrication and installation of the Turnkey Prototype System
5. Maintenance of the Prototype System for a period of one year from acceptance
6. Reporting and participation in DOE PV program reviews, design reviews, and meetings.

The PV array was sized to provide an annual output energy above 50% of the total estimated annual residential electrical load, including the diversified base electrical load and heating or cooling electrical loads.

The Solarex team consisted of Mueller Associates, Inc., Price and Partners Architects, and Custance Brothers Construction Co.

Solarex provided the program management and specifications for the electrical system, fabricated the PV modules and array J-box, and supervised the system installation.

Price and Partners provided the architectural design of the full-size residence. Mueller Associates provided the engineering design, performance and specifications of the full size residence and the prototype structure, and Custance Brothers built the prototype structure and installed the complete system.

The prototype structure was completed at MIT Lincoln Laboratory's Northeast Residential Experiment Station during the month of April, 1981 and the PV system turned on in July of 1981.

1.0 RESIDENCE DESIGN

The basic philosophy guiding design of the conceptual residence was to achieve a smoothly integrated, roof-mounted PV array on a medium-priced house. The residential design was also to be highly marketable in the U.S. Northeast. This implied that the house should reflect architecture common to the area and incorporate features that buyers expect. These factors suggested that the PV array and its associated equipment should have a minimal visual impact and not restrict architectural style or dominate the structure. PV systems not meeting these criteria are unlikely to be adopted by the mass market.

1.1 Basic Design Approach

The approach towards this design exercise was to determine the most common current architecture styles, to identify the trends leading up to this point, and then to project future residential designs to the time when PV reaches its anticipated penetration into the mass market (circa 1986). This review yielded two basic observations. First, buyers of single-family homes are unwilling to give up the features and amenities they expect in a residence. Therefore, most new houses will probably continue to be of at least the same size as today (1,500 to 2,000 square feet) and of conventional appearance. Moderately priced homes will continue to be built mostly by small, local contractors without assistance from professional architects. Most houses will be built on speculation. These factors have a profound influence on design of the PV array. Second, due to the spiraling cost of electricity and fossil fuel, and to new building codes, future residences will be more energy conservative than those of today. Typical conservation measures will include increased insulation, double- or triple-glazed windows, vapor barriers, higher efficiency space conditioning equipment, and programmable thermostats. Energy conservation

through such measures is generally the most cost-effective approach and also imposes relatively few constraints upon design or siting. In addition, builders and inspectors can easily relate to this approach since these measures can be easily quantified: a builder can quote high R-values to aid in selling a house and inspectors can quickly check for code compliance.

Reduced energy costs through the use of renewable energy will typically occur only after the energy conservation features discussed above have been implemented. The use of solar energy implies concern for solar orientation. This may limit the number of houses that can be located within a given area. Even the layout of streets may be affected, and shading by adjacent structures or trees is a concern.

Although siting will be a factor in the use of solar energy, it should not be a major obstacle. Accordingly, once the basic conservation measures have been instituted, the next most cost-effective method of reducing purchased energy is through the use of selected solar features. The most cost-effective and marketable solar features for residences include passive concepts that provide a moderate solar fraction and active domestic hot water heaters. Solar passive features that tend to dominate the residence, such as Trombe walls, and active features that require a significant capital cost, such as a heating system, will probably not be widely incorporated into medium-priced houses. Passive solar concepts that are relatively low in capital cost, integrate well with and do not dominate the house design, and are easy to construct or install will be the types of solar features the mass market will adopt.

Passive is generally seen to be an amenity. It is this feature, rather than its difficult-to-quantify energy savings and life-cycle cost aspects, that can make it sell. Thus, such

passive concepts as direct gain, daylighting, mass walls, overhangs, and sunspaces/greenhouses will probably be the most typical passive features in new residential construction. These concepts can readily be integrated into typical house designs. Typical applications will be for such features to moderate, rather than dominate, the response of the residence to changing environmental conditions. Other passive concepts which may impose severe architectural constraints, such as Trombe walls, will probably not be widely accepted.

Given that future houses will first be highly energy conservative and then incorporate some moderate passive solar features, the next logical step towards energy savings should be the addition of a PV system (assuming DOE price goals are met or other financial incentives are provided). In addition to reducing energy costs still further, a PV system offers the owner at least two other benefits: some degree of independence from the utility (an emotional incentive), and an opportunity to be an income generator by selling back to the utility grid (a financial incentive). Section 210 of the recently enacted Public Utility Regulatory Policies Act of 1978 (PURPA) will, if upheld in the courts, greatly encourage this movement.

It is believed that because of the above design philosophy, conservation and passive measures will result in new residence having significantly less energy consumption than existing residences. A residential PV system's generation of electricity, however, is only partially coincident with the load. Heating and lighting loads typically peak during non-daytime hours. Accordingly, it will take a relatively long time for a PV system that does not incorporate storage to pay for itself only by displacing the residential electric load. It therefore appears that the incentives of partial energy independence and income

generation may be the major motivations for widespread adoption of residential PV systems.

The above residential design philosophy is graphically summarized in the progression of Figure 1.1.

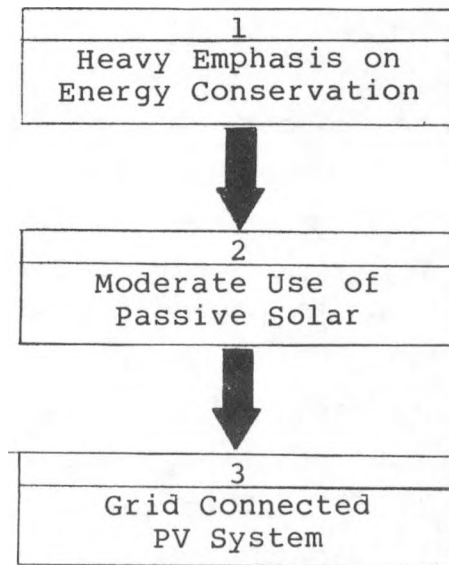


Figure 1.1 Conceptualization of the Future Residential Design Process

1.2 Conceptual Design

The design philosophy outlined above implies that the designer must follow an integrated, logical approach to the problem of excessive energy costs. The identified solutions must be self-consistent. This means, for instance, that when envisioning future PV applications, a designer should not simply assume that the existing (circa 1981) typical residence represents a good load model. Future residences will consume significantly less energy per square foot than current houses. Furthermore, both daily and annual load profiles will be different since internal gains will now displace a greater per-

centage of the envelope losses/gains. Commonly accepted comfort criteria may also change. This all has strong implications for design of an appropriately sized PV array.

Early in the design process for this project, it became evident that a certain dichotomy exists between the requirements for a passive house and a PV house. Most passive features require large south-facing glass areas. This generally results in a reduced south-facing roof area. PV systems, however, require a significantly large, unobstructed, south-facing roof area. This constraint limited passive design flexibility somewhat since it was desired to maintain a certain size PV array. However, since only a moderate use of passive was envisioned, this problem did not prove to be a severe design constraint.

Design of the Conceptual Residence proved to be something of an iterative procedure, involving both architect and engineer. The resulting design meets the original goal of a moderately priced, highly marketable house that smoothly integrates a PV array onto the roof and is also representative of architecture in the U.S. Northeast. The basic features of the Conceptual Residence are as follows:

- Two-story colonial
 - 1,660 square feet of conditioned area (not including sunspace)
 - Three bedrooms, two-and-a-half baths
 - Unfinished basement
 - Wood frame construction
- Highly energy conservative
- Moderate use of passive solar
- Well-integrated PV array
- Lower relative cost due to compact design and simple construction.

- Flexible design to allow incorporation of optional architectural features
- Marketable design

The two-story colonial design is very common in the U.S. Northeast, and is often what buyers prefer. Its adaptation to PV marks a definite departure from almost all previous PV residential design efforts which assumed a contemporary style. Our intent is to demonstrate the feasibility of incorporating solar (passive and PV) features into more traditional architecture. If PV requires a contemporary design, then a large number of potential buyers will be uninterested.

The Conceptual Residence is depicted graphically in Figures 1.2-1 through 1.2-4.

In concert with the original design philosophy, this conceptual residence incorporates a significant number of energy conservation features. These are detailed below.

- Heavy insulation: R-38 ceiling, R-27 walls, R-12 perimeter
- Triple-glaze windows on east, north and west
- Double-glazed windows on south
- Night insulation (R-5) for windows
- Vapor barrier for low infiltration
- Electrical raceways that do not penetrate the vapor barrier
- Air lock entries
- Compact shape
- Closets/bathrooms on north side as buffer zone
- High efficiency (2-speed) heat pump
- Heat pump desuperheater for hot water
- Deciduous trees on south, east and west for shading; evergreens on north for winter wind protection

1-7



SHEET NO 4	PERSPECTIVE AUGUST 18, 1980	PHOTOVOLTAIC RESIDENCE <small>SOLAREX - MIT</small>	MUELLER ASSOCIATES, INC. CONSULTING ENGINEERS	PRICE & PARTNERS ARCHITECTS
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Figure 1.2-1

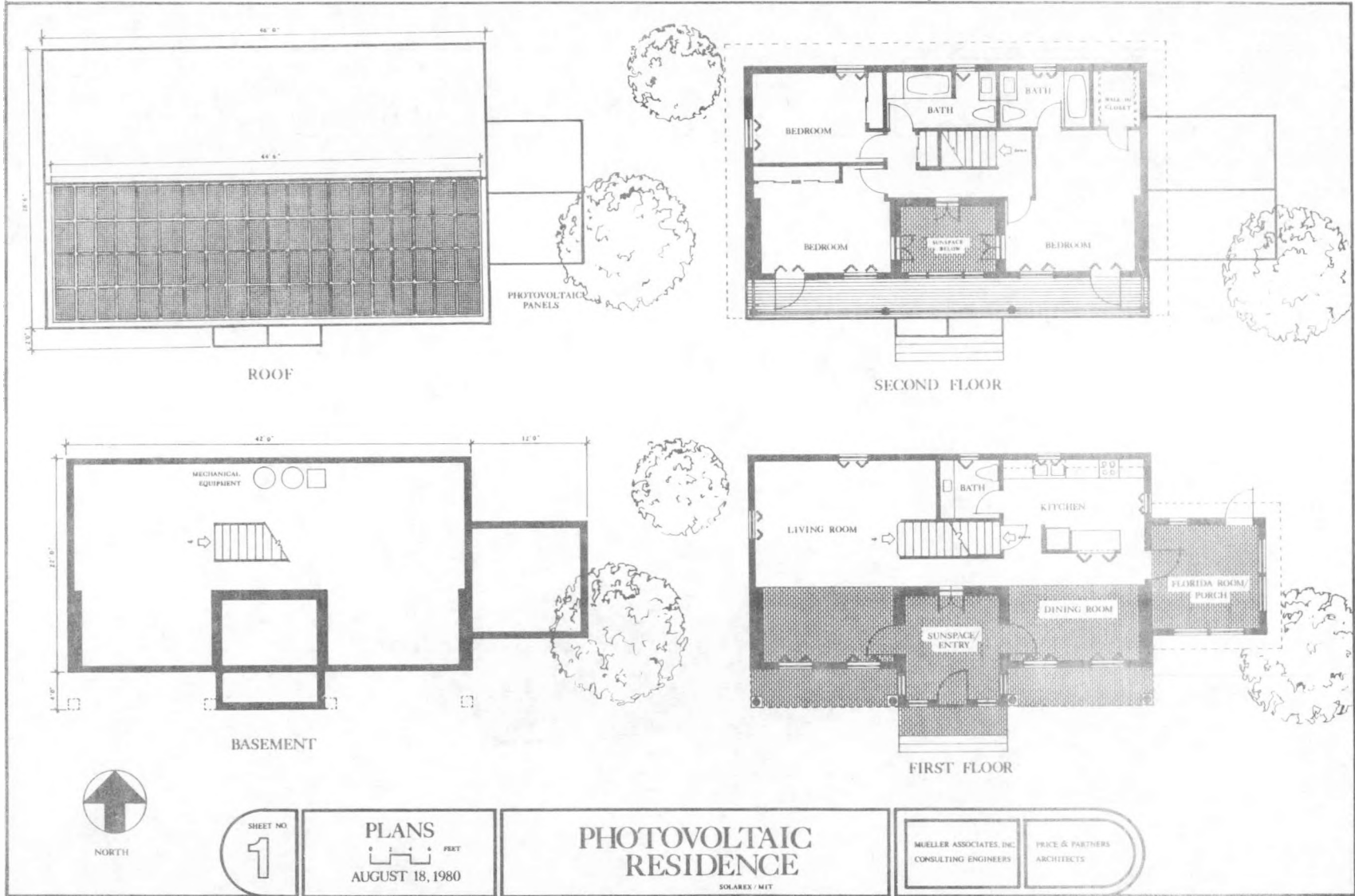


Figure 1.2-2

6-1



Figure 1.2-3

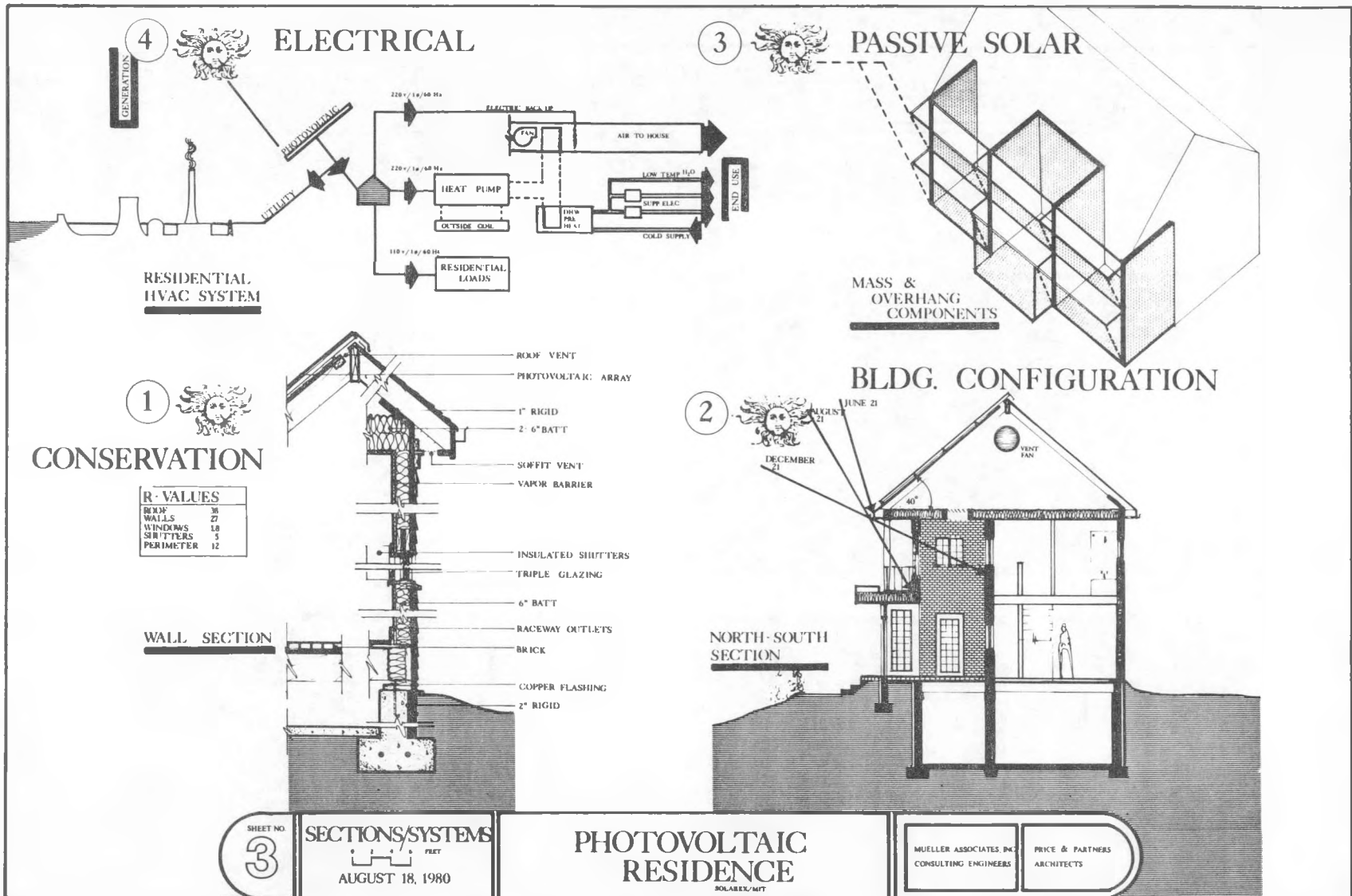


Figure 1.2-4

The specific passive solar features incorporated into this Conceptual Residence are as follows:

- Large south-facing glass area (200 ft²)
- Reduced glass on north, east, and west
- Two story greenhouse/sunspace
- Increased internal mass on south side (in walls and floor)
- Overhangs for summer shading on south
- Cross ventilation for cooling.

1.3 Space Conditioning/Domestic Hot Water Systems

The conceptual heating, cooling, and hot water system is presented in Figure 1.3-1. Space cooling is provided since this is typical of most new residential construction in the Northeast. Electricity was assumed as the prime heating energy source since (when used with a heat pump) it is more effective than oil and will probably soon be cheaper than gas. Accordingly, a high efficiency, 2-speed heat pump (Carrier Weathermaster III, model 38TQ040/38HQ960/28TQ042) was specified. It was noted, however, that even the smallest available unit was oversized (in terms of traditional sizing criteria) for the projected peak cooling load. In the heating mode this unit also has more than ample capacity. Oversizing can lead to inefficiencies due to rapid cycling. This is not a serious problem in the heating mode since the thermostat's anticipator can be adjusted for longer cycles. The hot water desuperheater also taps off some of the heat pump's heating capacity, thus making the unit more appropriately sized. Oversizing is therefore primarily a cooling mode issue. Two basic problems occur: infrequent cycling resulting in excessive air stratification and stagnation, and insufficient dehumidification. The former problem can be resolved simply by operating the circulating fan. The latter problem is more

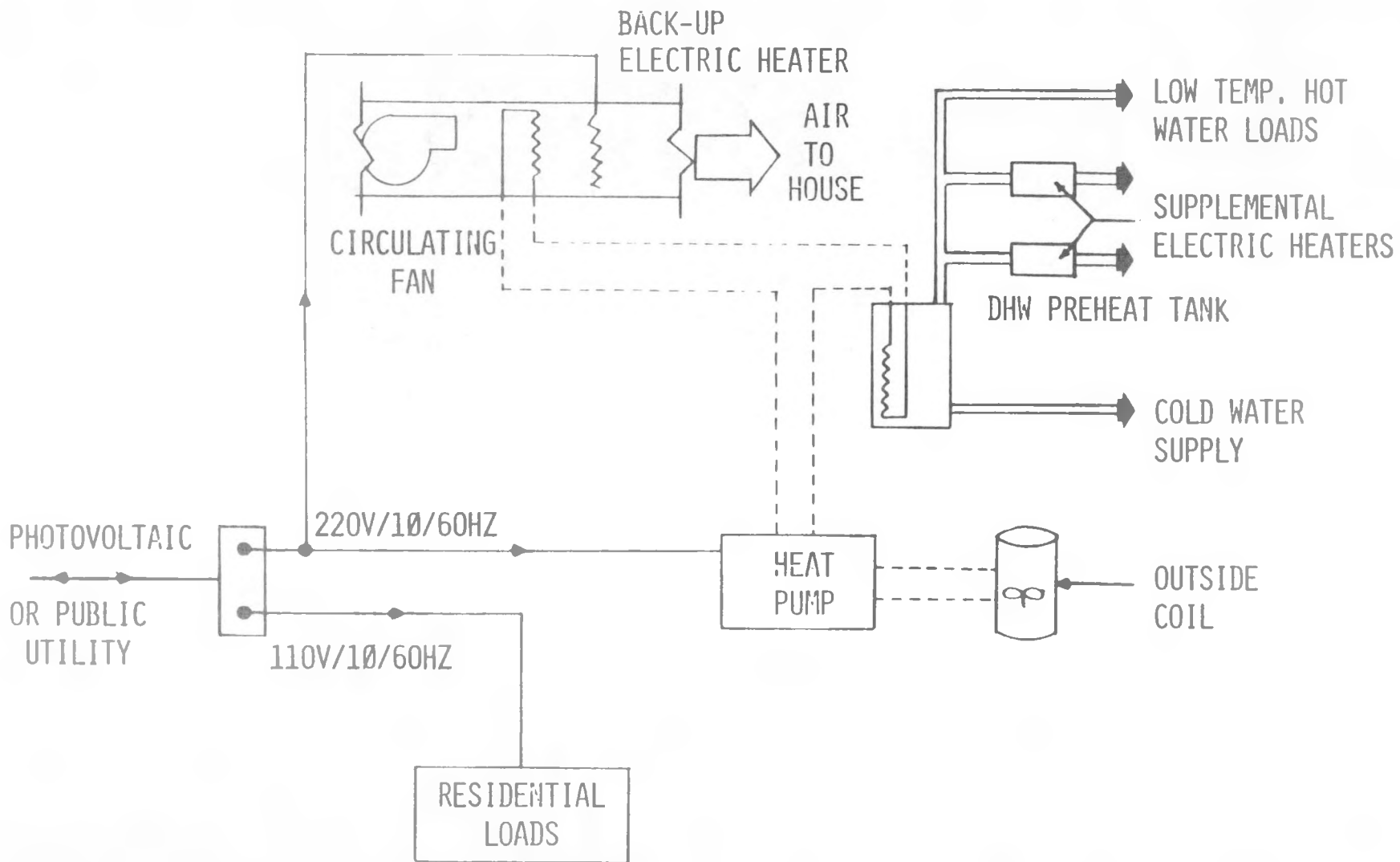


Figure 1.3-1 Residential HVAC and Hot Water System Schematic

serious and may, if either ambient humidity or internally generated moisture is severe enough, require ductwork modification (bypass) or installation of a separate dehumidifier. During summer the desuperheater aggravates the situation by improving the heat pump efficiency. This situation suggest that, as residential loads get smaller, heat pump manufacturers should consider reducing the size of their equipment, redesigning their units for lower sensible heat ratios.

Hot water is supplied primarily through desuperheating hot freon discharged from the heat pump compressor. A Carrier Hot Shot Heater Reclaimer, model 38HG900011, was specified to accomplish this. This equipment taxes the heat pump when it is in the heating mode, but assists it in the cooling mode. This is a highly efficient (equal to an annual COP about 2.0) and inexpensive (less than \$300) means of obtaining hot water. However, this equipment does not permit water heating when the heat pump is not in use (i.e. - periods of moderate weather). Backup heaters are thus needed. The most thermally efficient and inexpensive way of doing this is to use small booster heaters at selected points of use.

Cost Estimate

The projected 1981 cost of this house, exclusive of the PV system, lot, and site improvements, is \$80,000. This assumes construction as a tract-built house.

1.4 Residential Loads Energy Analysis, Manual ASHRAE Procedure

In order to calculate the annual contribution of the PV system, it is obviously necessary to determine the various annual energy loads. The indoor design conditions assumed were 25.6°C (78°F) for cooling and 20°C (68°F) for heating. Boston,

Massachusetts weather was used as a representative northeastern climate. The given hot water usage was 227 liters (60 gallons) per day at 60°C (140°F). It is believed that these latter two parameters merely represent historical trends and are unrealistically high for future residences. A hot water consumption of perhaps 114 liters (30 gallons) per days at 43°C (110°F) and 114 liters (30 gallons) per day at 60°C (140°F), and a baseline diversified electrical load of 15 kWh per day appear more reasonable.

Given the above design conditions, standard ASHRAE calculation procedures (2) for this Conceptual Residence indicate a peak heating load of 8,600W (29,350 Btuh) and a peak cooling load of 5700W (19,450 Btuh). These values, in conjunction with the specified equipment, equate to the following estimated annual energy consumption:

Heating	4,700 kWh/yr	(16 x 10 ⁶ Btu/yr)
Cooling	2,300 kWh/yr	(7.8 x 10 ⁶ Btu/yr)
Hot Water	2,150 kWh/yr	(7.2 x 10 ⁶ Btu/yr)
Diversified	7,300 kWh/yr	(25 x 10 ⁶ Btu/yr)
Total	16,450 kWh/yr	(56 x 10 ⁶ Btu/yr)

This is a very rough estimate using the ASHRAE degree day procedure for heating loads, the ASHRAE equivalent full-load cooling hours procedure for cooling loads (3), and assuming that the hot water heat pump can meet (as per manufacturer claims) the domestic hot water loads while using only half the electricity of an electric resistance hot water heater. However, since passive and internal gains are not treated adequately by the standard ASHRAE procedures, this annual heating load is unquestionably high. Despite the errors and approximations inherent in these procedures, it is interesting to note that these rough estimates do indicate substantially less energy consumption for this size

house than is common for current houses. This results from the emphasis on energy conservation.

Residential loads were also calculated through a much more accurate procedure involving use of the TRNSYS computer simulation program (4). This analysis, which indicated significantly less energy consumed for heating and cooling, is discussed in detail in the following section.

1.4.1 Detailed Computerized Simulation: Loads and PV System

Future residential PV systems are expected to be connected to the utility grid without battery storage. Auxiliary energy will be purchased from the grid and excess sold back to it. This situation is encouraged by the PURPA regulations. Calculation of the amount of electricity generated by a PV array is a relatively simple procedure, especially if cell temperature and start-up/shut-down effects are ignored. However, calculation of the amount of PV energy generated that will actually be used to meet a time-dependent residential load is a complex procedure. Nevertheless, this is a major question affecting the local economic visibility of PV systems.

In view of the above observation, it was decided to study in detail the performance of the PV system and its interaction with the residential loads. This was accomplished through use of the TRNSYS Version 10.1 computer program, modified to include a PV system model. TRNSYS is a transient simulation program developed by the University of Wisconsin. It provides for the dynamic simulation of a solar energy system, auxiliary components, and building loads through the simultaneous solution of algebraic and differential equations. TRNSYS gives an hour-by-hour simulation of the energy flows within a solar energy system/building. Hourly weather data provide the dynamic ambient conditions. Internal loads can also be specified for a given daily cycle.

TRNSYS is a modular program, and each module mathematically models its counterpart in a real world system. Information flow between components follows the actual mass and energy flows. Linkage of the TRNSYS mathematical components parallels the piping and ductwork connections in the mechanical and electrical system.

This TRNSYS simulation computed the building loads and the contribution of the PV array towards these loads. The program calculated instantaneous heating or cooling loads, considering internal gains, solar gains, and infiltration and conductive losses/gains. Details of the specific equations are provided in the TRNSYS manual. The PV array functions independent of the building and does not affect load determination calculations.

Since the most up-to-date version of TRNSYS available at the time of this study did not contain a PV subroutine, it was necessary to add one. A PV model developed at MIT Lincoln Laboratory was utilized for this purpose (5). This PV model assumes maximum-power-point tracking and an inverter with a constant efficiency of 90 percent. Calculations of cell temperature are sensitive to the type of mounting concept employed.

The flow diagram of the TRNSYS 10.1 simulation model, presented in Appendix A, identifies the inputs, outputs, and connections for each solar energy system component. Several algebraic operators were grouped together and represented by one box, as were the output devices. Little detail is lost by these combinations. Values for the parameters and inputs came from a variety of sources. Wall areas, roof areas, window locations and areas, overhang sizes and locations, and insulation values were obtained from the architectural drawings. Wall heat transfer

coefficients were calculated by the Solar Energy Laboratory at the University of Wisconsin for the wall construction materials and thickness as given in the drawings. (ASHRAE Fundamentals does not list wall transfer coefficients for such a tight, well-insulated structure.) Heat pump performance was modeled after the Carrier, Weathermaster III, two-speed system. Unfortunately, it was not possible to model the hot water desuperheater. The PV parameters were based on the Solarex semicrystalline panel. These values were tested for compatibility and stability by Lincoln Laboratory. The internal gain profiles and the distributed load profiles were derived from The Office of Technology Assessment study entitled "Application for Solar Technology to Today's Energy Needs." This document assumes a family of four and a total daily distributed electrical energy consumption of 19.6 kWh.

This TRNSYS simulation study constrains the indoor temperature to be greater than 19°C (66.2°F) and less than 26°C (78.8°F). If the ambient conditions and internal loads are such that they drive the indoor temperature below 19°C, the thermostat switches the heat pump on. When the heat pump has raised the space temperature to 20°C (68°F), the thermostat shuts it off. (The thermostat is assumed to have a 1°C hysteresis.) The space temperature is allowed to fluctuate freely up to 26°C. At that point two modes of operation are possible. When indoor temperatures are driven above 26°C, cooling is required. If the ambient temperature is below 25°C (77°F), it is assumed that cooling is accomplished by natural ventilation; i.e., the occupants open windows. For cooling when the ambient temperature is 25°C or greater the thermostat switches on the heat pump until the space temperature has dropped to 25°C.

This TRNSYS simulation could not completely simulate all the passive/conservative aspects of the conceptual residence. Thus

the results obtained are probably conservative and actual loads would be lower. The internal mass walls were simulated by assuming a high capacitance for the internal space. The effect of the overhangs was directly simulated. The sunspace/greenhouse, however, was difficult to simulate. This could be done only indirectly through assumptions concerning internal mass and control set temperatures. However, a manual calculation using PEGFIX indicated only a nominal net energy flow of 880 kWh (3×10^6 Btu)* vented from the sunspace to the rest of the house. This contribution is not very significant. However, the sunspace does provide a very pleasant living environment and is nearly self regulating. As such it adds to the marketability of the house.

A complete listing of the TRNSYS program used to simulate this conceptual residence can be furnished by Solarex on request. Also included in the program output are the monthly summaries of an annual (8,760 hour) simulation, the hour-by-hour print-out for typical winter week, and an hour-by-hour print-out for a typical summer week. Summary results and histograms for these items are included in Appendix A.

This detailed simulation study has led to some very interesting observations, many of which could not be made through any other approach. The major observations of this simulation study are discussed below:

- The annual loads and electrical energy required to meet the loads are as follows:

* NOTE: A nodal program which has capability of calculating the hourly temperature distribution within a single zone, such as sun space, and excess heat (and operating energy required to remove that excess heat) generated within the space.

	<u>Load</u> (kWh/yr)	<u>Electrical Consumed</u> (kWh/yr)
Heating	4220	1790
Cooling	1940	720
Hot Water	4300	2150
Diversified	<u>7150</u>	<u>7150</u>
Total	17590	11810

- The 5.2 kWp PV array produces 8460 kWh/yr.
- The PV system delivers 7610 kWh/yr of ac power to the house/grid.
- The coincidence of the PV-generated power and the residential electrical demand is such that 3,500 kWh/yr (46%) of the total PV system delivered power is directly applied to the demand and 4,110 kWh/yr (54 %) is delivered to the grid.
- The PV system therefore directly provides 30% of the total residential load. The remaining 70% (8310 kWh/yr) must be supplied by the grid.
- Assuming that the utility both sells and buys energy to/from the residence at 8.5¢/kWh (the 1981 base cost for the U.S. Northeast, DOE Region 1, as presented in the NBS Life Cycle Costing Manual), (7) the total annual residential bill would be \$360.
- The cooling load satisfied by ventilation (3980 kWh/yr) was twice that required to be satisfied by mechanical cooling (1940 kWh/yr).
- The months of May, June, and September required both mechanical heating and cooling.

- Natural (or forced) ventilation is required throughout the year.
- For each month the total residential load exceeded the PV array output.
- The PV array operated at efficiencies from 8.5 to 8.8%.
- Even during winter the PV system normally generated more power than the house required during the middle hours of the day. However, heating loads and, therefore, heat pump operation occurred mainly during nighttime hours.
- The PV array operated at a typical winter temperature of 15°C and a typical summer temperature of 40°C. This was 15°C above ambient in each case.
- The heat pump's average annual heating COP was 2.36, while its average annual cooling COP was 2.69.

The building loads and PV system output are indicated month by month in Figure 1.4-1. This provides a graphical summary of the detailed TRNSYS analysis.

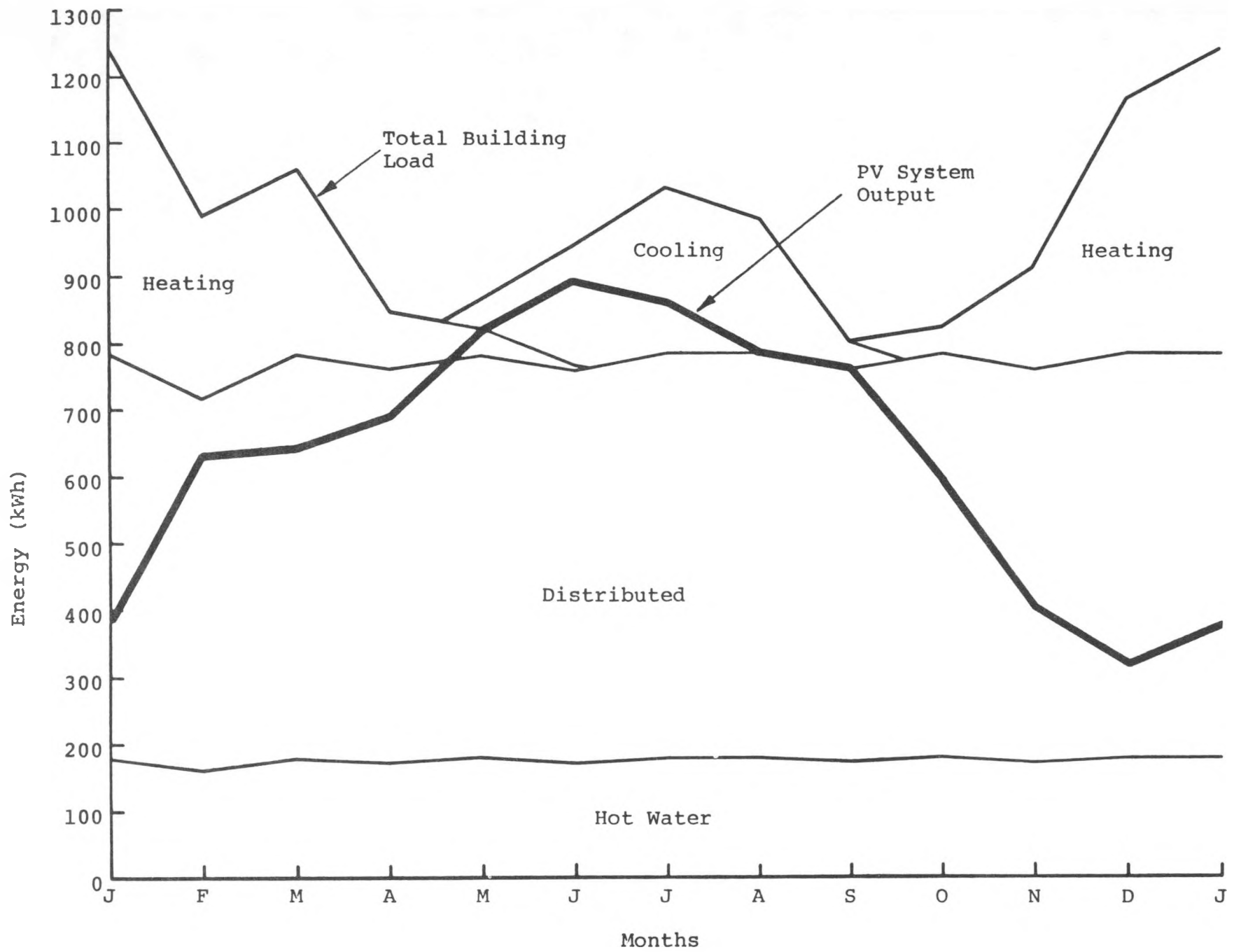


Figure 1.4-1. Monthly Profile of Building Loads and PV System Output

2.0 PROTOTYPE PHOTOVOLTAIC SYSTEM

2.1 Prototype Building

2.1.1 Design

The Prototype is intended to include an array/roof section that identically represents the roof mounting concept and roof structure of the Conceptual Residence. The space behind the array also presents the same environmental conditions as in the Conceptual Residence. Thus, the Prototype physically, aesthetically, and thermally represents the Conceptual Residence roof design. The remainder of the Prototype is intended to support the array/roof section and also house a small space for MIT Lincoln Laboratory test equipment and the PV balance-of-system equipment.

The above considerations comprise the design requirements for the Prototype. The actual construction documents for the Prototype, which was built at the MIT Lincoln Laboratory Northeast Residential Experiment Station, are contained in Appendix B.

2.1.2 Construction Process

The initial set of Prototype construction drawings/specifications were forwarded to MIT Lincoln Laboratory for review and approval. Following several minor changes, this document was approved and sent to selected local contractors, for quotes. This semiopen bid procedure was an effort to secure a reliable contractor at the lowest possible price. A total of twelve builders were contacted. Custance Brothers of Lexington, Massachusetts was selected as the lowest bidder.

Figure 2.1.2-1 is a photograph of the completed prototype system. Actual construction drawings are presented in Appendix B.

2.2 Mechanical

2.2.1 PV Module Details

The PV module utilized for this project incorporated the latest materials and processes developed by Solarex. The mechanical specifications were as follows:

1. 72 polycrystalline silicon cells - 10 cm x 10 cm with trident pattern
2. Cells were wired as two parallel strings of 36 cells in series
3. Module was a laminated structure with 0.187" thick Sunadex glass as superstrate
4. Six internal bypass diodes were incorporated which protected each 6 cells in series
5. Two "Solar-lok" connectors per module.

The details of this design are illustrated in Figure 2.2-1. The laminated structure and design was developed partially under the Solarex Block IV procurement.

2.2.2 Module Mounting Concept: Design Concerns

Myriad methods can be envisioned for mounting a PV array on a residential roof. Each approach has both advantages and disadvantages. There are four basic generic mounting concepts: standoff, direct, integral, and rack. One of the MIT Lincoln Laboratory ground rules for this project was that the selected PV mounting method could be a variation of any of these basic concepts.



Figure 2.1.2-1 Photograph of the Prototype Residence at the Northeast Residential Experiment Station

2-4

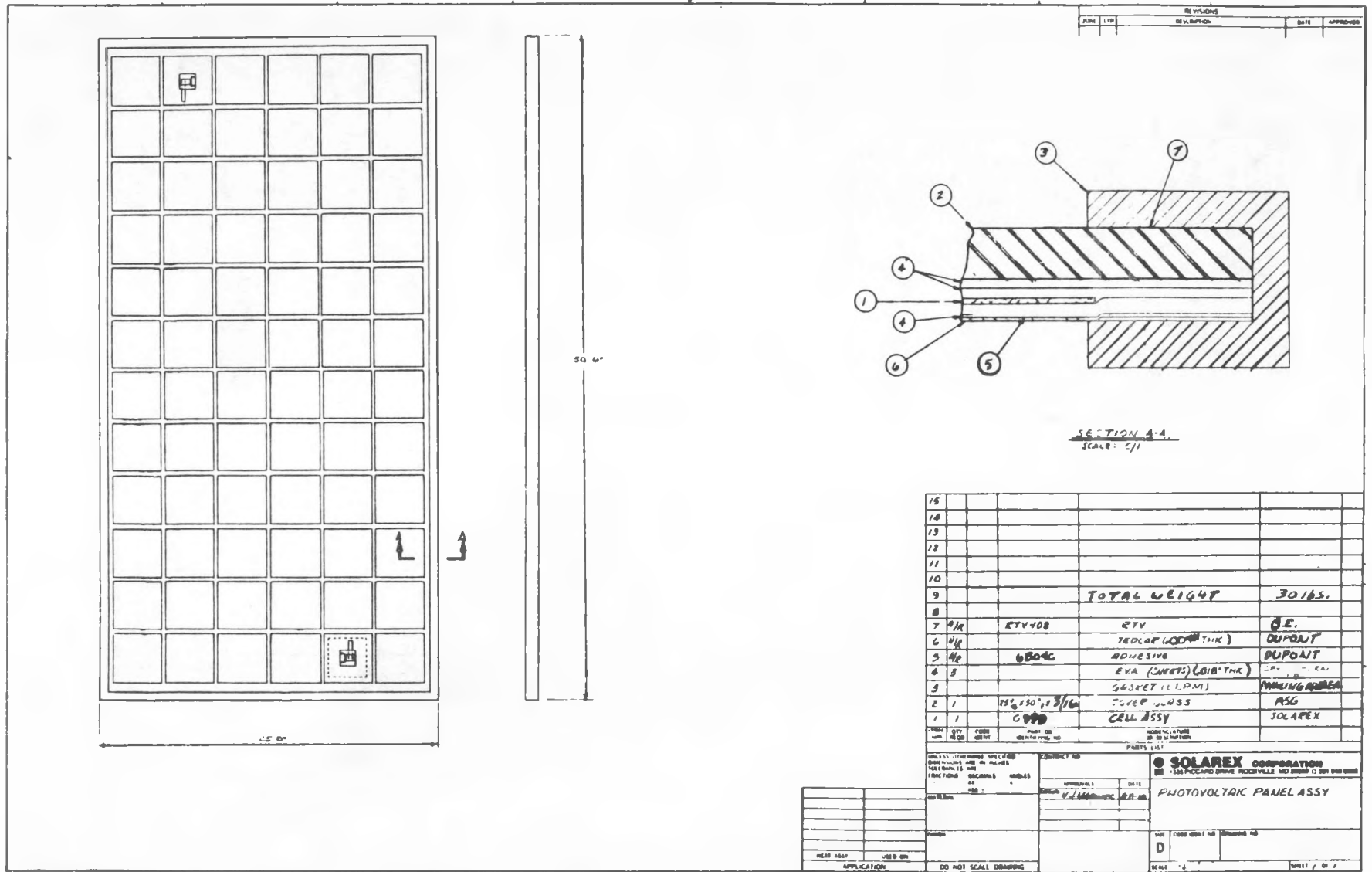


Figure 2.2-1 Photovoltaic Module Assembly for Northeast Residential Prototype

Early in the planning stages of this project, it was recognized that the PV mounting concept used, and the reasons for its selection, represented a major program element. Accordingly, this subject was given significant attention. The first step was to establish some basic design goals for the PV mounting system. In order to achieve mass marketing in the residential sector, it was decided that the design must be functional, low cost, and aesthetically acceptable. These conditions also imply that the design must furthermore (1) fit within common residential construction practices (i.e., not require any special tools, labor skills, or unusually precise carpentry); (2) be adaptable to various roof styles, slopes and materials; and (3) ideally also be adaptable to both new and retrofit construction. In addition, it is desirable that the design be acceptable to trade unions and (future) code and trade union regulations. It also should not constrain design of the house. In short, the PV mounting concept must be fully marketable and flexible. Innovative solutions were required in order to meet all these design criteria.

An initial review indicated that the standoff concept best satisfy the above criteria. However, prior to deciding upon a generic concept, a thorough review of all the various factors involved was conducted. Factors were grouped into four basic categories: Performance, Cost, Aesthetics, and Market Penetration; the major factors within each category are discussed below:

Performance

- The roof/array subsystem must satisfy three basic functions: waterproofing, bracing, and support of static and dynamic loads.

- The PV array must be able to provide a significant fraction of the reasonable roof area (about 800 ft² maximum).
- Differential thermal expansion between the various components (modules, support structure, roof, etc.) must not cause leaks or damage the PV array/roof components.
- System components must be able to withstand environmental exposure over the full lifetime of the system (approximately 20 years).
- System and/or components must meet appropriate fire and safety codes.
 - Future fire code is likely to be a revised version of UL790 - flame spread and firebrand tests are the most critical.
 - Maximum temperatures must not exceed material degradation or ignition points.
 - Electrical connection design should minimize shock hazard.
 - Modules should be resistant to physical damage.
 - Abnormal operation or maintenance of the system should not create a safety hazard (i.e., hot spots, etc.)
- Systems and/or components must meet appropriate electrical codes (revised NEC).
 - All electrical conductors must be sufficiently insulated from each other and the environment.
 - Module should withstand 1500 Vdc Hi-Pot test.

- Module voltage should be between 5 and 20 Vdc.
 - Array voltage should not exceed 300 V positive to negative.
 - Wires must be sized for maximum short circuit current.
 - Splices should be avoided.
 - Connections must be waterproof and also able to withstand moderate (approximately 15 lbs.) mechanical strain.
 - Support hardware must be groundable if electrically conductive.
- System and/or components must meet appropriate building codes (revised BOCA, Southern Building Code , or UBC).
 - Revised ANSI 58.1 (1980/draft) is the most likely model for common building codes - locally varying design loads.
 - Basic loading requirements:
 - 1) Modules must not collapse under loading (i.e., maintenance, wind, snow, etc.).
 - 2) Mechanical connections to panel and roof must withstand all stresses (positive, shear and negative).
 - 3) Building must not collapse under combined array/roof and environmental loads.
 - Components must not sag, weaken, or degrade due to elevated temperatures or solar radiation.
 - Components must withstand rough handling during shipping and installation
 - System must be designed for minimum maintenance

- System should utilize common building materials and assembly should be consistent with standard residential construction practices
- Components should be designed for foolproof field installation (i.e., design should not be dependent on a high level of quality control in the field)
- Cell operating temperature should be minimized in order to maximize electrical conversion efficiency
- Breakage of modules or support hardware should not compromise the water integrity of the roof
- Array net to gross area ratio should be maximized
- System design should permit replacement of small components (i.e., module jumper wires, individual modules, J-boxes, etc.)
- All required system functions should be satisfied with a minimum of redundancy between the various components
- System should have potential for recovery and utilization of thermal energy discharged from modules
- Performance monitoring should be possible
- System should minimize performance degradation due to abnormal environmental conditions i.e., shading (self or external), snow accumulation due to support structure obstructions or roof design, etc.

Cost

- Field labor should be minimized due to its relatively higher unit cost, potential for construction delays (i.e. weather, etc.), trade union conflicts, and lower quality control
- Modules and hardware must be accessible for maintenance and repair with the least disruption of generating capacity

- Assembly of system must minimize trade overlap, disruption of construction schedule, and contractor and subcontractor liability conflicts
- Mounting structure concept should be adaptable to different panel sizes
- Array should be adaptable to nonresidential roof systems (i.e. flat roofs in light commercial buildings and/or shopping malls)

Aesthetics

- Array should appear to be well integrated with the roof
- Array should conform to the size and shape of the roof and be well composed with respect to the building as a whole from the ground and street views
- Modules should fit snugly together and appear as one unit
- The plane of the array should be parallel to the plane of the roof where visible from the street or other properties
- Array should conform to the surrounding architectural style and context
- Wiring should not be visible or at least have a minimal visual impact
- All visible components should be similar in color to the dominant roof material
- Modules should be rectangular or square in shape to conform with the lines of the building
- Modules should have a nonglare surface
- Array finish should match the quality of the existing building materials
- Small modules are better for increased flexibility in conforming to the various roof sizes and shapes and also for improved appearance

Based on a review of these factors it was decided that the standoff mounting concept best meets these design objectives. The standoff concept promises:

- Simplicity of construction
- Low potential cost
- Support hardware which should be adaptable to various generic mounting concepts to reduce material costs
- A design which should minimize field decisions thereby reducing delays and improving quality control
- A design which should permit use of standard cost-cutting construction materials and subunits (i.e. - trusses, pre-built gable ends, ridge vents, etc.) and should not be dependent on one roofing system type
- A design which should be adaptable to various roof and building styles
- Individually removable modules
- Smaller (approximately 3 ft x 5 ft maximum) and lighter (approximately 50 lbs. maximum) components which represent lower unit replacement costs and simpler installation
- Modules and/mounting hardware which should be capable of incorporation into panels assembled by a distributor

Market Penetration

- Array should be located so that future buildings on adjacent lots will not obstruct sunlight falling on the array
- System should not limit building design by restricting either the interior spaces or the building envelope details
- System should be adaptable to a wide variety of new and existing residential constructions

- System design should be adaptable to various climatic and geographic zones
- System design should be adaptable for various roof tilts and azimuths
- Array should permit contractor flexibility in construction scheduling with the option for later addition of an array if necessary
- Array should be located so as to limit the need to remove or trim trees
- Array should be located so as to avoid light reflection into neighboring windows
- Array should be aesthetically well integrated onto a roof
- Array design should provide flexibility of construction techniques and timing
- Lack of need to create a waterproof/structural membrane and thus high long-term reliability
- Flexibility for various mechanical hold down schemes and electrical connection schemes
- Natural cooling of panels for enhanced efficiency
- Accessibility for maintenance/replacement
- Standardized module sizes not required

It is anticipated that building and electrical codes will not prohibit standoff designs.

Although the integral and direct-mounting concepts do offer some advantages, and may indeed be the best solutions for some specific applications, they do not appear to be as flexible or appropriate for mass residential market as the standoff concept. The cost savings (from displaced roofing materials) often claimed for these concepts are highly suspect in view of normal residential construction practices where tolerances are measured in

inches, lumber is normally warped, worker competence is erratic and too often poor, scheduling can be a problem and cranes or other lifting equipment are not readily available. An integral or direct mount would also require a builder to commit to PV early in construction, and then run the risk of not selling this relatively expensive feature. A standoff PV array can be added at any time. Furthermore, the residential construction industry is highly fragmented and resistant to radical changes. The integral mount has the dual handicaps of needing to be waterproof and also to provide a structural/membrane support. In addition, it restricts design by making cathedral ceilings difficult if not impossible to construct. The direct-mounting concept presents the major problems of waterproofing and electrical/mechanical interconnects. One interesting variation would be a direct-mounting concept in which waterproofing was not a requirement. However, such a concept would lose some of its displaced materials credit.

2.2.3 Selected Mounting Concept: Design Details

Given the decision to utilize a standoff concept, it then remained to develop a detailed design which met the original criteria. It immediately became obvious that major cost savings would be realized if the standard module frame could be eliminated. This item constitutes a structural redundancy which costs Solarex approximately \$35 per module. Its omission would also allow use of mechanical holding techniques common to the glazing industry. Deletion of this frame meant that the support structure would have to be more customized than previous designs - i.e., a simple bolting of the modules to a frame was impossible.

Cost could be minimized if commonly available materials were employed for the mounting system. A preliminary survey of skylight technology quickly indicated that this approach was

excessively expensive (approximately \$20-\$25 per ft²). Based upon this analysis it was decided to use a commonly available structural material, such as UnistrutTM, for the main support pieces. This material is inexpensive, available in a wide variety of shapes and fittings, and is easy to obtain. In addition, contractors are accustomed to working with it. Figure 2.2-2 schematically depicts the chosen rectangular mounting arrangement. Although the 3/16" tempered glass used for the module could withstand design wind/snow loads when unsupported on the short side, for reasons of safety it was decided to support/hold down the modules on all four sides. This approach also provides thrust bearings to oppose the natural tendency of the modules to slip downward.

A major problem was to decide how to hold the frameless modules down onto the metal UnistrutTM channels. Several options were considered, including: a metal closure cap which clips into place; an extruded EPDM gasket with a zip-lock similar to glazing technology, and a screw-in metal batten. These three concepts are depicted in Figure 2.2-3. All three concepts were felt to offer some advantages. A cost analysis was made to determine the best approach. This analysis resulted in the following material/labor cost estimate:

Metal closure cap - \$1900./\$1200
EPDM gasket - \$2300./\$1600.
Metal batten - \$2800./\$1600.

Based upon this and other design considerations (such as time limitations), it was decided to utilize the metal closure cap concept. It should be noted that the above cost estimate represents one-time purchasing of materials in small quantities. For large-scale application significant materials (approximately 50%) and labor (approximately 33%) cost savings should be realized. The chosen scheme also utilized painted steel

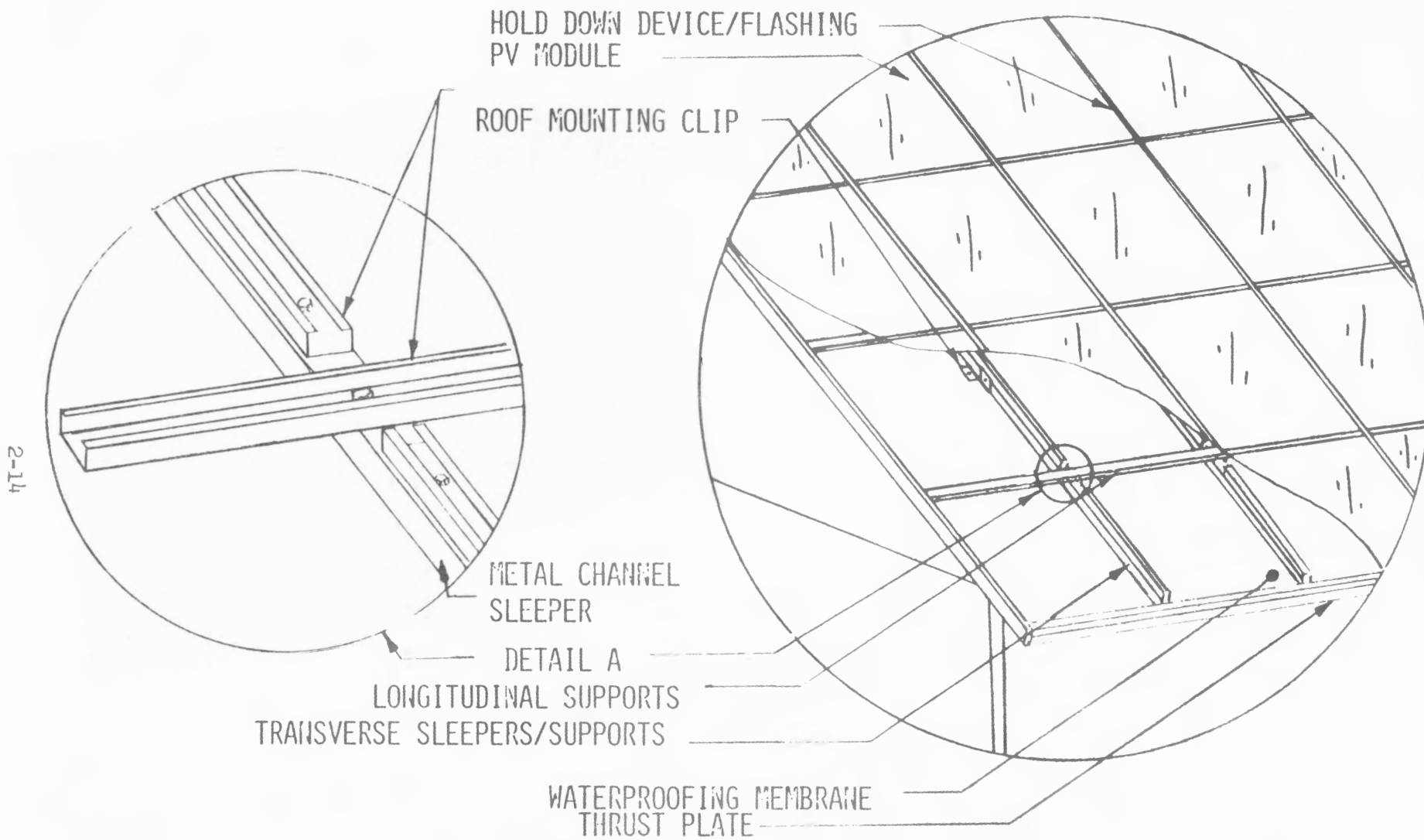
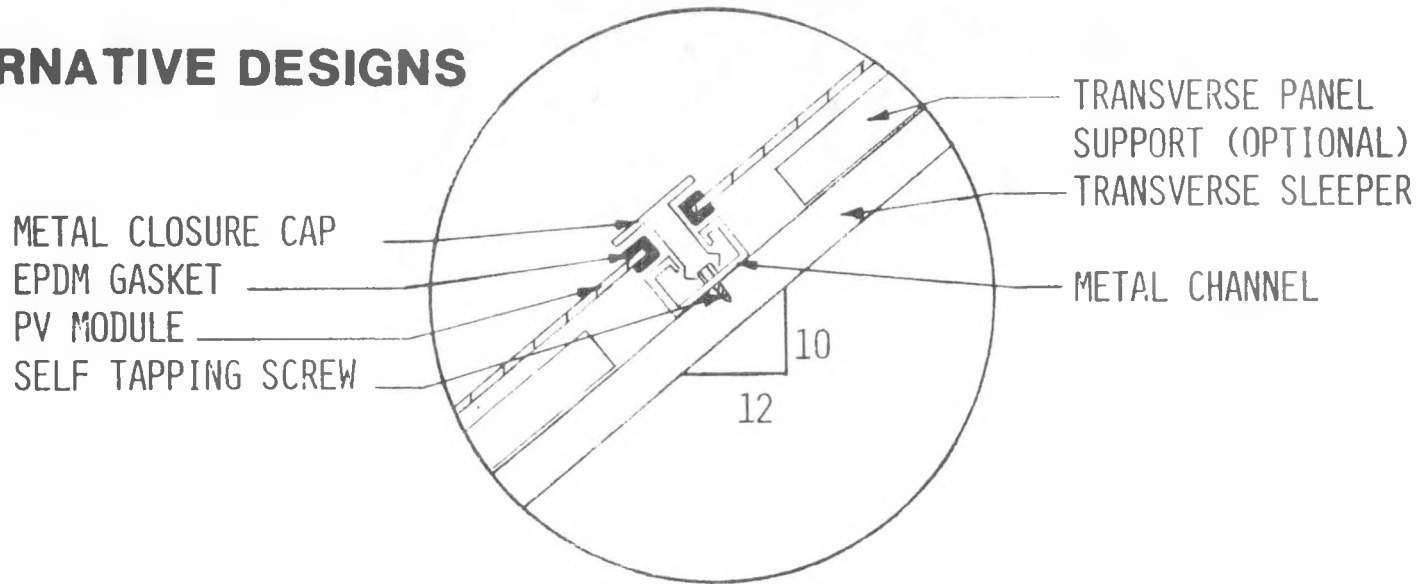
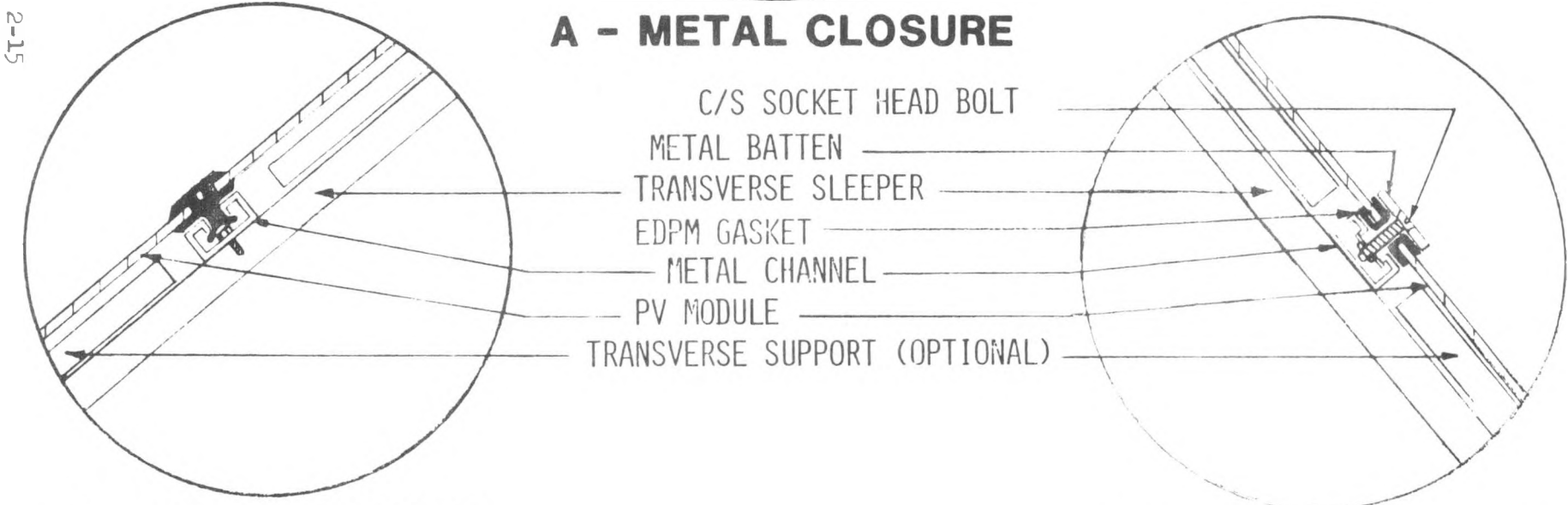


Figure 2.2-2 Standoff Concept

ALTERNATIVE DESIGNS



A - METAL CLOSURE



B - EPDM GASKET

C - METAL BATTEN

Figure 2.2-3 Hold Down Schemes

2-15

Unistrut™ parts which were somewhat oversized since aluminum was not available in the desired shapes.

The Unistrut PV array is secured to the roof through use of angle clips. Each vertical support member is attached with three clips. This concept is detailed in Figure 2.2-4. However, since the array was installed during the middle of winter, it was impossible to slide the upper part of the roof clip under a shingle without breaking the shingle. Accordingly, the clips were installed on top of the roof over a layer of waterproofing material.

A structural analysis of the resulting design was made in order to insure that it could handle all live and dead loads and meet local code. As is indicated in Figure 2.2-5, the design is more than sufficient to meet anticipated loads.

One of the major benefits of the standoff mounting concept is that it permits natural convection cooling on both sides of the PV modules. This increases their efficiency. In order to determine if the color of the roof covering material had any effect on the heat transfer characteristics of this assembly, it was decided to use white asphalt shingles for half of the roof and dark shingles for the other half. Test data should resolve this question.

Aesthetic considerations are often cited as a major impediment for standoff mounting schemes. It seems to be assumed that standoff concepts require a box-like construction which gives little regard to flashing or other architectural integration. This project used lightweight flashing on both the sides and top of the array. In addition, all flashing and the Unistrut™ hold-down caps were made a dark blue color to match the modules. The resulting array is so smoothly integrated with the structure

2-17

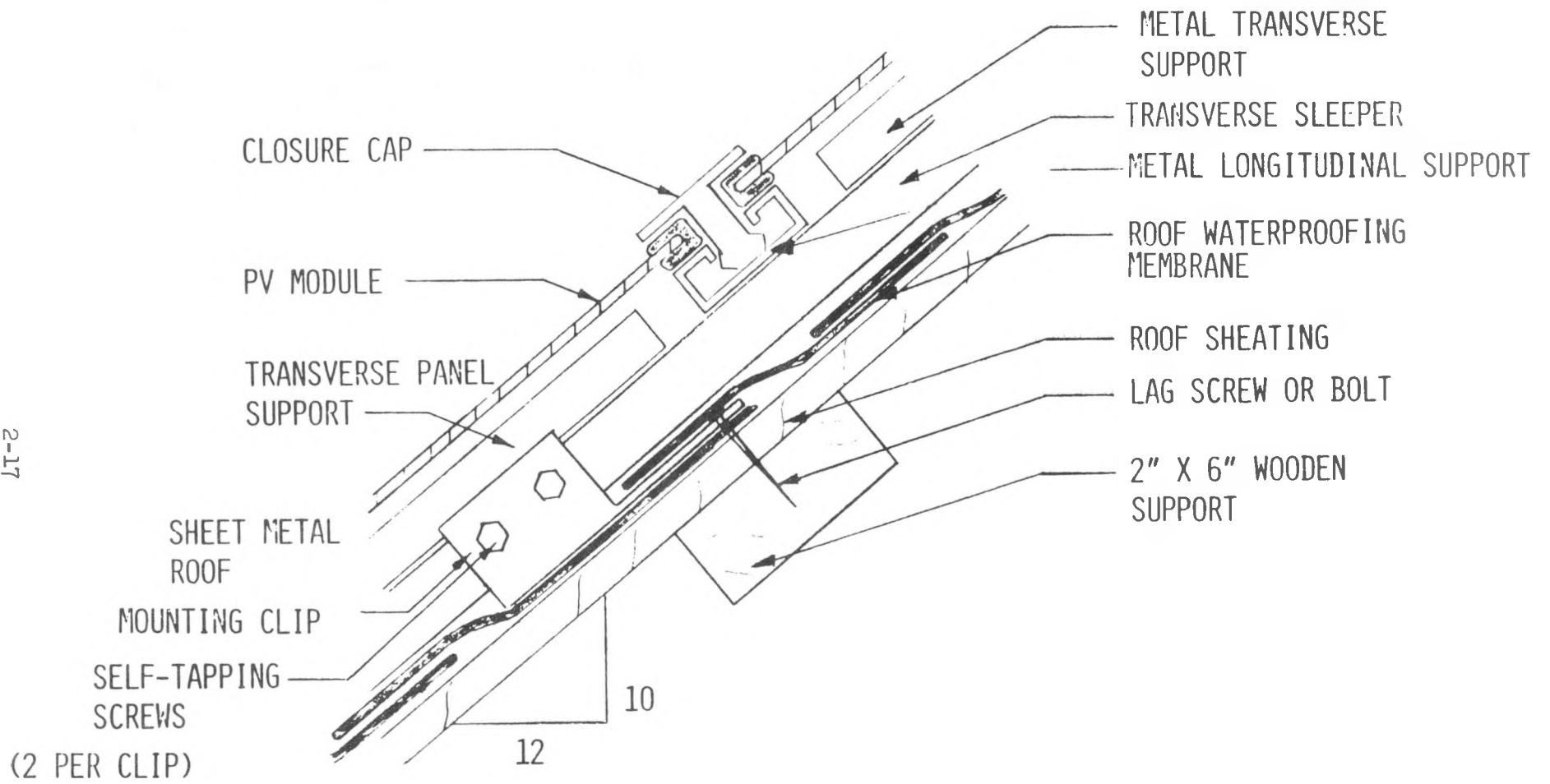


Figure 2.2-4 Roof Attachment Detail

SUPPORT STRUCTURE STRUCTURAL ANALYSIS

DESIGN CONDITIONS

MAXIMUM DEAD LOAD - 1.6 PSF

MAXIMUM WIND LOAD: PRESSURE - 30 PSF
 SUCTION - 15 PSF

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ANALYSIS

DESIGN CONDITION STRESS (PSI)	MAXIMUM ALLOWABLE STRESS (PSI)
12,000 - TRANSVERSE SUPPORTS	25,000
16,000 - ROOF MOUNTING CLIP	25,000
20 PLF - METAL CLOSURE CAP	50 PLF
MAXIMUM SPAN FOR UNSUPPORTED MODULE -	25 IN. (1/8" GLASS)
-	35 IN. (3/16" GLASS)

Figure 2.2-5

as to be almost unnoticeable were it to be elevated like a normal roof.

The final design is fully documented in Appendix B: Prototype Construction Documents. This design concept meets the original design criteria of low cost, functionality, and aesthetics.

2.2.4 Inverter Details

The inverter system utilized for this project was a 6 kVA "Sunverter"^R manufactured by Abacus Controls, Inc. It was housed in a single cabinet 24"W x 30"D x 60"H and weighed approximately 500 lbs. The inverter was shipped directly to the Northeast Residential Experiment Station after factory testing which was observed and approved by Solarex personnel.

2.3 Electrical

2.3.1 Module Electrical Characteristics

The residential PV module was wired internally as illustrated in Figure 2.3-1 with two parallel strings of 36 cells in series with redundant cross tabbing for the cell-to-cell paralleling. The typical electrical performance at AMI and 25°C was as follows:

Open circuit voltage - V_{OC}	=	19.9	volts
Short circuit current - I_{SC}	=	5.1	amps
Voltage at peak power - V_{pm}	=	16.0	volts
Current at peak power - I_{pm}	=	4.1	amps
Output power : peak - P_{pm}	=	65	watts

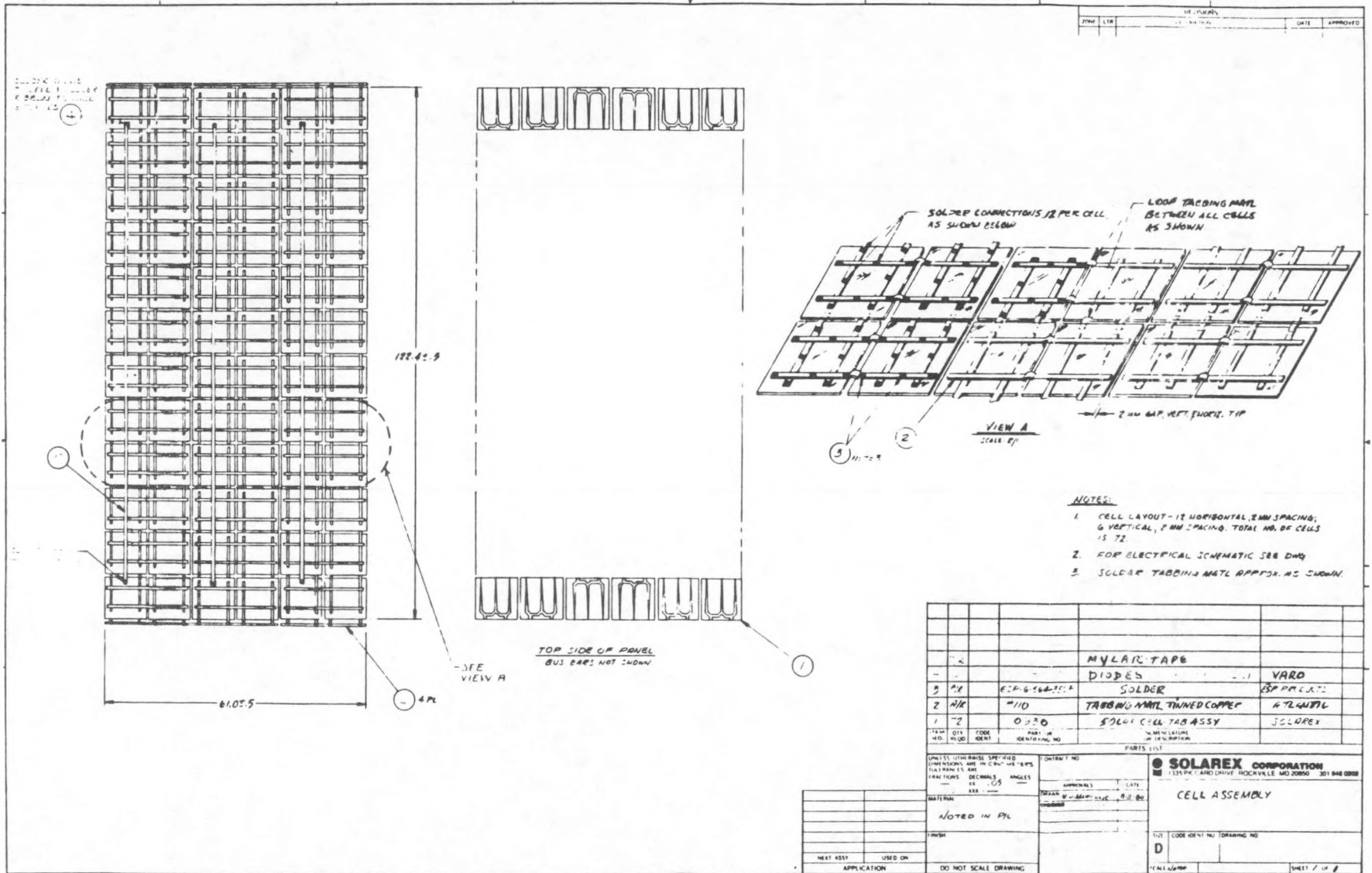


Figure 2.3-1. All Assembly- Northeast Residential Module

2.3.2 Module Physical Characteristics

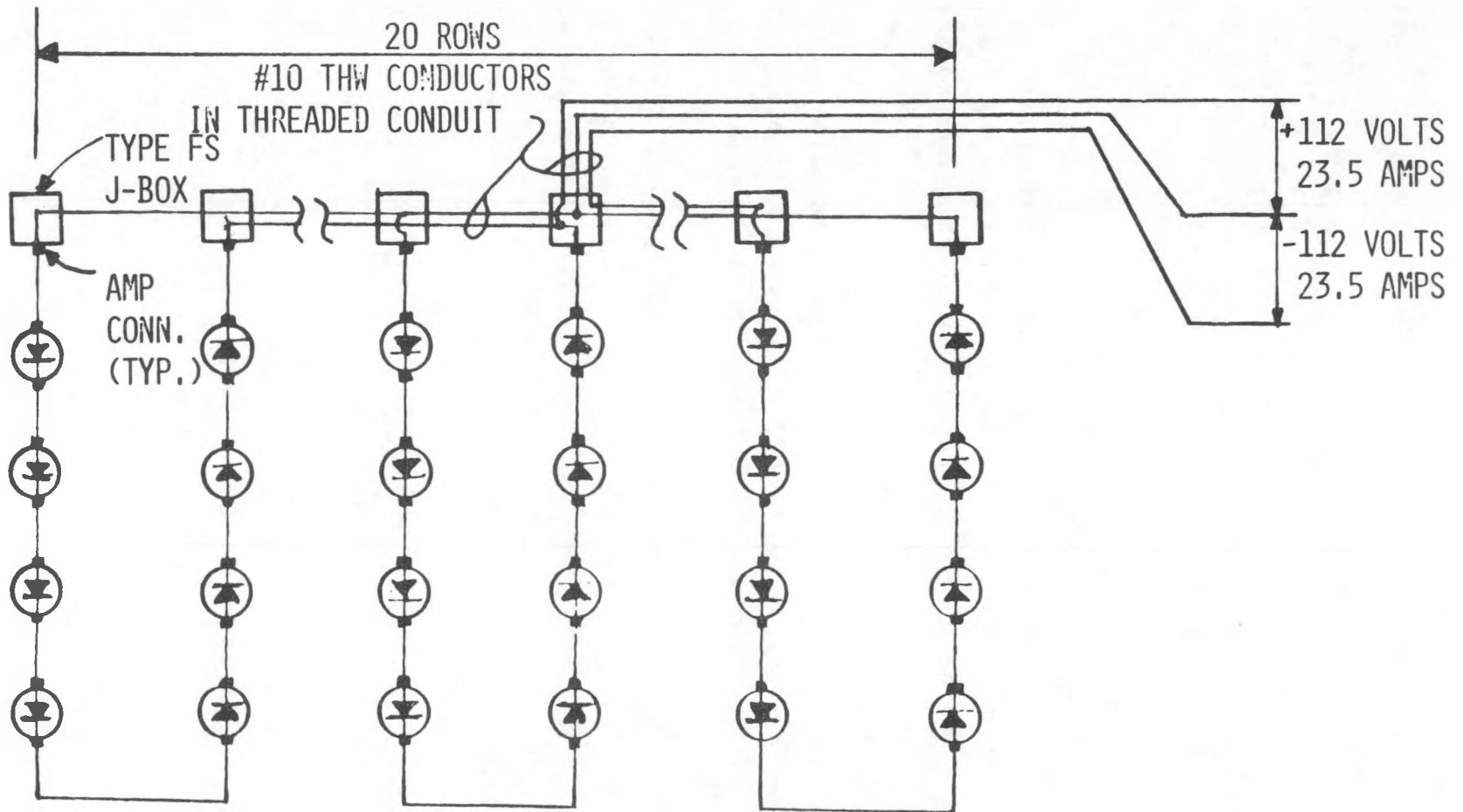
Each module withgasket has overall dimensions of 25.6" x 50.6" and is fabricated with an EPDM gasket. Each module weighs 30 lbs and is laminated with glass, EVA, silicon cells, EVA and Tedlar as illustrated in Figure 2.3-1.

2.3.2 Photovoltaic Array Wiring Layout

The initial array electrical configuration was five parallel strings of 16 modules in series for a total of 80 modules as illustrated above in Figure 2.3-2. The complete array was 17 feet, 3-3/8 inches high by 44 feet, 6-1/8 inches long (770 gross square feet).

However, because of the inverter start-up characteristics which required an array $V_{OC} = 267V$ the array was rewired as six parallel strings of 13 modules in series for a nominal array voltage of 210V. This final wiring plan is illustrated in Figures 2.3-3. The array is center-tapped between the 6th and 7th modules in series and two modules were left unconnected. Therefore the final typical array electrical performance was as follows when measured at AM1 and 25°C cell temperature:

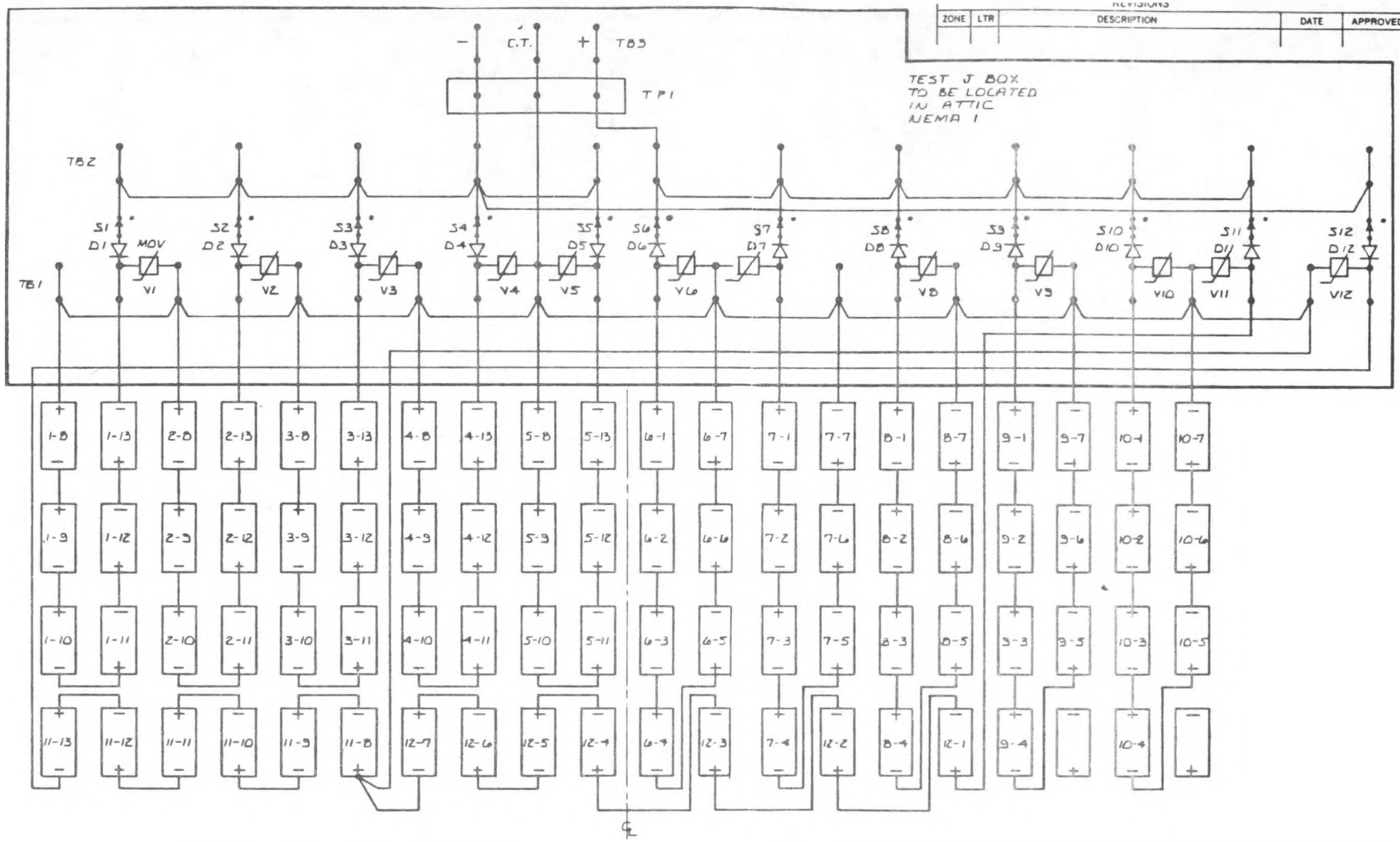
Number of modules	=	78
Tilt angle	=	45°
V_{OC}	=	260 volts
I_{SC}	=	30.6 amps
V_{pm}	=	208 volts
I_{pm}	=	24.5 amps
P_{pm}	=	5.1 K watts



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Figure 2.3-2. PV Array Electrical Schematic

ZONE	LTR	DESCRIPTION	DATE	APPROVE
------	-----	-------------	------	---------



2-23

FRONT VIEW OF PV ARRAY

QTY	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION
PARTS LIST			
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCE FRACTION =		CONTRACT NO.	SOLAREX CORPORATION 1335 PICCARD DRIVE ROCKVILLE, MD 20850 ☎ 301 948 0202
MATERIAL		APPROVALS	
FINISH		DATE	M I T N.E. RESIDENTIAL PV ARRAY AND TEST JUNCTION BOX WIRING DIAGRAM
NEXT ASSY USED ON		CHECKED	
APPLICATION		SCALE DRAWING	SIZE C CODE IDENT NO. DRAWING NO. 1079
		SCALE	SHEET 1 OF 1

Figure 2.3-3

2.3.4 System Electrical Configuration

The complete system block diagram is illustrated in Figure 2.3-4. The individual half strings were brought inside the prototype residence into a central box where each was terminated with a blocking diode: type SKS-047 rated at 30 V and 8 amps. Lightning protection consisted of varistors between center tap and + and - voltage, (GE model #V150LA20B). See Figure 2.3-4 for details.

The system block diagram shows the location of all disconnects fuses, grounding, wire sizes, etc. in general. The dc monitor panel and all components after the inverter were supplied by MIT Lincoln Laboratory .

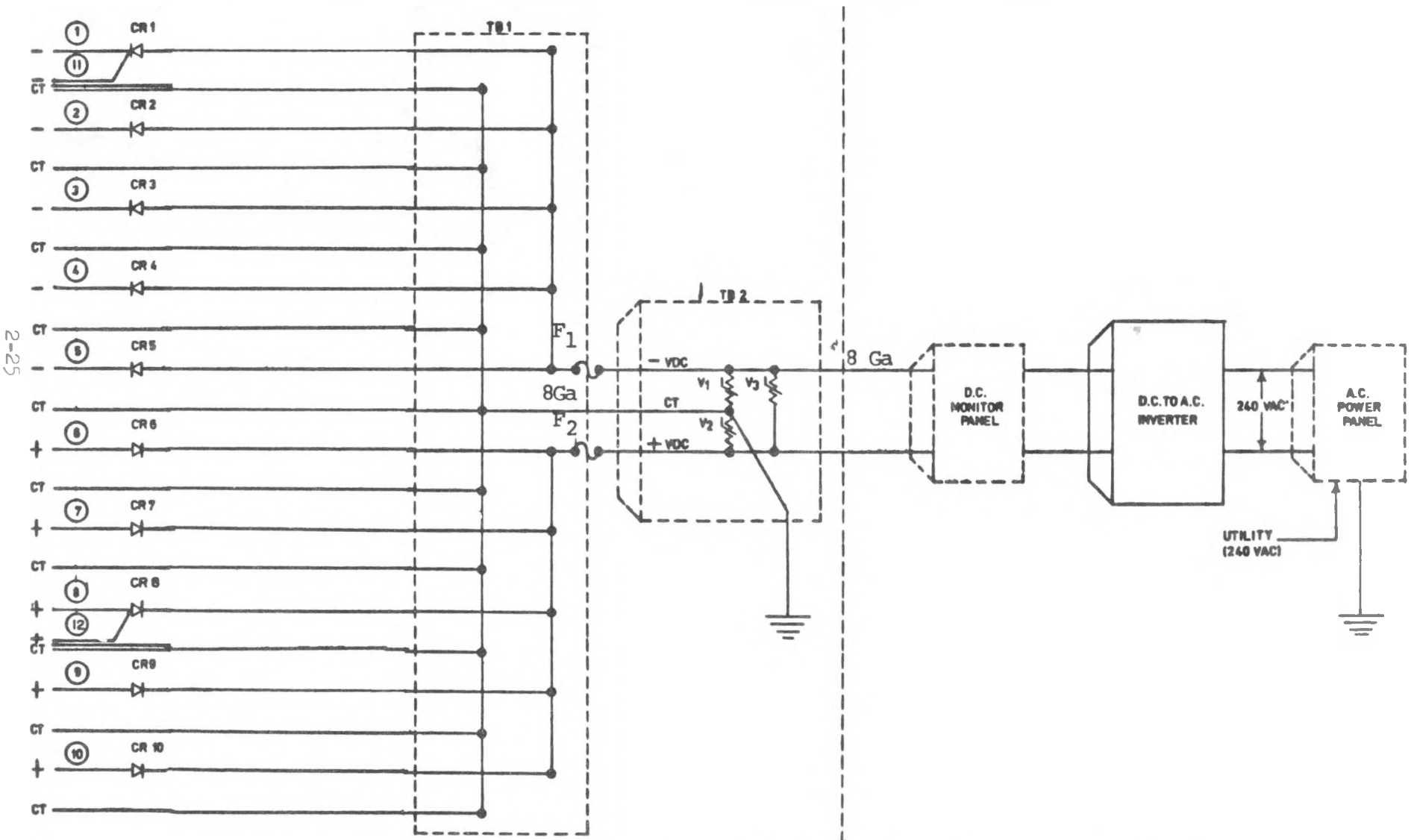
2.3.5 Power Conditioner Characteristics

The general Sunverter characteristics and specifications are presented in Table 2.3-1. The final and modified unit was designed to turn-on and turn-off daily via the output of a silicon reference or "pilot" cell that performs the double duty functions of insolation measuring during times when the Sunverter is off and as the reference to the maximum power point tracker when the Sunverter is on. For additional detail we refer the reader to the Technical Manual for the maximum-power-point tracker and insolation sensor contained in Appendix C.

The automatic control algorithm and user controls are illustrated in Appendix D.

Automatic turn on and turn off are accomplished with the maximum-power-point tracker in the same manner as was provided to Sandia on their dual bridge Sunverter. Figure 2.3-5 shows the sequence of events in flow-chart fashion. When the PV voltage exceeds 30V, the converter power supply comes on and provides power to low level logic circuits. As the PV voltage exceeds

- V1,2 - Varistors, V150LA20B, GE
- V3 - Varistor, V320LA40B, GE
- F1,2 - Fuse: 600V, 20A
- TB1 - (10) switch: 2 PSWT
(2) 271-A14, (1) SW192, Curtis
- TB 2 - C-151-5 TRW cinch connector (5 terminals), TRW
- CR 1 - (10): Diodes, 1N3212, Motorola



2-25

Figure 2.3-4 MIT/Northeast Residential Electrical

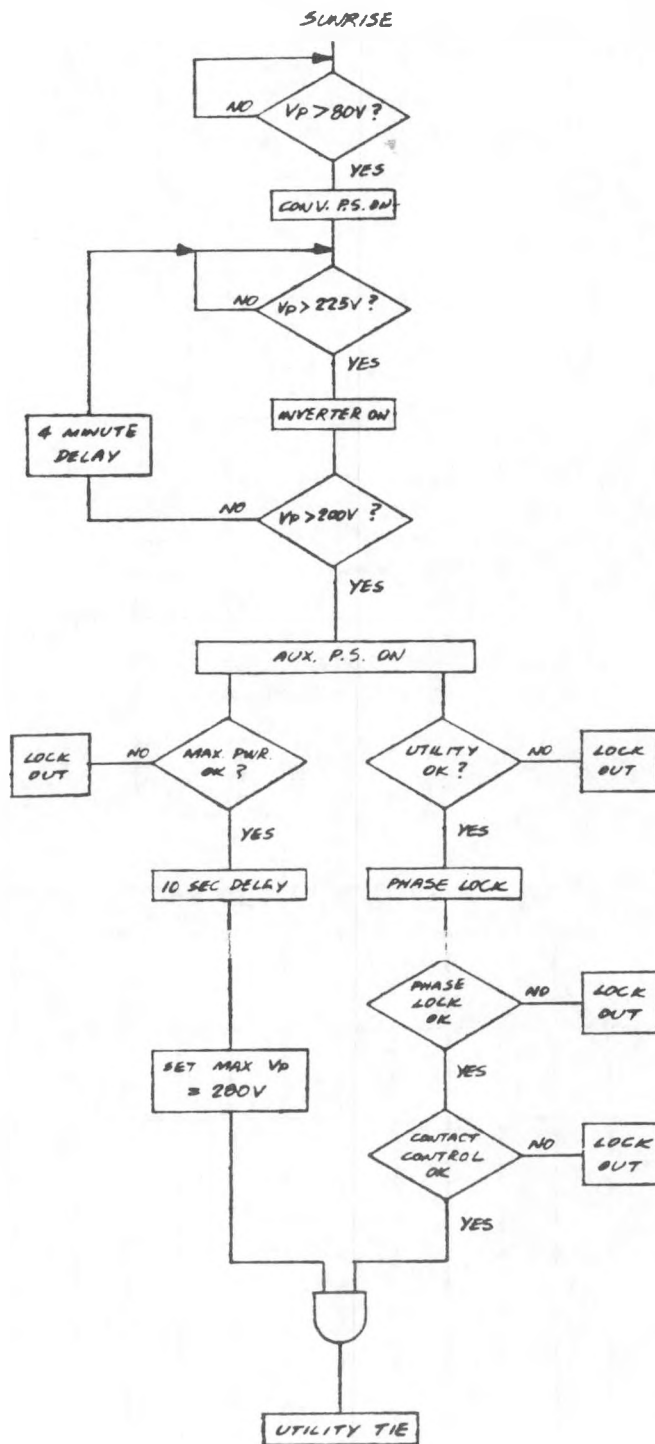


Figure 2.3-5 Start-Up Logic Flow Diagram

180V, the inverter is turned on by providing power to the transistor drive circuits. If the inverter goes below 160V, which logically could be caused by the inability of the PV voltage source to supply tare power, the inverter is left running or naturally shut down, and a four-minute delay is initiated. After four minutes, the PV voltage is again interrogated to determine whether it exceeds 180V. If it does, the inverter is again turned on, and the voltage at the PV cell is compared to 160V. If the PV voltage exceeds 160V, the auxiliary power supply, which supplies power to the maximum-power-point tracker and to the contactor control module, is turned on. The contactor control checks the utility voltage and initiates phaselock. After phaselock is accomplished and all parameters monitored by the contactor control are determined to be safe, the maximum-power-point tracker, after a ten-second delay, initiates a CLEAR COMMAND to the contactor control, which causes utility tie.

Normal shut down would occur at sunset when the voltage from the PV cell decreases below the 160V minimum. If the voltage again exceeds 180V, the inverter may walk around the four-minute delay loop a few times, but this is perfectly safe and far less costly than supplying dummy power resistors to load the solar array.

2.4 Code Issues

During design of the Conceptual Residence and Prototype, several code and safety issues were identified. These all centered around the PV system. The major code/safety questions are identified below:

- Wind loading on the array (particularly under lift) - what calculation procedures should be used?

- Fire safety, especially for standoff arrays that could encourage flame spread through a chimney effect - how will the revised UL Standard 790 treat this?
- Will external disconnects for the PV system be required for the safety of repairmen?
- Must the array automatically disconnect from the grid in case of grid power failure?
- Are highly flammable plastics acceptable on a roof even if they are encapsulated?
- Does the array support structure need to be grounded?
- Should lightning protection be required and to what extent?

These issues are not completely resolved at this time. However, solutions are being addressed by government-funded agencies (JPL), standards bureaus (UL), design engineers, and PV manufacturers. The basic conclusion is that it does not seem likely that any major code problems will arise which will be a serious impediment to widespread PV applications.

3.0 CONCLUSIONS, RECOMMENDATIONS, AND LESSONS LEARNED

3.1 Solarex Corporation

3.1.1 Modules:

Following our experience in the early development of the JPL-sponsored Block IV program, we were able to design a relatively low cost yet highly reliable module which could easily be fabricated, shipped and installed on the roof of a house. In fact, in quantity production (1,000 modules), the total materials cost of the module, less the silicon solar cells, is under \$35. Therefore, significant cost reduction can be realized in the future as cell costs are reduced.

The utilization of standard galvanized or painted support members for the array mounting hardware and the Solarlok quick connectors made the array installation quite simple.

3.1.2 Power Conditioner

The power conditioner* was a standard product called a Sunverter^R manufactured by Abacus Controls, Inc. The unit was shipped directly to the Northeast Residential Experiment Station and installed in less than one hour by a local electrician.

3.1.3 Total PV System

3.1.3.1 Final Check-out and Testing

The final check-out was accomplished by testing each series string as it was installed since each could be easily isolated from the other strings by the Solarlok J-box receptacles provided in the input J-box. Initially, the system was started-up and run for two days while monitoring array and PCU voltage and current

*NOTE: The history of the inverter performance over the first year of the project is complex and will be detailed in the MIT Lincoln Laboratory Final Report.

and PCU automatic sequencing. No initial problems were observed with the system.

Other lessons learned include the following:

- a. The installation experience confirmed our belief that the PV system could be installed by a local contractor with minimum supervision by an engineer or senior technician from Solarex. A carpenter and helper installed the array support structure, mounted the modules and installed the flashing. An electrician and helper mounted all J-boxes, installed all conduit and all wirings from the array, and mounted and wired the inverter (PCU). None of the modules was damaged during installation and the approximately 2' x 4' configuration was easy to handle.
- b. For ease of maintenance all array string wires should come together in one input J-box where they can be fused or switched-out separately for testing.
- c. Careful labeling of the modules is critical and will prevent incorrect installation.

3.1.3.2 Cost Reporting

The cost of installation was monitored and reported to MIT Lincoln Laboratory as required. These costs are summarized in three categories in Table 3.1-1.

TABLE 3.1-1.

<u>Item</u>	<u>Labor (\$)</u>	<u>Material (\$)</u>	<u>Total (\$)</u>
A. Array Installation			
Precutting of support structure	1308		1308
Install super structure	1120		1120
Install 80 PV modules	2980		2980
Frames, fasteners, flashing, etc.		1412	1412
			<u>6,820</u>
B. Array Wiring			
String wiring to J-boxes and to control box	530		530
Wire, J-boxes, connectors diodes, varistors, etc.		1034	1034
			<u>1,564</u>
C. PCU Installation & wiring			
Mounting & wiring	75		75
Power Cable		27	27
			<u>102</u>
			<u>8,486</u>

NOTE: Since this was a development project, the cost of the modules and the PCU was not precisely determined.

3.2 Mueller Associates

During this project a number of major observations were made concerning design of the PV modules, support structure, conceptual PV residence, codes and standards, and penetration of PV into the residential marketplace. Some of these observations were almost expected while others were surprises. Major observations are discussed below:

- Residential arrays of a nominally 5kWp are adequate to provide a significant energy savings for a typical residence in the U.S. Northeast.
- Future residences will consume even less purchased energy than those of today. Energy conservation features will dominate, followed by moderate solar passive features. PV will probably be installed only when these other measures have been taken.
- Envelope losses from future residences will be much smaller than at present. This implies that internal gains will meet a greater fraction of the gross heating load. This requires revision in load calculation procedures and in design practices.
- More attention must be given by designers/planners to solar orientation.
- The relationship between daily/seasonal loads and PV generated power for a typical Northeast residence is such that a significant fraction (greater than 50%) of the PV-generated power must be sold back to the utility.
- Most existing residential heating and cooling equipment is oversized for future, low energy consumption dwellings. In addition, air-conditioning units should be manufactured with lower sensible heat ratios due to the projected lower sensible cooling loads.
- Architects and engineers will have to coordinate more closely on design of future energy conserving/environmentally sensitive buildings.

- Heating/cooling systems should be designed to meet dynamic loads much more closely. This implies greater sophistication than current practice.
- Standards of comfort may need revision (both absolute numbers and allowable temperature swing).
- No major code barriers are seen which would limit the introduction of residential PV system.

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REFERENCES

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Appendix A

TRNSYS Flowchart for PV Residence in the Northeast

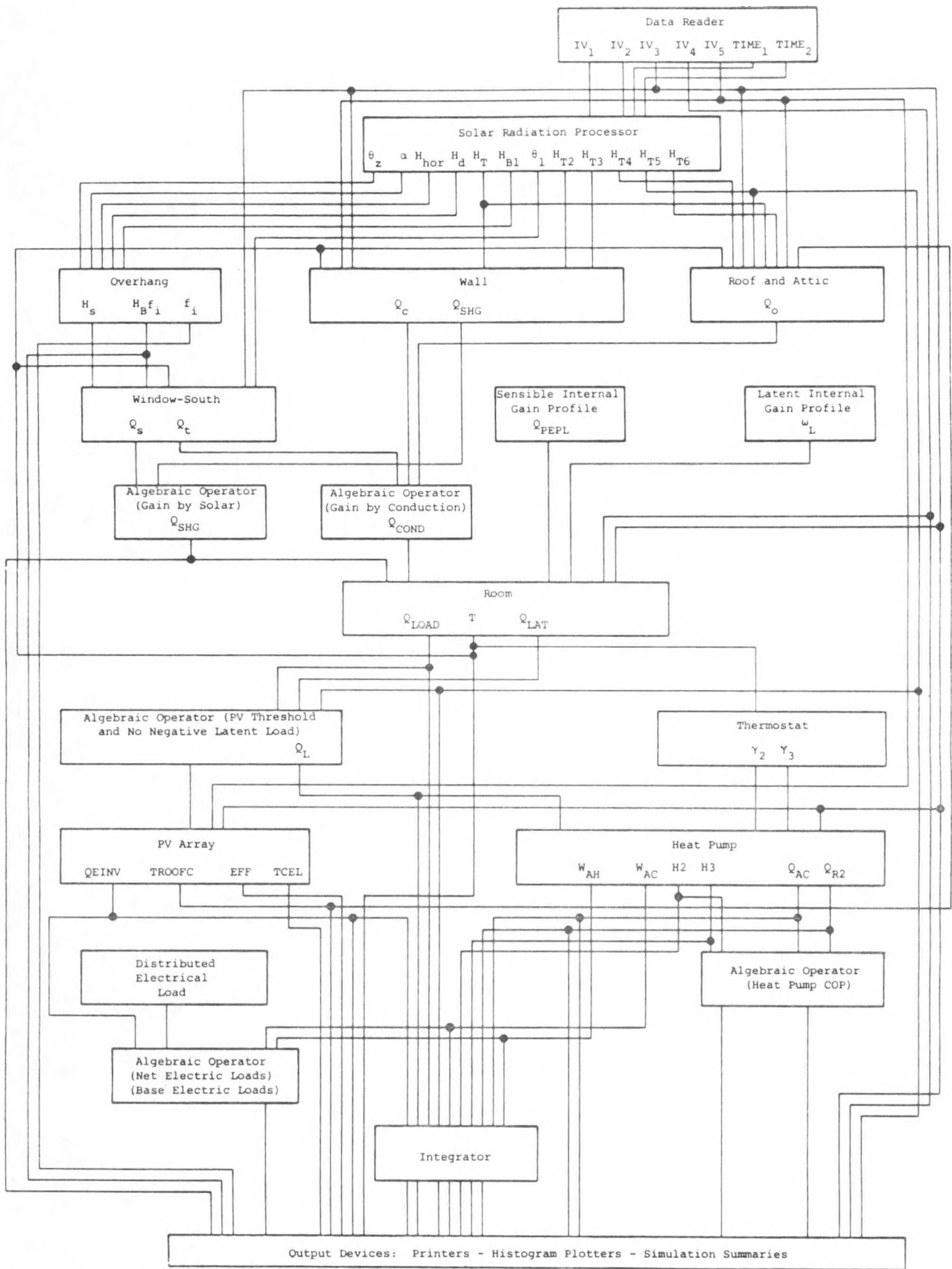


FIGURE A-1

A-2

NORTHEAST PHOTOVOLTAIC RESIDENCE
TRNSYS SIMULATION GLOSSARY

BILL = total electrical energy purchased from utility grid
[kJ/unit time]

ELETOT = total electrical energy used [kJ/unit time]

FENES = solar energy gain [kJ/unit time]

FWINDO = fraction of south window receiving direct insolation

HOURLHP = hours heat pump operated [hours]

HPCOLD = energy (heat) removed from space [kJ/unit time]

HPCOP = coefficient of performance of heat pump [dimensionless]

HPHOT = energy (heat) added to space [kJ/unit time]

HPWRKC = energy supplied to heat pump in cooling mode
[kJ/unit time]

HPWRKH = energy supplied to heat pump in heating mode
[kJ/unit time]

HRAMB = ambient humidity ratio [dimensionless]

INSOL = insolation on PV array [kJ/m²/unit time]

NETELE = electric energy used (or surplus) [kJ/unit time]

PVEFF = efficiency of PV array [%]

QEINV = PV array energy output [kJ/unit time]

QHPCLD = HPCOLD

QHPHOT = HPHOT

QLAT = latent cooling load of conditioned space (always ≥ 0)
[kJ/unit time]

QLDC = space cooling load [kJ/unit time]

QLDH = space heating load [kJ/unit time]

QSENS = sensible load of conditioned space (- is heating,
+ is cooling) [kJ/unit time]

SELL = total electrical energy for sale back to utility grid
[kJ/unit time]

TAMB = ambient temperature [°C]

TCEL = PV cell temperature [°C]

TCELL = TCEL

TROOF = temperature of south roof surface [°C]

TROOM = room temperature [°C]

WINSOL = direct insolation on south facade [kJ/m²/unit time]

NOTE: Time intervals are different for different modes of output. A key to the time intervals is:

- Outputs ending on the week (multiples of 168 hours) are weekly summaries. The time unit is one week.
- Outputs fourteen hours after the week are instantaneous profiles. The time unit is one hour.
- Histogram plots in mode 1 have time unit of one hour.
- Histogram plots in mode 2 are monthly integrals. The time unit is one month.
- Monthly simulation summaries have time unit of one month.

Typical Winter Week TRNSYS Simulation Results

A-6

1.027E+03	0.	2.393E+03	0.	0.	-2.393E+03	0.	0.	0.
TAMB	HRRMB	TROOM	TCEL	TROOF	PVEFF	FENES	WINSOL	FWINDO
-1.800E+00	1.900E-03	1.900E+01	-1.800E+00	-1.800E+00	0.	0.	0.	0.
HISTOGRAM PLOT, MODE 1			TIME=	336.000				
TAMB	MIN=-20.00	MAX=40.00	TCELL			MIN=-20.00	MAX=60.00	
INTERVAL ENDING	HOURS IN INTERVAL		INTERVAL ENDING	HOURS IN INTERVAL	INTERVAL ENDING	HOURS IN INTERVAL		
-15.00	0.00	I	-15.00	0.00	I			
-10.00	33.00	I*****	-10.00	0.00	I			
-5.00	48.00	I*****	-5.00	4.00	I*****			
0.00	46.00	I*****	0.00	4.00	I*****			
5.00	41.00	I*****	5.00	12.00	I*****			
10.00	0.00	I	10.00	20.00	I*****			
15.00	0.00	I	15.00	7.00	I*****			
20.00	0.00	I	20.00	5.00	I*****			
25.00	0.00	I	25.00	0.00	I			
30.00	0.00	I	30.00	0.00	I			
35.00	0.00	I	35.00	0.00	I			
40.00	0.00	I	40.00	0.00	I			
			45.00	0.00	I			
			50.00	0.00	I			
			55.00	0.00	I			
			60.00	0.00	I			

TROOM	MIN=18.00	MAX=26.50	TROOF	MIN=-20.00	MAX=60.00
INTERVAL ENDING	HOURS IN INTERVAL		INTERVAL ENDING	HOURS IN INTERVAL	
18.50	0.00	I	-15.00	0.00	I
19.00	118.00	I*****	-10.00	28.00	I*****
19.50	6.00	I**	-5.00	45.00	I*****
20.00	7.00	I**	0.00	49.00	I*****
20.50	4.00	I*	5.00	42.00	I*****
21.00	2.00	I*	10.00	4.00	I**
21.50	4.00	I*	15.00	0.00	I
22.00	4.00	I*	20.00	0.00	I
22.50	5.00	I*	25.00	0.00	I
23.00	2.00	I*	30.00	0.00	I
23.50	1.00	I	35.00	0.00	I
24.00	3.00	I*	40.00	0.00	I
24.50	2.00	I*	45.00	0.00	I
25.00	3.00	I*	50.00	0.00	I
25.50	1.00	I	55.00	0.00	I
26.00	6.00	I**	60.00	0.00	I
26.50	0.00	I			

QEINV	MIN=500.00	MAX=30000.00	PVEFF	MIN=8.00	MAX=9.20
INTERVAL ENDING	HOURS IN INTERVAL		INTERVAL ENDING	HOURS IN INTERVAL	
2138.89	11.00	I*****	8.05	0.00	I
3777.78	6.00	I*****	8.10	0.00	I
5416.67	8.00	I*****	8.15	0.00	I

10333.33	2.00	I*****	8.30	0.00	I
11972.22	2.00	I*****	8.35	0.00	I
13611.11	5.00	I*****	8.40	0.00	I
15250.00	7.00	I*****	8.45	0.00	I
16888.89	1.00	I***	8.50	0.00	I
18527.78	1.00	I***	8.55	0.00	I
20166.67	0.00	I	8.60	0.00	I
21805.56	0.00	I	8.65	0.00	I
23444.44	0.00	I	8.70	6.00	I*****
25083.33	0.00	I	8.75	38.00	I*****
26722.22	0.00	I	8.80	8.00	I*****
28361.11	0.00	I	8.85	0.00	I
30000.00	0.00	I	8.90	0.00	I
			8.95	0.00	I
			9.00	0.00	I
			9.05	0.00	I
			9.10	0.00	I
			9.15	0.00	I
			9.20	0.00	I

INSOL	MIN=	100.00	MAX=	4100.00	HPCDP	MIN=	1.00	MAX=	3.40
INTERVAL	ENDING	HOURS	IN	INTERVAL	INTERVAL	ENDING	HOURS	IN	INTERVAL
300.00	9.00	I*****	1.10	0.00	I				
500.00	6.00	I*****	1.20	0.00	I				
700.00	4.00	I*****	1.30	0.00	I				
900.00	4.00	I*****	1.40	0.00	I				
1100.00	5.00	I*****	1.50	0.00	I				
1300.00	5.00	I*****	1.60	0.00	I				
1500.00	1.00	I***	1.70	0.00	I				
1700.00	2.00	I*****	1.80	5.00	I*****				
1900.00	1.00	I***	1.90	27.00	I*****				
2100.00	1.00	I***	2.00	19.00	I*****				
2300.00	3.00	I*****	2.10	8.00	I*****				
2500.00	4.00	I*****	2.20	4.00	I***				
2700.00	3.00	I*****	2.30	14.00	I*****				
2900.00	3.00	I*****	2.40	29.00	I*****				
3100.00	1.00	I***	2.50	10.00	I*****				
3300.00	0.00	I	2.60	2.00	I**				
3500.00	0.00	I	2.70	0.00	I				
3700.00	0.00	I	2.80	0.00	I				
3900.00	0.00	I	2.90	0.00	I				
4100.00	0.00	I	3.00	0.00	I				
			3.10	0.00	I				
			3.20	0.00	I				
			3.30	0.00	I				
			3.40	0.00	I				

1	HISTOGRAM-PLOT, MODE 2	TIME=	336.000	QLDH	MIN=	0.00	MAX=	24.00
NETELE	MIN=	SUM OF	MAX=	TIME	MIN=	SUM OF	MAX=	TIME
TIME INT	ENDING	INTEGALS	OVER	INT	ENDING	INTEGALS	OVER	INT
		TIME	INTERVAL			TIME	INTERVAL	
1.00	38231.85	I*****	1.00	69976.11	I*****			
2.00	41339.51	I*****	2.00	75987.19	I*****			
3.00	43218.58	I*****	3.00	79435.47	I*****			
4.00	44533.92	I*****	4.00	82011.72	I*****			
5.00	45749.27	I*****	5.00	84326.19	I*****			
6.00	46869.73	I*****	6.00	86576.91	I*****			
7.00	48874.12	I*****	7.00	85552.63	I*****			
8.00	56964.51	I*****	8.00	65634.04	I*****			
9.00	54513.49	I*****	9.00	57662.60	I*****			
10.00	38910.56	I*****	10.00	55582.98	I*****			
11.00	42077.74	I*****	11.00	45346.07	I*****			
12.00	43700.05	I*****	12.00	42069.18	I*****			
13.00	5273.74	I**	13.00	20286.12	I*****			
14.00	-70004.00	*****	14.00	10570.00	I****			

17.00	-203.04	I	17.00	15537.89	I*****
18.00	48691.68	I*****	18.00	8204.79	I***
19.00	59197.11	I*****	19.00	2670.89	I*
20.00	33264.90	I*****	20.00	8805.98	I***
21.00	32293.71	I*****	21.00	16967.19	I*****
22.00	32965.17	I*****	22.00	29500.46	I*****
23.00	33700.02	I*****	23.00	42089.17	I*****
24.00	36758.23	I*****	24.00	57708.22	I*****

BLDC TIME	MIN=	0.00	MAX=	24.00
INT	ENDING	SUM OF	INTEGRALS	OVER TIME INTERVAL
1.00		0.00	I	
2.00		0.00	I	
3.00		0.00	I	
4.00		0.00	I	
5.00		0.00	I	
6.00		0.00	I	
7.00		0.00	I	
8.00		0.00	I	
9.00		0.00	I	
10.00		0.00	I	
11.00		0.00	I	
12.00		0.00	I	
13.00		0.00	I	
14.00		0.00	I	
15.00		0.00	I	
16.00		0.00	I	
17.00		0.00	I	
18.00		0.00	I	
19.00		0.00	I	
20.00		0.00	I	
21.00		0.00	I	
22.00		0.00	I	
23.00		0.00	I	
24.00		0.00	I	

A-9

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*****
* SIMULATION SUMMARY FOR TIME = 168.000 TO 336.000 *
* *
* QSENS QLAT QPHOT QPCLD QEINV INSOL ELETOT SELL *
* -1.062E+06 0. 1.075E+06 0. 3.637E+05 6.516E+04 1.076E+06 1.739E+05 *
* *
* BILL *
* 8.862E+05 *
* *
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A-10

Typical Summer Week TRNSYS Simulation Results

A-11

A-12

1 HISTOGRAM PLOT, MODE 1 TIME= 4992.000
 TAMB : MIN= -20.00 MAX= 40.00
 INTERVAL ENDING HOURS IN INTERVAL

-15.00	0.00	I
-10.00	0.00	I
-5.00	0.00	I
0.00	0.00	I
5.00	0.00	I
10.00	0.00	I
15.00	4.00	I**
20.00	62.00	I*****
25.00	65.00	I*****
30.00	37.00	I*****
35.00	0.00	I
40.00	0.00	I

TCELL : MIN= -20.00 MAX= 60.00
 INTERVAL ENDING HOURS IN INTERVAL

-15.00	0.00	I
-10.00	0.00	I
-5.00	0.00	I
0.00	0.00	I
5.00	0.00	I
10.00	0.00	I
15.00	0.00	I
20.00	0.00	I
25.00	6.00	I*****
30.00	14.00	I*****
35.00	23.00	I*****
40.00	14.00	I*****
45.00	11.00	I*****
50.00	12.00	I*****
55.00	2.00	I**
60.00	0.00	I

TROOM : MIN= 18.00 MAX= 26.50
 INTERVAL ENDING HOURS IN INTERVAL

18.50	0.00	I
19.00	0.00	I
19.50	0.00	I
20.00	6.00	I*
20.50	1.00	I
21.00	0.00	I
21.50	0.00	I
22.00	1.00	I
22.50	4.00	I*
23.00	2.00	I
23.50	5.00	I*
24.00	3.00	I*
24.50	2.00	I
25.00	7.00	I**
25.50	4.00	I*
26.00	133.00	I*****
26.50	0.00	I

TROOF : MIN= -20.00 MAX= 60.00
 INTERVAL ENDING HOURS IN INTERVAL

-15.00	0.00	I
-10.00	0.00	I
-5.00	0.00	I
0.00	0.00	I
5.00	0.00	I
10.00	0.00	I
15.00	4.00	I**
20.00	51.00	I*****
25.00	53.00	I*****
30.00	41.00	I*****
35.00	19.00	I*****
40.00	0.00	I
45.00	0.00	I
50.00	0.00	I
55.00	0.00	I
60.00	0.00	I

BEINV : MIN= 500.00 MAX= 30000.00
 INTERVAL ENDING HOURS IN INTERVAL

2138.89	18.00	I*****
3777.78	13.00	I*****
5416.67	12.00	I*****
7055.56	5.00	I*****
8694.44	4.00	I*****
10333.33	1.00	I**
11972.22	6.00	I*****
13611.11	4.00	I*****
15250.00	2.00	I**
16888.89	5.00	I*****
18527.78	3.00	I*****
20166.67	5.00	I*****
21805.56	6.00	I*****
23444.44	0.00	I
25083.33	0.00	I
26722.22	0.00	I
28361.11	0.00	I
30000.00	0.00	I

PUEFF : MIN= 8.00 MAX= 9.20
 INTERVAL ENDING HOURS IN INTERVAL

8.05	0.00	I
8.10	0.00	I
8.15	0.00	I
8.20	0.00	I
8.25	0.00	I
8.30	0.00	I
8.35	0.00	I
8.40	0.00	I
8.45	0.00	I
8.50	0.00	I
8.55	0.00	I
8.60	24.00	I*****
8.65	45.00	I*****
8.70	15.00	I*****
8.75	0.00	I
8.80	0.00	I
8.85	0.00	I
8.90	0.00	I
8.95	0.00	I
9.00	0.00	I
9.05	0.00	I
9.10	0.00	I
9.15	0.00	I
9.20	0.00	I

9.20 0.00 I

INSOL	: MIN=	100.00	MAX=	4100.00	HPCOP	: MIN=	1.00	MAX=	3.40
INTERVAL	ENDING	HOURS	IN	INTERVAL	INTERVAL	ENDING	HOURS	IN	INTERVAL
300.00		11.00	I*****		1.10	0.00	I		
500.00		12.00	I*****		1.20	0.00	I		
700.00		8.00	I*****		1.30	0.00	I		
900.00		5.00	I*****		1.40	0.00	I		
1100.00		6.00	I*****		1.50	0.00	I		
1300.00		4.00	I*****		1.60	0.00	I		
1500.00		3.00	I*****		1.70	0.00	I		
1700.00		1.00	I**		1.80	0.00	I		
1900.00		1.00	I**		1.90	0.00	I		
2100.00		5.00	I*****		2.00	0.00	I		
2300.00		2.00	I****		2.10	0.00	I		
2500.00		3.00	I*****		2.20	0.00	I		
2700.00		1.00	I**		2.30	0.00	I		
2900.00		4.00	I*****		2.40	0.00	I		
3100.00		3.00	I*****		2.50	0.00	I		
3300.00		1.00	I**		2.60	0.00	I		
3500.00		3.00	I*****		2.70	2.00	I**		
3700.00		3.00	I*****		2.80	35.00	I*****		
3900.00		6.00	I*****		2.90	0.00	I		
4100.00		0.00	I		3.00	0.00	I		
					3.10	0.00	I		
					3.20	0.00	I		
					3.30	0.00	I		
					3.40	0.00	I		

41-V

1 HISTOGRAM PLOT, MODE 2 TIME= 4992.000

NETELE	: MIN=	0.00	MAX=	24.00	QLDH	: MIN=	0.00	MAX=	24.00
TIME INT	ENDING	SUM OF	INTEGRALS	OVER	TIME INT	ENDING	SUM OF	INTEGRALS	OVER
			TIME	INTERVAL				TIME	INTERVAL
1.00		3780.00	I*		1.00	0.00	I		
2.00		3780.00	I*		2.00	0.00	I		
3.00		3780.00	I*		3.00	0.00	I		
4.00		3780.00	I*		4.00	0.00	I		
5.00		3780.00	I*		5.00	0.00	I		
6.00		3503.31	I*		6.00	0.00	I		
7.00		-654.26	I		7.00	0.00	I		
8.00		1545.87	I		8.00	0.00	I		
9.00		-13306.09	*****I		9.00	0.00	I		
10.00		-35966.13	*****I		10.00	0.00	I		
11.00		-21070.75	*****I		11.00	0.00	I		
12.00		-3360.32	*****I		12.00	0.00	I		
13.00		-13405.44	*****I		13.00	0.00	I		
14.00		-40559.37	*****I		14.00	0.00	I		
15.00		-49255.02	*****I		15.00	0.00	I		
16.00		-33989.60	*****I		16.00	0.00	I		
17.00		-14956.95	*****I		17.00	0.00	I		
18.00		43584.72	I*****		18.00	0.00	I		
19.00		66701.50	I*****		19.00	0.00	I		
20.00		35782.15	I*****		20.00	0.00	I		
21.00		28890.27	I*****		21.00	0.00	I		
22.00		22224.87	I*****		22.00	0.00	I		
23.00		14232.22	I****		23.00	0.00	I		
24.00		8190.00	I**		24.00	0.00	I		

QLDC	: MIN=	0.00	MAX=	24.00
TIME INT	ENDING	SUM OF	INTEGRALS	OVER
			TIME	INTERVAL
1.00		0.00	I	
2.00		0.00	I	
3.00		0.00	I	
24.00		0.00	I	

QLDC TIME	MIN-INT	ENDING	SUM OF INTEGRALS	MAX= 24.00	OVER TIME INTERVAL
1.00			0.00	I	
2.00			0.00	I	
3.00			0.00	I	
4.00			0.00	I	
5.00			0.00	I	
6.00			0.00	I	
7.00			0.00	I	
8.00			0.00	I	
9.00			0.00	I	
10.00			6022.46	I***	
11.00			20493.82	I*****	
12.00			32783.58	I*****	
13.00			42620.97	I*****	
14.00			48999.52	I*****	
15.00			48490.98	I*****	
16.00			45581.65	I*****	
17.00			42921.69	I*****	
18.00			55455.66	I*****	
19.00			49305.80	I*****	
20.00			22177.37	I*****	
21.00			13543.14	I*****	
22.00			10802.78	I*****	
23.00			4446.62	I**	
24.00			0.00	I	

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* SIMULATION SUMMARY FOR TIME = 4824.000 TO 4992.000 *
* *
* OSENS      QLAT      QHPHOT      QHPCLD      QEINV      INSOL      ELETOT      SELL *
* 8.983E+05  1.740E+05  0.          4.436E+05  6.925E+05  1.256E+05  7.095E+05  3.090E+05 *
* *
* BILL *
* 3.260E+05 *
* *
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Appendix B
Prototype Construction Documents

SPECIFICATIONS

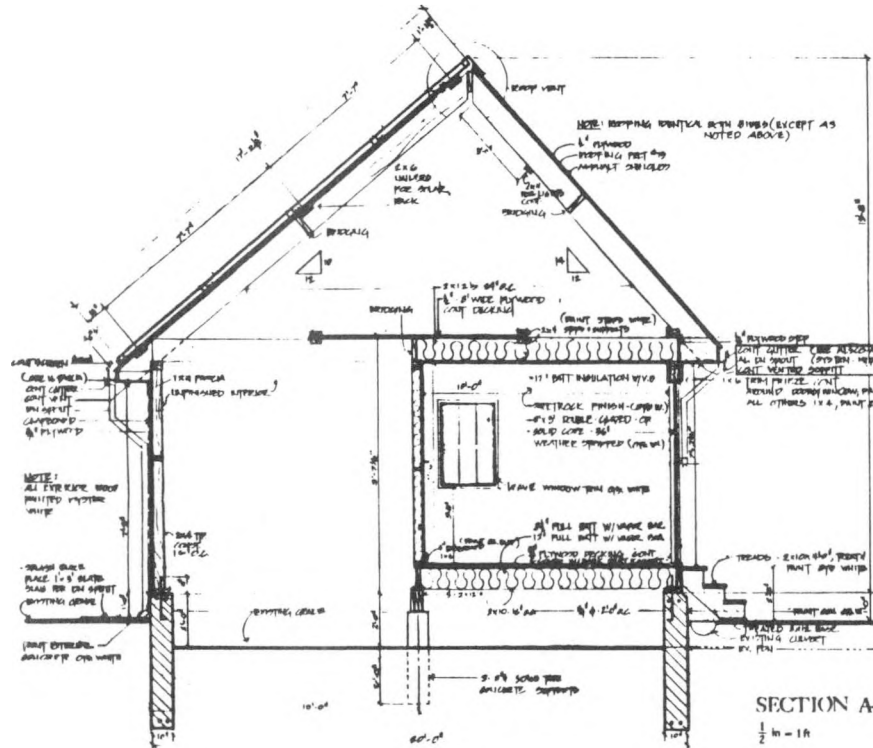
SPECIFICATIONS

- The low and ends of the plane of building shall govern the construction. The contractor shall obtain all required permits, licenses, etc. necessary for construction.
- Metal shall be selected as shown on drawings. Manufacturer's name and finishing shall be Pittsburgh Plate and Steel's original blue (blue gray). Paints and enamels shall be pre-bid and white as shown on drawings. Screens at end of building shall be original blue.
- Unless otherwise noted all dimension lumber shall be #2 yellow pine or fir. All lumber shall be straight and free from defects. All lumber in contact with masonry is to be treated with preservative. Provide double nailing for roof sheathing on rafters. Sheathing siding shall be Memphis Corp. professional exterior (60 lbs. x 9 1/2 in. width) or approved equal. All trim shall be same or pine.

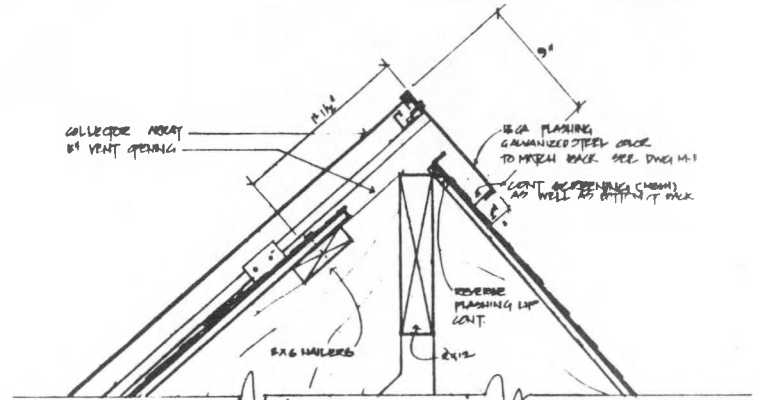
- Install insulation as shown on drawings to meet the following R-values with built insulation. Ceiling R-20. Floor R-20. Walls R-11. See drawings for required depth. Foiled insulation shall serve as adequate vapor barrier protection.
- Shingles shall be 140 lb. asphalt. Use dark gray on north roof and bottom three rows and east half of south roof. Use white on remainder of east half of south roof. Before applying shingles, cover roof sheathing with 15# saturated roofing felt. Use double nailing run on shingles.
- Weather strip windows and doors. Caulk where necessary. Windows shall be vinyl clad wood. IPULLA All doors shall be solid wood. Provide knockdown threshold on outside doors. Stuff opaque around window and outside doors with built insulation. Porch screens for window and outside doors which are removable. (Optional) Door hardware shall be brass in color and all doors shall be lockable by key.

- Cypress board shall conform to ASTM C 10-86. Provide double nailing on soiling. All exterior work (except prefabricated insulation) shall receive not less than three coats of paint including the prime coat. All sheet metal work shall be painted with one heavy coat, on both sides, of rust inhibiting paint before erection, and two coats of the same material after being set in place. Interior of sunlouver room shall receive three coats of Opaco white paint. All interior trim shall receive three coats of Colonial Blue.
- Exterior doors and siding shall be Cypress white. Exterior door shall be Colonial Blue. Paints trim around outside doors and windows shall be Colonial Blue.
- All paint shall be semi-gloss. Interior carpeting of sunlouver room only shall be Indoor/outdoor plain pattern dark silver gray.

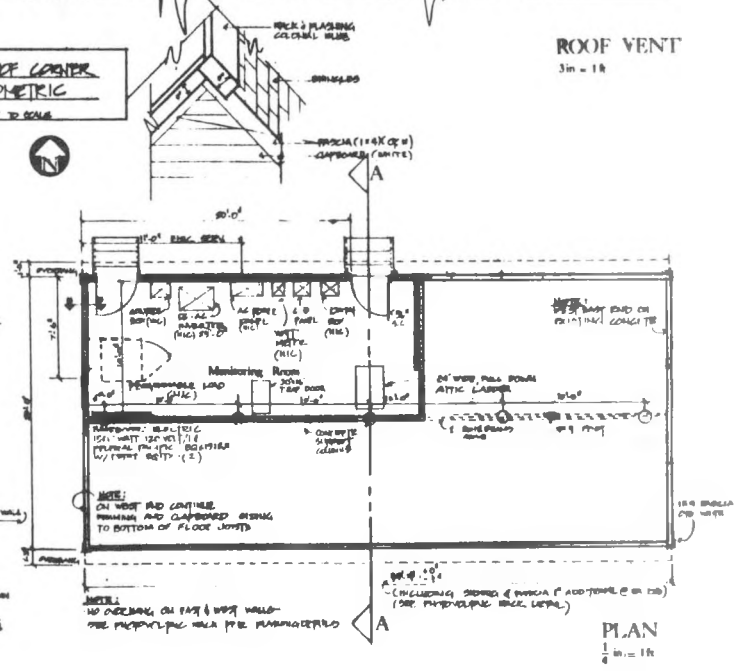
B-1



SECTION AA
1/2 in = 1 ft



ROOF VENT
3 in = 1 ft



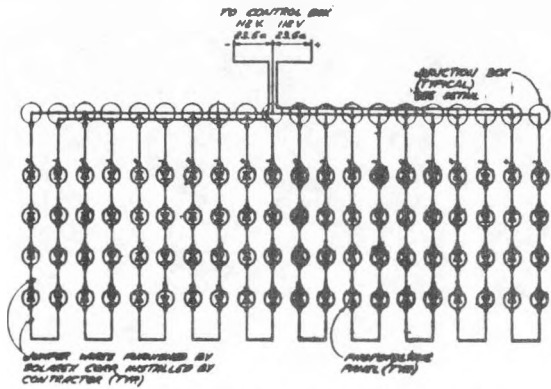
PLAN
1/4 in = 1 ft

PANEL "A" SCHEDULE

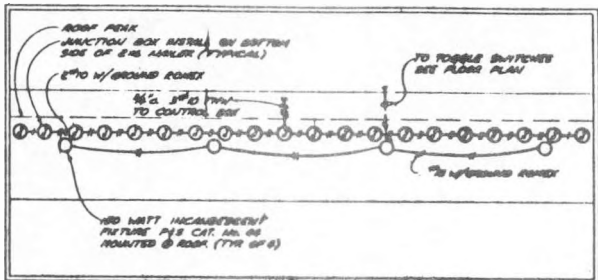
100/200 VOLT., 3 WIRE, 1 PHASE, 100A. R.L.O.					
CTL. NO.	EQUIPMENT IDENT.	VOLTS	AMPS	TRIP	PANEL
1	LIGHTS	100	100	20	1
2	RECEPTACLES	100	100	20	1
3	BASEBOARD HTW	100	100	20	1
4	BASEBOARD HTW	100	100	20	1
5	RECEPTACLES	240	100	30	2
6-8	SPACES (H)	100	100	20	1
10-12	SPACES	100	100	-	1

NOTES:
1. PANEL SHALL BE SQUARE 8 TYPE GFCI WITH GROUND BUS KIT

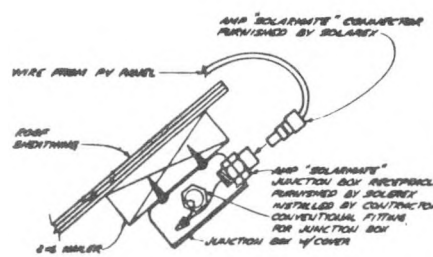
- GENERAL NOTES:**
1. PHOTOVOLTAIC PANELS SHALL BE PROVIDED BY SOLARIX CORPORATION AND INSTALLED BY THE CONTRACTOR UNDER SOLARIX SUPERVISION.
 2. CONTRACTOR FURNISHES THAT PANELS RECEIVE ELECTRICAL ENERGY FROM SYSTEM BY 240 VOLT. 2-WIRE SYSTEM FROM SERVICE TO PHOTOVOLTAIC PANELS. PANELS IN CONTROL BOX SHALL BE INSTALLED WITH ALL PANELS ARE WIRING.
 3. BUILDING SHALL BE INSTALLED ON SITE NO. 020-4 OF THE N.I.T.J. (SOLAR LAB PLANT FACILITY, GROUND, MD).
 4. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE GROUNDING SYSTEM. THE CONTRACTOR SHALL PROVIDE FOR ALL NECESSARY GROUNDING POINTS.
 5. ELECTRICAL POWER AND GROUND ARE AVAILABLE AT THE SITE.



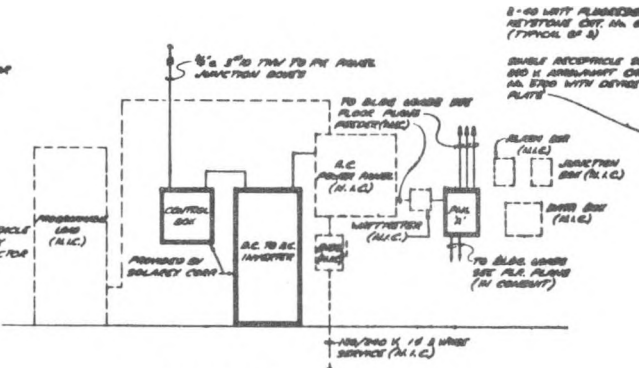
PHOTOVOLTAIC PANEL WIRING SCHEMATIC
NO SCALE



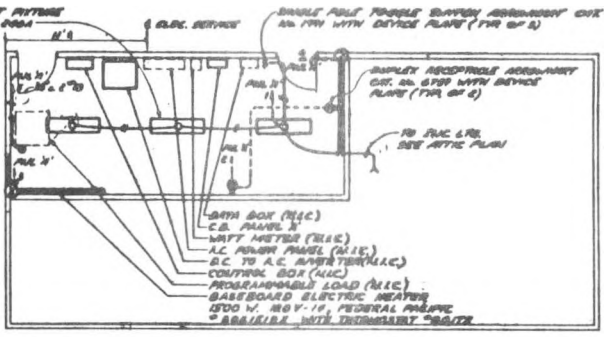
ATTIC PLAN
SCALE: 1/8" = 1'-0"



DETAIL - PV PANEL JUNCTION BOX
NO SCALE



ELECTRICAL RISER
SCALE: 1/8" = 1'-0"



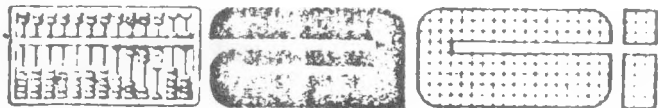
FLOOR PLAN
SCALE: 1/8" = 1'-0"

B-3

<p>PHOTOVOLTAIC RESIDENCE PROTOTYPE</p>	<p>ELECTRICAL PLANS AND DETAILS</p> <p>DATE: 11/1/77 SCALE: AS NOTED</p>	<p>HEET NO. E-1 OF 1</p>
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Appendix C

Technical Manual for Max Power Tracker and Insolation Sensor



abacus controls inc.

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201-526-6010

APPENDIX C

TECHNICAL MANUAL

MAX POWER TRACKER AND INSOLATION SENSOR

1. GENERAL

The max power tracker and insolation sensor provides a means of turning an Abacus Controls Sunverter on when there is sufficient power from the array on the roof. This is accomplished by shorting a pilot cell and measuring the short circuit current.

After the Sunverter turns on, the pilot cell is used to establish the open circuit voltage of a typical cell on the roof. This, in conjunction with a small negative voltage, provides the maximum power point signal to the Logic and Control Card in the Sunverter.

2. THEORY OF OPERATION

Refer to schematic diagram 41194. Whenever the +5V is available in the Sunverter and the 5V delayed is absent, the pilot cell is operated in the short circuit mode. This is accomplished at transistor Q3, which is energized by resistor R77. The current level from the pilot cell is tested at IC13 pins 4 and 5; the trip point of the comparator is adjustable with the power sense resistor.

IC13 pins 10, 11, and 13 is a comparator that senses photovoltaic voltage with hysteresis: In the upward direction, the output at pin 13 is low to 185V DC and high at voltages greater than 185; in the downward direction, the output at pin 13 remains high to 160V, below which the output voltage is low.

The voltage high signal and the current high signal are compared logically at IC14. When both signals are true the low voltage supply is turned on via transistor Q4. This initiates turn on of the low voltage power supply which initiates the start up of the 5V delay signal. This signal, in turn, replaces the voltage high-current high signal at IC14 pins 9 and 10, and turns transistor Q3 off at IC13 pins

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1, 6, and 7.

The circuit at IC1, Q1, and Q2 forms a delayed contactor reset circuit. Capacitor C3 remains shorted until the inverter is turned on. As capacitor C3 charges, comparator IC1 causes transistor Q2 to energize and the one-shot multivibrator at IC1 pins 8, 9, and 14 to develop a high voltage pulse. This interrupts the conduction of transistor Q1 for approximately one second which resets the contactor control card.

At the same time that IC1 pins 1, 6, and 7 conducts, IC1 pins 2, 4, and 5 transfer from the conducting state to the open state. This energizes a negative signal that is significantly delayed through op amp IC4 pins 5, 6, and 7 to form a negative voltage that will be subtracted from the open circuit voltage of the array. The open circuit voltage from the array enters op amp IC4 pins 12, 13, and 14 through the open circuit voltage adjust. This network provides the reference for the max power tracking and is compared to the actual photovoltaic voltage entering pin B through resistor R33. If, for some reason, the max power voltage would be below 160V, the auctioneer circuit limits the low end voltage to 160V.

Op amp IC4 pins 8, 9, and 11 forms an error amplifier for the reference and voltage feedback signals. Op amp IC4 pins 1, 2, and 3 provides the stabilizing network for the max power track closed loop.

3. ALIGNMENT PROCEDURE

There are six adjustments on the max power tracker and insulation sensor printed circuitcard. These should be adjusted in the order indicated.

1. Power Sense
2. Undervoltage
3. Hysteresis
4. 160V Undervoltage Protection
5. Open Circuit Voltage (OCV)
6. Max Power Point (MPP)

3.1 Power Sense

The power sense adjustment should be made in the morning or evening with a unit at the near cycling condition. A recorder on

array voltage would be helpful. The adjustment should be such that a turn on attempt is not made when the array has insufficient power to sustain operation.

CAUTION: It is better to lose a small amount of running time than to cycle on and off.

3.2 Undervoltage

The undervoltage trip adjust should be made with the sunverter operating in the line tie manual mode. The array voltage can then be adjusted with the manual power set adjust. The undervoltage trip should be set in the upward direction at 185V.

3.3 Hysteresis

The hysteresis adjust should be made in the same manner as the undervoltage trip except that the voltage should be lowered to 160V after it has been above 185V.

NOTE: Adjustments (2) and (3) should be repeated as there is a small amount of interaction between the two adjustments.

3.4 160V Undervoltage Protection

The 160V pot is adjusted with the contactor switch off and the sunverter in the phaselock position at no load. The max power tracker/insolation sensor should be on an extender card. The voltage at the junction R35 and R75 should be set to 8.4V.

3.5 Open Circuit Voltage (OCV)

The open circuit voltage adjust should be set under the same conditions as the 160V voltage. In order to remove the subtracting voltage from the MPP pot, either turn the MPP pot in the CCW direction for zero ohms or place a short circuit across C3, which will cause the comparator IC1, pins 2, 4, and 5, to short circuit the MPP pot as it does during turn on. The output of the final stage integrator in the max power tracker, pin A, should be monitored with a voltmeter. The OCV adjust should be set so that the output of the integrator slews low from a high position. This is a necessary condition to have a soft start at the time of line tie.

3.6 Max Power Point (MPP)

The max power point adjust is made in the line tie position after the sunverter has been running for one-half hour longer at an insolation level greater than .6. If an AC power measurement, the

adjustment can be made to maximize the AC power. IF no AC power measurement is available, the DC power can be maximized. For an alternate method, the output voltage of the sunverter can be adjusted to be 78% of the open circuit array voltage.

Appendix D
Sunverter Specifications

SUNVERTER SPECIFICATIONS

INPUT

1. Input is from a photovoltaic array with or without a battery.
2. Input DC voltage range is 160 to 240VDC.
 - 2.1 Automatic start-up at 180VDC.
 - 2.2 Automatic turn-off at 160VDC.
 - 2.3 Automatic turn-off at 240VDC or 250VDC.
3. Ripple current returned to utility: 2% rms of DC current.

OUTPUT

Nominal output is 240VAC 60Hz Single Phase.

4. Utility intertie
 - 4.1 Two wire 240VAC (utility supplies neutral for 120V/120V).
 - 4.2 Output current is phaselocked to utility voltage, resulting in unity power factor.
 - 4.3 Output current is amplitude regulated with amplitude set by internal calibrated adjustment or signal from the max power track module.
 - 4.4 Harmonic distortion of the current into the utility is 5% THD.
 - 4.5 Automatic disconnect if utility voltage is less than 216VAC.
 - 4.6 Automatic disconnect if utility voltage is greater than 264VAC.
 - 4.7 Automatic disconnect if current exceeds rating.
 - 4.8 Automatic disconnect if phaselock is broken.
 - 4.9 Automatic disconnect on loss of utility.

5. Stand Alone

- 5.1 Three wire 240VAC 60Hz Single Phase.
- 5.2 Voltage regulation $\pm 2\%$.
- 5.3 Voltage is phaselocked to utility voltage if present; otherwise, 60Hz $\pm .25$ Hz.
- 5.4 Voltage harmonic distortion: 4% THD, 3% maximum any one frequency.
- 5.5 Automatic disconnect if inverter voltage is less than 216VAC.
- 5.6 Automatic disconnect if inverter voltage is greater than 264VAC.
- 5.7 Current limit protected and short circuit protected.

CONTROLS AND DISPLAYS

6. Front Panel

- 6.1 On-Off Switch
 - 6.2 Mode Select
 - a. Stand alone (inverter to load)
 - b. Utility intertie (utility to load, inverter in parallel when available)
 - 6.3 DC On Light
 - 6.4 AC On Light
 - 6.5 Contactor Open (red)
- ### 7. Inside Sunverter
- 7.1 Power level set adjustment (utility mode)
 - 7.2 Contactor Reset
 - 7.3 Contactor On-Off
 - 7.4 Frequency Adjust
 - 7.5 Voltage Adjust

GENERAL

8. Efficiency is 87% or greater from 20% load to full load.
9. Tare power is 250W maximum at 200VDC input.
10. Cooling is forced air as required (fans automatically turned on and off by thermal switch)
11. Size is 24"w x 30"d x 60"h.
12. Weight is 500 lbs. (10KVA)
13. Input/output isolation: 1500VAC hipot.

SAFETY FEATURES

(These are in addition to automatic turn-offs and disconnects cited above.)

14. DC On-Off Switch
15. Input fuses, both lines
16. Output fuses, both lines
17. Automatic turn-off for power transistor over temperature.