A NEW HORIZON IN SINGLE-PLY ROOFING (FREE ELECTRICITY FOR EVERY HOME)

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We are harnessing the results of over 30 years of progress in photovoltaic (PV) technology in various forms and have found numerous applications for it. During the same period of time, the roofing materials science and technology have advanced dramatically. Besides the traditional roofing materials such as tiles, shakes, galvanized steel, and bitumen-based materials, over 500 new roofing and waterproofing membranes have been introduced to the construction industry during the past 20 years worldwide. Relevant standards for these materials already exist or are being developed.

The increasing concern for depletion of nonrenewable fossil fuel and environmental issues has created ample opportunity for a clean and economical energy source. As of the last ten years, single-ply roofing membranes are enjoying their proven status as a mature industry. The photovoltaic single-ply roofing membrane is a logical solution to these environmental concerns by providing free electricity from the roof of every building on which it is applied.

The author describes a patented development of PV and single-ply roofing technology utilizing the state of the art in PV cell fabrication techniques. This new class of flexible roofing membranes could practically be applied to any shape and type of roof. References and sources of information are provided.

KEYWORDS

Application, bifunctional, design, electricity, photovoltaic, prototype, research, roofing membrane, single-ply.

INTRODUCTION

Conventional roofing materials, such as asphalt shingles, bituminous built-up roofing, clay tiles, galvanized steel (standing seam), copper, aluminium, cedar shakes, etc., are being used extensively worldwide and their use will continue in the future.

Parallel with the advancement of photovoltaic technology, which has reached the stage of maturity, this paper proudly gives an overview of the last two decades of progress in roofing science and technology. By 1989, single-ply membranes covered 61 percent[1] of the flat and sloped commercial/industrial roofs in the U.S., which compared to 1971 was only 1-2 percent. Their chemical compositions are based on reinforced or nonreinforced polymeric, elastomeric and modified bituminous materials and are extensively used in the U.S., Canada, Europe and other parts of the world.

Prototypes of a few square feet of a photovoltaic single-ply roofing membrane were developed and evaluated in 1986. The process relates to a bifunctional roofing membrane providing environmental protection to host structures while generating free electricity as a stand-alone power system for residential, commercial and light industrial structures.

ROOF DESIGN, STRUCTURE AND COMPONENTS

The general perception of a roof is a system which protects a building's contents and inhabitants from the adverse effects of the environment such as rain, snow, wind, sun, etc. The roof deck may be built of corrugated steel, wood, concrete or other materials. The exterior surface of the roof deck has to be made impervious to moisture migration in vapor or liquid form. Therefore, based on indoor relative humidity, a sheet of vapor retarder may be required. To increase the thermal efficiency, a thermal insulation material is applied over the vapor barrier. This insulating material should be protected from mechanical damage and the harmful effects of ultraviolet radiation.

SINGLE-PLY ROOFING MATERIALS

The use of various types of roofing membranes now enters into the picture. All the available single-ply membranes such as EIP, EPDM, PVC, CPE, CSPE, PIB, modified bitumen, etc., are all candidates for use as the base material for photovoltaic single-ply roofing membranes. The single-ply membranes can be fabricated in rolls with a width of between 1 and 15 meters and 10 to hundreds of meters in length utilizing factory seaming. Single-ply membranes are prefabricated in thicknesses between 1mm and 4mm (0.040″ and 0.120″, and even thicker for modified bitumen) and used for roofing and waterproofing in commercial, industrial and residential buildings. But so far, only their waterproofing properties have been utilized.

The membranes are applied either fully adhered, mechanically fastened or the membrane can be loosely laid and kept in place by a ballasting material. This material is usually round stones or concrete pavers, and only the edges of the membrane are actually attached to the roof deck. The fully adhered and mechanically fastened applications are required. Ballasting of the photovoltaic single-ply roofing membrane defeats the purpose of its intended function since the membrane is not exposed to sunlight.

The application standards of this new breed of single-plies will be very similar to existing specifications, guidelines, codes and practices reflected by the single-ply industry's manufacturers and professional associations.[2,3] These groups include the Single Ply Roofing Institute (SPRI) in the United States and the Single Ply Roofing Association (SPRA) in the United Kingdom.

It is of paramount importance to design the roof for positive drainage and avoid the ponding of water on the roof. A ½″ (13mm) to 1″ (25.4mm) positive slope per foot (30.48cm) has been found to be sufficient for so-called "flat" roofs. For photovoltaic single-ply roofing membranes, the same minimum slope rule applies. In the northern hemisphere, if the slope is facing south, a more efficient collection of solar radiation is achieved—the most efficient slope being 45°. In the southern hemisphere, a northerly slope would be more efficient. (Refer to Figure 1 for average mean solar radiation for the United States.) Ponding will cause dirt accumulation and reduce cell efficiency, therefore it should be strictly avoided.

The details, such as flashings and counterflashings, rooftop equipment stands, curbs, drains, roof edges, vents, parapet walls and expansion joints, are treated as usual. They use the same category of single-ply membrane material. These areas of the roof are not utilized for gaining electricity and are flashed in the normal manner.

The lap joint techniques used are either hot-air or solvent welding, pressure sensitive adhesives with release paper or any other contact adhesive to achieve a durable, uniform, watertight seam of the membrane. The PV membrane design allows for this lap joint by providing an approximate 7.5cm (3") "selvage edge" on one side of the roll (in machine direction) which does not contain cells to allow for the lap. End lap provisions must also be provided for accordingly.[4] This permits the entire field area of the roof to contain cells for generation of electricity.

SCIENTIFIC PRINCIPLES OF PHOTOVOLTAICS

Historical Background

The Photovoltaic Specialists Conferences, held annually, are the best documentary source of information about the state of the art in photovoltaic science and technology. Each conference consists of up to 400 papers comprised of the technological achievements in the field of photovoltaics over the previous year. (In May 1990, the twenty-first conference was held.) The author does not find it necessary to elaborate on these aspects and confines himself to the description and importance of the developed photovoltaic single ply roofing membrane. However, it has to be mentioned that the photovoltaic technology during the past 30 years has advanced tremendously. The publication of several books and thousands of scientific papers, and issuance of numerous patents are all milestones on the path of this revolutionary progress.

By 1980, we had already used the solar heating and cooling principles extensively as indicated by T. Lucas,[5] and by 1984, K. Zweibel and P. Hersch[6] laid down the basic photovoltaic principles and methods. The U.S. Department of Energy (DOE)[7] has formulated a five-year research plan (1987-1991) with an approximate annual budget of $55 million for advancement and utilization of photovoltaic science and technology.[8]

Today, the design of stand-alone photovoltaic systems has become a reality. In collaboration with Sandia Research Laboratories,[9] the development and compilation of a handbook for such stand-alone photovoltaic systems has been devised.

DEVELOPMENT OF PHOTOVOLTAIC SINGLE-PLY MEMBRANE

Rationale and Specific Design Considerations

As early as the 1950s until 1986, the most common substrate for photovoltaic cells was glass. The glass had to be treated specially for this purpose. All depositions had to be transparent. During the mid-80s, the Japanese PV industry succeeded in producing photovoltaic tiles, which had to be interconnected to obtain the electrical output of all individual tiles combined.

In the United States, the photovoltaic films were deposited on flexible stainless steel and polyamide film. Francovitch[10] used triangular polystyrene foam blocks having a 120cm base and a 60cm height with variable lengths (from 10-20 meters or more) on the substrate, alternately using a portion of one side of the blocks with reflectors and the opposite side with photocells embedded in elastomers. This system had several disadvantages and limitations; it was confined only to flat roof design with only a small portion of the roof utilized for generation of electricity, and also installation of reflectors would add to the total cost.

The author,[11] in the Second Symposium on Roofing Research and Standards Development, provided an overview on the scientific principles of photovoltaics and the stages of development in PV roofing membranes.

In contrast to conventional PV modules, no glass substrate or rack to support the glass modules are used. Any of the already available single-ply roofing membranes (thermoplastic, elastomeric or modified bitumen) could successfully be used for their waterproofing properties and as a substrate for photovoltaic cells and films. These PV membranes can be directly applied on the roof deck or insulation using the above-mentioned techniques.

Utilizing the chemical, physical and engineering knowledge of single-ply roofing membranes in combination with existing photovoltaic technology, a revolutionary new breed of membrane was developed providing two functions in one system—waterproofing and generating electricity.

TESTING AND EVALUATION

Durability, Functionality and Performance Criteria Considerations

At the early stages of PV development, the cell efficiencies were between the 1-2 percent range and corresponding values presently are between 10-12 percent. The objective of scientists are close to 15 percent cell conversion efficiency for single-layer type photovoltaic cells. However, with multi-layer (or "cascade") type cells, a conversion efficiency of up to 30 percent has been achieved.

It has to be mentioned that a small percentage loss of electrical output is always to be expected whenever a manipulation such as cell to module arrangement or module to array arrangement occurs. A similar output loss exists during conversion from DC to AC current. These facts have to be taken into consideration during the design stage.

A massive testing and evaluation program, spearheaded by the DOE, various hydroelectric plants, and multinational oil corporations' laboratories and power plants is underway to answer the numerous questions regarding the photovoltaic process. These testing and evaluation results are reported during the photovoltaic specialists conferences and are available in the published proceedings.

All the facts indicate that the massive production potential of PV energy has just started and its universal utilization is within reach.

As a pilot project, three pieces of photovoltaic single-ply roofing membrane prototype (two pieces, 30cm x 60cm each and one piece, 40cm x 80cm) were fabricated under contract at ISET Laboratories[12] PV Research and Development facilities in Los Angeles under the supervision of Dr. Vijay

Kapur, president. Actual photographs of the prototype pieces can be found in Figures 4 and 5. Refer to the I-V (Impedance-Voltage) curves in Figures 2(B) and 2(C) for the smaller and larger prototype pieces, respectively.

Amorphous silicon cells interconnected with wires and contact bars were used. Other types of PV cells can be used equally well. However, the size and shape of the cells (semiconductors) is dictated by the designer's option, intended function and expected efficiency of the membrane's electrical output. Refer to Figure 2 for actual dimension of the cells used in one of the prototype pieces. Figure 3(A and B) shows the larger prototype piece, and schematic of the wiring and cell configurations. Figure 3(C and D) shows a cross-section of the membrane layers.

APPLICATION OF THE PHOTOVOLTAIC MEMBRANE

Design Criteria for Stand-Alone Residential Photovoltaic Systems

To meet user expectations, the following areas must be considered during the design and planning for proper balance of system components selection and economic life-cycle costing: Load determination, system sizing, solar source data, economic analysis, installation details, hardware specifications, and an operation and maintenance plan.[13,14,15,16]

System components that could be used with this bifunctional, single-ply roofing membrane would not differ from other components and accessories currently in use with other functioning stand-alone, self-contained photovoltaic systems. Selection of these items would depend on the expanse of the application and the user's photovoltaic discretion and/or consultation. Balance of system components are not discussed in this paper, however references are cited that cover these topics.

As far as potential problems due to impact of hail, dropped tools, etc., are concerned, they are the same as those for conventional exposed single-ply membrane materials. The rate of accidental failure of individual cells can be assessed in a method similar to that conducted by NMSEI investigations discussed below.

In addition to the above items, existing household items may need to be replaced since older appliance models could have extensive loads on the PV system. Further recommendations may include gas clothes dryers and stove-oven combinations to utilize less expensive inverters and lower PV system load capacities.

In other conventional photovoltaic techniques, such as photovoltaic farms, extra large amounts of land are occupied by enormous arrays. In contrast, photovoltaic single-ply roofing membranes utilize the available roof area and there is no demand for land. There is no additional installation of aluminium framed glass panels, tilting stands, etc., because the roof membrane combines both functions in a single waterproofing layer with enhanced cost-effectiveness.

For estimation of PV system requirements, it is necessary to calculate the PV single-ply roofing membrane area in square meters that would be needed to satisfy the average daily electric requirement:

$$\text{Membrane Area } (m^2) = \frac{\text{Average daily load requirement in (kWh/day)}}{\text{Insolation (kWh/m}^2\text{/day) x PV System efficiency}}$$

When mechanical fasteners are used for the attachment method, the screws and bars should preferably be located at the lap joint seams and where no screw will run through cells or wires.

In the case of modified bitumen-based photovoltaic single-ply roofing membranes, the torch or hot asphalt used should not have any effect on the cells at normal safe application temperatures which would not otherwise adversely affect the modified bitumen membrane integrity.

PRIMARY ADVANTAGES

With the subsequent installation of this membrane by more and more users, the greater the positive environmental impact based on the fact that no noise or chemical pollution is generated. Also, no other energy sources are consumed other than available solar radiation, which would otherwise be left unused. Thus, the photovoltaic single-ply membrane:

- Provides environmental protection to the structure where it is installed.
- Collects solar energy and converts it into electrical power with the desired characteristics.
- Generates usable electrical power, when installed on a typical residential or commercial structure, in a magnitude of thousands and millions of watts respectively, since the amount of electricity generated is directly proportional to the roof surface area (12-15 volts and approximately 10 watts per square foot).
- Can be installed on roofs of any type configuration (i.e., gradual slope, sharp pitch, flat, domed or in any combination thereof).
- Remains flexible after manufacture, including encapsulation of the solar cells, so that it is capable of being rolled up for transport and unrolled at the construction site.
- Has all the critical electrical interconnections to the solar cells performed at the factory under controlled conditions, as opposed to those being built at the site. Electrical connections between membrane sheets are done with flat, waterproofed "in-seam," male/female connectors.
- Can be easily installed at the construction site using the fully adhered and lap joint techniques customary to single-ply membranes.
- Requires little or no maintenance after the system is installed; protective layer is dirt repellant, adequate slope eliminates dirt build-up, settled particulates will wash off or be blown off by wind. (In extremely polluted areas, occasional washing with mild detergent and hose should be sufficient.)
- Provides 10-30 years of free electricity depending on the cell type and quality incorporated during manufacture. The membrane itself is protected from the adverse environmental exposure during this period. The original service life and the long-term waterproofing integrity of the single-ply base component is greatly increased due to the shielding effect of the upper layers.
- No more pollution. It's a clean, safe and silent provider of free electricity sufficient for every household's consumption. Depending on geographical area, as low as one-half to one-third of the roof covered with PV membrane will be sufficient, allowing for overcast and rainy

days. In the U.S., an average of between 2.5 and 7.5 kWh/m^2 insolation is provided by the sun daily.

ECONOMIC ADVANTAGES

Life-Cycle Cost Comparison

During the 1950s, the price of PV electricity was prohibitively expensive ($1,000—$1,500/kWh). In 1989, the price has dropped as low as 30¢/kWh and prospectives for 1995, is to lower the price even to a fraction of that. According to Maycock,[17] photovoltaics will be fully economic for massive use before a major utility can design, purchase, and install its next large-scale power plant. Photovoltaic systems installed on the roofs of residences in the U.S. will be fully competitive with other sources of electricity within the next decade. If we seriously begin to adopt photovoltaics now, as much as 10 percent of the nation's electric energy can come from this source by the year 2000. After that, the percentage should increase steadily.

It has to be mentioned that the population in the U.S. is about 5 percent of the world's inhabitants and consumes more than 30 percent of the world's available energy sources. This makes the utilization of PV energy even more desireable for U.S. consumption.

Photovoltaics is a rapidly evolving technology. New cell design concepts, new materials from which to make cells, steadily increased efficiencies, and simplified production techniques virtually assure the mass production of low cost, long-lived cells.

Consider the following scenario:

- Costs will continue to decline, just as they have historically, with a pronounced drop occurring when automated factories begin high-volume production of thin film or ribbon arrays.
- Residential uses will grow at an exponential rate, and utilities and their customers will work out new relationships regarding the production, use and pricing of electricity (an area in which there are already some interesting precedents). Simultaneously, the utilities will begin to experiment with their own photovoltaic collectors as these become relatively more attractive when measured against fossil and nuclear plants, which carry high capital, fuel, and operation and maintenance costs.
- Homeowners will begin to experiment with energy storage systems to see them through the evening hours and the inevitable rainy days. (Here again, there are imaginative technological developments, including improved batteries and inertial storage in flywheels.)
- In addition to supplying electrical power for household uses, including air conditioning and space heating (normally by heat pump), photovoltaic systems will gain increasing popularity as the principal source of power for the family automobile. Five hundred square feet of photovoltaic array will take care of household power needs, except for air conditioning and heating. Double this array, and photovoltaics can recharge the battery for powering the family auto.
- Banks and financial institutions will be quite happy to lend money for a system guaranteed to last 20 or more years. Household insurance will routinely include wind, hail, or storm damage to the roof.
- The customer will be able to service his own system, obtain service as needed, or buy an annual maintenance contract.

From several economical evaluation reports available, the author selected the following cost-efficiency calculations done by V. Vernon Risser,[18] an independent consultant. Risser is also project director in a program to develop a working model of a solar heated and electrified home for the Navajo homes under a contract with the Western Area Power Administration (WAPA). In this stand-alone, PV-powered, single family housing project, three design parameters were considered: 1) the PV system should satisfy the inhabitants basic electrical needs (refer to Table 1); 2) the PV system should require minimal maintenance; and 3) the PV system can be expanded, if desired. In this particular project, the following load requirements were established showing an average usage of 57 kWh per month.

In addition, the configuration provides only 12 vdc (volts direct current) which eliminates the need for an inverter and reduces the system's complexity and maintenance.

In the project's summary, the total material cost for building the house (excluding appliances) was $16,127.48, of which $7,075 was for photovoltaics. The labor cost was $8,397.99 of which $1,500 was devoted to electrical subcontracting. The total cost of the house including material, labor and miscellaneous/appliances was $31,987.41.

It is estimated that the price of a conventional roof usually varies between 6-8 percent of the total cost of a single-story structure depending on the roofing system design, materials and components. In this case, the price of the roof and electricity for a period of an estimated 20 years was 26.8 percent of the total cost of the house.

However, one can easily imagine an average monthly electric bill of $60 over a twenty-year period (for a total of $14,400) or an $80 electric bill over a twenty-year period (for a total of $19,200), added to the price of a house at say, $47,000 for a total of $66,200, for the cost of the house plus twenty years of electricity is already 29 percent of the cost. Compared to the previous project, this exceeds the building costs fitted with photovoltaics, and the PV project includes the cost of the electrical appliances as well.

In Table 2, statistics of consumption of electricity per residential unit are estimated at 300-400 kWh average per month, or 10-13.5 kWh average per day.

Another study conducted by the NMSEI[19] indicates that over a 20-year period, with maintenance intervals of every 2 years, the electrical outputs for their photovoltaic model shown both in linear and exponential factors never dropped below 95% After maintenance regardless of the number of years between intervals, the efficiency jumped back to 100 percent. The only difference in maintenance was the number of repairs that were made based on the interval rate. The percentage of failures did not increase based on the maintenance factors.

In this investigation specifically, the impact of module, panel and string failures on power and energy production were simulated using software developed by the NMSEI. The following conclusions were reported:

- It was determined that maintenance increased revenues for the specific cases analyzed, if module replacement is not required.

- The value of maintenance decreases for lower failure rates.
- As frequency of maintenance increased, revenues increased.
- Module failures have a proportionally larger impact on energy production than higher level sub-system failures (panels, strings, etc.)
- The number of modules connected in parallel impacts the significance of module failures. A worst case situation of 3 or 4 modules in parallel was noted.
- Systems using modules with low fill factors are less affected by failures.

Since the electrical configuration of the system plays a strong role in failure impact, system design methods should be developed that include failure and maintenance parameters. The significant difference of failure impact for module parallel configuration and fill factor show that the area of failures and maintenance must be combined with system design. In addition, emerging photovoltaic technologies such as amorphous silicon, require different approaches to system design from a failure viewpoint. The ultimate goal of this research was the design of a methodology that determines the best maintenance schedule given the system electrical design and required economic performance.

SUMMARY/CONCLUSION AND FUTURE TRENDS

As explained, the sun contains an inexhaustible supply of energy compared to the amount of nonrenewable energy stored in the earth, such as natural gas, coal and crude oil. According to Jenkins,[20] the available fossil fuels is estimated to a finite total of 10.6 million terawatt-hours, as opposed to 350 terawatt-hours every year, which would be infinitely obtained from the sun.

(1 terawatt-hour = 1 trillion watts per hour)

With continuing research and government support, the photovoltaic industry can become a billion dollar enterprise in the mid-1990s and multibillion by the year 2000. At the same time, it will generate cultural and industrial opportunities because it will alter the way we think about energy and will ultimately effect world economic relationships.

Within the next fifteen years—perhaps sooner—photovoltaic systems can be the preferred, most economic energy option for providing electricity for homes, offices, schools, automobiles and light industry. It can also provide electricity for remote sites, miles from any central utility, throughout the United States and major parts of the world.

How we proceed to develop photovoltaic energy inevitably and intimately intertwine with the uses we choose to make of it. The future depends on our ability to reach imaginative solutions as the generation of power is decentralized and utilities ease away from their role as suppliers to assume more the role of brokers.

The audience of photovoltaic scientists, engineers and authorities of the Department of Energy, and researchers acting in an official capacity, such as ASTM,[21] are the most appropriate levels through which cooperation of the photovoltaic community and single-ply membrane manufacturers accomplish the further research and development and mass production of photovoltaic single-ply roofing membranes.

The stakes are very high, and we cannot wait until every aspect of the technology is completely ready for commercialization. Photovoltaics have been proven successful sources of electric power for satellites orbiting around the earth in the past 20 years. Single-ply roofing membranes have also attained a stage of maturity during this same period. Like any other technology, a prototype building with photovoltaic single-ply roofing membranes should proceed the full-scale manufacturing production for mass consumption. Photovoltaic power and the changes that it will bring are inevitable. We would be well advised to deal with these realities affirmatively and deal with them now.

We are face to face with a watershed decision on a new energy technology. Photovoltaic technology is no longer exotic, casting a distant rosy glow over the twenty-first century. We must begin to treat it as a practical, current reality to be integrated fully into our decisions about energy supplies.

The author envisages that in the near future, stand-alone photovoltaic systems will become an essential part of various shapes and types of roofs (see Figure 6). In other words, the conventional single-ply roofing membranes will be advanced to a higher level of universal utilization by becoming bifunctional; namely waterproofing of the building and silent provider of free electricity sufficient for all the needs of every household.

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Load	Description	Daily Use
Refrigerator	10 ft.,^{3} 30 W	5-10 hrs.
Lights	Fluorescent	4-6 hrs.
Water Pumps	180 W total	3 hrs.
Television	12″, B/W, 60 W	6 hrs.
Miscellaneous	Fan, Radio, 45 W	6 hrs.

Table 1 *Configuration Load Requirements.*

$/kWh	$/month	or $/year	for 20 years
.12	$36.95	$443.47	$ 8,870
.15	$60.00	$720.00	$14,400
	$80.00	$960.00	$19,200

Table 2 *U.S. Utility Energy Consumption Values.*

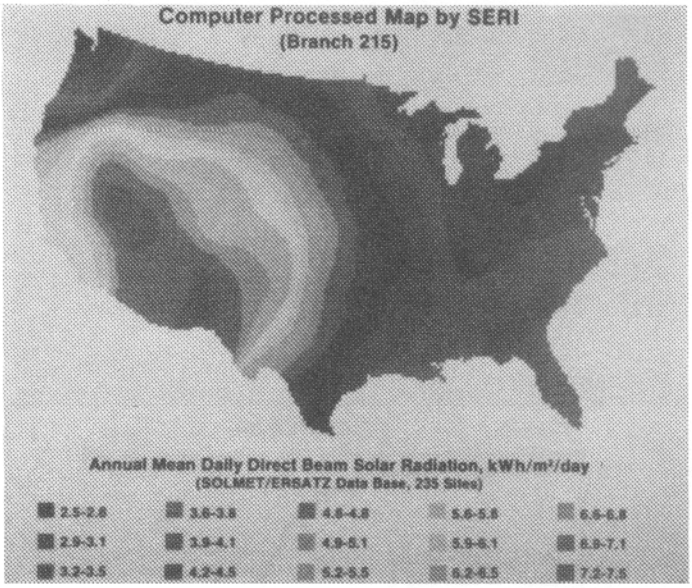

Figure 1: *Computer processed map by SERI (Branch 215) annual mean daily direct bean solar radiation KWh/m^2/day (SOLMET/ERSATZ Data Base, 235 Sites). Note: Due to a lack of high quality historical measurements and the limited number of sites, this assessment contains uncertainties (as high as 20 percent at any given location) and is valid only on a regional scale.*

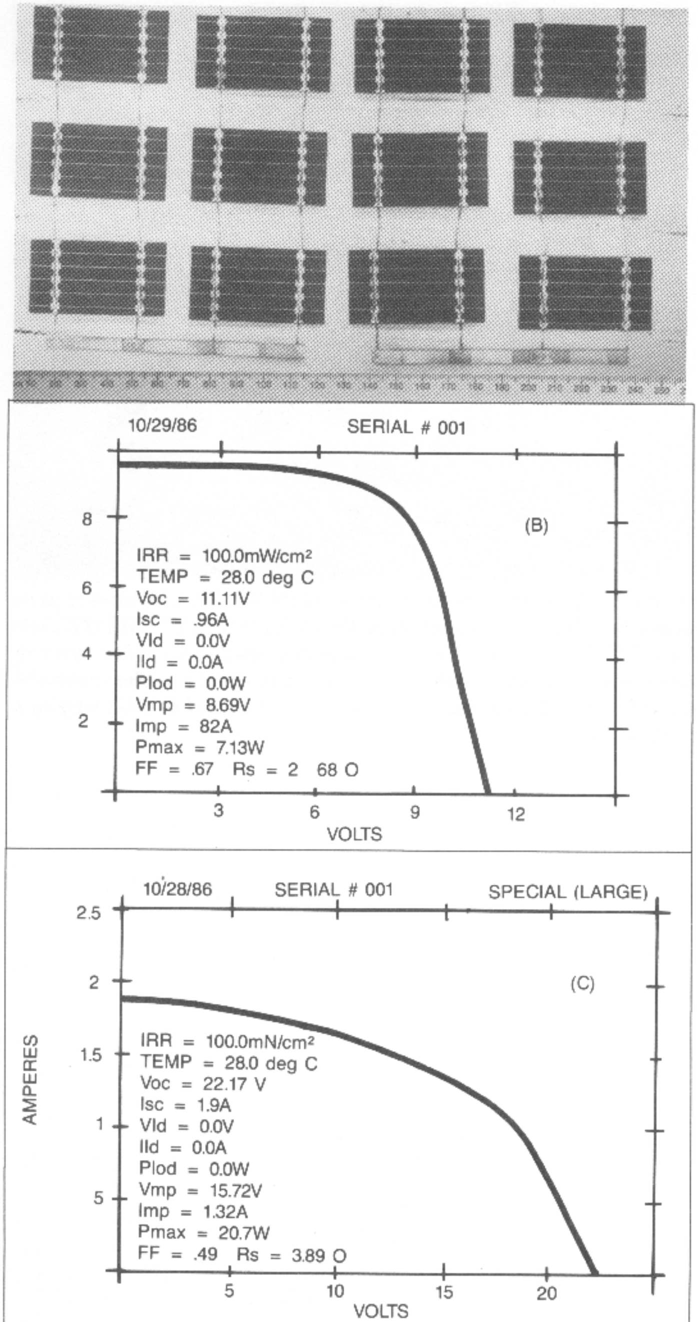

Figure 2: *The actual cell configuration and wiring (A) of the two small reinforced PVC-based membranes and the computer generated I-V Curves (B and C) obtained of both the large and small prototypes. IRR = (Insolation) Irradiation, TEMP = Temperature (°C), Voc = Voltage Open Current, Isc = Power Short Circuit (Amps), Vld = Load Voltage, Ild = Load Current (Amps), Plod = Load Power (Watts), Vmp = Voltage Maximum Power, Imp = Current Maximum Power (Amps), Pmax = Maximum Power (Watts), FF = Fill Factor, Rs = Resistance (Ohms).*

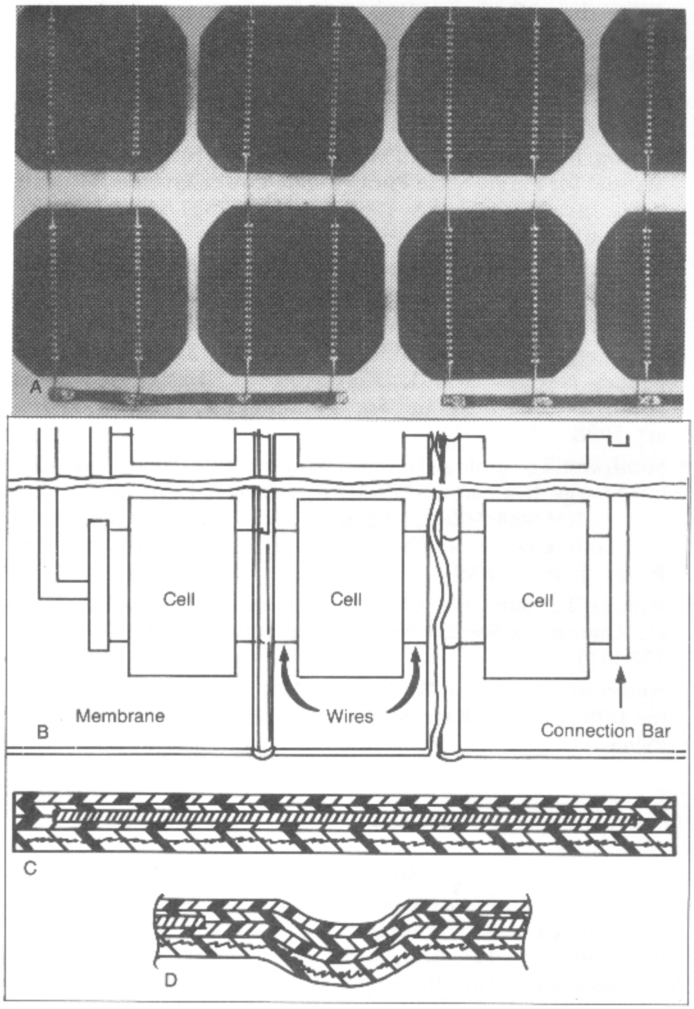

Figure 3: *(A) Shows one of the actual PV single-ply roofing membrane prototypes. The schematic drawing (B), shows the electrical wiring. The cross-section (C), shows a schematic representation of the membrane layers,[4] and the grooved area (D), shows an exaggerated illustration provision for additional flexibility for rolling and unrolling of the membrane during application. The membrane fabrication is based on parameters; various degrees of vacuum, temperature, and manufacturing speeds, for all classes of single-ply roofing membranes.*

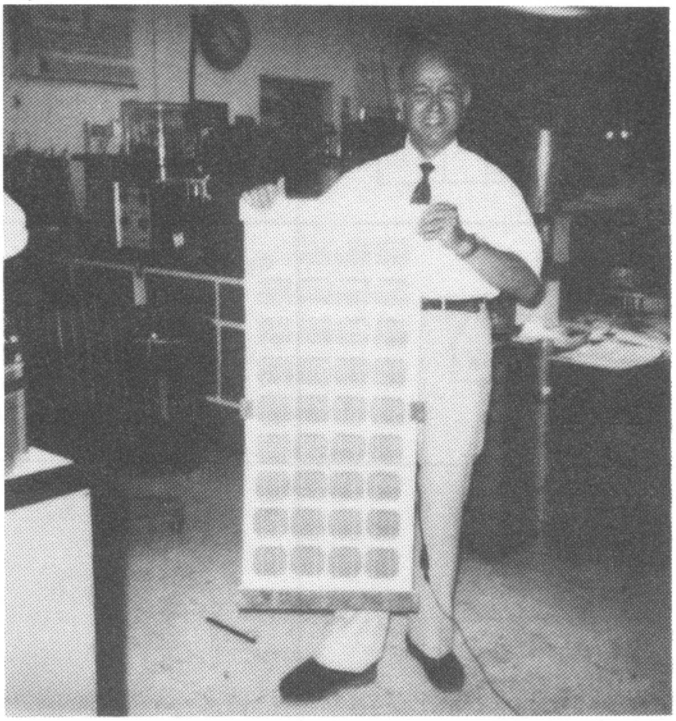

Figure 4: *The birth of the photovoltaic single-ply roofing membrane took place at ISET Laboratories on October 30, 1986 in Los Angeles, California. The author is holding the larger piece.*

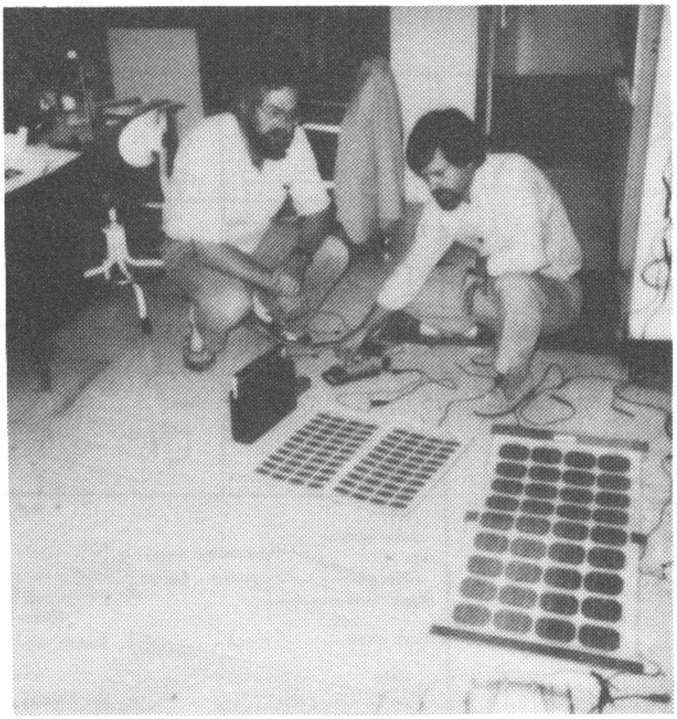

Figure 5: *One large and two smaller prototypes were fabricated. Dr. B. Basol of ISET and his technician are measuring the voltage and amperage of the samples (October 30, 1986).*

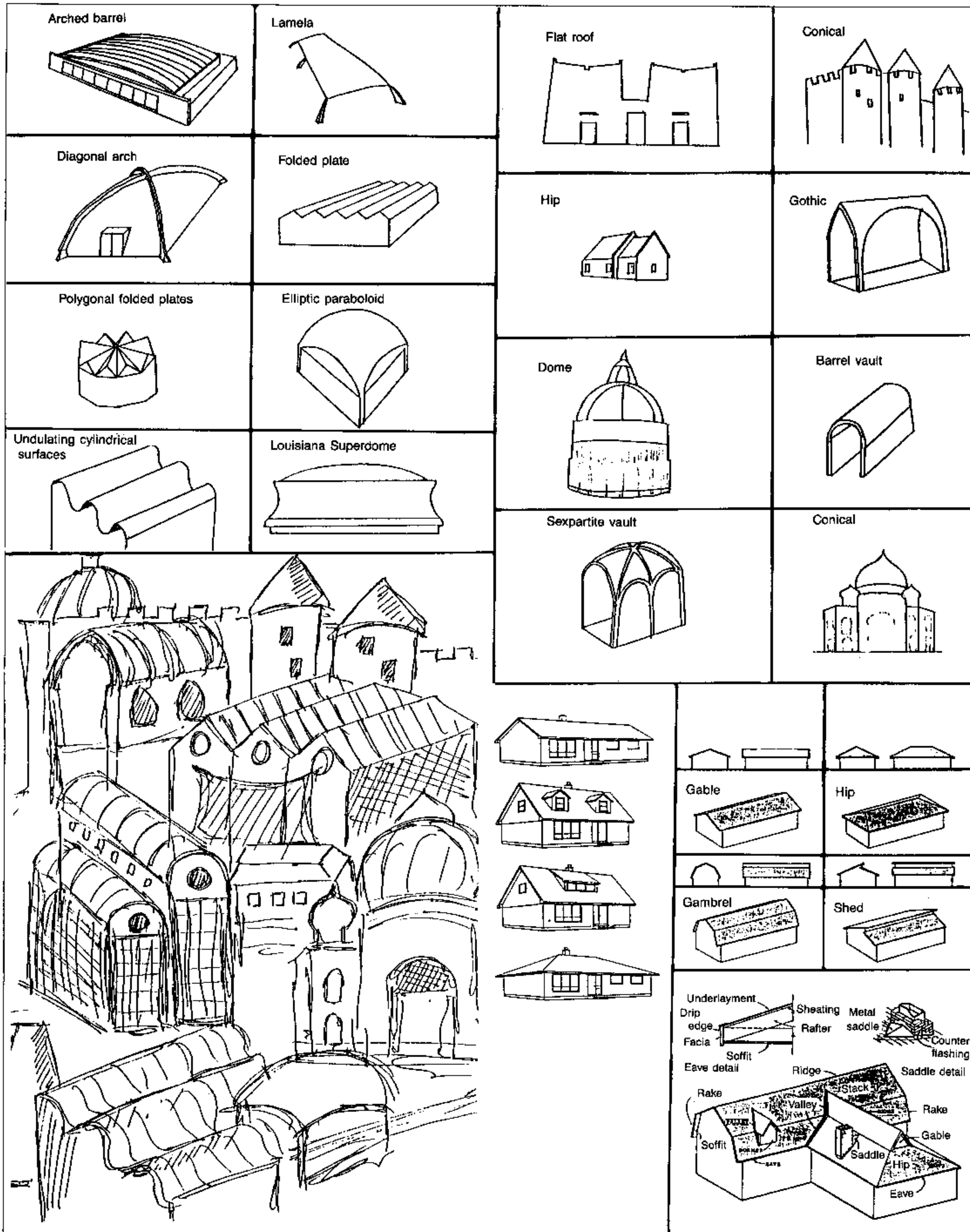

Figure 6: Above are some examples of the unlimited roof structures where the photovoltaic single-ply roofing membrane can be applied.