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COMMERCIAL/INDUSTRIAL PHOTOVOLTAIC MODULE AND ARRAY REQUIREMENT STUDY

Low-Cost Solar Array Project, Engineering Area. Final Report

By
T. Hood
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December 1981

Work Performed Under Contract No. NAS-7-100-955698

Research and Solar Applications Division
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U.S. Department of Energy

Solar Energy

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COMMERCIAL/INDUSTRIAL

PHOTOVOLTAIC MODULE AND ARRAY REQUIREMENT STUDY

JPL CONTRACT NO. 955698

FLAT-PLATE SOLAR ARRAY PROJECT
ENGINEERING AREA

FINAL REPORT

December 1981

The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of flat-plate solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

Prepared for

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ABSTRACT

Burt Hill Kosar Rittelmann Associates has conducted a study to identify design requirements for photovoltaic modules and arrays used in commercial and industrial applications.

Building codes and referenced standards were reviewed for their applicability to commercial and industrial photovoltaic array installation. Four general installation types were identified - integral (replaces roofing), direct (mounted on top of roofing), stand-off (mounted away from roofing), and rack (for flat or low slope roofs, or ground mounted). Each of the generic mounting types can be used in vertical wall mounting systems. This implies eight mounting types exist in the commercial/industrial sector. Installation costs were developed for these mounting types as a function of panel/module size. Cost drivers were identified. Studies were performed to identify optimum module shapes and sizes and operating voltage cost drivers. The general conclusion is that there are no perceived major obstacles to the use of photovoltaic modules in commercial/industrial arrays. However, there is no applicable building code category for photovoltaic modules and arrays and early additional work is needed with standards writing organizations to develop commercial module and array requirements.

As some obstacles could make PV extremely costly, this report makes recommendations to the PV industry which will facilitate a more successful product entrance into the building industry.

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SECTION 1

SUMMARY

This report presents the results of a study conducted by Burt Hill Kosar Rittelmann Associates. The objective of the study was to determine the design requirements for commercial/industrial photovoltaic modules and arrays. The approach used in accomplishing these objectives was to review existing building codes and their referenced standards for their applicability to commercial/industrial photovoltaic module and array installations; to investigate the influence of other members of the building industry; to conduct studies of important attributes of the commercial/industrial building to the array, and attributes of the modules and arrays to their installation; and to design and cost a number of array mounting installation types to determine cost drivers.

The commercial/industrial building industry is large and complex with many players whose jurisdictions may overlap and whose interests may be diametrically opposed. Because of this, it is an industry which relies on laws--building codes--to establish a minimum level of construction to protect the consumer. Supporting building codes (laws) are standards, which are voluntary and help interpret and measure the law, and manuals of accepted practice, which advocate appropriate installations and constructions. Interpretation of the laws (codes) is left with the local building code official, who may reject a product if, in his estimation, it does not meet code. To become a reality, commercial/industrial modules, arrays and photovoltaic power systems will have to comply with this existing framework.

To that end, existing building codes and their reference standards were reviewed to determine what, if any, applicable requirements may be imposed on photovoltaic modules and arrays. Although this review produced design implications for modules and arrays, one major result of the review is that there is no current building code category for photovoltaic power systems. Consequently, local building code officials can arbitrarily categorize modules and arrays so that undue restrictions or outright rejection can occur. In the early stages of photovoltaic development and implementation, code variances will be sought in order to permit their use. The variance procedure will require that the designers of the system and its components supply adequate data and information

on photovoltaics, the system and its hardware to allow the local building code officials to assess its safety for a given installation. To prevent the need for variances in the future, the photovoltaic module and component manufacturers must begin a dialog with the model code agencies for the inclusion of photovoltaics in the code. Requirements for commercial/industrial photovoltaic power systems and their components should be developed by the consensus process and, since this is a new evolving technology, these requirements should be couched in the language of performance statements that are flexible enough to permit rather than inhibit new technology and development.

As the code development process is a lengthy one, photovoltaic module and component manufacturers should begin immediately to incorporate into their designs code acceptable features. Until adequate data is available for the code official to assess the safety features of photovoltaic modules, it is recommended that the design and application be limited to a single function, i.e. an electrical generator. The code requirements become extremely stringent when addressing roof and wall sections. This implies the limited use of integral mounted photovoltaic modules which are shipped to the site as a composite material, consisting of the exterior and interior skins of the building. Therefore, simplicity in design and its application will allow the code official, who may be uninformed with regards to photovoltaics and its application, to assess safety. In the future, as safety and performance data becomes available, the module manufacturer can address new markets by designing and fabricating multi-function devices, a building product as well as an electrical generator.

As it takes approximately four years to modify the National Electrical Code (NEC), a photovoltaic sub-committee has been established to generate appropriate code statements for the NEC, specifically addressing photovoltaics. The long term classification of the photovoltaic system as a "Premanufacturered Item with Internal Wiring" would offer the most latitude for product development while still preserving the necessary safety requirements. This will also insure factory quality with regard to internal panel wiring.

In addition, product approval of modules is necessary for their eventual acceptance by local building code officials. Early work is needed with approved nationally recognized testing laboratories to familiarize them with photovoltaic modules. (Underwriters' Laboratories, Inc., is currently under contract to the JPL/FSA project to investigate safety requirements for modules and arrays.)

Having identified the construction sequence, the participants in the building process and following the codes and standards review, studies of important commercial/industrial building and array attributes were conducted; and design and costing of possible array mounting configurations were performed. An investigation of the applications where photovoltaics were deemed most likely to be utilized in the near term and the code restrictions on such occupancies indicated similar restrictions on the design of photovoltaic modules and arrays. Therefore, the costs associated with installation of photovoltaics on these various occupancy types--shopping center, real estate office, dental office, high school and small machine shop--are not influenced by the specific application. Module costs were not considered. However, all peripheral costs associated with the support, installation, and wiring of modules to form arrays were studied. The array area was fixed at 14,400 square feet to permit normalization of the results. Parametric studies of varying array voltages, wire lengths, panel sizes and termination types were performed. The studies, as was the code standard review, were confined to the module and array and not to the entire photovoltaic system.

In addition to the above mentioned parametric studies, an investigation as to the appropriate size and shape of the photovoltaic module and panel was performed. As a result of this study, it was determined that the module size providing the most flexibility in its ability to integrate with conventional industrial/commercial structural systems would be a 4' x 5' nominal module. It is important to note that these are center line to center line dimensions and not actual module sizes. In addition to the module requirements, the maximum panel size was determined to be 8' x 40', which is the maximum allowable size which is transportable by truck on the open highway. In order to provide large panels which will be widely accepted by the design profession, visual, if not functional flexibility, must be designed into a panel. Therefore, intra-panel joints become critical and should yield visual flexibility, allowing the designer of the building to provide visual sizes and shapes other than the supplied panel size and shape. This will eliminate the need for the photovoltaic panel supplier to manufacturer and inventory many panel sizes.

From these studies, it was determined that an integrally mounted array, where the modules act as the exterior and interior skin of the building, will be required to meet extremely stringent code requirements. Therefore, integrally mounted arrays and modules designed for such applications should not be considered until adequate data on photovoltaic safety has been gathered. It was also determined that a direct mounted array, wherein modules are a waterproof membrane, composed of 4' x 5' modules incorporated in a 8' x 40' panel electrically connected using crimp type connectors in a system whose voltage is 600 volts was optimum from a cost and aesthetic standpoint. The installed cost of this array configuration is estimated to be $12.50 per square meter (1980 dollars). Note that this cost is extremely detail specific and does not include the cost of the module. Standoff and rack mounted arrays were considerably more expensive ranging from $15.52 to $24.00 per square meter for the best cases. The additional costs associated with the rack and standoff mounting concepts are a result of the increased materials required for the rack and standoff material.

It is important to note that life cycle cost effectiveness of a photovoltaic array may not be the only requirement a potential building owner will use when assessing the desirability of installing photovoltaics on a building. Typically, developers, speculators and future owners of commercial/industrial buildings consider initial cost as far more critical when making a determination about equipment and building characteristics, and tend to minimize the life cycle cost aspect of their evaluation. This implies the need for an aggressive sales and marketing campaign by the photovoltaic manufacturer and the building and system designer. In addition, tax credits and depreciation allowances for photovoltaic systems will play a key role in their potential cost effectiveness and acceptance in the commercial/industrial sector.

In a commercial/industrial sector, unlike the residential sector, it will be possible to find photovoltaic modules mounted on wall surfaces as well as roof surfaces. In this regard, the codes addressed the applications separately; and module manufacturers will likewise be required to address wall mounted and roof mounted applications in their design process. Direct mounted roof applications will be considered roofing materials by building code inspectors. This is an advantage because roofing materials are required to be qualified by U.L. 790, "Tests for Fire Resistance of Roof Covering Materials", Class A, B, or C, which qualifies the roofing as an entity. The roof composites, exterior surface, in the commercial/industrial sector, may consist of any of the three roof covering classifications, A, B, or C, as the critical feature of the roof is the overall composite fire rating and not the surface material.

Standoff and rack mounted arrays may, when mounted on walls, require firestops behind the array to reduce the potential of flame spread. In addition, considerations must be given to the penetrations which will occur as a result of racks and standoff and the problems associated with waterproofing. As previously identified in the Residential Photovoltaic Requirements Study, DOE/JPL 955149-70/1, plastics are addressed in great detail in the codes; and their use should be carefully analyzed and restricted as required by the code. Plastics must be in conformance with a code-specified test, ASTM D635, "Flammability of Rigid Plastics Over 0.05 Inches in Thickness".

A means of grounding and lightning protection should be provided in order to protect personnel from shock and the array from damage associated with a nearby lightning strike. Work is currently underway at Underwriters' Laboratory to identify the proper grounding and lightning protection systems.

Finally, modules and arrays should be designed to be maintenance-free and have a design life of 20 years or more, which is consistent with roofing materials and building skin materials. As previously identified to minimize the aesthetic effects, flexibility must be provided in the panel design to provide sizes and shape variations visually, while limiting the number of panel sizes manufactured and housed by the manufacturer.

SECTION 2
INTRODUCTION

This report documents a study of design requirements for photovoltaic modules and arrays used in commercial/industrial/institutional applications. The study was performed by Burt Hill Kosar Rittelmann Associates for the Engineering Area of the Jet Propulsion Laboratory's Flat-Plate Solar Array Project under Contract Number 955698 as a part of the U.S. Department of Energy's Solar Photovoltaic Conversion Program.

This study emphasizes the need to and means by which the photovoltaic manufacturer can begin to understand the decision making process for the commercial/industrial/institutional sectors pertaining to the utilization of photovoltaic modules, panels and arrays. The study attempts to take into account present trends to predict commercial/industrial/institutional building design requirements for photovoltaic modules and arrays. The study identifies participants who have an impact on the utilization of photovoltaic modules, and arrays, how and when they impact the design/construction sequence and what the PV manufacturer can do to minimize each participant as a barrier to the widespread development of photovoltaic-generated power utilization.

The direct objectives of this study were:

- Identify crucial points and participants in the building project sequence related to PV module and array utilization.
- Identify mechanical and electrical design requirements for commercial/industrial/institutional photovoltaic modules and arrays.
- Identify salient size parameters for PV modules and select optimum examples.
- Evaluate potential operating voltages for PV arrays.
- Identify salient economic parameters and their effect on PV module and array design, installation, operation and maintenance.

To accomplish these objectives, the report acknowledges the realities of the building industry to the photovoltaic industry. Building codes, an important set of legal guidelines recognized by participants as the primary source of regulatory restraint, are reviewed (as are their referenced standards) for applicability to commercial sector photovoltaic modules and array installations. Numerous variables impacting size, shape, materials or mounting configuration, are analyzed. Various array mounting configurations and potential users are studied to determine economic design criteria and resultant cost drivers. The results of this effort are presented in this report.

2.1 TERMINOLOGY

Terminology used in the final report are illustrated in Figure 2.1. These come from the preliminary set of photovoltaic terminology and definitions established in 1978 by members of the Photovoltaics Program. The term "Commercial Photovoltaic Power System" was not in the original definitions, but is provided for completeness.

SOLAR CELL--THE BASIC PHOTOVOLTAIC DEVICE WHICH GENERATES ELECTRICITY WHEN EXPOSED TO SUNLIGHT

MODULE--THE SMALLEST COMPLETE, ENVIRONMENTALLY PROTECTED ASSEMBLY OF SOLAR CELLS AND OTHER COMPONENTS (INCLUDING ELECTRICAL TERMINATIONS) DESIGNED TO GENERATE DC POWER WHEN UNDER UNCONCENTRATED TERRESTRIAL SUNLIGHT

PANEL--A COLLECTION OF ONE OR MORE MODULES FASTENED TOGETHER, FACTORY PREASSEMBLED AND WIRED, FORMING A FIELD INSTALLABLE UNIT

ARRAY--A MECHANICALLY INTEGRATED ASSEMBLY OF MODULES TOGETHER WITH SUPPORT STRUCTURE AND OTHER COMPONENTS, AS REQUIRED, TO FORM A FIELD INSTALLED DC POWER PRODUCING UNIT

BRANCH CIRCUIT--A NUMBER OF MODULES OR PARALLELED MODULES CONNECTED IN SERIES TO PROVIDE DC POWER AT THE SYSTEM VOLTAGE

COMMERCIAL PHOTOVOLTAIC POWER SYSTEM--THE AGGREGATE OF ALL BRANCH CIRCUITS (ARRAY(S)) TOGETHER WITH AUXILIARY SYSTEMS (POWER CONDITIONING, WIRING, PROTECTION, CONTROL, UTILITY INTERFACE) AND FACILITIES REQUIRED TO CONVERT TERRESTRIAL SUNLIGHT INTO ELECTRICAL ENERGY SUITABLE FOR CONNECTION TO A BUILDING'S ELECTRICAL DISTRIBUTION SYSTEM OR A UTILITY ELECTRIC POWER GRID

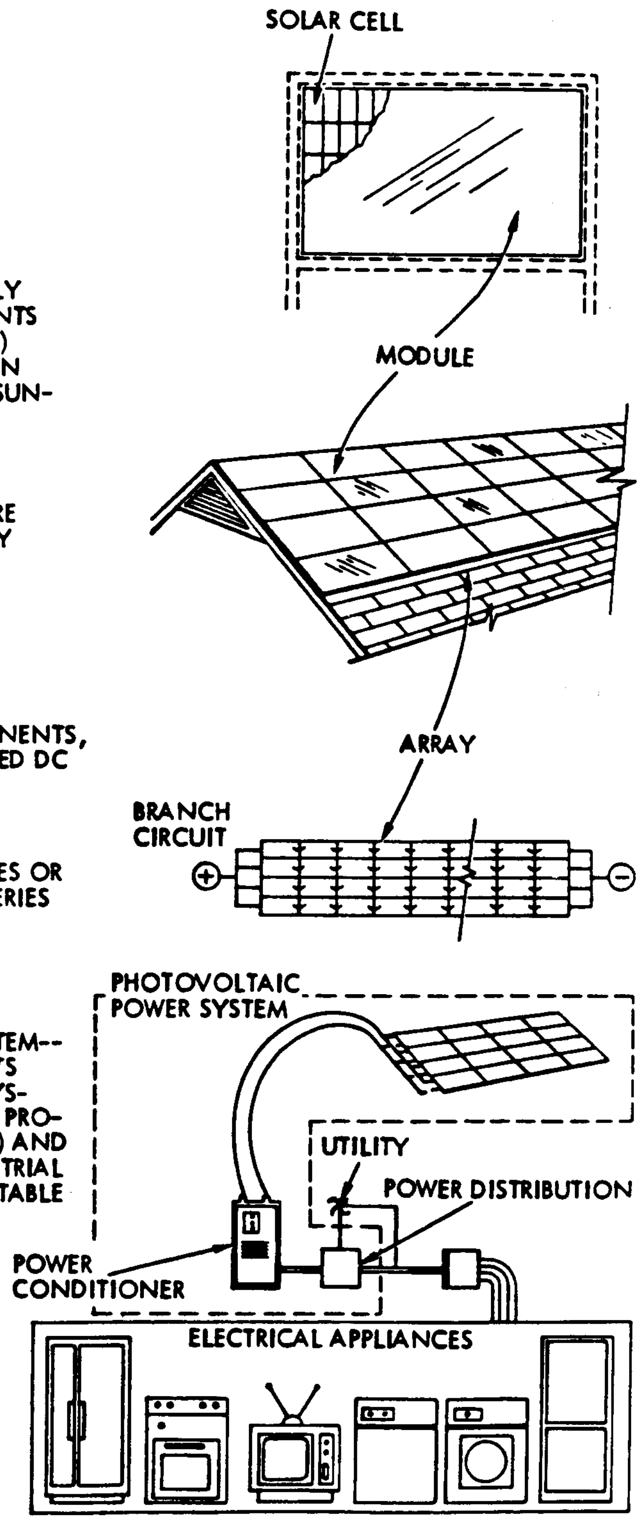


Figure 2.1 Commercial Photovoltaic System Terminology

2.2 COST BASES

Costs presented in the final report are expressed in 1980 constant dollars unless stated otherwise.

2.3 UNITS

Despite attempts to change it, the United States construction industry remains rooted in the English system of units. It is not anticipated that the conversion of the industry to SI units will be easy or painless. Almost all building codes and their referenced standards use English units. Rather than indiscriminantly convert all measurements to SI units, it was decided to leave the English units as best representative of the industry today.

SECTION 3

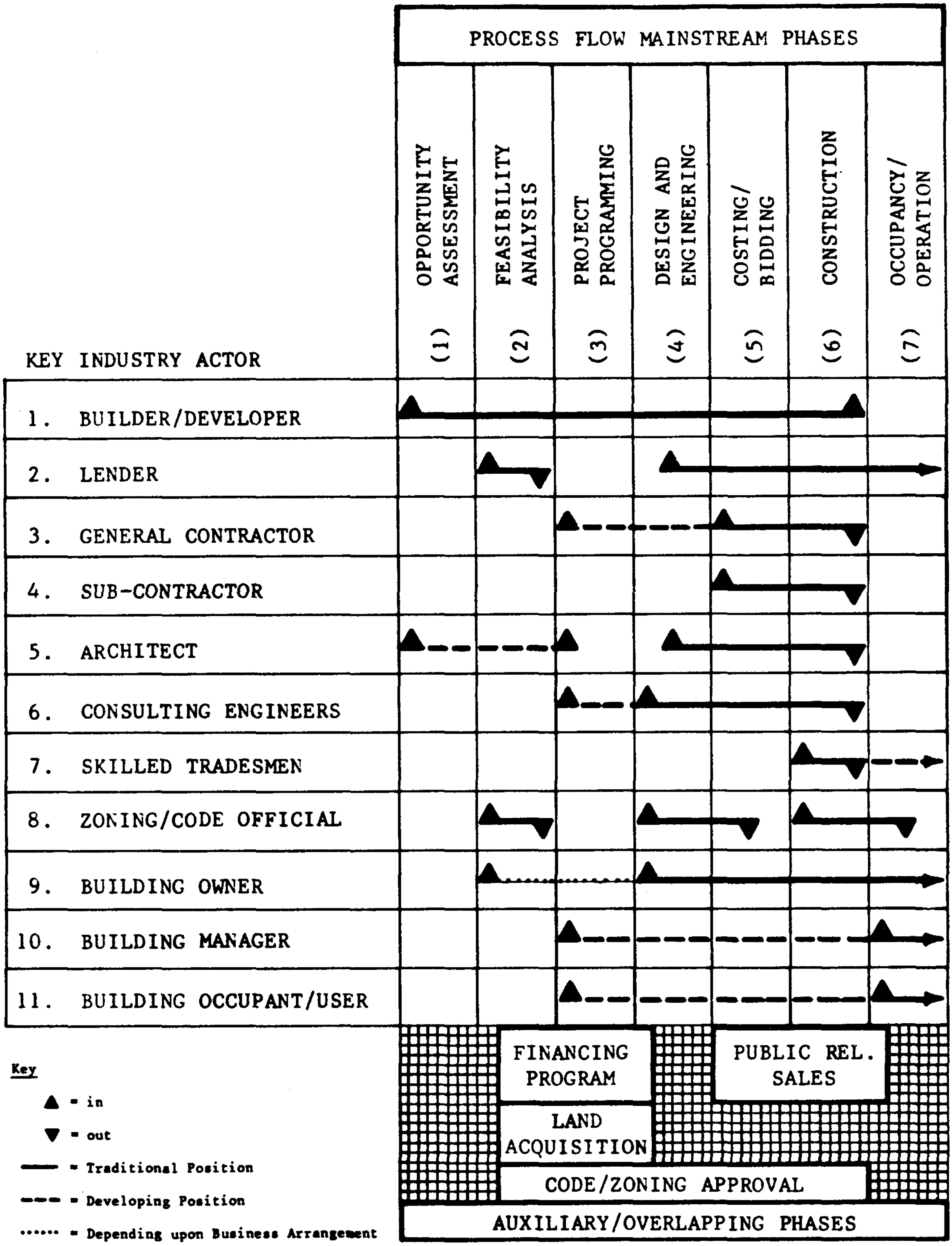
BUILDING PROJECT SEQUENCE

The Photovoltaic manufacturer must address a wide variety of variables in the commercial/industrial sector if modules, panels and arrays are to be accepted on a large scale. To address only "regulation" per se is to ignore some critical 'reality of the building industry' issues. Before getting to an analysis of barriers to the widespread development of photovoltaics, it is advantageous to review the building construction progress sequence. Later sections of this report refer to this sequence often. The sequence itself is fairly consistent from one project to the next. It usually falls in this order:

- Opportunity Assessment - Developer formulates an idea and solicits an Architect's services.
- Feasibility Analysis - Financial and regulatory analysis are applied to the project.
- Project Programming - Users and Technical Consultants provide design parameter input.
- Design and Engineering - Architects and Engineers produce final drawings and specifications under the watchful eye of the Owner and Developer as well as Zoning and Code Authorities.
- Costing/Bidding - Project is let out for bid to numerous Contractors who compete for the project construction contract.
- Construction - Building is actually built by a variety of General Contractors, Sub-contractors and Trades people under the supervision of Zoning and Code Officials and the Owner through the Architect.
- Occupancy/Operation - Tenants and Managing agents assume use of the completed building after the Code Official issues the Certificate of Occupancy.

Figure 3.1 depicts the complexity of these overlapping participants.

The complexity of the problem does not stop there. Figure 3.2 illustrates the magnitude of the number of actors involved nationally. Not only does the photovoltaic manufacturer have to convince over ten key actors before a project may utilize the product, those actors are going to change from project to project.



Duration and Entry/Exit Points of Selected Key Actors in Building Industry Development Process

Figure 3.1

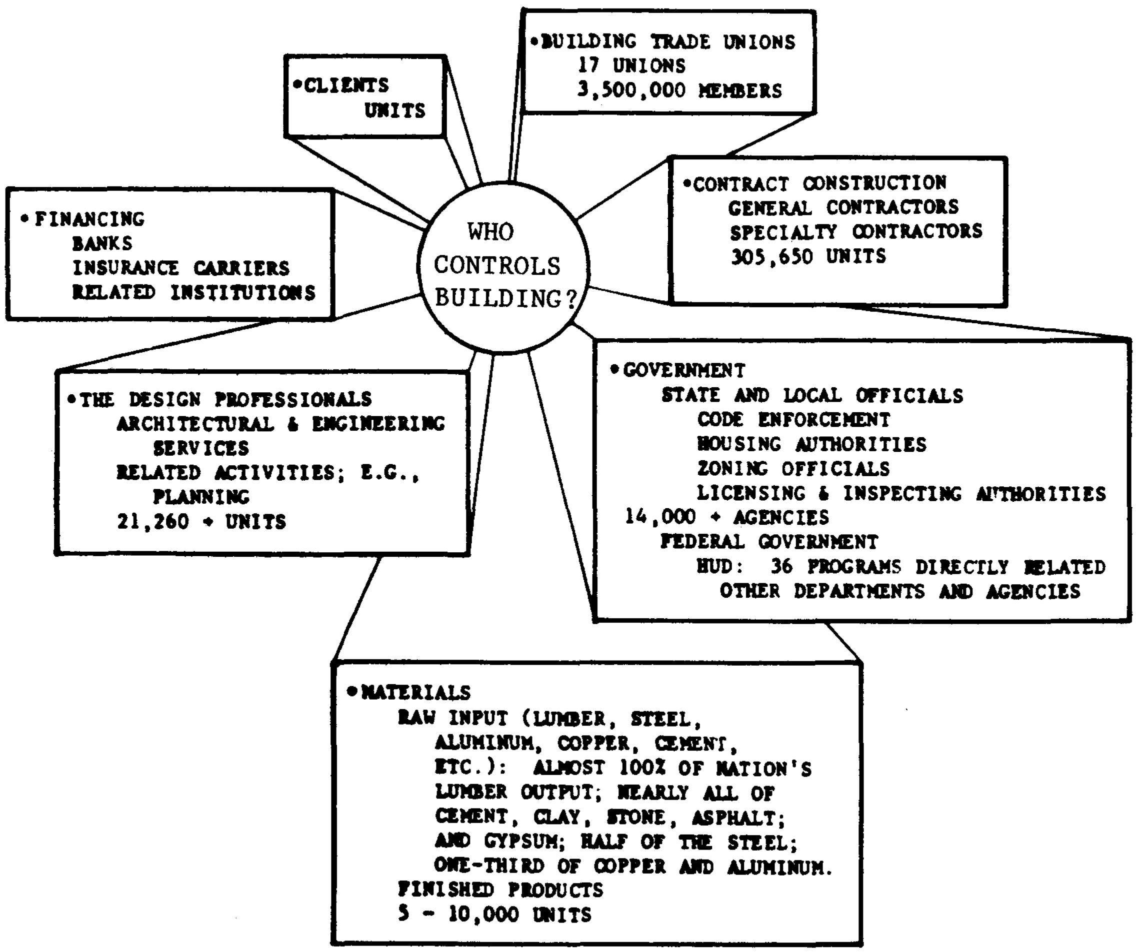

•BUILDING TRADE UNIONS
17 UNIONS
3,500,000 MEMBERS
•CLIENTS
UNITS
•CONTRACT CONSTRUCTION
GENERAL CONTRACTORS
SPECIALTY CONTRACTORS
305,650 UNITS
• FINANCING
BANKS
INSURANCE CARRIERS
RELATED INSTITUTIONS
WHO
CONTROLS
BUILDING?
•THE DESIGN PROFESSIONALS
ARCHITECTURAL & ENGINEERING
SERVICES
RELATED ACTIVITIES; E.G.,
PLANNING
21,260 + UNITS
• GOVERNMENT
STATE AND LOCAL OFFICIALS
CODE ENFORCEMENT
HOUSING AUTHORITIES
ZONING OFFICIALS
LICENSING & INSPECTING AUTHORITIES
14,000 + AGENCIES
FEDERAL GOVERNMENT
HUD: 36 PROGRAMS DIRECTLY RELATED
OTHER DEPARTMENTS AND AGENCIES
•MATERIALS
RAW INPUT (LUMBER, STEEL,
ALUMINUM, COPPER, CEMENT,
ETC.): ALMOST 100% OF NATION'S
LUMBER OUTPUT; NEARLY ALL OF
CEMENT, CLAY, STONE, ASPHALT;
AND GYPSUM; HALF OF THE STEEL;
ONE-THIRD OF COPPER AND ALUMINUM.
FINISHED PRODUCTS
5 - 10,000 UNITS

Figure 3.2

The pertinent question asked in Figure 3.2 is "who controls building?". The answer is - it depends upon the time frame of the project in the construction sequence. There are obviously some critical points in the sequence where a decision for or against photovoltaics is a life or death one for the product. These will be identified below along with some strategies on how the photovoltaic manufacturer may encourage favorable decisions. These critical points occur where individual actors pass judgment on the suitability of the product to achieve their own particular performance criteria. These may include efficiency, investment return, hazard to occupant, aesthetics, maintenance, liability risk, hazard to community, threat to established divisions of employment or even depreciation for tax purposes.

Photovoltaic manufacturers must know at which point in the construction sequence to supply particular actors with particular information about PV products. Otherwise, PV manufacturers can only deluge all actors with all of the existing data pertinent to all possible criteria and hope the actors will read it. Another option may be to provide nothing and hope the appropriate actors ask. Neither of these alternatives is very palatable. Therefore, analysis of the building project sequence and the actors involved must identify the critical points mentioned above when specific actors need specific information about PV products. Once this is accomplished, each actor's decision must be considered a possible barrier to the utilization of photovoltaics.

This report will subsequently describe strategies for:

- Encouragement of decisions favoring the use of photovoltaics.
- Encouragement of decisions not eliminating the use of photovoltaics.
- Paths of further study where present strategies seem ambiguous or unclear.

The image painted above seems to portray the building industry as the nine-headed Hydra which sprouts two more barriers for photovoltaic manufacturers to overcome for every one hurdled. However, there is one set of criteria which lends order and structure to this complex system, and takes priority over even economic criteria. These criteria are the assorted regulatory requirements

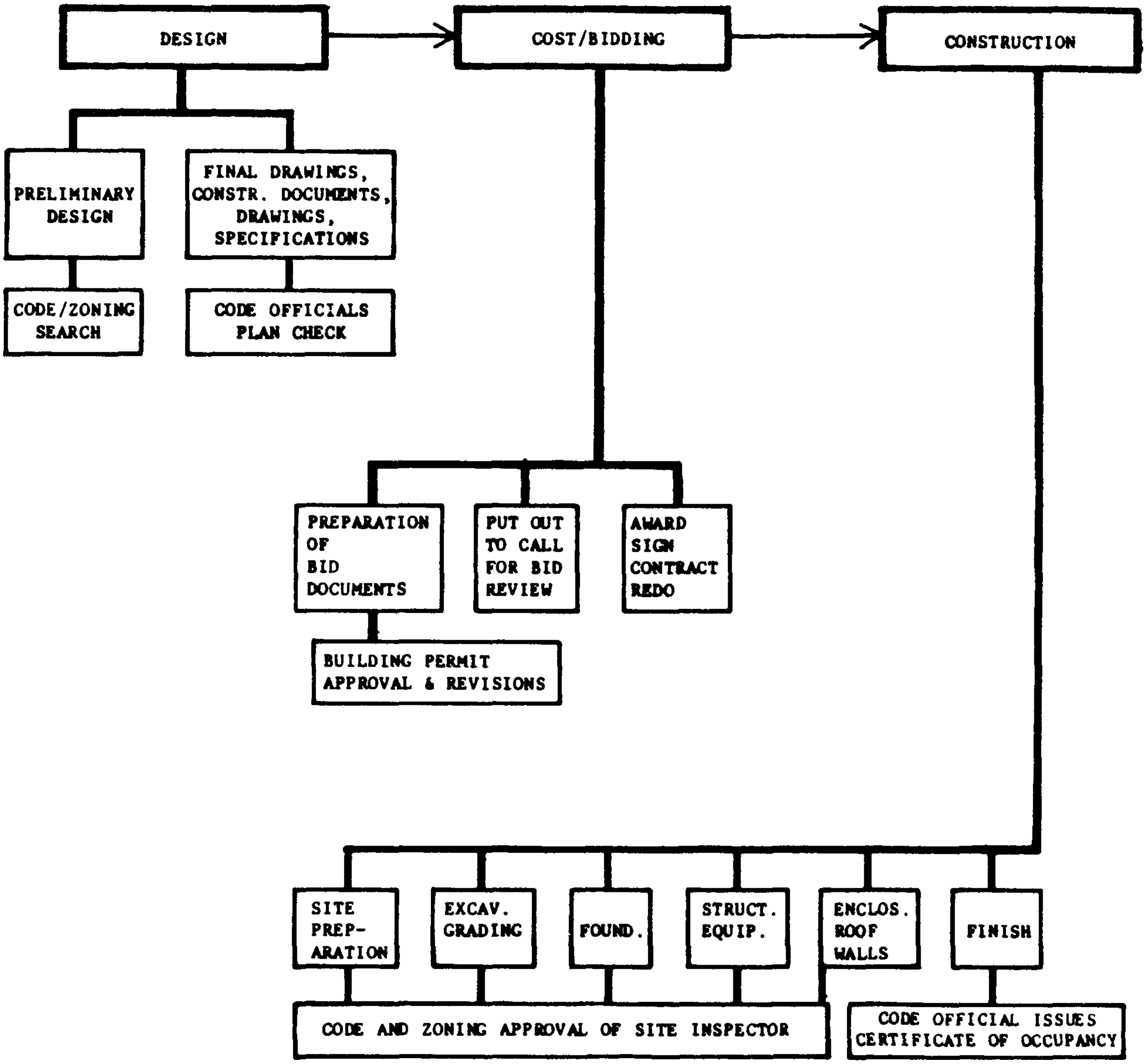

DESIGN
COST/BIDDING
CONSTRUCTION
PRELIMINARY DESIGN
FINAL DRAWINGS, CONSTR. DOCUMENTS, DRAWINGS, SPECIFICATIONS
CODE/ZONING SEARCH
CODE OFFICIALS PLAN CHECK
PREPARATION OF BID DOCUMENTS
PUT OUT TO CALL FOR BID REVIEW
AWARD SIGN CONTRACT REDO
BUILDING PERMIT APPROVAL & REVISIONS
SITE PREP-ARATION
EXCAV. GRADING
FOUND.
STRUCT. EQUIP.
ENCLOS. ROOF WALLS
FINISH
CODE AND ZONING APPROVAL OF SITE INSPECTOR
CODE OFFICIAL ISSUES CERTIFICATE OF OCCUPANCY

Figure 3.3

enacted within each of the 14,000 plus agencies listed under "Government" in Figure 3.2. Government Regulation forms the basic skeleton for the building industry. If we ignore the actors themselves for a moment and focus on a detailed view of the segment of the building project sequence from Design to Construction in Figure 3.3, it is easy to see that code and zoning officials control, through an inspection/approval/permit issuance procedure, each step.

Since regulatory compliance is necessary for any building to be constructed, it must always rank at the top of each actor's list of design criteria priorities. Therefore, it is necessary to comply with the codes; and the remainder of the criteria, economic, aesthetic, or technical, are less critical, although important. The following sections of this report will give descriptions of the building industry, the players involved, and an overview of building codes and standards. The primary focus will be on the building codes as they do or do not address photovoltaic modules, panels and arrays. As the codes do not address PV directly, interpretations of the codes will be discussed and the potential influence these may have on the design of PV modules, panels and arrays.

SECTION 4

PARTICIPANTS IN THE BUILDING SEQUENCE

The number of actors in the commercial building sector is immense. They fall into broad categories outlined under the Building Project Sequence section in Figure 3.2. In the course of design and construction of a building, photovoltaic modules, panels and arrays must be scrutinized and evaluated by most of the actors in the process. These actors could include:

- Architects
- Engineers
- Contractors
- Subcontractors
- Building Managers
- Building Owners
- Developers
- Bankers
- Insurance Carriers
- Materials Suppliers
- Code Officials
- Zoning Officials
- Federal Safety Inspectors
- Trade Unions

Each of these actors has a varying amount of influence over the building project and the materials and equipment which are used in the project. Only the decision of these actors to exclude photovoltaic products, or the increase in cost of the product (through additional regulatory requirements) stand as barriers to the utilization of photovoltaics in commercial/ industrial construction. Photovoltaic manufacturers must both alert designers to the advantages of available products as well as minimize or eliminate fears associated with use of the product. These two issues will be dealt with separately in "Getting One's Foot in the Door" and "Completing the Transaction" below.

4.1 GETTING ONE'S FOOT IN THE DOOR

The Design Professional:

The first order of business is to sell photovoltaics to the front line of the commercial/industrial construction actors, which include the building designers, architects, engineers, planners, developers and, as will be seen below, the code official. It goes without saying that advertising in all of the places building materials are advertised, be it oral, verbal or visual graphics, actually generates an interest in either a developer who seeks to capitalize on photovoltaics or in a designer who seeks to explore the photovoltaic potential of a project.

However, one of the top questions for designers and developers during feasibility studies is, "Will photovoltaics pass the scrutiny of regulatory agencies?" For the design professional, this question is closely tied to the legal principle of negligence per se (or negligence as a matter of law). This principle states that in the event of a building code violation where:

- The building code enactment contemplates or envisions an occurrence which would result in damage,
- Provisions of the building code were designed to avoid such an occurrence,
- The plaintiff in a lawsuit falls under a class of persons whose interests were intended to be protected by the building code,
- The building code violation in question was a proximate cause of the plaintiff's injury or damage,

the design professional assumes personal liability for the consequences of any resulting personal injury or property damage.

These provisions would seem to protect a design professional in the case of a technological innovation such as photovoltaic products which are not even considered within the framework of existing building codes. However, the legal principle of negligence per se may be misused. A jury may be biased against the design professional by elevating common law negligence, utilizing the language of building codes, to what the lawyer claims to be negligence per se. The jury could be further confused by arguments that since building codes are enacted for the protection of the public that the design professional has violated the welfare of the plaintiff by utilizing materials or methods not sanctioned by building codes. Thus prejudiced, the jury may become anxious to accept the standard of conduct which building codes offer. Such altered judgment could weigh very heavily against the design professional when the jury establishes fault or determines fair compensation for damages. Therefore, design professionals have a strong disincentive, reinforced by professional liability insurance carriers, to avoid the use of innovative products and technologies.

Frequently, as would generally be the case with photovoltaic installations, an agreement would be negotiated with the Building Code Official or Inspector to permit the safe use of photovoltaic modules, panels or arrays. However, in Johnson vs. Salem Title Company 425 P. 2d 519, the Oregon State Supreme Court rejected an architect's claim that a code official's approval for a wall design, which collapsed under heavy wind loading, relieved the architect of liability. So, even this method of new product introduction must be cautiously and judiciously utilized by design professionals. When a designer specifies this new product in preference to an established product, however, the door to legal claims (filed in the event of product failure) has been unlocked.

Upon a product's failure, for whatever reason, the building owner is apt to seek relief from the manufacturer, the installer and the specifier of the product. However, a manufacturer can fall back on the contention that the product was never intended to be installed in the manner which the design professional has specified. The installer may contend that he was never in agreement with the specification, but faithfully upheld his end of the contractual agreement. The design professional has no scapegoat, he has been charged with the legal and moral responsibility of designing and constructing all phases of the built environment. The responsibility for the designer's own product is graphically stated in this quotation, extracted over ninety years ago in an age when steam heating equipment was an innovative product:

> <u>Hubert</u> v. <u>Aiken</u>, (1890) supra, 2 NYS 711,712.
>
> "...No one would contend that in this day an architect could shelter himself behind the plumber, and excuse his ignorance of the ordinary appliances for sanitary ventilation by saying that he was not an expert in the trade of plumbing. He is an expert in carpentry, in cements, in mortar, in the strength of materials, in the art of constructing the wall, the floors, the staircases, the roofs, and is in duty bound to possess reasonable skill and knowledge as to all these things, and when, in the progress of civilization, new conveniences are introduced into our homes, and become, not curious novelties, but the customary means of securing the comfort of the unpretentious citizen, why should not the architect be expected to possess the technical learning respecting them that is exacted of him with respect to other and older branches of his professional studies? It is not asking too much of the man who assumes that he is competent to build a house at a cost of more than $100,000, and to arrange that it shall be heated by steam, to insist that he shall know how to proportion his chimney to the boiler. It is not enough for him to say, "I asked the steamfitter," and then throw the consequences of any error that may be made upon the employer who engages him, relying upon his skill. Responsibility cannot be shifted in that way."

There have developed, over the intervening years, techniques for dealing with potential legal problems with respect to specification of innovative products. If these products are to be selected with proper thought, the potential performance of the product must be well-documented. The very fact that a product was conscientiously documented provides a certain security for the designer. This principle is graphically outlined in Paxton v. Alemeda County 259 Pac. 2d 934, 938 (1953). In this case, conflicting professional experts' testimony as to the suitability of a particular roofing system which led to the injury of a falling workman, was apparently decided by the presence of documentation of the architect's own structural calculations. In fact, the law only requires the designer to act using his best judgment in the light of present knowledge commonly held by practicing design professionals in the same location. Even if reflection indicates an error, the design professional has performed to the extent that the law requires.

The recent statistics dealing with professional liability, percentage of firms experiencing liability claims and resulting professional liability insurance rates, underscore the importance of avoiding legal risk for a design professional. See Figures 4.1 and 4.2 below.

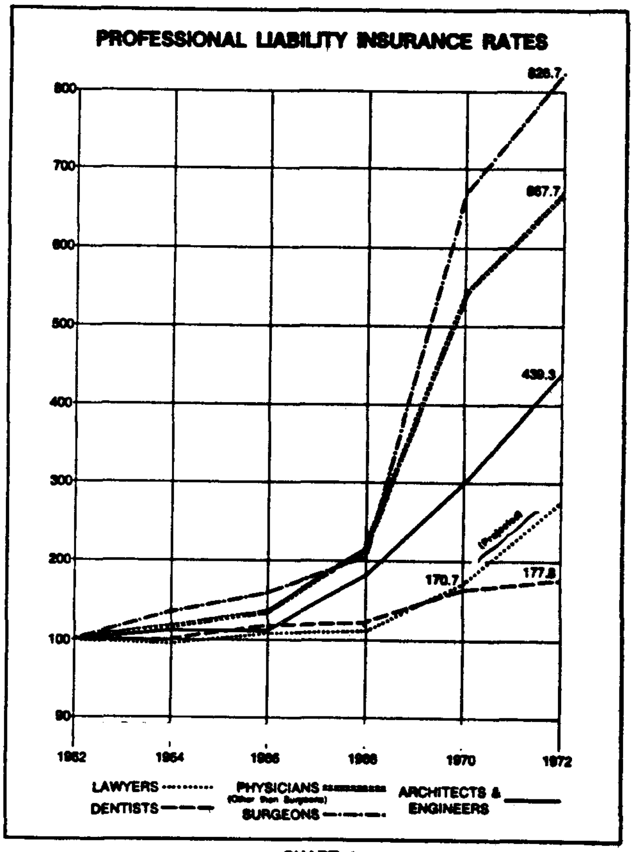


CHART 1

Figure 4.1

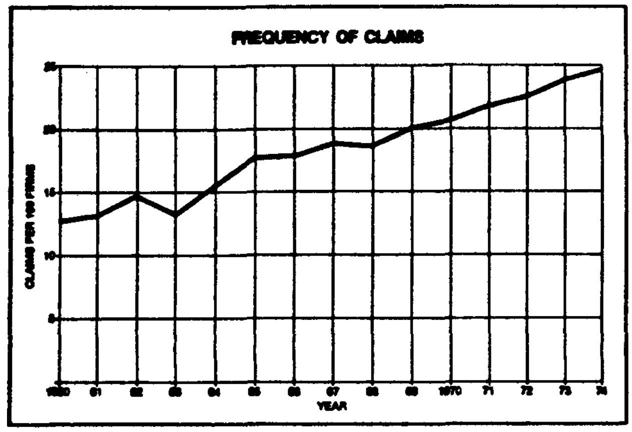


CHART 2

Figure 4.2

Personal injury, as Figures 4.3 and 4.4 show, is a relatively small percentage of claims. Although the percentage of claims for personal injury have risen from 15.1% in the 1960 - 1964 period, to 23.6% during the 1970 - 1975 period, the percentage of claim cost had risen relatively less.

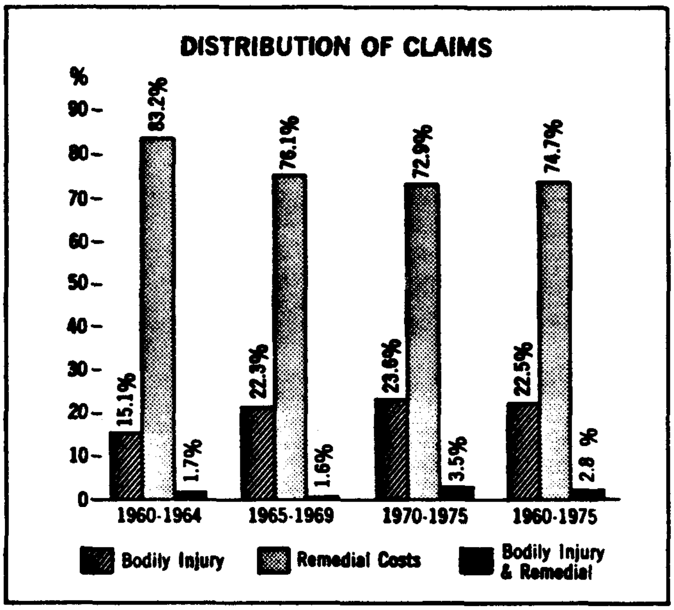


Figure 4.3

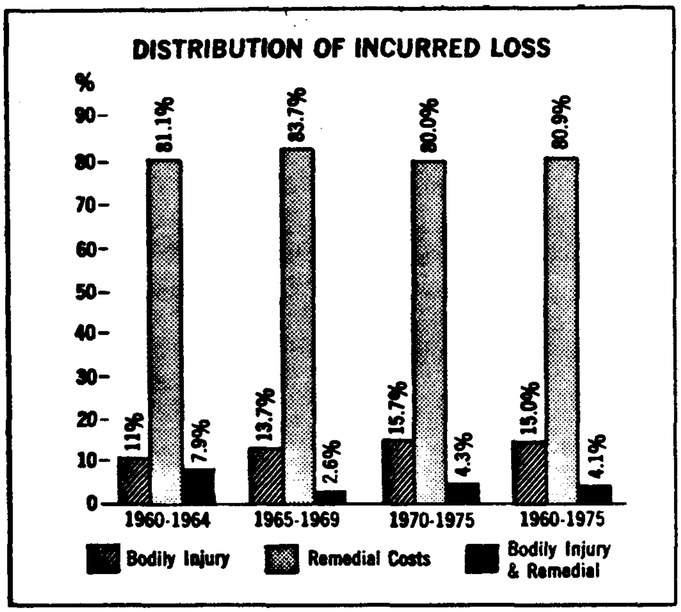


Figure 4.4

One final note on personal injury: almost half (48%) of the claims against design professionals for personal injury are filed by construction workers or their families. This has occurred despite contracts which clearly relieve the design professional of construction site safety procedures responsiblity. The statistical increase of bodily injury claims can be traced in part to rewritten worker's compensation statutes which immunize employers from liability claims.

However, the design professional is susceptible to claims along two fronts. There is no liability immunity from claims for possible third parties who may be judged responsible. Many states dictate a $50,000 maximum payment for death or permanent disability and claimants must sometimes look elsewhere for additional compensation. Architects are frequently perceived to have either the insurance or assets to suit this purpose. The second major source of legal claims is from the insurance company attempting to recover monetary benefits awarded to injured workers. These suits are brought under the right of subrogation, in the injured worker's name.

Legal counselors advise design professionals to document all phases of specification through construction, from the product itself to the manner which it is applied to a building. Photovoltaic manufacturers could provide several services which would increase the design professional's propensity to specify that innovative products:

- Provide product information, both verbally and orally.
- Provide lists of unbiased consumers who are familiar with the same product under similar circumstances (including owners, designers, contractors and inspectors).
- Provide technical literature defining the strengths and limitations of the product.
- Provide records, when questioned, of bad results or limits to the product's usefulness and what is being done to correct weaknesses.
- Provide information on field representatives and services agents. Include information on warranties.
- Provide assurances that financial and production capacities are not being overextended.
- Provide information on replacement and maintenance. Address the possibility of major destructive array failure.
- Provide for written approval for shop drawings to verify that a PV module is suited for a particular application.

- Provide field supervisors for certification of installation techniques on major projects.

- Provide installation safety procedures for contractors. Identify safety hazards to installers.

Professional designers must be skeptical of innovative products, least they leave themselves open for harsh penalties by the legal community. Early PV installations will not be sanctioned within the existing framework of the building codes. The design professional will be asked to bear the legal and moral responsibility for the potential failure of PV modules, panels and/or arrays. It is of paramount importance that the manufacturer of photovoltaic products provide design professionals with as much technical data as possible. To enable the designer to assume the risks associated with the specification of an innovative product, the designer must be able to rationally defend a PV installation. A product which is not regulated by building codes must live up to minimum public expectations for personal safety and welfare. These expectations must be interpreted by the building code official from the building code. Such an interpretation is made on the basis of two separate types of information. One is a comparison between an innovative product and some particular material or assembly referenced within the building code document. Such a comparison may be made on the basis of similar functions or similar materials. For instance, a sloped PV module which covered window openings, in an awning like manner, may be required to comply with the code requirements for awnings. The second type of information which building code officials may draw upon for PV arrays to comply with existing building codes is the overall minimum level of safety which the code affords to the public. If, in the opinion of the code official, the array does not achieve that minimum level of safety, the array will be disallowed. Therefore, the design professional must work in concert with the manufacturer and the code official in the design and subsequent approval of PV arrays prior to their normal acceptance in the building codes.

The utilization of innovative products such as photovoltaics suggests a tremendous reliance on the interpretation of the code documents, as they

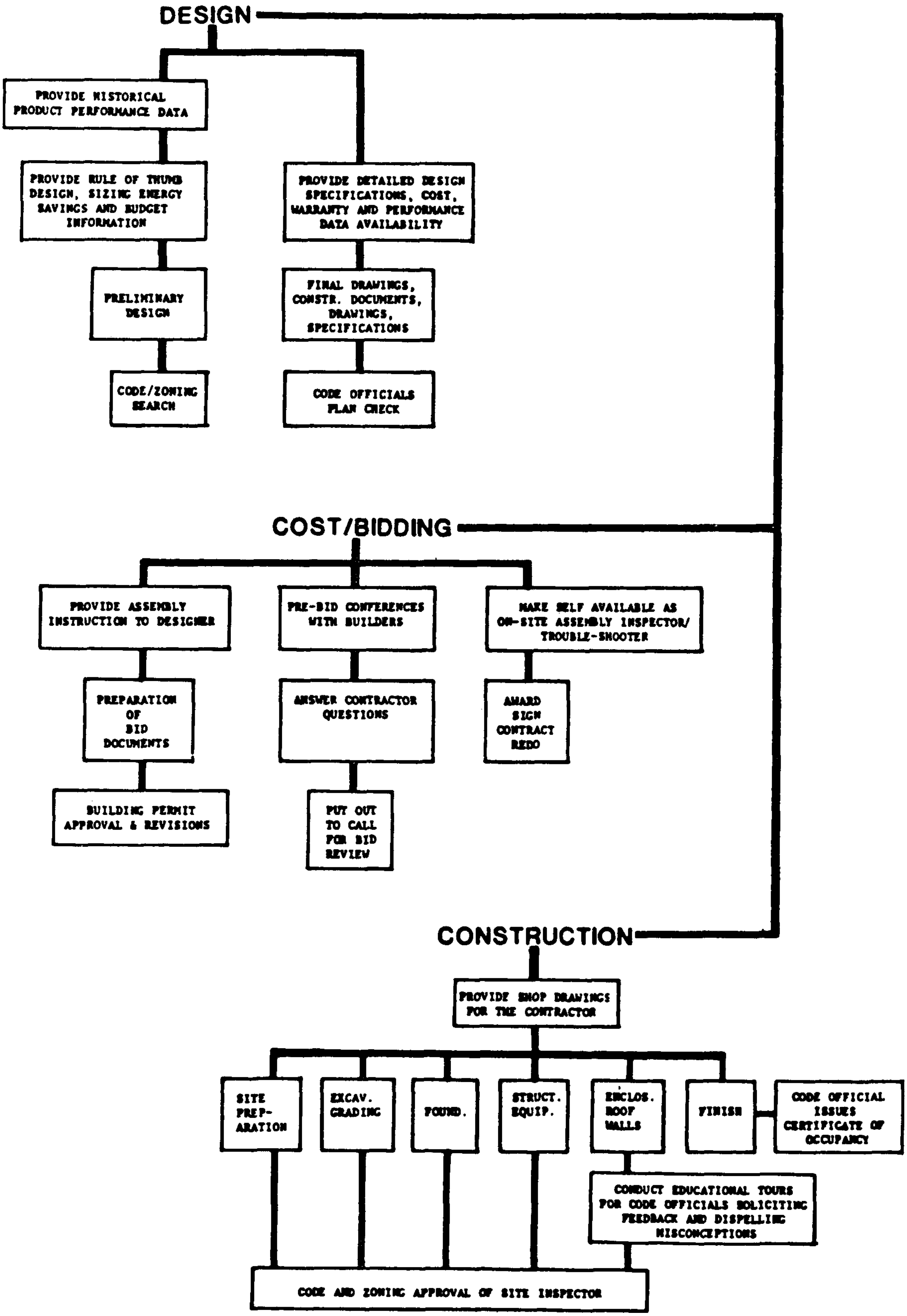

DESIGN
PROVIDE HISTORICAL PRODUCT PERFORMANCE DATA
PROVIDE RULE OF THUMB DESIGN, SIZING ENERGY SAVINGS AND BUDGET INFORMATION
PRELIMINARY DESIGN
CODE/ZONING SEARCH
PROVIDE DETAILED DESIGN SPECIFICATIONS, COST, WARRANTY AND PERFORMANCE DATA AVAILABILITY
FINAL DRAWINGS, CONSTR. DOCUMENTS, DRAWINGS, SPECIFICATIONS
CODE OFFICIALS PLAN CHECK
COST/BIDDING
PROVIDE ASSEMBLY INSTRUCTION TO DESIGNER
PREPARATION OF BID DOCUMENTS
BUILDING PERMIT APPROVAL & REVISIONS
PRE-BID CONFERENCES WITH BUILDERS
ANSWER CONTRACTOR QUESTIONS
PUT OUT TO CALL FOR BID REVIEW
MAKE SELF AVAILABLE AS ON-SITE ASSEMBLY INSPECTOR/ TROUBLE-SHOOTER
AWARD SIGN CONTRACT REDO
CONSTRUCTION
PROVIDE SHOP DRAWINGS FOR THE CONTRACTOR
SITE PREP-ARATION
EXCAV. GRADING
FOUND.
STRUCT. EQUIP.
ENCLOS. ROOF WALLS
FINISH
CODE OFFICIAL ISSUES CERTIFICATE OF OCCUPANCY
CONDUCT EDUCATIONAL TOURS FOR CODE OFFICIALS SOLICITING FEEDBACK AND DISPELLING MISCONCEPTIONS
CODE AND ZONING APPROVAL OF SITE INSPECTOR

Figure 4.5

exist. As a previous section on Building Project Sequence suggests, the Building Code Official is involved continually through the project and has ample opportunity to deny or to restrict the use of photovoltaics so that the design professional must consider from the very conceptualization of the project the attitude of the local code official toward this new technology. Figure 4.5 identifies instances where PV manufacturers might provide technical support for design professionals.

Code officials are the chief code enforcement authorities. They are responsible for seeing that those engaged in the building industry adhere to the requirements of the building code. To understand the personalities involved, it would be valuable to understand some of the incentives and disincentives of the office. As recently as the 1970's, the median salary of the chief code official was $10,586, as can be seen in Figure 4.6.

Minimum and Maximum Salaries of Building Officials by City Size: 1970

City Size	Number of Cities Reporting		Median Salary		Median Salary of Chief Building Official
	Beginning	Maximum	Beginning	Maximum	
Over 500,000	12	12	$10,002	$15,833	$21,712
250,000-500,000	11	11	7,818	10,683	16,650
100,000-250,000	53	52	7,869	9,956	14,017
50,000-100,000	95	95	7,993	9,995	12,750
25,000-50,000	173	179	7,636	9,653	11,693
10,000-25,000	206	220	7,134	9,085	9,387
All Cities	575	598	7,490	9,600	10,586

Source Computed from 1970 Survey of Local Building Departments by Charles G. Field and Francis T. Ventre.

Figure 4.6

Only large cities can afford the training programs and incentives necessary for a strong staff. Advancement in a building department is limited by its typically small size. Generally speaking, these officials are not covered by civil service and few belong to unions. More than 85% of all building officials reporting in 1970 serve without term of office, at the whim of political appointment. Half of the remainder hold only single year appointments. See Figure 4.7. The code official is subjected to continual political pressure.

Chief Building Officials Appointed for Term of Office: 1970

Appointed for Term	*Number of Cities Reporting*	*Percent*
Yes	117	13.5
No	749	86.5
Total	866	100.0

Source: Computed from 1970 Survey of Local Building Departments by Charles G. Field and Francis T. Ventre.

Table 3-9
Term of Office for Chief Building Officials: 1970

Number of Years	*Number of Cities Reporting*	*Percent*
1	58	51.3
2	25	22.1
3	3	2.7
4-6	25	22.1
7-15	0	0.0
16	2	1.8
Total	113	100.0

Source: Computed from 1970 Survey of Local Building Departments by Charles G. Field and Francis T. Ventre.

Table 3-10
Building Officials Covered by Civil Service or Represented by Unions: By Location and City Sizes: 1970

	Civil Service %			*Union Representation %*		
	No. Reporting	*Yes*	*No*	*No. Reporting*	*Yes*	*No*
Central City	154	57.1	42.9	153	13.7	86.3
Suburban	410	42.0	58.0	409	6.1	93.9
Independent	320	20.9	79.1	320	3.1	96.9
City Size						
Over 500,000	13	92.3	7.7	13	30.8	69.2
250,000-500,000	12	83.3	16.7	12	33.3	66.7
100,000-250,000	61	60.7	39.3	60	15.0	85.0
50,000-100,000	113	57.5	42.5	113	11.5	88.5
25,000-50,000	223	48.9	51.1	220	6.8	93.2
10,000-25,000	415	22.4	77.6	417	2.9	97.1
All Cities	898	37.1	62.9	896	6.5	93.5

Source: Computed from 1970 Survey of Local Building Departments by Charles G. Field and Francis T. Ventre.

Figure 4.7

In fact, over half of all building officials are 50 years old or older. See Figure 4.8. Code officials tend to be professionally long lived. The average tenure for the chief official of a department is seven years. Coupled with the fact that over 90% of the positions in building departments are appointments of one year or less and that over a quarter of building departments responding were one man operations, a picture of political bureaucracy develops.

Ages of Local Officials: 1970

	Number Cities Reporting	Age 20-29	30-39	40-45	50-59	60	Total
Chief Building Officer	790	1.6	15.6	30.8	37.8	14.2	100%
Senior Building Officer	471	1.5	12.7	30.6	36.5	18.7	100%
Most Recently Appointed Building Officer	401	8.7	27.4	28.2	28.2	7.5	100%

Source Computed from 1970 Survey of Local Building Departments by Charles G. Field and Francis T. Ventre.

Figure 4.8

The smaller the building department, the more generally susceptible to "local" pressures and the longer innovative technologies take to be put into use.

Occupational Backgrounds of Local Building Officials: 1970

	Percent Reporting							
	Number Reporting	Union Bldg. Trades	Non-Union Bldg. Trades	General Contractor	Engineer	Architect	Other Govt.	Other
Chief Building Official	815	28.8	21.4	42.4	26.8	8.6	24.8	14.1
Senior Building Official	522	39.0	29.3	28.8	6.7	2.3	20.9	14.8
Most Recently Appointed Building Official	433	33.1	25.2	29.8	9.9	2.5	20.3	17.5

*Row totals do not equal 100% because some checked more than one background component.
Source Computed from 1970 Survey of Local Building Departments by Charles G. Field and Francis T. Ventre.

Figure 4.9

Established building trades resist technological change as an established political party would resist political change. These established powers will attempt to preserve the status quo by influencing the susceptible code official. Except in the largest of cities, code officials are unable to shield themselves behind bureaucratic anonymity. Photovoltaic manufacturers will have to overcome the established bias of local interests, competing manufacturers, contractors, materials suppliers, and installers as well as the political influence which they have imposed upon building officials against innovative products and technologies.

The burden is upon the photovoltaic manufacturer to get into the smaller "local" areas to convince code officials of the safety and acceptability of the PV products, frequently through local design professionals. The manufacturer must work to establish relations with local materials suppliers, contractors and installers simultaneously so as to develop their own place in the established construction industry framework. Education will be the primary activity in dealing with Building Code Agencies and personnel.

Getting one's foot in the door is only the first step. There is a great deal more the photovoltaic manufacturer must do before the transaction is complete. Granted, once the design professional and the code official select and approve photovoltaics for use, the bulk of the job of selling PV has been accomplished. However, each of the remaining actors in the building sequence has a certain amount of influence in possibly eliminating or limiting the use of the product.

4.2 COMPLETING THE TRANSACTION

After convincing planners, architects, engineers, developers and code officials as to the acceptability of photovoltaics, there are still other actors remaining along the path to construction who threaten the eventual utilization of the product. For example:

- Building owner may dislike the modern image that PV suggests.
- Building manager may fear service and maintenance difficulties.
- Insurance carriers may refuse to cover arrays or may set premium rates artificially high.
- Contractors and subcontractors may build in an exorbitant fear factor when bidding a project.
- Trade unions may compete for the rights to install PV arrays.

Each of these issues is developed below. The problems associated with these issues are addressed at length, and possible strategies for the avoidance of pitfalls are suggested.

. Building owner may dislike the modern image that PV suggests.

A building owner can reject PV for any arbitrary reason. By selling PV to the design professional, (architect or engineer) who acts as the agent of the owner concerning technical and aesthetic issues, the manufacturer relinquishes to that design professional the job of securing design approvals from the building owner. If the design professional is not fully educated in all of the particulars of the products he is attempting to sell to the building owner, the owner could easily be frightened away by his own personal misconceptions. The desire for a more "traditional" or "classical" image, for marketing or personal reasons, can disrupt the normal material selection process. When the architect is not capable of proper product representation, the manufacturer must educate the building owner more directly.

. Building manager may fear service and/or maintenance difficulties.

The building manager must devise a plan by which the PV array can be efficiently maintained for both continued acceptable performance and correction of system damage. Various maintenance tasks require decidedly different levels of training. The quality and timing of maintenance is more crucial in certain tasks, and as such, requires tighter organizational control.

No easy formula exists for prescribing what a PV manufacturer can do to allay the maintenance complexity fears of the building manager. Some of the salient variables which will determine the eventual maintenance-management policy in a PV project are identified below (see also Section 12 of this report).

Some occupancies may have more serious maintenance problems than others. For example, schools may experience higher vandalism rates, industrial users may experience array coverplate soiling by their own smokestack emissions, commercial retail establishements may tend to have a small and poorly trained maintenance staff, and a restaurant may have greasy exhaust fumes which cloud roof mounted or adjacent arrays. A manufacturing plant may tend to have maintenance staff experienced in both cleaning and machinery replacement, well-trained to maintain photovoltaic arrays.

The scale of the building project may be extremely important. A large single user or a group of smaller users may have the combined resources necessary to achieve the appropriate blend of untrained and technically sophisticated employees in house for the building manager to call upon. Otherwise, the manager must count on outside agencies for the cleaning, painting, inspecting, monitoring and even scheduling. For example: a school district with a full time maintenance staff could utilize a district's electrician for the inspection of the wiring system as well as the replacement of damaged modules; the district's maintenance director for the scheduling of periodic inspection, cleaning and evaluation; and a custodian within the building itself to periodically clean the covering material and inspect for physical damage. However, a small retail shop or a doctor's office may not have a building manager and may rely on maintenance contracts for regular building upkeep.

Studies analyzing the skills necessary for the successful operation and maintenance of a photovoltaic array could be correlated with studies identifying personnel and their level of training typically found in commercial/industrial applications. This would assist photovoltaic manufacturers in determining the type of maintenance staff or staff support the industry must provide. Design of the module, panel and array mounting should be considerate of future preventative and corrective maintenance staff support.

- Insurance carriers may refuse to cover arrays or set premiums artificially high.

The photovoltaic manufacturer must consider the effect of two distinct insurance costs. The first, with direct effect on the manufacturer, is product liability insurance. The second, with an indirect effect on the manufacturer, is that insurance necessary to protect the building owner against damage loss or liability peril.

Product Liability Insurance:

"The law recognizes that parties in different relationships have differing standards of care. A party handling dangerous instrumentalities, for example, may be held liable where injury occurs, even under circumstances where the party was not negligent. See Corporale v. C. W. Blakeslee & Sons, Inc. 149 Conn. 79, 175A 2d 568 (1961). Under certain circumstances, a party may be said to warrant or guarantee the fitness or adequacy of a product he manufactures or sells; if the product is not fit for intended use, the party is held liable for damages, even though there may be no proof of damages."[1]

In the referenced case above, it was necessary for the court to find the instrumentality capable of causing harm involved a risk of probable damage or injury to the extent that it can be termed intrinsically dangerous. While the design professional is only expected to possess the requisite skill and knowledge and use his best judgment, despite the possible appearance of mistakes or defects in the plans and specifications produced, the manufacturer is not permitted the luxury or exercising judgment or discretion.

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1 Sapers, Carl M.; Cases and Materials on Construction Law, manuscript, copyright 1973, p. 57

The mechanics of procuring product liability coverage seem to be rather clear. The manufacturer retains an insurance broker who negotiates a rate with the insurance carrier. The procedure looks something like this:

- Manufacturer submits drawings, sketches, specifications, performance data and anything else which can describe the product to the insurance company.

- Engineers and technical experts for the insurance company analyze the product and provide comments as well as request clarifications from the manufacturer.

- Manufacturer clarifies ambiguities in the initial presentation and considers comments made by the insurance carrier. Manufacturer then resubmits the presentation to the insurance company.

- Insurance company revises and completes the analysis. A rate is quoted for the manufacturer.

This procedure is not difficult, but can be time consuming. The average time span for initial submission to final rate quotation can range from three months to a year. This task of data submittal, like most of the other tasks the PV industry will need to perform, is educational in nature. A time delay in the procurement of liability coverage at a reasonable rate could delay the initial market infusion date. (A list of product liability considerations to be addressed by a PV manufacturer has been developed by Carnegie-Mellon Univ. in a recent study for JPL. DOE/JPL 955846-81/1).

Building Owner's Insurance:

The building owner must protect his interests in two basic ways. The building owner, like the manufacturer, must be concerned with liability in the event of personal injury or property damage associated with photovoltaic arrays. Although the material put in place may be the responsibility of the manufacturer and the design professional, the methods utilized to maintain or alter the system are very important from a liability standpoint. Many warranties are voided by unauthorized maintenance work. Design professionals, therefore have a certain amount of protection against liability for a product which has been substantially altered through maintenance or renovation.

The second area of protection for a building owner is from damage due to fire or other calamity. The array is a big investment and to not insure such that it can be replaced in the event of fire or other natural disaster, would mean a loss of not only material goods but perhaps even lost operation time while a substitute power source is sought.

- Contractors and subcontractors may build in an exhorbitant fear factor when bidding a project.

The level of experience that a contractor has concerning the installation of a particular system or material assembly, affects the efficiency of the installation. Cost overruns are rooted in unforeseen problems. Installation techniques and the cost of special equipment often drive contractors (a conservative group in general) to pad their bids with excessive material waste or employee training estimations.

Generally, contractors cannot successfully bid jobs where they are unfamiliar with a material or system. If they are too conservative in their bid, then an experienced contractor will more accurately underbid, and if they are too liberal, job costs will soon create deficits not profits. However, in a new technology, even the competition is inexperienced. Over the years, contractors have developed a fear factor for new techniques and materials. This should establish competitive bids early in PV development.

By developing well defined installation guidelines and procedures by which the contractor can accurately estimate installation time and materials, much of the fear factor can be eliminated. The manufacturer can conduct pre-bid seminars for the contractors and subcontractors to eliminate much of the fear of the unknown. This is a common tactic in relatively young solar thermal installations. The seminar presentation can be a blend of installation methods; installation labor studies; materials price fluctuation data; and identification of manufacturer's installation support services, including warranties, inspections, supervision and approvals. The manufacturer generally seeks to allay the fears of contractors by correlating the innovative product with materials and assemblies with which the contractor will be familiar.

- Trade unions may compete for the rights to install PV arrays.

Labor disputes on a building site cause not only headaches for contractors but costly time delays and expensive compromise agreements. Photovoltaic arrays are quite ambiguous in their installation needs. The need for electrical connections will make them susceptible to the electrical workers demanding union representation. The need for mechanical fastenings make them susceptible to carpenters or sheet metal workers demands for union representation. Roofers could also project an argument for representation.

Trade union disputes occur on the job site during construction. Generally, such jurisdictional disputes, as they are called, can be avoided. By developing international agreements which offer guidelines delineating specific responsibilities for specific trades, potential ambiguity is officially resolved.

Jurisdictional disputes could occur on a national level. Potentially relevant trade unions should be identified early in the PV manufacturing process. Guidelines must be developed which outline the roles and responsibilities of each trade union. There will be no benefit in prefabricating electrical or mechanical systems if each and every union will require representation in the field.

One way to avoid labor confusion on the job site is to depend upon the design professional to specify the installer. This will attentuate the potential for conflict on the job site. However, if the industry falls back on this method, they will run a risk. At some time, the design professional will inadvertently omit installation criteria. This could lead to a jurisdictional dispute among trade unions competing for work.

This can, in turn, lead to a snowballing of labor problems on a national level where a variety of labor unions may claim responsibilities for the installation of photovoltaic arrays. Labor unions are extremely conservative with regard to innovative materials and technologies. They fear redivision of work and obsolescence. Traditionally, the trade unions provide the greatest resistance to innovative products. Older union members see themselves as losing their inherent experience advantage to younger workers. A poorly planned attempt to legislate an international agreement may lead to many unions requiring token representation on every installation job, even when not necessary.

Through proper foresight, the PV industry could take the initiative in the authorship of an international agreement outlining jurisdictional parameters for all potential trade unions. These parameters would be organized through committees of the large national labor unions, such as the Trade Council of the American Federation of Labor--Congress of International Organizations (AFL-CIO).

The impact of the labor unions extends into the factory of a prefabricator as well as onto the job site. In Massachusetts, plumbing in all prefabricated buildings constructed must be installed by Massachusetts licensed plumbers. In addition, the piping installed in a plant must be left exposed and accessible after the building components leave the prefabrication factory. Any prefabricated construction entering Massachusetts from another state must have fixtures removed and every inch of pipe uncovered and all piping ends capped so that the inspector of plumbing can observe compliance with the Massachusetts State Plumbing Code.

Clearly, any advantage gained in the photovoltaics industry (economically) through prefabrication can be lost through state or local efforts to preserve work for their own local interest groups.

SECTION 5

MOUNTING DETAILS

5.1 INTRODUCTION

The various mounting techniques for photovoltiac modules/panels/arrays in the commercial/industrial sector can be thought of to consist of four generic mounting types. These generic types have been previously developed for the residential market (Residential Photovoltaic Module and Array Requirement Study, JPL Contract No. 955149), however, their definitive boundaries appear to effectively describe whatever additional characteristics a commercial array might impose. It is therefore felt that illustrations and descriptions of these mounting types might be appropriate to facilitate the understanding of any future reference to them in this report.

It should be noted, however, that the commercial/industrial sector offers more flexibility for the integration of these four generic types than the residential does. For instance, the increased use of flat roofs in the commercial/industrial sector could lead to greater application of rack mounted PV systems. Two further reasons why rack mounted arrays may have much greater application in this sector are based on size and aesthetics. The larger commercial/industrial PV arrays will require a great deal more area than will be required for most residential applications, and therefore, either a large roof area (most likely flat) or ground space will be necessary. In either situation, rack mounted modules/panels will probably appear most feasible. Additionally, the aesthetic problem encountered in the residential sector with rack mounted arrays is less of a concern in the commercial industrial sector. The appearance of a "high-tech" solar PV array on a building in this sector may very well enhance the image for which the company is striving. These are both generalizations and may certainly not apply in every case in this sector. Nevertheless, the reader should be aware that the commercial/industrial sector is different from the residential sector in many ways, and that these differences should allow the designer of the PV mounting system a great deal more flexibility within these four generic mounting types.

FOUR GENERIC PV MOUNTING TYPES

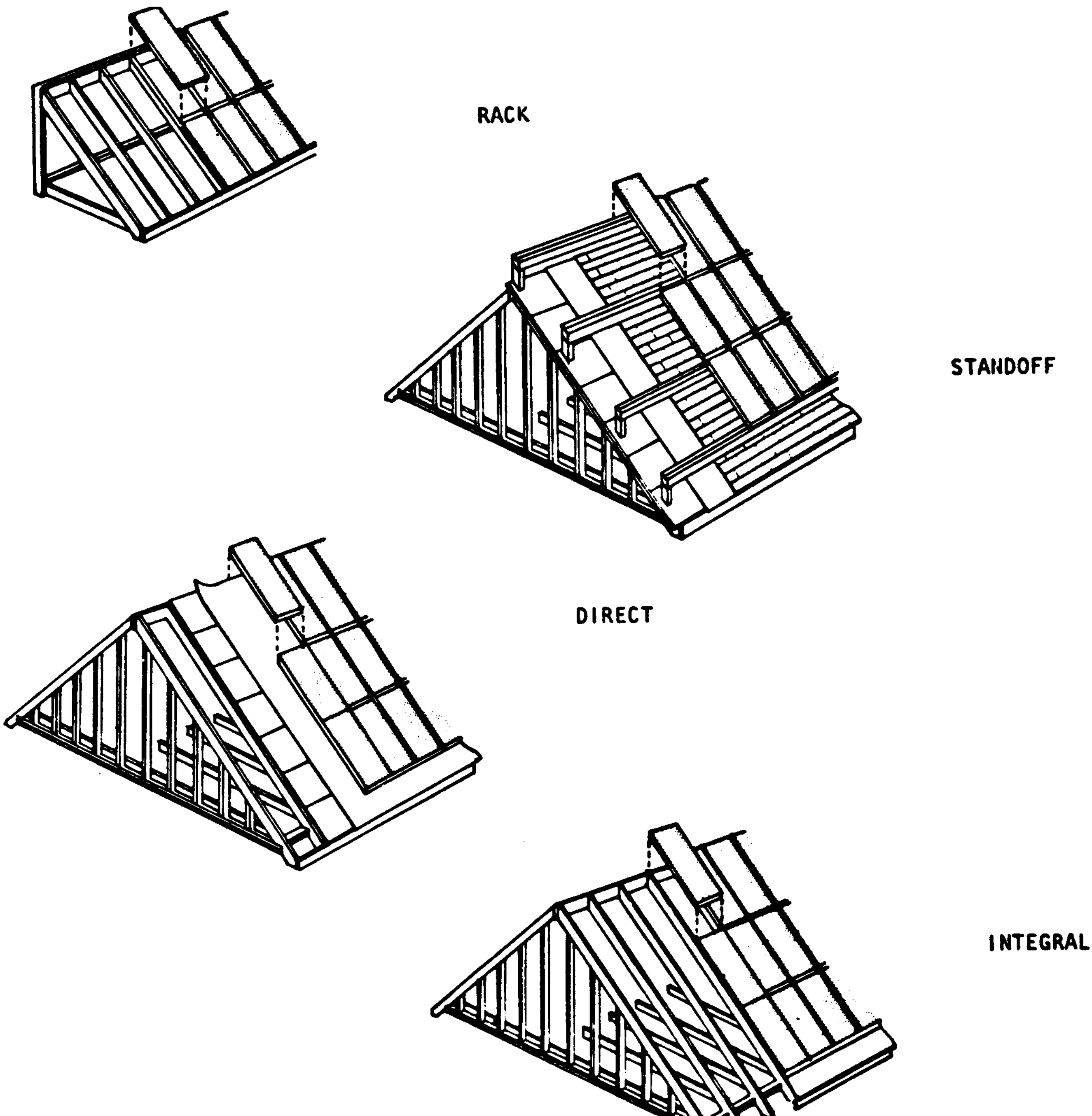

Figure 5.1

As commercial/industrial buildings can be considerably larger than residential buildings and with the prospects of photovoltaic panels functioning as building materials, wall mounting of PV arrays must be considered. Each of the mounting types could be used for wall mounting. Panel function and cost will be two of the factors influencing such a decision.

5.2 MOUNTING TYPE DESCRIPTIONS

The basic mounting types were developed on the assumption that rack and standoff mounted modules need not form a watertight membrane and that direct and integral mounted types would be required to form a watertight membrane for the building structure. Of equal importance, the rack and direct mounted systems can be used to support modules not capable of withstanding normal roof loads while the modules used in standoff and integral mountings must have the structural capability to take such design loads. The following is a detailed description of each of the mounting types.

1. Rack Mounting. By using a rack mounted photovoltaic array, the designer has some flexibility in the location of that array. The rack mounted array can be located on the ground away from the building or on the roof of the building. This mounting type might also allow for the change of tilt angle from site to site and from season to season. This technique also allows for structural independence of the module. That is, the module can be designed for the minimum amount of structural rigidity, i.e., resistance to dead loading and wind uplift, and integrity, thus reducing the cost of the module itself. Because of easy accessiblity, maintenance can be performed quickly and with relative ease, thus allowing for reduction in maintenance costs. Likewise, the costs associated with installation of the array should be comparatively lower.

   There are, however, some serious drawbacks to the rack mounting of PV arrays. Structural costs for the supports increase as the height of the array increases. This will cause the maximum realistic slant height of the rack mounted arrays to be on the order of 16 ft. Rack mounted modules at grade level are also susceptible to damage and could create a safety hazard. Ground mounted arrays may pose land availability problems, as well as local zoning ordinance problems. It may be necessary, therefore, to install fences around ground mountd arrays resulting in additional cost to the system. While ground mounted arrays pose special problems, rooftop installations of rack mounted modules also have their own inherent problems.

2. Standoff Mount. Elements that separate modules from the roof surface or wall are known as standoffs. By supporting the module away from the roof surface, air and water can pass freely under the module, minimizing problems of mildew and roof leakage. This will aid in cooling the photovoltaic module, thus improving module efficiency. In the event of a retrofit application, tilt angle can be optimized with the use of standoffs, thus eliminating dependence on roof pitch.

   Standoff modules will require similar resistance to dead loading and wind uplift loading as did rack mounted modules, however, the structural and land requirements may not be as stringent. By utilizing a frame which has structural integrity, module integrity can be minimized and module manufacturing costs will then be reduced. Modules with combustible material or materials that will contribute fuel to combustion in the event of a fire, could be of concern. They may be interpreted as contiguous areas of plastic in which case close review of the codes section on roof coverings must take place.

3. Direct Mount. Installation of direct mounted modules is accomplished by anchoring the modules to the roof or walls. The use of this mounting technique eliminates the need for additive structural supports. The modules will be placed on the waterproof membrane which is already on top of the roof sheathing, declining or wall spandral system. There will be need for module to module and array perimeter waterproofing and, therefore, the array will act as a waterproof membrane. There will also be a minimal credit for replacement of some roofing or siding materials.

Because of the direct mount system's intimate contact with the roof or wall, three major problems will exist. First, cooling of this type module will be a problem, for only the top surface will be cooled by convection. This will, of course, decrease the module efficiency. Second, electrical connections must be of a very unique type because the back surface of the modules will not be exposed for interconnecting purposes. Because of this, new and innovative techniques need to be developed for the electrical connection of direct mounted modules. Third, maintenance will be a problem for the replacement of modules will be more difficult as interconnects and attachments will be difficult to access. With the modules mounted directly to the roof or wall surface, module tilt is, therefore, dependent on roof pitch and requires the roof to be designed accordingly. Array area is restricted to the overall area of the south-facing slope of the roof or the south facade. This will present problems in applications where roof or wall area is very limited.

This mounting type allows for a broad variety of module design possibilities. The direct mounted module may be as typical as a standard flat plate module or as specific as shingle type module. Though these two examples are extreme cases, both are indeed examples of direct mounted photovoltaic devices. The innovative designer will, therefore, be able to arrive at many unique solutions to the design problem of commercial photovoltaic modules for direct mount application.

4. Integral Mounts. Integral mounting places the module within the roof or wall construction itself. Modules are attached to and supported by the roof or wall structural framing members and serve as the finished roof or wall surface. Due to the structural support given by the roof sheathing, removal of that roof sheathing may require additional structural support be given to the roof framing system. Watertightness is critical to avoid problems of water damage and mildew. As with the direct mounted modules, the integral mounted module's tilt angle is determined by roof pitch, and again requires the roof be designed accordingly. It should be mentioned that the commercial/industrial

sector could allow for the direct or integral mount to be placed on the wall of the building, not just the roof.

Modules to be used integrally must be constructed to the standard building tolerances. Because the array now becomes the roof or wall structure, modules must be designed to withstand all live loads that are specified for commercial application.

SECTION 6

BUILDING CODES

6.1 INTRODUCTION

European cities, at the height of the industrial revolution, were faced with a problem of crisis proportions; planning. Modern town planning sprang from the series of population increases and social reforms sweeping Europe in the mid-1800's, such as the English Reform Act of 1832 and the French and Belgian Political Revolutions. The industrial revolution caused city populations to rapidly increase. Industry could grow even in cities with no rivers, given the invention of the steam engine and the construction of canal systems which offered cheap transportation for even the bulkiest, heaviest goods.

Prior to the industrial revolution, one-fifth of the English population was urban. By 1830 the proportion of urban to rural was half. Today, only one-fifth of the English population is rural. By 1835, the feudal governing institutions were replaced by elected municipalities. They were responsible for public interventions such as roads, drainage, sewerage, housing and overall planning. H. M. Croome said of the period:

> "But the more the capitalistic technique grows up, the more complicated economic relationships become, the more each man's prosperity becomes bound up with that of others whom he may never have seen, the more necessary it is that each one's conduct of his life should come up to certain minimum standards. The town dweller's health, for instance, is no longer his own concern; in illness he is far more likely to infect his neighbors than the country dweller in an isolated cottage. Social responsibility--the sense that we are all members of one body--becomes more important... and so we find, following on the development of captialism, a paradoxical situation; the individualist's idea destroys the old solidarity and makes for the growth of capitalism, and capitalism, in turn, by increasing every individual's dependence on his neighbor, demands a return to that same solidarity..."[1]

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1 H. M. Croome and R. J. Hammond, "Economic History of Britian", London, 19o7, p. 207.

The conditions of the cities, where open sewers fed into the water supply, every inch of ground was built upon, roadways had no paving, domestic animals roamed the streets and speculators dictated both housing stock quality and price, led to the first swipe at regulatory restraint. Epidemics which spread from neighborhood to city to country to continent hastened these reforms. Building codes were born.

However, the problems were not wholly solved.

> "Building regulations are unique in that they are as much a statement of social attitudes and policies as they are of engineering and technology. To be responsive to one concern is not enough."[2]

Early regulators in Europe found that increasing regulatory requirements forced the poor to seek less expensive housing far from the center of town. Building regulations needed to be more than a statement of acceptable human standards, they needed to be affordable.

In the United States:

> "The law of building codes is grounded upon what is called the police power of the state. The police power is the source of all authority to enact building codes. It has never been exactly defined, and indeed the United States Supreme Court has said that it is 'incapable of any very exact definition.' Broadly speaking, it is the power of the state to legislate for the general welfare of its citizens."[3]

Some State Legislatures utilize State Building Codes as the manifestation of the State's police power. Most, however, delegate authority to a local governmental unit such as the municipal government. These locally designated entities or jurisdications, as they are called, adopt a code document as the reference document for local construction. These code documents can be self-written or written by a central body. Self-written codes require extensive research and can be quite expensive. For instance,

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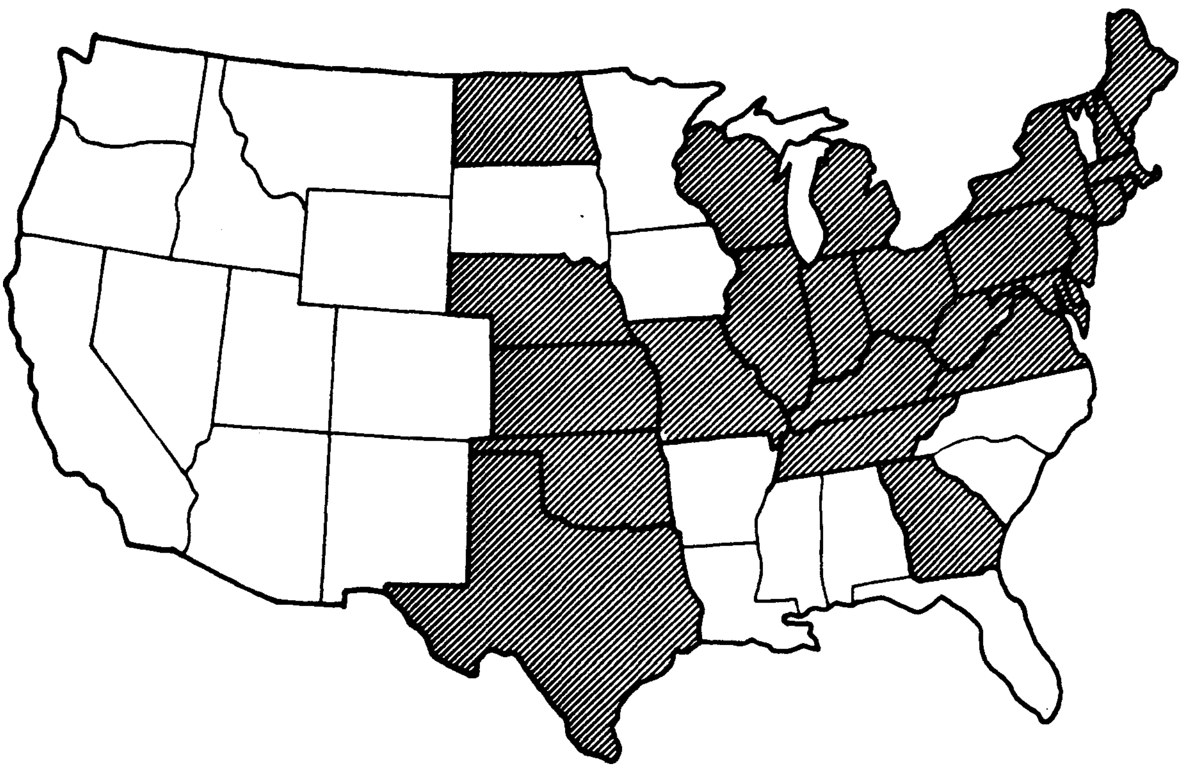
[2] Howard Markman, FPE, "A Case for More Rational and Explicit Building Regulations", Ventnar, New Jersey, 1978.

[3] From Charles S. Rhyne, "Survey of the Law of Building Codes", 1960.

the New York City building code, which has been recently enacted, cost over a million dollars to develop. Generally, a code jurisdiction will adopt a code document written by a central code official association or modify a version of such a document. These centrally written documents are called model building codes.

There are three model building codes which are of primary importance in the United States. The three are: the Building Officials & Code Administrators (BOCA) Basic Building Code, the International Conference of Building Officials (ICBO) Uniform Building Code, and the Southern Building Code Congress (SBCC) Standard Building Code. Each of these three codes has a particular regional sphere of influence. The BOCA Building Code is influential in the Northeast and Midwest (Figure 6.1).

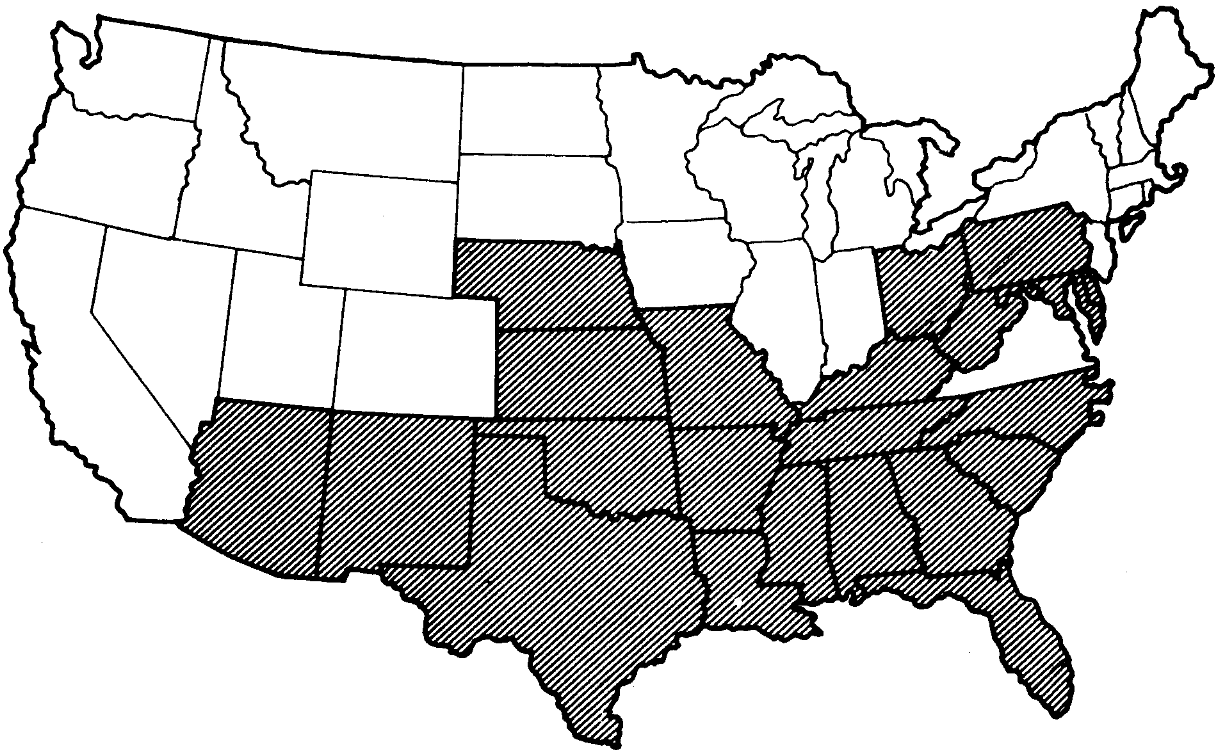


Shaded portions indicate areas where local jurisdictions have adopted one or more of the codes.

BUILDING OFFICIALS AND CODE ADMINISTRATORS INTERNATIONAL INC. (BOCA)

Figure 6.1

The SBCC Standard Building Code is influential in the Southeast (Figure 6.2).

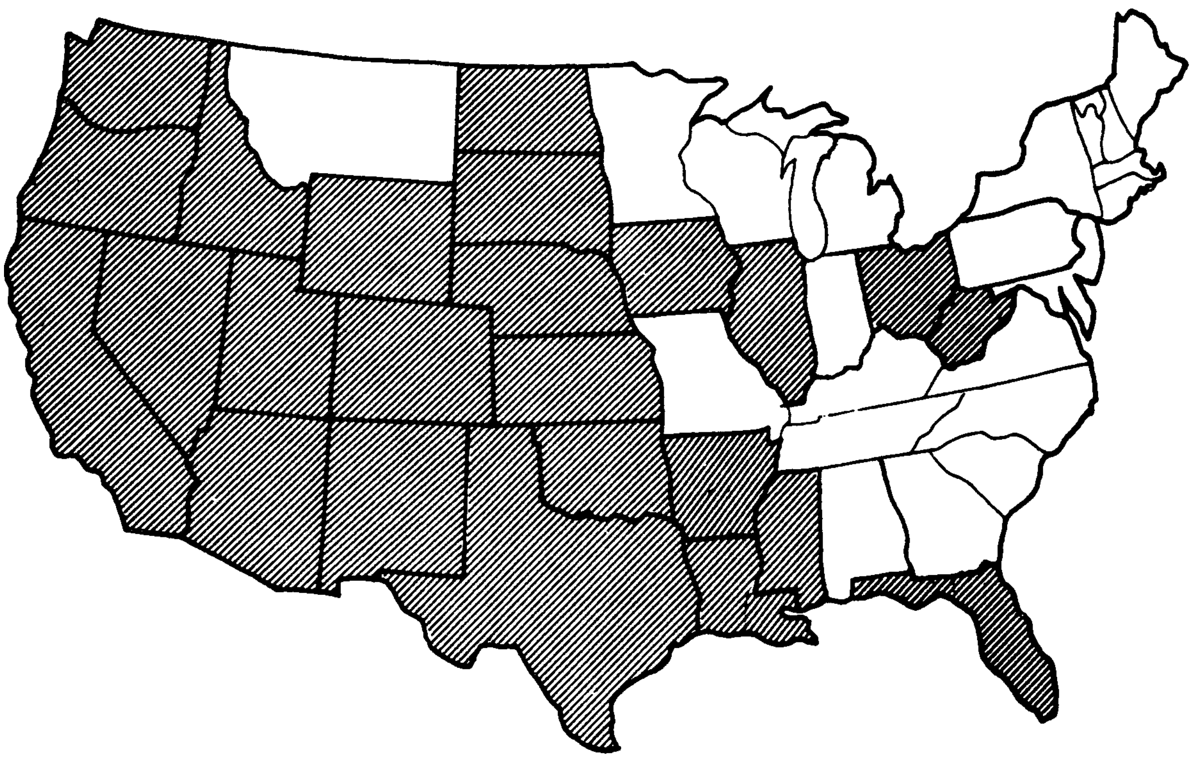


Shaded portions indicate areas where local jurisdictions have adopted one or more of the codes.

SOUTHERN BUILDING CODE CONGRESS INTERNATIONAL (SBCC)

Figure 6.2

The ICBO Uniform Building Code is influential in the West and Southwest (Figure 6.3).

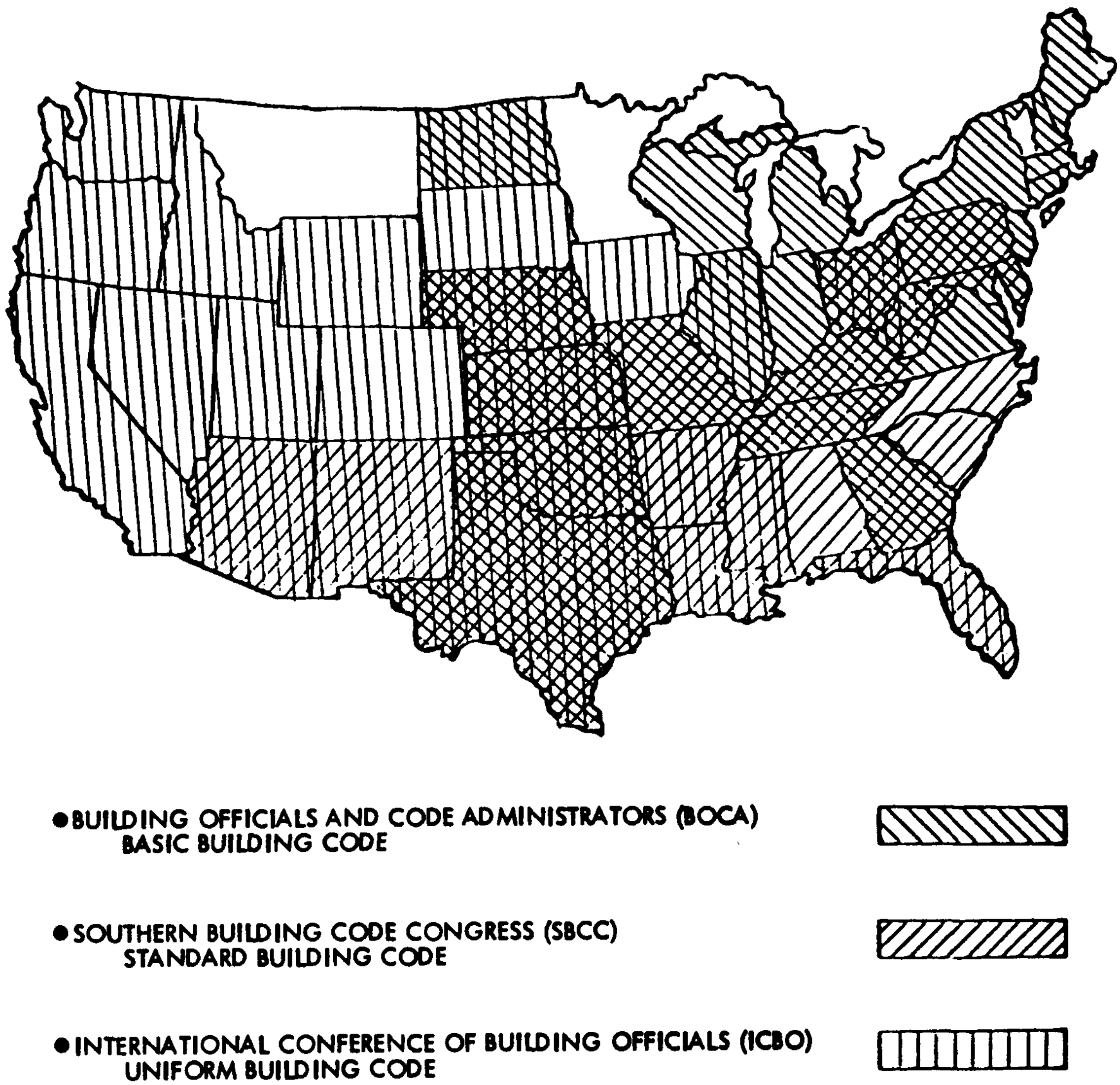


Shaded portions indicate areas where local jurisdictions have adopted one or more of the codes.

INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS

Figure 6.3

If the state by state coverage of the model codes is aggregated on one map, a fair amount of overlap is observed. In fact, the utilization of each of the three different model codes studied, in various jurisdictions across the state, (see Ohio, Texas, Nebraska, Kansas and Oklahoma on Figure 6.4) may lead to different code documents governing adjacent jurisdictions or even adjacent structures.



AGGREGATE CODE MAP

Figure 6.4

All three of these model building codes are analyzed below. In addition, two city building codes are analyzed to show the locally written and locally adapted model code side of the coin. These two are the Pittsburgh and Los Angeles building codes. The Pittsburgh Building Code is locally written and is infrequently updated. The Los Angeles Building Code is an adaptation of the ICBO Uniform Building Code.

The following three sections describe building codes in more detail. PV manufacturers must be concerned with two separate phases of building code interaction. The first is early acceptance, prior to official acceptance. The second is actually how severely building codes will actually regulate photovoltaic modules and arrays in the long term. The second section (6.2) describes in depth the relevance of current building codes to photovoltaic development. This is accomplished by both a description of the existing code documents and the identification of particular items within code documents which could be correlated to photovoltaic modules, panels and arrays. In addition, Section 6.3 attempts to interpret the codes, as written today, from the viewpoint of the code official. In other words, all sections of the codes which address a device or application which a code official may interpret as similar enough to a PV array, even if only visually similar, have been reviewed and discussed as to its potential impact on PV. Finally, the fourth section (6.4) describes the means by which building codes change.

In the very near term, the information garnered from the sections on the existing code documents is valuable for PV manufacturers. Code officials will compare a new technology with materials and systems which they are already familiar. By understanding the structure of existing codes, PV manufacturers can market a product which will not be objectionable from a regulatory point of view. It will be seen, after reviewing these sections, that the easiest means for a manufacture to penetrate the building industry marketplace has the limitation of function as one of its requirements. Early on the program PV should provide electricity, but should not function as a complex building component.

Over the course of time, as technology and the economies of construction change, so do the building codes. Photovoltaics, as a developing new technology, is somewhat of an anomaly in the construction industry. The magnitude of utilization for photovoltaic arrays on commercial/industrial buildings necessary for a successful program demands mention within code documents. It also demands periodic updating to account for technological strides in safety and performance. Likewise, as the use of the single function device, i.e. the PV electrical generator, becomes more widespread and as code officials begin to accept PV hardware and its application on buildings, manufacturers can begin to design multi-function hardware. This hardware could be as complex as a wall or roof section. The difficulties associated with the multi-functional approach become apparent when reviewing Section 6.2.

The photovoltaic manufacturer will have an opportunity to provide input to the code agencies writing the future photovoltaic safety performance codes. They must first understand how codes change and who has the primary authority to alter the content of the building codes. Section 6.3 identifies some of the inherent barriers to new technology being written into future codes. It also suggests ways to avoid such interference.

6.2 CORRELATION: EXISTING CODE REFERENCES TO PHOTOVOLTAICS

The building code official is responsible for the enforcement of the code documents as enacted within that locality or jurisdiction. The building department has a number of inputs into the building design and construction sequence as shown in Figure 3.3. The duties include plan check, building permit issue, revisions approval, site inspection and issuance of certificate of occupancy.

Photovoltaics per se are not mentioned in any of the three model codes or in any of the city codes analyzed. As a result, any code official inspecting drawings must approve or disapprove their installation on the basis of correlations which can be made to other known products or applications. Provisions are made in each of the three model codes (Figure

6.5) and the two city codes for innovative products and applications to be utilized.

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 101.3: MATTERS NOT PROVIDED FOR:

ANY REQUIREMENT ESSENTIAL FOR STRUCTURAL, FIRE OR SANITARY SAFETY OF AN EXISTING OR PROPOSED BUILDING OR STRUCTURE, OR ESSENTIAL FOR THE SAFETY OF THE OCCUPANTS THEREOF, AND WHICH IS NOT SPECIFICALLY COVERED BY THIS CODE, SHALL BE DETERMINED BY THE BUILDING OFFICIAL.

SECTION 107.4: ALTERNATIVE MATERIALS AND EQUIPMENT

THE PROVISIONS OF THIS CODE ARE NOT INTENDED TO PREVENT THE USE OF ANY MATERIAL OR METHOD OF CONSTRUCTION NOT SPECIFICALLY PRESCRIBED BY THIS CODE, PROVIDED ANY SUCH ALTERNATIVE HAS BEEN APPROVED. THE BUILDING OFFICIAL MAY APPROVE ANY SUCH ALTERNATIVE PROVIDED THE BUILDING OFFICIAL FINDS THAT THE PROPOSED DESIGN IS SATISFACTORY AND COMPLIES WITH THE INTENT OF THE PROVISIONS OF THIS CODE, AND THAT THE MATERIAL, METHOD OR WORK OFFERED IS, FOR THE PURPOSE INTENDED, AT LEAST THE EQUIVALENT OF THAT PRESCRIBED IN THIS CODE IN QUALITY, STRENGTH, EFFECTIVENESS, FIRERESISTANCE, DURABILITY AND SAFETY.

Figure 6.5

As can be seen above, with "approval", anything is possible. This "approval" is rather subjectively applied when the code official interprets a photovoltaic array as to whether it "...complies with the intent of the provisions of this Code...". "THE BOCA BASIC CODES ARE DESIGNED TO PROTECT PUBLIC HEALTH, SAFETY AND WELFARE THROUGH EFFICIENT AND EFFECTIVE USE OF AVAILABLE MATERIALS AND CURRENT TECHNOLOGY." (taken from inside the front cover, BOCA Basic Building Code 1981 edition).

The code official is apt to compare the array with building materials and subsystems more familiar to him. Correlations between photovoltaic arrays and modules and materials and subsystems currently addressed within existing code documents may be made on the basis of similar function or appearance. The basic function of the photovoltaic array can be found in the definition of photovoltaic: " capable of generating a voltage as a result of exposure to visible or other radiation".[1] The resulting

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[1] Dictionary of Scientific and Technical Terms, McGraw-Hill Book Company, Daniel W. Lapedes, Editor, New York ©1974, p 1116.

current which is produced is beyond the competence of the model codes themselves to regulate. As a result, the model codes defer judgment of electrical installation and equipment standards to the National Electric Code (Figure 6.6).

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 2000.3: ELECTRIC INSTALLATION STANDARDS

CONFORMANCE OF INSTALLATION OF ELECTRIC CONDUCTORS AND EQUIPMENT TO NFiPA70* LISTED IN APPENDIX A SHALL BE THE PRIMA FACIE EVIDENCE THAT SUCH INSTALLATIONS ARE REASONABLY SAFE FOR USE IN THE SERVICE INTENDED AND IN COMPLIANCE WITH PROVISIONS OF THIS CODE.

* THE NFiPA (NATIONAL FIRE PROTECTION ASSOCIATION) ARTICLE 70 IS ALSO KNOWN AS THE NATIONAL ELECTRIC CODE.

SECTION 20000.4: ELECTRIC EQUIPMENT STANDARDS

THE MATERIALS, APPLIANCES AND OTHER EQUIPMENT LISTED IN PUBLISHED REPORTS OF INSPECTED ELECTRICAL EQUIPMENT BY THE UNDERWRITERS LABORATORY INC. (U.L.), AND OTHER APPROVED AGENCIES AND TESTING ORGANIZATIONS, AND INSTALLED IN ACCORDANCE WITH ANY INSTRUCTIONS INCLUDED AS PART OF SUCH LISTINGS, SHALL BE APPROVED AS MEETING THE REQUIREMENTS OF THIS CODE.

Figure 6.6

Particular attention should be paid to the phrase "reasonably safe for use in the service intended and in compliance with provisions of this code." This delegates responsibility for electrical authority approval while retaining some "approval" (or disapproval) flexibility. (See also Figure 6.5.)

GENERAL STRUCTURE OF BUILDING CODES

When sectors of the construction industry other than one or two-unit residences are considered, the requirements governing those structures can become very complex. Model building codes consider such things as the type of occupant, the area of each floor and the number of stories or vertical height in determining that level of safety necessary for the constituant materials of a building.

Building materials must achieve the level of fire resistance with structural retention characteristics consistent with the specified construction type illustrated in Figure 6.7. If we utilize the 1981 Edition of the BOCA Basic Building Code again, Table 401 differentiates between some of the various structural elements found commonly in a building. (Similar tables can be found in the ICBO Uniform Building Code 1979 Edition, Table 17-A and SBCC Standard Building Code 1979 Edition, Table 600.)

Figure 6.7 outlines hours of fire resistance required for various building assemblies. They are "hours" as defined by a laboratory test written under the auspices of the American Society of Testing Materials (ASTM). There are numerous organizations such as ASTM; the American National Standards Institute (ANSI), the Underwriters Laboratory (UL), and the National Fire Protection Association (NFiPA), for instance, which author the procedures for such laboratory tests. Building codes utilize results from these tests, commonly referred to as standard tests or simply standards, as a basis for comparison to an arbitrary minimum performance level. These standard test procedures are not intended to depict actual stress, wear or hazard to a product or assembly. They do, however, attempt to depict approximate in service conditions. Frequently, building codes attempt to restrict materials which cannot perform acceptably under the stress of what may be considered the worst case; the hottest fire, the strongest wind, the deepest snow or the most debilitating handicap. The issue of worst case performance standards can be illustrated with an example.

Figure 6.7 depicts fire resistance ratings of structure elements in hours. These "hours" signify hours of exposure to flame of a certain characteristic. A sample is prepared in a particular manner, the edge conditions being obviously important, and mounted in a special chamber. Flaming gas jets produce temperatures delineated in Figure 6.8 as a function of time.

FIRERESISTANCE RATINGS OF STRUCTURE ELEMENTS (IN HOURS)

Structural element Note a		Type of construction Section 401 0									
		Type 1 Section 402 0		Type 2 Section 403 0			Type 3 Section 404 0			Type 4 Section 405 0	
		Noncombustible		Noncombustible			Combustible			Combustible	
		Protected		Protected		Unprotected	Heavy timber	Protected	Unprotected	Protected	Unprotected
		1A	1B	2A	2B	2C	3A	3B	3C	4A	4B
Exterior walls	(Section 1406 0 and Note b)										
1 Fire separation of 30' or more	Bearing	4	3	2	1	0	2	2	2	1	0
	Nonbearing	0	0	0	0	0	0	0	0	0	0
Fire separation of less than 6'	Bearing	4	3	2	1½	1	2	2	2	1	1 see Sec 503 2
	Nonbearing	2	2	1½	1	1	2	2	2	1	1 see Sec 503 2
Fire separation of 6' or more but less than 11'	Bearing	4	3	2	1	0	2	2	2	1	0
	Nonbearing	2	2	1½	1	0	2	2	2	1	0
Fire separation of 11' or more but less than 30'	Bearing	4	3	2	1	0	2	2	2	1	0
	Nonbearing	1½	1½	1	1	0	see Sec 404 0	1½	1½	1	0
2 Fire walls and party walls (Section 1407.0)		4	3	2	2	2	2	2	2	2	2
		← Not less than fire grading of use group—(see Table 1402) →									
3 Fire separation assemblies (Sections 312.0, 1409 0 and 1412.0)		← Fireresistance rating corresponding to fire grading of use group—(see Table 1402) →									
4 Fire enclosures of exits, exit hallways and stairways (Section 1409.0 and Note c)		2	2	2	2	2	2	2	2	2	2
5 Shafts (other than exits) and elevator hoistways (Section 1410.0 and Note c)		2	2	2	2	2	2	2	2	1	1
		← Noncombustible →									
6 Exit access corridors (Note g)		1	1	1	1	1	1	1	1	1	1
		← Note e →									
Vertical separation of tenant spaces		1	1	1	1	0	1	1	0	1	0
		← Note e →									
7 Dwelling unit separations		1	1	1	1	1	1	1	1	1	1
		← Note e →									
Other nonbearing partitions		0	0	0	0	0	0	0	0	0	0
		← Note e →									
8 Interior bearing walls, bearing partitions, columns, girders, trusses (other than roof trusses) and framing (Section 1411.0)	Supporting more than one floor	4	3	2	1	0	see Sec 404 0	1	0	1	0
	Supporting one floor only	3	2	1½	1	0	see Sec 404 0	1	0	1	0
	Supporting a roof only	3	2	1½	1	0	see Sec 404 0	1	0	1	0
9 Structural members supporting wall (Section 1411 0)		3	2	1½	1	0	1	1	0	1	0
		← Not less than fireresistance rating of wall supported →									
10 Floor construction including beams (Section 1412 0)		3	2	1½	1	0	Note d see Sec 404 0	1	0	1	0
11 Roof construction, including beams, trusses and framing arches and roof deck (Section 1412 0 and Note f)	15' or less in height to lowest member	2	1½	1	1	0	see Sec 404 0 Note d	1	0	1	0
				← Note e →							
	More than 15' but less than 20' in height to lowest member	1	1	1	0	0	see Sec 404 0 Note d	0	0	1	0
		← Note e →									
	20' or more in height to lowest member	0	0	0	0	0	see Sec 404.0 Note d	0	0	0	0
		← Note e →									

Notes applicable to Table 401

Note a. For special high hazard uses involving a higher degree of fire severity and higher concentration of combustible contents, the fireresistance rating requirements for structural elements shall be increased accordingly (see Section 600 2).

Note b. The fire separation or fire exposure in feet as herein limited applies to the distance measured from the building face to the closest interior lot line, the center line of a street or public space or an imaginary line between two buildings on the same property (see definition of fire separation, exterior fire exposure in Section 201.0)

Note c. Exit and shaft enclosures connecting three floor levels or less shall have a fireresistance rating of not less than one hour (see Sections 1409.1.3 and 1410 3).

Note d. In Type 3A construction, members which are of material other than heavy timber shall have a fireresistance rating of not less than one hour (see Section 1224 2)

Note e. Fire-retardant treated wood, complying with Section 1403.5 1 may be used as provided in Section 1403.5.2 (see Section 1405.9)

Note f. Where the omission of fire protection from roof trusses, roof framing and decking is permitted, horizontal or sloping roofs in buildings of Type 1 and Type 2 construction immediately above such members shall be constructed of noncombustible materials of the required strength without a specified fireresistance rating, or of Type 3A construction in buildings not over five stories or 65 feet in height (see Section 1413.3).

Note g. Exit access corridors serving 30 or fewer occupants may have a zero fireresistance rating (see Section 810.4).

Note h. 1 foot = 304.8 mm

Figure 6.7

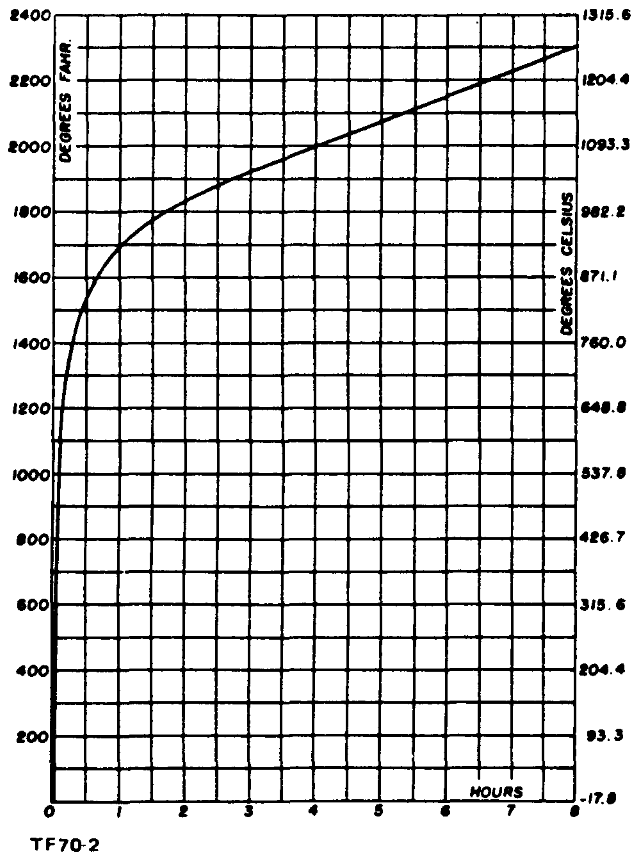

Figure 6.8

This is a rough description of ASTM-E 119, Standard Methods of Fire Test of Building Construction and Materials. The specimen is required to withstand the stress of a fire hose stream in addition to the heat and flame alone. If under these conditions an assembly or material can retain its structural characteristics for a certain period of the time, it is rated for that amount of time.

This standard was developed originally in 1917. It was based upon experimentation with condemned buildings which were packed full of wooden combustibles and set aflame. The curve depicted in Figure 6.8 was the result. This curve is not typical of a fire in modern day buildings with contemporary loading characteristics and furnishings. Figure 6.9 may be a more accurate portrayal of the time dependent nature of the temperature of a fire in comparison with the ASTM E119 curve (shown as a dotted line). Modern materials burn hotter than the old wood loaded test structures and the resulting fires terminate after a shorter period of time.

TIME-TEMPERATURE CURVE

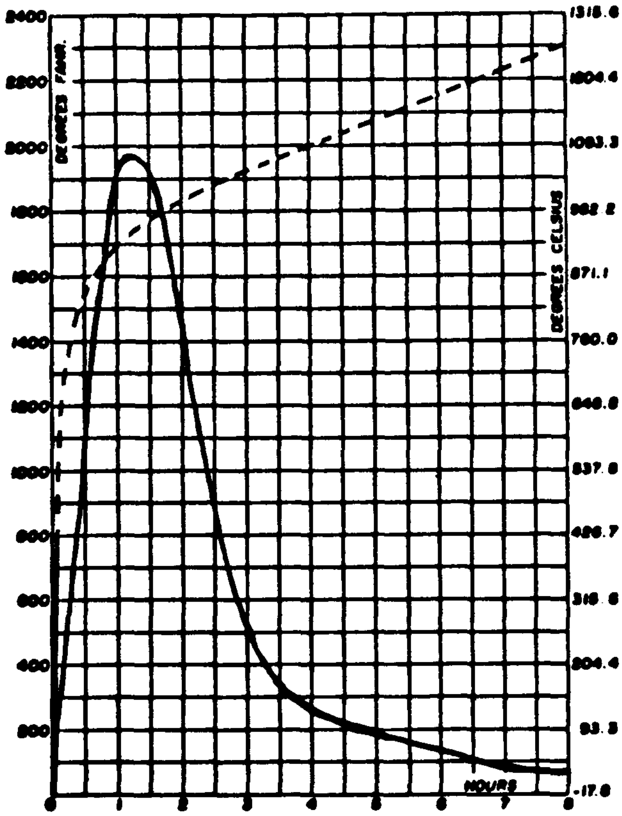

Figure 6.9

Many of the Standards referenced by the code official are written by product associations, such as the National Forest Products Association (NFoPA), American Institute of Steel Construction (AISC), American Concrete Institute (ACI), Aluminum Association (AA), Brick Institute of America (BIA), or the Steel Joist Institute (SJI). Situations where such standards are referenced within the codes are difficult to supplant with innovative materials. Generally, when a standard test procedure is written, it tends to depend directly upon the type of material being subjected to the test. Fire tests can be misleading in this way. The time dependent temperature curve illustrated in the previous example points out the differences between what was common for constituant materials and furnishings in 1917 and today. There are some real questions as to whether photovoltaic arrays can be rationally compared to traditional construction with this performance test.

Further analysis of fire resistance may be found below under fire resistance rated assemblies for both wall and roof locations.

Figure 6.10 is from the 1981 Edition of the BOCA Basic Building Code and illustrates an area and height dependence graphically. (Similar tables can be found in the ICBO Uniform Building Code 1979 Edition Table 5-C and 5-D and SBCC Southern Standard Building Code 1979 Edition Table 400.)

Figure 6.7 illustrates that as building height and/or total area increases and as the propensity for hazard in a particular occupancy type increases (for example, assembly-theatre occupancies are inherently more hazardous than business occupancies and are, therefore, less severely restricted), the more restrictive the construction type must be.

To further complicate matters, each of the model building codes establishes areas or zones of particular fire hazard. The terminology varies from Fire Zone to Fire Limits to Fire District. The criteria which distinguishes "inside Fire Limits" to "outside Fire Limits" are fairly consistent from code to code (see Figure 6.11). The ensuing tightening of fire resistance performance requirements within these Fire Zones, Districts or Limits are also fairly consistent. Generally, occupancies designated High Hazard are not permitted within Fire Limits. Wood frame and unprotected combustible and noncombustible construction are more severely restricted within Fire Limits.

HEIGHT AND AREA LIMITATIONS OF BUILDINGS

Height limitations of buildings (shown in upper figure as stories and feet above grade), and area limitations of one or two story buildings facing on one street or public space not less than 30 feet wide (shown in lower figure as area in square feet per floor). See Note a.

N.P.—Not permitted
⊠ Unlimited

Use group				Type 1 Noncombustible Protected Note b		Type 2 Noncombustible Protected		Type 2 Noncombustible Unprotected	Type 3 Combustible Heavy Timber	Type 3 Combustible Protected	Type 3 Combustible Unprotected	Type 4 Combustible Protected	Type 4 Combustible Unprotected
			Note a	1A	1B	2A	2B	2C	3A	3B	3C	4A	4B
A-1-A	Assembly, theatres	With stage and scenery		Unlimited	6 St. 75' 14,400	4 St. 50' 11,400	2 St. 30' 7,500	1 St. 20' 4,800	2 St. 30' 7,200	2 St. 30' 6,600	1 St. 20' 4,800	1 St. 20' 5,100	N P
A-1-B	Assembly, threatres	Without stage (motion picture theatres)		Unlimited	Unlimited	5 St. 65' 19,950	3 St. 40' 13,125	2 St. 30' 8,400	3 St. 40' 12,600	3 St. 40' 11,550	2 St. 30' 8,400	1 St. 20' 8,925	1 St. 20' 4,200
A-2	Assembly, night clubs and similar uses			Unlimited	4 St. 50' 7,200	3 St. 40' 5,700	2 St. 30' 3,750	1 St. 20' 2,400	2 St. 30' 3,600	2 St. 30' 3,300	1 St. 20' 2,400	1 St. 20 2,550	1 St. 20' 1,200
A-3	Assembly	Lecture halls, recreation centers, terminals, restaurants other than night clubs		Unlimited	Unlimited	5 St. 65' 19,950	3 St. 40' 13,125	2 St. 30' 8,400	3 St. 40' 12,600	3 St. 40' 11,550	2 St. 30' 8,400	1 St. 20' 8,925	1 St. 20' 4,200
A-4	Assembly, churches, schools		Note c	Unlimited	Unlimited	5 St. 65' 34,200	3 St. 40' 22,500	2 St. 30' 14,400	3 St. 40' 21,600 Note d	3 St. 40' 19,800	2 St. 30' 14,400	1 St. 20' 15,300 Note d	1 St. 20' 7,200 Note d
B	Business			Unlimited	Unlimited	7 St. 85' 34,200	5 St. 65' 22,500	3 St. 40' 14,400	5 St. 65' 21,600	4 St. 50' 19,800	3 St. 40' 14,400	3 St. 40' 15,300	2 St. 30' 7,200
F	Factory and industrial			Unlimited	Unlimited	6 St. 75' 22,800	4 St. 50' 15,000	2 St. 30' 9,600	4 St. 50' 14,400	3 St. 40' 13,200	2 St. 30' 9,600	2 St 30' 10,200	1 St. 20 4,800
H	High hazard		Note e	5 St. 65' 16,800	3 St. 40' 14,400	3 St. 40' 11,400	2 St. 30' 7,500	1 St. 20' 4,800	2 St. 30' 7,200	2 St. 30' 6,600	1 St. 20' 4,800	1 St. 20' 5,100	N P
I-1	Institutional, restrained			Unlimited	6 St. 75' 18,000	4 St. 50' 14,250	2 St. 30' 9,375	1 St. 20' 6,000	2 St. 30' 9,000	2 St. 30' 8,250	1 St. 20' 6,000	1 St. 20' 6,375	N P
I-2	Institutional, incapacitated			Unlimited	8 St. 90' 21,600	4 St. 50' 17,100	2 St. 30' 11,250	1 St. 20' 7,200	2 St. 30' 10,800	2 St. 30' 9,900	1 St. 20' 7,200	1 St. 20' 7,650	N.P
M	Mercantile			Unlimited	Unlimited	6 St. 75' 22,800	4 St. 50' 15,000	2 St. 30' 9,600	4 St. 50' 14,400	3 St. 40' 13,200	2 St. 30' 9,600	2 St. 30' 10,200	1 St. 20' 4,800
R-1	Residential, hotels			Unlimited	Unlimited	9 St. 100' 22,800	4 St. 50' 15,000	3 St. 40' 9,600	4 St. 50' 14,400	4 St. 50' 13,200	3 St. 40' 9,600	3 St. 40' 10,200	2 St. 35' 4,800
R-2	Residential, multi-family			Unlimited	Unlimited	9 St. 100' 22,800	4 St. 50' 15,000 Note f	3 St. 40' 9,600	4 St. 50' 14,400	4 St. 50' 13,200 Note f	3 St. 40' 9,600	3 St. 40' 10,200	2 St. 35' 4,800
R-3	Residential, one and two family			Unlimited	Unlimited	4 St. 50' 22,800	4 St. 50' 15,000	3 St. 40' 9,600	4 St. 50' 14,400	4 St. 50' 13,200	3 St. 40' 9,600	3 St. 40' 10,200	2 St. 35' 4,800
S-1	Storage, moderate		Notes g and h	Unlimited	Unlimited	5 St. 65' 19,950	4 St. 50' 13,125	2 St. 30' 8,400	4 St. 50' 12,600	3 St. 40' 11,550	2 St. 30' 8,400	2 St. 30' 8,925	1 St. 20' 4,200
S-2	Storage, low			Unlimited	Unlimited	7 St. 85' 34,200	5 St. 65' 22,500	3 St. 40' 14,400	5 St. 65' 21,600	4 St. 50' 19,800	3 St. 40' 14,400	3 St. 40' 15,300	2 St. 30' 7,200
T	Temporary, miscellaneous			Unlimited	Unlimited								

Notes applicable to Table 505

Note a. See the following sections for general exceptions to Table 505.
Section 505.4 Allowable area reduction for multi-story buildings.
Section 506.2 Allowable area increase due to street frontage.
Section 506.3 Allowable area increase due to automatic fire suppression system installation.
Section 507.0 Unlimited area one story buildings.
Section 508.1 Allowable height increase due to automatic fire suppression system installation.

Note b. Type 1 buildings permitted unlimited tabular heights and areas are not subject to special requirements that allow increased heights and areas for other types of construction (see Section 506.5).

Note c. The tabular area of one story school buildings of Use Group A-4 may be increased 200 percent provided every classroom has at least one door opening directly to the exterior of the building. Not less than one half of the required exits from any assembly room included in such buildings shall also open directly to the exterior of the building (see Section 506.4).

Note d. Auditoriums in buildings of Use Group A-4 of Type 1, 2A, 2B, 3A, 3B or 4A construction may be erected to 65 feet in height, and of Type 2C, 3C or 4B construction to 45 feet in height (see Section 508.2).

Note e. For exceptions to height and area limitations of buildings of Use Group H see Article 6 governing the specific use. For other special fireresistive requirements governing specific uses, see Section 1405.0.

Note f. For exceptions to height of buildings of Use Group R-2 of Types 2B and 3B construction, see Section 1405.6.

Note g. For height and area exceptions covering open parking structures, see Section 628.0.

Note h. For height and area exceptions covering petroleum bulk storage buildings, see Section 1405.3.

Note i. 1 foot = 304.8 mm; 1 foot^2 = 0.093 m^2.

Figure 6.10

1981 BOCA BASIC CODE

SECTION 501.2 FIRE LIMITS

THE FIRE LIMITS SHALL COMPRISE THE AREAS CONTAINING CONGESTED BUSINESS, COMMERCIAL, MANUFACTURING, AND INDUSTRIAL USES OR IN WHICH THE USES ARE DEVELOPING. THE LIMITS OF SUCH AREAS ARE DESCRIBED AS BOUNDED BY (TO BE SPECIFIED).

SECTION 501.3 OUTSIDE FIRE LIMITS

ALL OTHER AREAS NOT INCLUDED IN THE FIRE LIMITS SHALL BE DESIGNATED AS OUTSIDE FIRE LIMITS.

Figure 6.11

Fire Limits were established originally to curtail the danger of uncontrollable conflagration in these "congested business, commercial, manufacturing and industrial uses..." The existance of Fire Limits points to a clear distinction between protection from oneself and from one's neighbors. If statistics show photovoltaic array owners to be "bad neighbors", the PV installation could result in increased cost to building owners for less flammable construction type materials both for the building with a PV array as well as neighboring buildings. Zoning ordinances could begin to exclude the use of photovoltaic arrays if the danger of expensive regulatory compliance scares away potential commercial/industrial development prospects.

PV module cover material may be either glass or plastic. Depending upon the type of cover material, its performance under standard test procedures and its historical performance on buildings, the pottant material may be scrutinized by the code official. This could make almost any module subject to the inherent restrictions imposed on "plastic" materials.

Although the trend is for glass cover material, plastics may play an important part in the future of photovoltaics. Therefore, the following discussion will give the reader a portion of the historical development of plastics in the building industry and, subsequently, its inclusion in the codes. The PV module manufacturer will then be able to evaluate the problems of product approval when plastics are used as cover material. Note, however, the composite of the module will ultimately be required to meet code; not the cover material only. (See Section 6.3 for further discussion on composites.)

In building codes which classify materials on the basis of previous experience, any new material can present classification problems. How can it be adequately compared to other materials already utilized and understood within the context of the construction industry? Plastics have been in use in the construction industry only since World War II. Clear acrylic astrodomes originally designed for B-29 bombers began to appear in residential applications on the west coast. Architects, code officials and fire marshals began to hurriedly ask; "Where can this material be utilized? What safety precautions are necessary? How does it perform under emergency conditions?"

The first problem was the definition of a plastic. Plastic is a generic term applied to a broad variety of synthetic materials. The word "plastic" does in no way accurately describe the performance characteristics of the specific material in question.

> Plastic - noun, chem. One of a large class of synthetic organic compounds capable of being molded, extruded, cast or otherwise fabricated into various shapes, or of being drawn into filaments for textiles.[1]

Plastic is a non-technical term which is popularly applied to hundreds of materials.

> "How do you provide for the control of something as dynamic, something as multifarious, something as heterogeneous, as this tremendous, proliferating line of products of the chemical industry?"[2]

It was the inability of building codes to deal with the variety of properties possessed by synthetic materials which led to a generic "plastic" label. Building codes discuss assemblies such as walls, roofs,

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[1]Funk and Wagnalls Standard Encyclopedic Dictionary; J. G. Ferguson Publishing Company, Chicago, ©1972, p. 504.

[2]Fritz J. Rarig, "Codes that Guide the Plastics Industry", Plastics in Architecture, summer session, June 1967, p. 29.

stairwells and canopies. However, they also address specific materials themselves. Articles Eleven and Twelve of the 1981 Edition of the BOCA Basic Building Code (pp. 229-269) deal with "Materials and Tests" and "Steel, Masonry, Concrete, Gypsum and Lumber Construction" respectively. Article Twenty-Four addresses Light Transmitting Plastic Construction.

In the 1976 Edition of the ICBO Uniform Building Code address materials throughout Part VI - Engineering Regulations - Quality and Design of the Materials of Construction. Chapters 24 - 28 address masonry, wood, concrete, steel and aluminum. Chapter 52 addresses plastics and Chapter 54 addresses glass and glazing. In the 1976 Edition of the SBCC Standard Building Code, Chapter 14 - 18 address masonry, steel, wood, lathing, plaster and gypsum. Chapters 26 and 27 address light transmitting plastics and glass.

However, unlike masonry, steel, wood, gypsum or glass, different types of plastics show a wide range of physical performance characteristics (see Figures 6.12 and 6.13).

Building codes have not regulated each of the materials which are commonly termed "plastic". There were more "plastics", even in the 1960's, than the sum of all different "conventional materials" regulated within the codes. The early emphasis was on regulation which would eliminate rapid burning plastics. A system of plastics classification which identified rapid burning, slow burning and self-extinguishing plastics was developed.

The differences between burning rates were established through small scale standard test methods which, as can be seen frequently in standards, are not intended to reflect the actual burning characteristics of the plastics under in service fire conditions (see Figure 6.14).

American Society for Testing and Materials Abbreviations Relating to Plastics (ASTM Standards, Vol. 27, 1968).

Term	Abbreviation	Thermo-plastic	Thermo-setting
Epoxy, epoxide	EP		
Perfluoro(ethyl-ene-propylene) copolymer	FEP	•	
Polycarbonate	PC	•	
Polyethylene	PE	•	
Poly(methyl methacrylate)	PMMA	•	
Polymonochloro-trifluoroethylene	PCTFE	•	
Polypropylene	PP	•	
Polytetrafluoro-ethylene	PTFE	•	
Poly(vinyl acetate)	PVAc	•	
Poly(vinyl alcohol)	PVAL	•	
Poly(vinyl butyral)	PVB	•	
Poly(vinyl chloride)	PVC	•	
Poly(vinyl chloride-acetate)	PVCAc	•	
Poly(vinyl fluoride)	PVF	•	
Poly(vinyl formal)	PVFM	•	
Silicone plastics	SI		

Figure 6.12

Table 2
Selected Properties of Plastics

Property	ASTM Test Method	ABS Acrylonitrile-Butadiene-Styrene	PMMA Acrylic	CA,CAB, CAP, CN, CP, EC Cellulosics	EP Epoxies	FEP, PCTFE, PTFE,PVF Fluoro-plastics	MF Melamine-Form-aldehyde	PA Nylon Polyamide	PF Phenol-Form-aldehyde
Tensile Strength, psi	D638-D651	4000-8000	7000-11,000	2000-9000	4000-30,000	2000-7000	5000-13,000	7000-35,000	3000-18,000
Elongation, per cent	D638	2-300	2-10	5-100	0.5-70	80-300	0.30-0.90	10-320	0.13-2.25
Tensile Modulus, 10^5 psi	D638	0.23-1.03	0.35-0.50	0.065-0.60	0.001-3.04	0.05-0.30	1.2-2.4	0.11-1.80	0.25-5.00
Compressive Strength, psi	D695	7000-22,000	11,000-19,000	2000-36,000	1000-40,000	1700-10,000	20,000-45,000	6700-24,000	10,000-70,000
Compressive Modulus, 10^5 psi	D695	0.17-0.39	0.37-0.46	–	–	– to 0.12	–	0.185-0.248	–
Flexural Yield Strength, psi	D790	5000-27000	12,000-17,000	2000-16,000	1000-60,000	7400-9300	9000-23,000	no break to 17,500	4000-60,000
Flexural Modulus, 10^5 psi	D790	0.20-1.30	0.39-0.47	–	–	– to 0.20	–	0.14-1.14	– to 2.4
Hardness, Rockwell	D785	R75-M100	M80-M105	R34-R125	M80-M120	R25-95 (Shore) D50-D80	M110-M125	R108-E75	M37-E101
Impact Strength, ft-lb/in notch	D256	1.0-10	0.3-0.5	0.4-8.5	0.2-10	3.0 to no break	0.24-6	1.0-5.5	0.2-18
Thermal Conductivity, Btu/ft²/in./hr/°F	C177	1.3-2.3	1.2-1.7	1.1-2.3	1.2-8.7	0.9-1.7	1.9-4.9	1.5-2.5	0.9-6.4
Thermal Expansion, 10^{-6}/°F	D696	39-73	28-50	44-111	3-55	25-66	11-25	7-83	14-33
Resistance to Heat, Continuous, °F		140-230	140-200	115-220	200-550	300-550	210-400	175-400	200-550
Burning Rate, in./min	D635	slow to self-extinguishing	slow	self-extinguishing to very fast	slow to non-burning	none to self-extinguishing	nonburning to very slow	self-extinguishing to slow-burning	none to slow
Effect of Sunlight	–	none to slight yellowing	none	Slight to discoloration, embrittlement	none to slight	none to slight bleaching	slight to darkening	slight dis-coloration	darkens
Clarity		translucent to opaque	Excellent to opaque	Transparent to opaque	transparent to opaque	transparent to opaque	translucent to opaque	translucent to opaque	transparent to opaque
Machining Qualities		Good to excellent	Fair to excellent	Good to excellent	poor to excellent	excellent	fair to good	fair to excellent	poor to good
24-hr Water Absorption, ⅛-in. thickness per cent	D570	0.2-0.45	0.3-0.4	0.8-7.0	0.08-4.0	0.00-0.04	0.08-0.80	0.4-1.5	0.1-2

Table 2
Selected Properties of Plastics (*continued*)

Property	PC Poly-carbonate	Polyesters	PE Polyethylene	PP Poly-propylene	PS, SAN, SBP, SRP Polystyrene	SI Silicones	UF Urea-Form-aldehyde	UP Urethanes	PVAc, PVAl, PVB, PVC, PVCAc, PVFM
Tensile Strength, psi	8000-20,000	800-50,000	1000-5500	2900-9000	1500-20,000	800-35,000	5500-13,000	175-10,000	500-9000
Elongation, per cent	0.9-1.30	0.5-310	15-1000	2-700	0.75-80	– to 100	0.5-1.0	10-1000	2-450
Tensile Modulus, 10^5 psi	0.35-1.85	0.3-2.0	0.014-0.18	0.1-0.9	0.15-1.4	0.0009-3.0	1.0-1.5	0.01-1.0	0.05-0.6
Compressive Strength, psi	12,500-19,000	12,000-50,000	– to 5500	3700-8000	4000-22,000	100-18,000	25,000-45,000	20,000	1000-22,000
Compressive Modulus, 10^5 psi	0.3-0.45	–	– to 0.15	– to 0.3	– to 0.53	–	–	0.004-0.1	– to 0.6
Flexural Yield Strength, psi	13,500-30,000	8000-80,000	– to 7000	5000-11,000	5000-26,000	– to 35,000	10,000-18,000	– to 9000	– to 17,000
Flexural Modulus, 10^5 psi	0.34-1.20	– to 2.0	– to 0.35	0.125-0.825	– to 1.8	–	1.3-1.6	0.01-0.35	– to 0.4
Hardness, Rockwell	M70-R118	60(Barcol)-E98	D30(Shore)-R15	R30-R110	R50-E60	40(Shore)-M95	M110-M120	20A(Shore)-M28	10A(Shore)-M85
Impact Strength, ft-lb/in notch	1.2-17.5	0.2-16.0	0.5-2.0 to no break	0.5-20.0	0.25-11.0	– to 15	0.25-0.40	5 to flexible	0.4-20 Impact strength varies with type and amount of plasticizer
Thermal Conductivity	0.7-1.5	1.2-7.2	2.3-3.6	0.6-1.2	0.3-1.0	1.0-3.8	2.0-2.9	0.5-2.1	0.9-20
Thermal Conductivity, Btu/ft²/in./hr/°F	10-37	7-56	56-195	16-57	19-117	4-167	12-20	56-112	28-195
Resistance to Heat, Continuous, °F	250-275	250-450	180-275	190-320	140-220	400- >600	170	190-250	120-210
Burning Rate, in./min	self-extinguishing	slow to non-burning	slow to self-extinguishing	slow to non-burning	slow to non-burning	none to slow	self-extinguishing	slow to self-extinguishing	slow to self-extinguishing
Effect of Sunlight	slight color change	none to slight yellowing, embrittlement	unprotected crazes fast, weather resistance available	unprotected crazes fast, weather resistance avail	slight yellowing	none to slight	pastels, gray	none to yellowing	slight
Clarity	transparent to opaque	transparent to opaque	transparent to opaque	transparent to opaque	excellent to opaque	clear to opaque	transparent to opaque	clear to opaque	transparent to opaque
Machining Qualities	fair to excellent	poor to excellent	fair to excellent	fair to good	fair to good	fair to good	fair	fair to excellent	poor to excellent
24-hr Water Absorption, ⅛-in. thickness per cent	0.07-0.20	0.01-1.0	· 0.01-0.06	· 0.01-0.05	0.03-0.6	– to 0.2	0.4-0.8	0.02-1.5	0.02-3.0

Figure 6.13

1. *Burning Rate.* (ASTM D635) One end of a 1/4-inch by 1/2-inch by 5-inch horizontal bar of the plastic is held in a 1-inch high Bunsen burner flame for 30 seconds (Figure 3.16) and the rate at which it burns is noted. It if does not ignite after the first 30 seconds the test is repeated. It is generally recommended by the industry that any plastic that burns faster than 2-1/2 inches per minute be excluded from building applications, even though this rate is termed moderate. Materials that burn at less than 1-1/2 inches per minute are termed slow burning. A few rates are: acrylic, 1.0; styrene, 1.1; polyethylene, 1.0; most nylons, vinyls, and vinylidene are self-extinguishing.

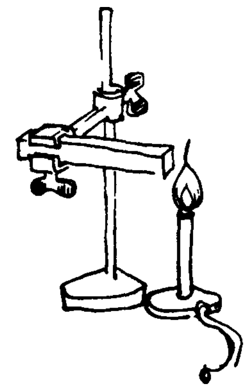

Figure 6.14

Plastic materials are defined in terms of two categories of "approved" plastics as defined in Figure 6.15 below:

BOCA BASIC BUILDING CODE 1981 EDITION

2400.2.1 APPROVED PLASTIC: AN APPROVED PLASTIC SHALL BE ANY THERMOPLASTIC, THERMOSETTING, OR REINFORCED THERMOSETTING PLASTIC MATERIAL WHICH HAS A SELF IGNITION TEMPERATURE OF 650 DEGREES F. (343.33 DEGREES C.) OR GREATER WHEN TESTED IN ACCORDANCE WITH ASTM D1929 LISTED IN APPENDIX A, A SMOKE DENSITY RATING NOT GREATER THAN 400 WHEN TESTED IN THE MANNER INTENDED FOR USE BY ASTM E84 LISTED IN APPENDIX A OR NOT GREATER THAN 75 WHEN TESTED IN THE THICKNESS INTENDED FOR USE ACCORDING TO ASTM D2843 LISTED IN APPENDIX A, AND WHICH MEETS ONE OF THE FOLLOWING COMBUSTIBILITY CLASSIFICATIONS:

CLASS C1: PLASTIC MATERIALS WHICH HAVE A BURNING EXTENT OF 1 INCH (25 MM) OR LESS WHEN TESTED IN NOMINAL POINT 0.60 INCH THICKNESS, OR IN THE THICKNESS INTENDED FOR USE, BY ASTM D635 LISTED IN APPENDIX A; OR

CLASS C2: PLASTIC MATERIALS WHICH HAVE A BURNING RATE OF 2.5 INCHES PER MINUTE (1.06 MM/S) OR LESS WHEN TESTED IN NOMINAL POINT .060 INCH THICKNESS, OR IN THE THICKNESS INTENDED FOR USE, BY ASTM D635 LISTED IN APPENDIX A.

Figure 6.15

All of the building codes under study here are consistent in this regard.

To deal with the hundreds of synthetic materials and hundreds of conditions in which the building industry would utilize those many "plastics", dozens of standard test methods would need to be written. Instead, building code promulgators decided upon some small scale tests for plastics and drew an artificial line through the test performance results. All those plastics having tests results exceeding the artificial minimum were "approved", all those falling short of the minimum performance line were not.

When the building code officials were regulating plastic materials in the codes, they first considered the feelings of the fire marshal as described in Figure 6.16 below.

> "No building official with any sense is going to propose a code change which has not first been approved by the fire department, particularly a change that will provide for the use of combustible materials. We quickly encountered from the fire officials an almost uniform response. The fire fighter has first the problem of locating the fire and rescuing occupants. He must intentionally enter a building that is on fire to find out if there is anyone to be rescued. He must locate the people that must be rescued and carry out rescue operations. Almost simultaneously he has to determine how he is going to fight the fire. He must confine it as rapidly as he can. He is concerned about contents. He is concerned about heights and areas, he is concerned about windows, he is concerned about roof, wall, and floor construction. The fire fighters said, "Look, we have no prejudice against your materials. We want them to be used. We hope they will be used, but we don't want you to do anything that makes more hazardous the conditions that confront us in a building that is on fire. Our fire-fighting equipment, our safety equipment, our extinguishing devices are all based on the problems created by conventional materials. We are familiar with fires. We expect to encounter difficulties in fighting fire. We don't expect a fire to be safe. We know a fire is dangerous. We are used to dealing with the hazards created by conventional materials. We do not want you to introduce anything into the building that is going to produce an extraordinary hazard for which we are not prepared, such as a tremendous amount of smoke or some deadly gas that will knock us out or make it impossible for us to find the occupants of the building or which will kill them under conditions where they shouldn't be killed."[1]

Figure 6.16

[1]Fritz J. Rarig, "Codes that Guide the Plastics Industry", Plastics in Architecture, summer session, June 1967, p. 36-37.

Fire fighters are accustomed to current materials and systems. They are unattracted to the prospects of hazard based upon new technologies or materials of which they have a poor understanding.

> "This is why the fire fighters insisted that we write into the codes, as a condition of their approval, a provision that a plastic material shall produce no more smoke than wood or paper burned under comparable conditions and shall have products of decomposition no more toxic in point of concentration than those of wood or paper burned under comparable conditions."[2]

However, as Albert Dietz[3] points out in Figure 6.17 below:

> "Because the chemical constituents of plastics are similar to those of wood, paper, and fabrics, the products of combustion are also similar. What those combustion products will be in any given fire depends not only upon the chemistry of the materials but on the condition of burning. With plenty of air, the principal combustion products of most plastics, woods, papers, and fabrics are harmless carbon dioxide and water; but with an oxygen deficiency there may be large volumes of carbon monoxide and smoke. Smoke evolution is also a function of composition--some of the least flammable plastics may give off the heaviest smoke. If constituents such as chlorine, fluorine, nitrogen, and sulfur are present in the plastic, they will also be present in the gases given off."

Figure 6.17

Therefore, the test methods established for comparison of plastics are seemingly subjective and should tend to favor particular plastics, mounting configurations and combustion environments.

Plastic materials are permited in a variety of wall and roof applications which may pertain to the end use of a photovoltaic array. Among these are:

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[2]Fritz J. Rarig, "Codes that Guide the Plastics Industry", Plastics in Architecture, summer session, June 1967, p. 38.

[3]Albert Dietz, "Plastics in Architecture", MIT Press, p. 72.

WALL

- Plastic glazing (see plastic glazing)
- Plastic veneer (see veneer)

ROOF

- Plastic skylight (see skylight)
- Plastic roofing material (see roof covering)

The broad range of properties of the various plastics utilized in construction are only beginning to be intuitively understood. The many types of "plastics" and their wide range of properties make it difficult to address all of them in the codes. Glass is the opposite case. The properties for glass, be it heat strengthened, fully tempered, rough rolled plate or sandblasted are consistent enough to be governed by rough, rule of thumb comparisons to regular plate or sheet glass as a norm.

The primary concerns for glass as a material are fire safety and impact loading. Not only are the occupants of the building in need of protection from the glass, but passersby below glazing installations must be protected from flying debris.

In a wall mounting condition, fire spread is the chief fire safety concern when analyzing glass. Fire spread can occur in one of two ways. Either the fire can come from another building or it can come from another location within the same building.

The following section on specific code references will:

- Define each code reference
- Describe the restrictions which building codes place on such restrictions
- Identify PV mounting configurations which code officials may logically correlate with such specific references.

A summary, conclusions and recommendations section follows the code references themselves. In cases where correlation is logical and justified, strategies will be suggested by which photovoltaic manufacturers can promote such an interpretation. Conversely, when the requirements for compliance with building code references (which could be illogically or unjustifiably correlated to photovoltaic modules, panels or arrays) pose a possible threat to the long or short range market growth for PV in the commercial/industrial sectors, strategies will be suggested for "building a defense" against such an interpretation.

Early favorable interpretations are critical for a speedy and successful infusion of photovoltaics into the marketplace. If a precedence is set for highly restrictive performance requirements or area restrictions, for instance, an "industry norm" could develop which would take time to alter.

Through education of the building industry and through proper planning, photovoltaic manufacturers can produce products intended for particular mounting applications that comply with existing requirements for materials and assemblies.

During the course of this study, the attempted identification of potential barriers within the building codes brings to light the possibility that subjective assessment of photovoltaic products by officials from over 14,000 building agencies is apt to be difficult to predict. As a result, it is possible only to identify potential interpretations that code officials could make and discuss the probability of that occurrence. Most of the interpretations are dependent on the mounting configuration (integral, direct, standoff, and rack) and location (roof, wall, or ground). There are eight combinations of these mounting applications.

Mounting applications:

- INTEGRAL WALL MOUNT
- INTEGRAL ROOF MOUNT
- DIRECT WALL MOUNT
- DIRECT ROOF MOUNT
- STANDOFF WALL MOUNT
- STANDOFF ROOF MOUNT
- RACK ROOF MOUNT
- RACK GROUND MOUNT

6.3 BUILDING CODE REFERENCES

The information in this section has been divided into the three basic mounting locations:

- Wall Locations
- Roof Locations
- Ground Locations

Each of these three will be discussed separately. Under each of these headings a listing will appear which consists of topical areas/sections of the codes which may be interpreted by a code official as similar to PV or a PV installation. In this way a manufacturer of photovoltaic modules can properly design his module for a desired use in preparing a defense or justification for review by the code official. Each of these three locations is followed by a summary, conclusions and recommendations section.

6.3.1 WALL LOCATIONS:

The following list of building component assemblies may be interpreted as having visual or functional similarities with Integral Wall, Direct Wall or Standoff Wall Mounted PV arrays:

- Awning
- Curtainwall
- Fire resistance rated assembly
- Glazing
- Insulation
- Interior surface finish
- Maintenance equipment support
- Veneer
- Vertical passage firestopping

Along with sections of the building codes which regulate the use of each assembly, commentary on the impact to the development of PV markets resulting from restrictions imposed by any such correlations is presented. Conclusions are stated addressing how much interpretations should be encouraged or discouraged.

AWNING:

definition:

Awnings may be either fixed or retractable structures supported entirely from the building with no vertical supports bearing directly on the ground.

code restrictions:

A special permit which gives the code official the opportunity to inspect plans for awnings may be required. Although awnings may either be fixed or retractable, they must be entirely supported from the building without vertical support to ground (otherwise they more resemble canopies). The covering must be 7 - 9 feet above the sidewalk. They may be restricted in their distance of projection horizontally. This varies from code to code. The awning may not be permitted to extend closer than 1 - 2 feet from the curb. It may be restricted to 5 - 7 feet from the face of the building. Above the first story, awnings may be restricted to a 4 foot projection.

Generally, awnings are metal, glass or canvas covered. Codes restrict frame to be of noncombustible materials (according to ASTM E-136 Test for Noncombustibility of Elementary Materials). When combustible framing is permitted, it is required to have a one hour fire resistance rating (according to ASTM E-119 - Methods of Fire Tests of Building Construction and Materials). The ICBO Uniform Building Code, 1976 Edition permits the use of approved (see Figure 6.19) plastics for covering material. Building codes recognize the secondary function of awnings, i.e. shading or facade decoration. As such, they permit the covering to be a combustible material (canvas, or perhaps plastic).

mounting configuration:

Utilization of "PV awning arrays" may be one way to address the issue of inclination when mounting an array on a vertical wall. It is doubtful that there is any advantage to be gained from extending beyond the projection limits for awnings outlined above. A standoff wall mounting configuration which has both an "awning appearance" and a shading function may be prone to an awning interpretation. If such an interpretation is made, the restrictions seem to be manageable.

CURTAINWALL:

definition:

Curtainwalls are exterior non-bearing enclosure walls which are not supported at each story.

code restrictions:

As such, the fire resistance requirements outlined in Figure 6.9 apply. Since a curtainwall supports its entire vertical height on a direct ground bearing, connection with the primary structural system of the building must be made with noncombustible, corrosion resistant anchors. Related assembly requirements may be found under glazing and veneers.

mounting configuration:

PV arrays integrated into a curtainwall system featuring glazing and/or spandrel panels will be considered by designers. There are no perceived barriers to the utilization of photovoltaic modules in a curtainwall framework. However, the requirements for exterior surface materials as well as structural dead, wind and earthquake loading must be considered with curtainwall designs.

FIRE RESISTANCE RATED ASSEMBLY:

definition:

Hours of fire resistance with structural characteristics retained is perhaps the most basic of all U.S. building code requirements. These "hours" are determined by ASTM E119 <u>Methods of Fire Test of Building Construction and Materials</u>. The historical development of this standard as well as the present day procedure for conduction of the test is described in detail on Pages 6-13 to 6-15 of this report. This test method was among the very earliest (1917) to establish an artificial minimum "standard" by which all assemblies would subsequently be measured for fire resistance rating. The portion of the table from ASTM E119 relating construction type to exterior wall structural element is repeated for discussion in Figure 6.18 below.

code restrictions:

FIRE RESISTANCE RATINGS OF STRUCTURE ELEMENTS (IN HOURS)

Structural Element Note a		type of construction section 401.0									
		Type 1 Section 402.0		Type 2 Section 403.0			Type 3 Section 404.0			Type 4 Section 405.0	
		Noncombustible		Noncombustible			Combustible			Combustible	
		Protected		Protected		Unprotected	Heavy Timber	Protected	Unprotected	Protected	Unprotected
		1A	1B	2A	2B	2C	3A	3B	3C	4A	4B
Exterior Walls	(Section 1406.0 and Note b)										
Fire separation of 30' or more	Bearing	4	3	2	1	0	2	2	2	1	0
	Nonbearing	0	0	0	0	0	0	0	0	0	0
Fire separation of less than 6'	Bearing	4	3	2	1-1/2	1	2	2	2	1	1 See Sec 503 2
	Nonbearing	2	2	1-1/2	1	1	2	2	2	1	1 See Sec 503 2
Fire separation of 6' or more but less than 11'	Bearing	4	3	2	1	0	2	2	2	1	0
	Nonbearing	2	2	1-1/2	1	0	2	2	2	1	0
Fire separation of 11' or more but less than 30'	Bearing	4	3	2	1	0	2	2	2	1	0
	Nonbearing	1-1/2	1-1/2	1	1	0	See Sec. 404 0	1-1/2	1-1/2	1	0

Figure 6.18

The portion of interest, exterior walls--structural element, is broken down according to two variables: proximity to other buildings, and bearing versus nonbearing walls. Due to the possibility of bearing walls losing structural strength in a fire or under the impact load of a hose stream, they have more strict fire resistance rating requirements, overall. Likewise, the proximity to other buildings is an important variable when considering fire spread; as the proximity decreases, so do the requirements for fire resistance (but only for nonbearing walls).

The avoidance of shading problems for PV arrays may dictate a certain minimum separation from other buildings. Therefore, the inherent reduction of fire resistance for nonbearing walls at increased building separations could work to the advantage of the photovoltaic industry. Bearing walls, however, have the strictest requirements of any assembly listed in the building codes. These requirements do not reduce as the distance between buildings increases as they did for nonbearing walls. Therefore, there is an incentive to utilize a nonbearing wall to mount a PV array. The ability to avoid a need for a fire resistance rating for the wall on which the array is mounted could be critical in avoiding building code conflict.

The Underwriters' Laboratories Fire Resistance Directory, January 1979 Edition, lists typical wall sections[1]. Various materials manufacturers combine products to devise these typical wall sections. The typical wall section is subsequently tested by the Underwriters' Laboratories in accordance with the test procedures outlined in ASTM E119 Methods of Fire Test of Building Construction and Materials. If a fire rating must be attained (see Figure 6.18), there are advantages to having these wall sections "listed". In the past five years, design professionals have been forced by code officials to rely more and more heavily upon the hour ratings listed in the U.L. Fire Resistance Directory for code compliance requirements. Figure 6.19 shows an example of a fire rated wall assembly.

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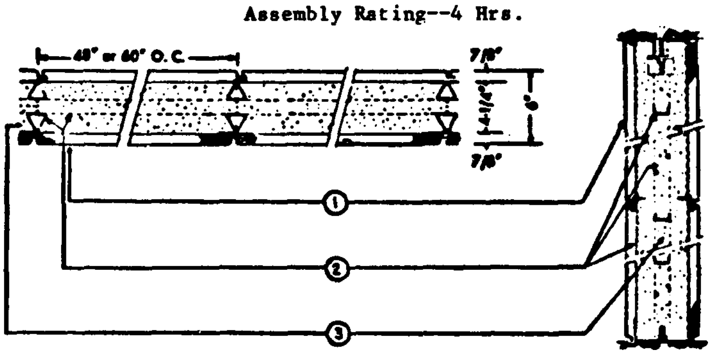
[1] Fire Resistance Directory, Underwriters' Laboratories, January 1979 Edition, pp. 472 - 559.

Design No. U001
(Formerly 10--4 Hr.)
Assembly Rating--4 Hrs.



1. Partition Panel Units*--Porcelain enameled panels each attached to studs of steel frame with three No. 8, 5/8 in. long sheet-metal screws. Glass-fiber insulated panels attached on exterior face and uninsulated panels on interior face of wall.
   Lusterlite Corp.

2. Steel Frame--Attached to masonry with 1/2-in. diam. bolts 1-1/2 in. long and expansion anchors spaced 4 to 9 in. on both sides of each vertical stud. Loading not to exceed 8,910 lbs. per stud.
3. Concrete--94 lbs. (1 bag) of cement to 4 cu. ft. of vermiculite aggregate* and 0.35 lbs. of air-entraining agent.
   Construction Products Div., W. R. Grace & Co. of Canada, Ltd.
   Hyde & Co., Ltd., F.
   Hyzer & Lewellen
   Mica Pellets, Inc.
   Robinson Insulation Co.
   Vermiculite-Intermountain, Inc.
   Vermiculite Products, Inc.
   Zonolite Construction Products Div., W. R. Grace & Co.

*Bearing the UL Classification Marking

Figure 6.19

The "listing" of photovoltaic modules by UL would encourage designers to specify the products. Designers and code officials alike have little fear of legal backlash from problems arising in UL approved products. Designers must only show reasonable care in the selection of materials "in the light of present knowledge" about such materials. Code officials likewise must only show that reasonable proof of public safety is present in the design to approve construction. The UL classifications and listing is considered to be adequate proof of safety to the public.

mounting configurations:

Theoretically, each wall section must be rated for fire resistance according to the ASTM E119 test procedures referenced above. For years, code officials permitted layers of materials to be applied over fire resistance rated wall sections and assumed that the fire resistance rating would be retained. However, in more recent years, code officials interpret additional surface layers as altering the thermal characteristics of the composite wall section sufficiently to require new fire resistance ratings (e.g. a typical wall section with a PV array attached to the exterior).

GLAZING:

definition:

Glazing is a term used to describe transparent wall panels. Glazing requirements within building codes were originally conceived to deal with the problems (particularly fire and impact hazard) associated historically with glass. With the utilization of synthetic materials which were transparent, like glass, but had different fire and impact characteristics, the term glazing no longer meant glass alone. Code officials had come to understand glass and how it performed under impact and fire loading. Glazing regulation was entirely material specific. Different types of glass did not perform radically differently. Different manufacturing processes for glass can alter impact and fire loading characteristics depending upon heat strengthening or full tempering, embedding of wire mesh, annealing, rolling or floating processes. However, the development of these processes has not radically altered the thinking of code officials about glass. Some types of glass are somewhat better than others under particular forms of fire and impact loading.

The synthetic glazing materials which are currently under development are transparent like glass. However, this is where much of the correlation ends. Unlike glass, these snythetic materials may ignite, smoke, degrade in sunlight, produce toxic emissions and deform over time. In addition, these synthetics, unlike glass, have a broad range of physical properties; and there are not just a few of these synthetics being used in the building industry or being considered for use, there are scores, perhaps even hundreds.

code requirements:

Code officials gave up long ago attempting to regulate each of the many synthetic materials being considered for use in the building industry. Code officials demanded simplification of these numerous new synthetics. The result was a set of regulations governing the minimum performance of all synthetic materials. They were all lumped together under the generic classification of "plastics".

The following discussion includes both "glass" and "plastic" materials regulated by building codes as well as wall mounted "glazing" assemblies. The differences in requirements for plastic glazing and glass are outlined. Much of the success of the photovoltaic industry to produce an economical and safe product hinges on the constituent materials of the modules. The fact that PV modules are essentially sandwich panels which have the potential for a wide variety of constituent materials--glass, acrylic, steel, concrete, ethylene vinyl acetate, aluminum, polyvinyl butyral, tedlar and silicon, to name a few--leaves the PV industry open to a very wide range of material specific requirements found throughout the codes.

Building Codes regulate the use of glass as a glazing material on the basis of hazard from flame spread and human impact. When concerned with fire spread, most occupancy types require the use of a wall panel at least 3 feet in height between glazing mounted one over the next vertically when the building in question exceeds 3 stories in height. This wall panel or spandrel panel must equal the rating for exterior walls found in Figure 6.9. Required ratings depend upon the proximity of the wall to other property or buildings. In the case of photovoltaic arrays, due to shading concerns, an assumption may be made that the proximity to other structures will be in excess of 30 feet of separation. Spandrel panels are discussed in greater detail under veneers which follows. The logic behind this vertical separation is to prohibit a fire from jumping from floor to floor by breaking the window in one room and exposing the outside of the building to flame until the window on the next floor breaks, as glass breaks easily under exposure to flames. (See Figure 6.20)

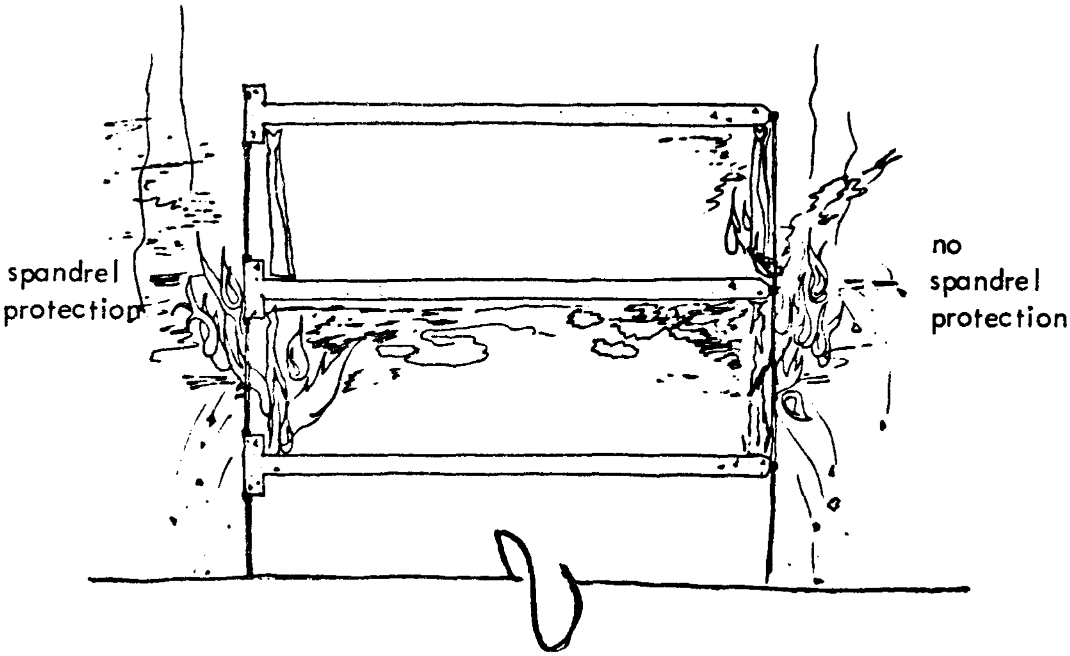


Figure 6.20

Generally speaking, windows are not permitted in walls of buildings which are within 3 - 5 feet of each other. Window's fire resistance must be rated at 3/4 hours if wall is within 10 - 20 feet. This fire resistance rating is established through ASTM-E119 Fire Tests of Building Construction and Materials. Generally, a distance less than twenty feet from the building line of another structure is an unacceptable distance for a PV array and, because of potential shading difficulties, is unlikely to occur. A 3/4 hour fire resistance rating is thus unlikely.

In most occupancy types (except perhaps Assembly and Hazardous Divisions), approved plastics are permitted as a glazing material. However, they are restricted to 25-30% of the wall face of the story on which they are installed. According to the building codes, automatic fire suppression equipment may raise the permissible area of glazing to 50-100% of the total wall area per story. The total square footage of glazing is limited to 12-16 square feet per panel with a maximum of 3-4 feet of vertical height above the first story and 10 feet on the first floor. These must be separated from story to story by 3-4 feet of noncombustible material surface finish. The plastic materials may not be permitted at heights over 75 feet.

Photovoltaic arrays interpreted as a plastic glazing material face some tough restrictions. The discontinuity of the array, forced by intermediate horizontal bands of noncombustible material, provide some serious electrical connection problems, as well as the obvious problem of reduced productive area.

As is seen frequently in the codes, the utilization of fire suppression equipment relaxes a great many restrictions. This expense is a substantial one, however, and its justification may have to come from a number of related benefits. These could include insurance, total area, aesthetic or other benefits.

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 201.0 GENERAL DEFINITIONS:

PLASTIC WALL PANELS: PLASTIC MATERIALS WHICH ARE FASTENED TO STRUCTURAL MEMBERS, OR TO STRUCTURAL PANELS OR SHEATHING, AND WHICH ARE USED AS LIGHT TRANSMITTING MEDIA IN EXTERIOR WALLS.

Figure 6.21

Related to plastic glazing is the light transmitting plastic wall panel, as defined in Figure 6.21. These are typically translucent or corrugated plastics which integrate into a similarly formed metal sheet siding system. These panels are limited in area according to Figure 6.22 below.

AREA LIMITATION AND SEPARATION REQUIREMENTS FOR PLASTIC WALL PANELS[a]

Fire separation (ft.)	Class of plastic	Max. % area of ext. wall in plastic panels	Max. sq. ft. single area	Minimum separation of panels (ft.) Vertical	Horizontal
Less than 6 ft.	---	NP[c]	NP	---	---
6ft. or more but less than 11 ft.	C1	10	50	8	4
	C2	NP	NP	---	---
11 ft. or more but less than 30 ft.	C1	25	90	6	4
	C2	15	70	8	4
Over 30	C1	50	Not limited	3[b]	0
	C2	50	100	6[b]	3

Note a See Section 2403 3 for combination of glazing and wall panel areas permitted
Note b See Section 2403 1.5
Note c Not permitted
Note d 1 foot = 304.8 mm. 1 square foot = 0.093 m^2

Figure 6.22

Due to shading considerations, a fire separation (see Figure 6.23) of over 30 feet may be assumed. Even with C1 plastics (see Figure 6.22), only 50% of the wall face may be covered with a plastic veneer. Although horizontal PV bands of the veneer are possible, they must be separated vertically by a 3 to 4 foot band of noncombustible material (as determined by ASTM E136 Test for Noncombustibility of Elementary Materials).

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 201.0 GENERAL DEFINITIONS:

FIRE SEPARATION; EXTERIOR FIRE EXPOSURE: THE DISTANCE IN FEET MEASURED FROM THE BUILDING FACE TO THE CLOSET INTERIOR LOT LINE, TO THE CENTER LINE OF A STREET OR PUBLIC WAY OR TO AN IMAGINARY LINE BETWEEN TWO BUILDINGS ON THE SAME PROPERTY.

Figure 6.23

As previously stated for plastic glazing, a module which extends through the wall from inside surface to outside surface (found only in some integral mounting configurations) may be the only application where the code official may interpret the module as a plastic wall panel. The obvious disadvantage of limited surface area would provide the same sort of electrical interconnection and surface area continuity problems encountered in the assessment of plastic glazing.

mounting configuration:

Any wall mounted PV array which is inclined from vertical over 15 to 30 degrees may be subject to the requirements outlined above. The appearance of broad expanses of glass or of plastic may lead to a glazing interpretation despite the inability of PV modules to transmit light, the common function of glazing materials. Integral wall mounts would be especially susceptable to such glazing interpretations.

INSULATION:

definition:

An insulation material is utilized in most wall sections to inhibit heat flow, either into or out of a structure.

code restrictions:

Building codes seem to be headed in the direction of mandatory energy savings features in the interest of public welfare. The Los Angeles building code refers to the insulative standards set within the California Administrative Code Title 25. However, this is only a possible trend. Insulation to comply with energy savings concerns certainly does not need to come within the PV module itself unless the module is intended to form a prefabricated composite wall panel which extends from inside surface material to outside surface material.

The building codes have another more direct public welfare concern. Even though the material for insulation is generally protected from mechanical destruction with some sort of hard exterior and interior surface finish, the insulation may potentially become involved in combustion. Figure 6.26 identifies ten major types of insulation material. "Combustibility" has been identified according to the minimum standards established in ASTM E136 - Standard Test Method for Noncombustibility of Elementary Materials. Values for surface spread characteristics, flame spread, fuel contribution and smoke developed are derived from ASTM E84 - Test for Surface Burning Characteristics of Building Materials results.

Insulation Materials	ASTM E136 Combustibility	ASTM E84 Flame Spread	Fuel Contrib.	Smoke Developed
Cellular Glass	Noncombustible	5	---	0
Cellulose	Combustible	15 - 40	0 - 40	0 - 45
Fiberglass	Noncombustible	15 - 20	5 - 15	0 - 20
Mineral Fiber	Noncombustible	15	0	0
Perlite	Noncombustible	0	0	0
Polystyrene Foam	Combustible	5 - 25	5 - 80	10 - 400
Polyurethane Foam	Combustible	25 - 75	10 - 25	155 - 500
Polyisocyanurate Foam	Combustible	25	5	55 - 200
Vermiculate	Noncombustible	0	0	0
Urea-Based Foam	Combustible	0 - 25	0 - 30	0 - 10

Figure 6.24

Five of the ten insulations listed in Figure 6.24 are rated "combustible" according to the results of ASTM E136. Of these five, four are foamed plastics. These are polystyrene, polyurethane, polyisocyanurate and urea-based foams. The other is cellulose which is shredded or milled wood pulp and/or recycled paper.

When analyzing glass versus plastic glazing materials, building codes regulated the function of "glazing" based upon the material associated traditionally with glazing: glass. The advent of "plastics" (see glazing--plastics, Pages 6-35 to 6-39) forced code officials to alter their thoughts about light transmitting media. Foamed plastics had a similar effect on insulation materials. Typically, fire hazard is approached on a fairly vague and general manner as illustrated in Figure 6.25:

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 1318.0 THERMAL AND SOUND INSULATING MATERIALS

1318.1 - GENERAL: INSULATING BATTS, BLANKETS, FILLS OR SIMILAR TYPES OF MATERIALS INCORPORATED IN CONSTRUCTION ELEMENTS INCLUDING VAPOR BARRIERS AND BREATHER PAPERS OR OTHER COVERINGS WHICH ARE PART OF THE INSULATION, SHALL BE INSTALLED AND USED IN A MANNER THAT WILL NOT INCREASE THE FIRE HAZARD CHARACTERISTICS OF THE BUILDING OR ANY PART THEREOF.

Figure 6.25

Before the advent of foamed plastics, prevalent insulating materials were mainly noncombustible natural mineral materials; mineral fiber, fiberglass, cellular glass, perlite and vermiculite. Cellulosic insulation has some special requirements. They must have a flame spread rating of 25 or less when tested in accordance with ASTM E84 Test for Surface Burning Characteristics of Building Materials. Also, they must meet the requirements outlined within CPSC Standard 16 CFR Parts 1209 and 1404; The Consumer Products Safety Commission: Cellulose Insulation - Interim Safety Standard.

Foam plastics themselves are heavily scrutinized within building codes. All foam plastics and foam plastic cores in manufactured assemblies must achieve a smoke development rating of 450 according to ASTM E84: Test for Surface Burning Characteristics of Building Materials. They must also have a flame spread rating of 75 or less according to the same ASTM E84 test. A half inch gypsum barrier or the equivalent which provides a 15 minute barrier during a fire is required between foam plastics and habitable spaces. Such a barrier must inhibit temperature change of over 250°F as well as remain intact for the 15 minute period.

Some of these requirements are somewhat relaxed, although not completely eliminated, when less fire resistive construction is utilized (such as Types 2C, 3, or 4 in Figure 6.7) in conjunction with fire suppression equipment. In the end, an array may be forced to undergo full scale testing to satisfy the building code official to demonstrate limited flame spread.

mounting configuration:

Over the course of time, photovoltaic modules may develop into complete building component wall panels which are utilized in prefabricated construction. Near term, however, the desire to expel heat from the module as quickly as possible for electrical efficiency's sake may preclude the use of thermal insulation materials. However, if for some reason the PV manufacturer should include insulation materials, the restrictions outlined above would apply.

INTERIOR SURFACE FINISH:

definition:

Any material exposed to occupants on the interior of a building which serves a decorative, acoustical or protective function must comply with the requirements for interior surface finishes. This includes any interior exposed construction.

code restrictions:

Any surface exposed to the interior space of a building, where occupants will be exposed to and confined with the materials, will need to meet some minimum requirements for the avoidance of hazard to occupants. Code officials may be concerned with long-term degradation of the surface materials. Any flaking, peeling or dust generation, especially where these materials are recognized as potentially hazardous to humans when inhaled, ingested or exposed to skin or eyes, will be disallowed. However, fire hazard is of particular concern.

Any surface material 1/28" thick (1 mm or 35.7 mils) which is no more of a fire hazard than paper and applied to a noncombustible backer will be permitted on the interior of buildings. Noncombustibility is determined according to ASTM E136 Test for Noncombustibility of Elementary Materials. Also, a noncombustible base covered with less than an eighth of an inch of combustible material having a flame spread rating of 50 or less according to ASTM E84 Test for Surface Burning Characteristics of Building Materials will be permitted.

For other interior surface materials not meeting this criteria, a smoke development rating of over 450 according to ASTM E84 is not acceptable. All surface finishes satisfying this requirement are divided into three groups as described in Figure 6.26.

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 1421.5.3 FLAME SPREAD CLASSIFICATIONS

THE CLASSIFICATION OF INTERIOR SURFACE FINISHES REFERRED TO HEREIN CORRESPOND TO FLAME SPREAD RATINGS DETERMINED BY ASTM E84 (TEST FOR SURFACE BURNING CHARACTERISTICS OF BUILDING MATERIALS) AS FOLLOWS. CLASS I FLAME SPREAD, 0-25, CLASS II FLAME SPREAD 26-75, CLASS III FLAME SPREAD 76-200.

Figure 6.26

Figure 6.27 illustrates the various classifications of flame spread permitted for required vertical exits and passage ways, corridors providing exit access and room or enclosed spaces.

INTERIOR FINISH REQUIREMENTS[h]

Use groups	Required vertical exits and passageways[d]	Corridors providing exit access	Rooms or enclosed spaces[a]
A-1 Assembly, theatres	I	I[f]	II[b]
A-2 Assembly, night clubs	I	I[f]	II[b]
A-3 Assembly halls, terminals, restaurants	I	I[f]	II[b]
A-4 Assembly, churches, schools	I	II	III
B Business	I	II	III
F Factory and industrial	I	II	III
H High hazard	I	II	III[g]
I-1 Institutional, restrained	I	I	I[c]
I-2 Institutional, incapacitated	I	II	I[c]
M Mercantile walls,	I	II	III
ceilings	I	II	II[e]
R-1 Residential, hotels	I	II	III
R-2 Residential, multi-family dwellings	I	II	III
R-3 Residential, 1 and 2 family dwellings	III	III	III
S-1 Storage, moderate hazard	II	II	III
S-2 Storage, low hazard	II	II	III

Note a. Requirements for rooms or enclosed spaces are based upon spaces enclosed in partitions of the building or structure; and where fire resistance rating is required for the structural elements, the enclosing partitions shall extend from the floor to the ceiling. Partitions which do not comply with this shall be considered as enclosing spaces, and the rooms or spaces on both sides thereof shall be counted as one in determining the applicable requirements for rooms or enclosed spaces. The specific use or occupancy thereof shall be the governing factor regardless of the use group classification of the building or structure. When an approved automatic fire suppression system is provided, the interior finish of Class II or III materials may be used in place of Class I or II materials respectively, where required in the table.
Note b. Class III interior finish materials may be used in places of assembly with a capacity of 300 persons or less.
Note c. Class III interior finish material may be used in administrative areas. Class II interior finish materials may be used in individual rooms of not over 4 persons capacity. Provisions in Note a allowing a change in interior finish classes when fire suppression protection is provided shall not apply.
Note d. Class III interior finish materials may be used for wainscoting or paneling for not more than 1,000 square feet of applied surface area in the grade lobby when applied directly to a noncombustible base or over furring strips applied to a noncombustible base and firestopped as required by Section 1422.0.
Note e. Class III interior finish materials may be used in mercantile occupancies of 3,000 square feet or less gross area used for sales purposes on the street floor only. (Balcony permitted.)
Note f. Lobby areas may be Class II.
Note g. Where building height is over two stories, shall be Class II.
Note h. The classification of interior finishes referred to herein correspond to flame spread ratings determined by ASTM E84 listed in Appendix A as follows: Class I flame spread, 0-25; Class II flame spread, 26-75; Class III flame spread, 76-200 (see Section 1421.5.3).
Note i. 1 square foot = 0.093 m^2

Figure 6.27

As can be plainly seen, less hazardous occupancy use groups (such as 1 and 2 family residential, low and moderate hazard storage) generally have lower flame spread rating requirements. On the other hand, where the consequences of a fire for a heavily populated or confined space (such as night clubs, prisons, theaters or hospitals) are severe, the flame spread requirements are severe. Generally, the flame spread requirements for horizontal and vertical circulation paths are more stringent than those for rooms and enclosed spaces.

The requirements for interior surface materials may be satisfied when the "plastic" material found exposed in the room is in a layer less than 1/28 of an inch (1 mm or 37.5 mils) thick and applied directly to a noncombustible layer as described above. The burden on the PV manufacturer is to reasonably illustrate that any "plastic" layer is, indeed, no more of a fire hazard than paper. As is noted in Figure 6.17, products of combustion from various plastics (as with wood and thus paper) vary as the composition of the material and quantity of oxygen available for combustion differ. The PV manufacturer must assemble reasonable data from various tests which will convince code officials of the module's safety as an interior surface finish.

mounting configuration:

An integral wall mounted module which extends through the wall from the outside to the inside surface of the building would be the only mounting configuration of concern for an interior surface finish interpretation. Utilizing an inside surface material with a flame spread rating lower than Class I, only serves to limit the number of potential instances where a module can be utilized. Plastic materials utilized in light transmitting applications (see Section 6.22), or those PV modules which a code official may correlate with plastic glazing, must meet the requirements for interior surface finish materials. This may be a particular concern where the module has what may be interpreted as a "plastic" substrate exposed to the interior space. The requirements outlined in this section also apply to thermal and acoustical insulation when exposed to the interior sapce of the building.

MAINTENANCE EQUIPMENT SUPPORT:

definition:

Maintenance support structure shall be considered to be any device which is intended to provide structural support for the safety of maintenance employees (both skilled and unskilled maintenance employees) and installation personnel, where pertinent. This structure may include fastening devices for straps, safety belts or lines or it may include tracks or rails for carts, platforms or similar maintenance equipment.

code restrictions:

Building codes are primarily concerned with the safety of workmen who must maintain the PV array. Maintenance can be broken down into two subgroups; preventative (periodic) maintenance and corrective (sporadic) maintenance.

Due to the potential need to clean the array or to visually inspect the modules, periodic access to the array may be necessary. When the array is to be accessed from the outside, any building over 50 feet or 4 stories in height must have anchors or other approved safety devices for all window openings. If translated to PV, this could mean anchors for each module or panel. These anchors must be of approved design and of corrosion resistive materials and attached securely to the window frame or to the exterior wall of the building itself. This approval must be subjectively awarded or denied by the code official. Cast iron and cast bronze are prohibited.

The additional risk of contact with electrically live parts makes PV module replacement inherently more hazardous than periodic maintenance. In addition, replacement of a module may be required as a result of the physical destruction of the module. The resulting replacement would be more hazardous yet. Safety lines and straps could be a necessity. Even if an electrical shock itself were not to endanger the worker directly, the increased danger of a fall necessitates special safety precautions. Code officials are similarly concerned about conductive materials utilized for maintenance equipment which may increase the hazard to the worker.

mounting configurations:

Any wall mounting configurations may be required to have maintenance support equipment if periodic maintenance is anticipated.

VENEERS:

definition:

Veneers are thin layers of waterproof exterior surface material which are either adhered or mechanically fastened to a structural backer.

code restrictions:

Adhesives may be required to be one quarter to five-eighths inch thick. They must have half of the area of the veneer directly adhered to the backer. The total area of an adhered module may be restricted to five square feet. The greatest single edge may be restricted to three feet, and the maximum weight per square foot area is fifteen pounds. If adhered modules weigh less than three pounds per square foot, there are no dimensional or area restrictions. Mechanical fasteners must be noncombustible and corrosion resistant. These fastening devices must carry the compressive and tensile wind loads applied to modules as well as the shear loads experienced from dead loading.

Building codes address three different types of veneer materials which may be of general interest when correlating veneers to PV wall mounted arrays: metal, plastic and glass veneers.

Metal veneers must be made corrosion-resistant by coating materials, if not inherently resistant. The veneer must be supported on an approved metal frame which is also protected from corrosion by galvanizing, paint or some other approved means. These approvals must be subjectively awarded or denied by the building official. Metal veneers may be required to be grounded as described in Figure 6.28.

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SECTION 1307.4 GROUNDING METAL VENEERS:

> GROUNDING OF METAL VENEERS ON ALL BUILDINGS SHALL COMPLY WITH THE REQUIREMENTS OF ARTICLE 20 AND NFiPA 70 (THE NATIONAL ELECTRIC CODE, 1981 EDITION).

Figure 6.28

Plastic veneers must be "approved plastics" as defined in Figure 6.15. Plastic veneers may not be permitted above the first story within fire limits. Outside fire limits, plastic veneer may not be permitted over 35 feet. Sections of plastic veneer are restricted to 200 square feet inside fire limits and 300 square feet outside fire limits. Such sections must be separated by four feet of noncombustible material vertically. Material must be noncombustible according to ASTM E136 Test for Noncombustibility of Elementary Materials.

The ICBO Uniform Building Code permits the use of any plastic veneer which can pass as a noncombustible material according to ASTM E136 Test for Noncombustibility of Elementary Materials or any material which has a thickness of less than one-eighth inch which is applied to a noncombustible backer and has a flame spread rating of 50 or less according to ASTM E84 Test for Surface Burning Characteristics of Building Materials. The maximum dimension or area of such plastic material is not regulated. Otherwise, "approved plastics" experience the same restrictions outlined above.

For veneers less than one inch thick, the Los Angeles building code requires that the module be less than four square feet in area. The greatest dimension of the module must be four feet or less. The total area of a side or story of a building regulated by the Los Angeles building code is 30% coverage with a plastic veneer.

The primary code concern for glass veneers is the secure connection of the material to the exterior structure of the building. All codes studied suggest a combined utilization of adhesive mastics, corrosion resistant metal ties, and corrosion resistant metal clips. The greatest area the module can be is ten square feet with the greatest side being four feet. Special consideration is given to the edge conditions of the glass. The edges themselves must be square and not mitred. The corners of the glass must be rounded. Joints are of similar concern, due to the consequences of fracture. One thirty second to One-sixteenth inch is necessary for all joints. Where the units meet a nonresilient edge, a quarter inch joint is required. In addition, glass veneer may not be permitted at heights exceeding 35 feet.

In all wall mounted configurations where the PV array does not deviate more than 15 to 30 degrees from vertical, code officials may be prone to look at exterior surface veneer requirements for similar materials. The two obvious issues are flame spread, as is most strictly regulated for plastic veneers, and breakage with resulting potential for pedestrian injury below, as is most strictly regulated for glass. Obviously, with the exposed surface of a PV module being either a plastic or a glass, these two related issues are the top candidates for consideration. The restrictions associated with plastic veneers may apply to "plastic" PV modules. As is pointed out in a description of "plastics" as a material, if under fire conditions the synthetic potant of a PV module makes it perform more like a plastic, even though the cover material may be glass, the restrictions associated with plastic veneers may be applied to the array. The dimensional and total area restrictions associated with plastics are fairly severe, not the least of which may be the need to use "approved plastics". Similarly, the need to restrict the dimension of the module to ten square feet or to a maximum edge of four feet could hamper the development of a more economical, larger module.

mounting configuration:

The PV array, due to the need for occasional module replacement and periodic maintenance will probably be mounted in a fairly unusual mounting system which may not correlate exactly with the mounting systems typically found for veneers addressed in the codes. Due to the differences in mounting methods between veneers as addressed in the codes and PV arrays, avoidance of area restrictions placed upon glass veneers based on the propensity for the units to break, endangering people below, may be successfully argued by the PV manufacturer.

VERTICAL PASSAGE FIRESTOPPING:

definition:

Any vertical opening which would permit the spread of flame or smoke in the event of a fire may be required to be plugged.

code restrictions:

Building codes insist that all buildings be firestopped at each floor, between ceiling and roof and at least at eight foot intervals to prevent the free spread of flame from one section of the building to the next. Masonry walls furred with a combustible material must be firestopped. The materials which are utilized for firestopping must be noncombustible as determined by ASTM E-136 Standard Test for Noncombustibility of Elementary Materials. Specific materials permitted by the codes include: brick, concrete, gypsum, iron, steel, asbestos, metal lath, cement or gypsum plaster, mineral wool and rock wool.

mounting configurations:

Since fire spread prevention is the obvious motivation in the definition of firestopping, fire dampers may be an alternative to prevent flame passage through vertical passages. However, due to the inherent heat generation of a photovoltaic array, a heat sensitive damper operation mechanism may prove to be inappropriate. Fire dampers must meet the requirements of UL 555 Standard for Fire Dampers. This may prove to be more expensive than firestopping but more desirable from an array operations performance standpoint.

Wall mounted PV arrays may be subject to these firestopping requirements. This could pose some heat transfer problems if cooling via ducted air from behind is employed, for instance. This could be particularly important in a curtain wall system which is structurally independent of the floor. Natural openings would therefore occur from ground to roof which need to be firestopped.

WALL LOCATION CONCLUSIONS:

If PV arrays are to be utilized in wall locations requiring a fire resistance rating, PV manufacturers must consider listing PV arrays as part of typical wall section in the Underwriters' Laboratory's Fire Resistance Directory.

It is not difficult to picture Figure 6.19 as a typical wall section listed in the UL Fire Resistance Directory which may incorporate a PV module or panel as an exterior surface finish. In addition, it is not difficult to imagine several PV manufacturers producing similar products and sharing the expense of the UL test procedure as concrete manufacturers in Figure 6.19, item number three have.

If wall mounted PV array is inclined from vertical at less than 15 to 30 degrees, wall veneers and glazing systems most resemble the array.

There are many reasons, however, as to why either a veneer or a glazing system are not a perfect fit. Veneers are restricted primarily due to their combination of large weight and mounting systems. PV arrays will be very light compared to most traditional veneers. Also, the function of a veneer is to serve as a surface finish, which due to its exposed surface, is also true to the PV array. Although this function is primarily the same in appearance; materials and mounting systems for PV wall mounted arrays may more closely resemble glazing systems. The function of a glazing system is to transmit light, on the other hand, which does not occur in a PV module.

Veneers are primarily restricted to prevent material from falling off of a building, endangering people below. This would not be a primary problem with PV arrays as the mounting details would probably be more refined than veneers and weight of the PV module would be significantly lower than most veneer materials. Glazing systems are primarily concerned with spread of fire and with human impact hazard. Plastic surface materials, perhaps including pottant materials, could cause flamespread hazards. However, if the PV array were merely a layer over other building materials, there would not be the same flame spread hazard that is normally associated with glazing systems as described above under glazing.

For wall applications, there would seem to be some serious incentive to avoid the use of "plastics" in order to avoid the restrictions placed on plastic wall panels and glazing. To fall back on the UL labeling or insurance industry approval of a product as described in Figure 6.29, may circumvent such a problem. Since the elimination of "plastic" pottant material is unlikely, the performance of glass covered modules under fire conditions (or, more accurately, under standard testing procedures for fire performance evaluation) may loom as the single most important question mark. If early performance in standard tests or in service demonstrates that a glass cover breaks readily and pottant behind smokes, ignites or oozes out, the entire module could face some of the tough area restrictions imposed on plastics.

Over all of these codes and standards and influencing all of them, including those of the federal government, are the standards of the insurance industry. These are embodied in the National Building Code and the standards and recommendations of the National Fire Protection Association, the American Insurance Association, Factory Mutual, and the Factory Insurance Association. This again is an extra legal pattern of control. Those who generate these standards and codes make no claim for them of legal status. Actually, their standards are accorded great weight because they are outside the tug and pull of political negotiation and stress and are presumed to be objective because they are promulgated by persons solely concerned with the highest standards of fire safety and electrical safety. They are given great weight by building officials who are interested in staying out of jail. It is axiomatic if a fixture, for example, had a UL label; no jury is going to convict you for malfeasance because you permitted it to be used despite the fact that it might not have been in accordance with your code. There is, of course, even more reliance on UL Standards in those localities that don't have a code. Almost without exception, a UL approved applicance can go in whether there is an applicable regulation or not. Most architects and engineers actually specify in terms of UL requirements and UL labels. A good many plastics have moved into building--courtesy of the UL label on the appliance or fixture of which the plastic is a component notwithstanding anything in the building code to the contrary.[2]

Figure 6.29

Complete through-the-wall sections where the PV array contains all materials from inside surface material will increase resistance from regulatory restriction greatly.

Such a through-the-wall section PV panel will complicate regulatory compliance primarily by giving more and more opportunity for the building code official to reject the array. The code official will be judging interior surface finish, exterior surface finish, fire resistance rating, electrical subsystem and insulation materials and unless the most stringent requirements for each is met, the chances of various code officials rejecting the "prefabricated building

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[2]Fritz Rarig, Codes that Guide the Plastics Industry, Plastics in Architecture, Summer Session, Massachusetts Institute of Technology, June 1967, pp. 26-27.

panel" are quite high. Remember too that the code official may be faced with local pressure to resist the use of prefabricated building systems. Local carpenters and contractors may perceive an adjustment of work allocation which leaves them with relatively less employment. This could lead to pressure on code officials to refuse these prefabricated panels as well. Design professionals may object to a lack of interior surface finish selection or a lack of choice for thermal resistance coefficients as well. These all point toward severe disincentives in a complicated prefabricated building panel approach to photovoltaic panel manufacture and marketing.

6.3.2 ROOF LOCATION:

The following list of building component assemblies may be interpreted as having visual or functional similarities with Rack Roof, Integral Roof, Direct Roof or Standoff Roof Mounted PV arrays:

- Awning
- Fire rated assembly
- Fire stopping
- Insulation
- Interior surface finish
- Maintenance support structure
- Roof covering
- Roof sign
- Roof structure
- Skylight
- Vapor barrier

Along with sections of the building codes which regulate the use of each assembly, commentary on the impact to the development of PV markets resulting from restrictions imposed by any such interpretational correlation is presented. Conclusions are stated addressing how such interpretations should be encouraged or discouraged. When the discussion(s) are similar or identical to those given earlier under "Wall Location", reference will be made to that section.

AWNINGS:

definition:

The definition and code requirements for awnings, identified under WALL LOCATIONS, AWNINGS, would apply to roof mounted PV arrays interpreted as awnings. (See Page 6-28.)

mounting configuration:

Any array mounted at the edge joint wall and roof (see also MANSARD ROOF, Page 6-74) may be considered to be an awning by code officials. Code officials are particularly concerned when any part of a building roof extends over public domain beyond the face of the wall.

FIRE RESISTANCE RATED ASSEMBLY:

definition:

The concept of fire resistance rating and its importance to the regulation of fire safety in buildings is outlined in depth under WAll LOCATIONS, FIRE RESISTANCE RATED ASSEMBLY (see Page 6-31). Fire resistance is rated in hours of resistance with structural integrity retained. These hours are determined by comparison of actual test sample assemblies constructed and exposed to the temperatures described in Figure 6.10 as a function of time.

code restrictions:

The building codes rate roof system fire resistances as a function of construction type and, in some cases, of uppermost story ceiling height as can be seen in Figure 6.30.

BOCA BASIC BUILDING CODE 1981 EDITION

FIRE RESISTANCE RATINGS OF STRUCTURE ELEMENTS (IN HOURS)

ROOF CONSTRUCTION INCLUDING BEAMS, TRUSSES AND FRAMING ARCHES AND ROOF DECK (SECTION 1410.0 AND NOTE F)	15' OR LESS IN HEIGHT TO LOWEST MEMBER	2	1-1/2	1	1	0	SEE SEC. 404.0	1	0	1	0
	MORE THAN 15' BUT LESS THAN 20' IN HEIGHT TO LOWEST MEMBER	1	1	1	0	0	SEE SEC. 404.0	0	0	1	0
	20' OR MORE IN HEIGHT TO LOWEST MEMBER	0	0	0	0	0	SEE SEC. 404.0	0	0	1	0

NOTES APPLICABLE TO TABLE

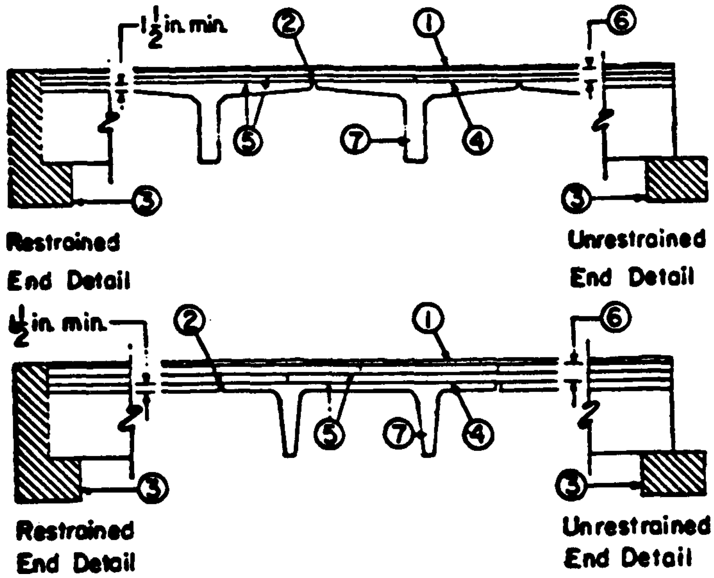
NOTE F. WHERE THE OMISSION OF FIRE PROTECTION FROM ROOF TRUSSES, ROOF FRAMING AND DECKING IS PERMITTED, HORIZONTAL OR SLOPING ROOFS IN BUILDINGS OF TYPE 1 OR TYPE 2 CONSTRUCTION IMMEDIATELY ABOVE SUCH MEMBERS SHALL BE CONSTRUCTED OF NONCOMBUSTIBLE MATERIALS OF THE REQUIRED STRENGTH WITHOUT A SPECIFIED FIRE RESISTANCE RATING OR OF TYPE 3A CONSTRUCTION IN BUILDINGS NOT OVER FIVE STORIES OR 65 FEET IN HEIGHT (SEE SECTION 1413.3).

Figure 6.30

Other model codes simply list a single fire resistance requirement for roof construction. Some codes typically offer no credit (in rating reductions) for increased ceiling height. The values for the ICBO Uniform Building Code and the SBCC Standard Building Code are practically the same as the values for roof construction at 15 feet or less in height to lowest member depicted in Figure 6.30.

As can be seen, there is a necessity to achieve a fire resistance rating within the roof system to be accepted across the entire spectrum of construction types (and thus extensively in the building industry). In the past five to ten years, the building industry has developed a greater and greater reliance upon the fire resistance ratings assigned to particular roofing system designs (such as are depicted in Figures 6.31, 6.32 and 6.33) as tested and published by Underwriters Laboratories.

Design No. P912
Restrained Assembly Rating--2 Hr.
Unrestrained Assembly Rating--1-1/2 Hr.



1. Roof Covering*--Class A, B or C Built-Up Roof Covering Materials consisting only of felt and asphalt (or coal tar pitch) materials in alternate layers. See Building Materials Directory.

1A. In lieu of Item 1, roof covering consisting of:
Built-Up Roof Covering Materials*, Class A, B or C consisting of one layer of Sheathing Material* loosely laid over optional layer of dry asbestos felt or fiberglass mat separator sheet, covered with 10 psf of 1/2 to 2-1/2 in. diam. river-bottom stone. Lap detail per manufacturer's specification. See Building Materials Directory.
    Brass Systems Inc.--Types C, CV, CVT, FK
    Dynamit Nobel of America Inc.--Types SMA, SV, S-60.

2. Joint--Precast concrete units to be butted together.

3. Minimum Bearing--3 in.

4. Sheathing Material*--Optional 0.004 in. thick vinyl or 0.009 in. thick kraft-faced vapor barrier applied with adhesive to concrete slab, overlapped approx. 2 in. on sides.
    The B. F. Goodrich Co.
    Celotex Corp., The
    Nashua Corp.
    Reflecto-Barrier Sales Co.

5. Adhesive*--To be used with board insulation. Applied at rate shown below in 1/2 in. wide ribbons, approx. 6 in. O.C. beneath each layer of board.
    The B. F. Goodrich Co.--0.4 gal./100 sq.ft.
    Johns-Manville Corp.--0.4 gal./100 sq.ft.
    Reflecto-Barrier Sales Co., Inc.--0.4 gal./100 sq.ft.

6. Mineral and Fiber Boards*--For max. thickness and number of layers required, see below. Min. thickness is 2-1/16 in. when Item 1A is used. Otherwise, min. thickness is 1-3/4 in. When more than one layer is required, each layer of board to be offset in both directions from layer below a min. of 6 in. in order to lap all joints.
    Celotex Corp., The--2 layers, max. thickness 3 in.
    Grefco, Inc.--2 layers, max. thickness 3 in.
    Johns-Manville Corp.--Min. 2 layers, max. thickness 8 in.
    Owens-Corning Fiberglas Corp.--1 or more layers, max. thickness 5 in.

7. Precast Concrete Units*--Single- or double-stemmed, lightweight or normal weight aggegate. See Precast Concrete Units category for names of manufacturers.

8. In lieu of Item Nos. 1 and 6, the insulated built-up roof covering may consist of the following:
    A. Gypsum Wallboard*--1 in. total thickness, 24 in. wide. The wallboard is placed in the adhesive and positioned so that the wall board and precast concrete unit joints are staggered a min. 6 in.
        United States Gypsum Co.--Type R.
    B. Roof Covering*--Class A, B, or C consisting only of felt and asphalt (or coal tar pitch) in alternate layers as specified in the Building Materials Directory.
    C. Foamed Plastic*--Nominal 24 in. by 48 in. size. Min. thickness 3 in. Inner layer placed into warm asphalt flood coat. No adhesive required between layers if multiple layers are used.

        Dow Chemical Co.--Type RM
    D. Crushed Stone--Max. size 1-1/2 in. spread at a rate of 1,000 lbs. per 100 sq.ft. on the outer layer of foamed plastic.

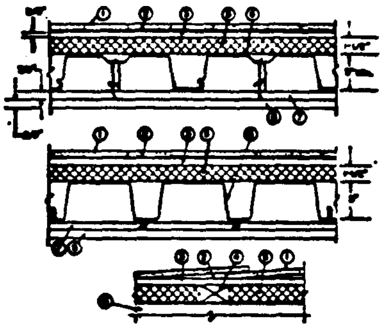
9. Foam Plastic*--(Not Shown)--Optional. Rigid foamed plastic insulation, 2 by 4 ft. boards. Min. thickness 1 in. Max. thickness 4 in. Secured to roof covering by means of asphalt glaze coat. Care to be taken to insure proper adhesion of insulation. When applied in more than one layer, successive layers shall be installed over preceding layer without attachment. Covered with crushed stone, 1-1/2 in. max. size, spread on top of foamed plastic at a rate of 10 to 20 lb. per sq.ft.
    Dow Chemical Co.

*Bearing the UL Classification Marking

Figure 6.31

Design No. P502
Restrained Assembly Rating--1 Hr.
Unrestrained Assembly Rating--1 Hr.

Design loading to be governed by deflection of L/360.

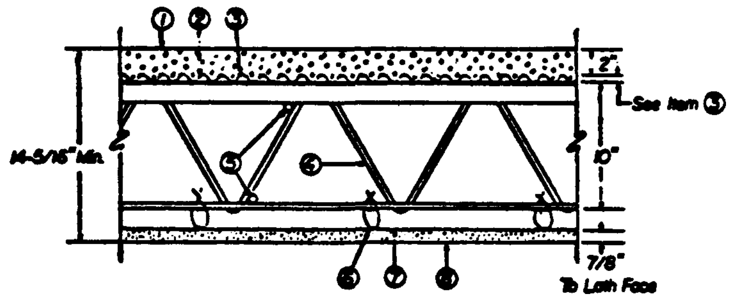


1. Clay Roofing Tiles--Nom. 14 by 9 by 3/4 in. clay roofing tiles, interlocking lips, with two nailing holes. Nom. weight, 1.1 lb. each. Attached to roof with 1-1/4 in. long galv. steel barbed roofing nails. Adjacent rows staggered 4-1/2 in.
2. Base Sheet--Asphalt-saturated rag felt, Classified as Built-Up Roofing Covering Materials* (see Classified Building Materials Index). One layer of 43 lb. felt or two layers of 30 lb. felt. Attached to roof deck with 3/4 in. long galv. steel barbed roofing nails spaced 30 in. O.C. lengthwise and 18 in. O.C. across the sheets. Adjacent sheets overlapped 4 in.
3. Roof Deck--Exterior grade plywood, 3/8 in. thick. Attached to crests of steel deck units with 2-1/4 in. long self-drilling, self-tapping Phillips-nailing strips (Item 4) are used, plywood sheets attached to nailing strips with 4d nails spaced 16 in. O.C. along sides and 24 in. O.C. in the field.
4. Nailing Strips--(Optional)--Nominal 2 by 3 in. Douglas fir lumber. Spaced approx. 48 in. O.C. perpendicular to steel deck. Attached to crests of steel deck with 2-1/4 in. long self-drilling, self-tapping Phillips-head steel screws spaced 24 in. O.C.
5. Mineral and Fiber Boards*--24 by 48 by 1-1/2 in. thick. When nailing strips are used, boards placed between and perpendicular to nailing strips.
   Grefco, Inc.
   Johns-Manville Corp.
6. Steel Roof Deck--Classified as Steel Floor and Form Units.* 3, 4-1/2, 6, or 7-1/2 in. deep galv. units, 12 or 24 in. wide, 20 MSG min. fluted units. Welded to supports 12 in. O.C. max. 1 Units with interlocking standing-rib-type side joints button-punched or welded together 36 in. O.C. along side joints.
   Inland-Ryerson Const. Prods. Co.--Types 3N, H.
   Robertson Co., H. H.--Types 5, 21.
7. Furring Channel--No. 25 MSG galv. steel, 2-3/8 in. wide by 7/8 in. deep, spaced 16 in. O.C. except 6 in. O.C. at wallboard end joints. Secured to steel deck with a double strand of 18 SWG galv. steel wire, spaced 24 in. O.C., inserted through two 1/8 in. diam. holes drilled through crest or valleys of steel deck or to integral hanger tabs in valleys of steel deck. Adjoining lengths of channels lapped 6 in. and tied at both ends of lap with double strand of 18 SWG galv. steel wire. When no cold-rolled channels are used, max. depth between top of furring channel and bottom of steel deck to be 3 in. Where a large plenum depth is desired, furring channels wire tied with a double strand of 18 SWG galv. steel tie wire to 1-1/2 in. cold rolled channels formed from 16 MSG painted steel and suspended from steel deck with 12 SWG galv. steel wire. No. 12 SWG wires pig-tailed through deck or secured to integral steel deck hanger tabs. Spacing of 1-1/2 in. cold rolled channels not to exceed 24 in. O.C.
8. Wallboard, Gypsum*--5/8 in. thick, attached with long dimension perpendicular to furring channels. Wallboard fastened to furring channels with wallboard screws spaced 1 in. and 6 in. from side joints and 12 in. O.C. in the field of each board. Wallboard strip, 3 in. wide by 5/8 in. thick, centered over end joints on back surface of boards. Joints may be covered with joint tape and compound or left uncovered.
   United States Gypsum Co.--Foil-backed Type C.
9. Screw, Wallboard--(Not Shown)--No. 6 Phillips-type (flathead) self-drilling, self-tapping screws, 1 in. long. Screw heads may be exposed or covered with joint compound. Screws may be driven either flush or slightly indented (not deeper than 1/64 in.) into the exposed surface of the wallboard.

*Bearing the UL Classification Marking

Figure 6.32

Design No. P405
Restrained Assembly Rating--3 Hr.
Unrestrained Assembly Rating--3 Hr.



1. **Roof Covering*--Class A, B or C Built-Up Roof Covering Materials consisting only of felt and asphalt (or coal tar pitch) Materials in alternate layers. See Building Materials Directory.**
2. **Perlite Concrete--6.2 cu. ft. perlite concrete aggregate* to 94 lb. portland cement, and 1-1/2 pt. air-entraining agent. Compressive strength 80 psi min.**
   Airlite Processing Corp. of Florida
   Perlite Industries, Inc.
   Perlite Popped Products
   Redco, Inc.
3. **Steel Roof Deck--(Unclassified)--Min. 9/16 in. deep and 25-3/4 in. wide, galv., corrugated steel deck. Min. gauge is 28 MSG continuous over three or more spans. Welded to each joist with 14 MSG welding washers 12 in. O.C. adjacent sheets overlapped one corrugation or, Classified Steel Floor and Form Units*--Noncomposite 9/16, 15/16, 1-5/16, or 1-1/2 in. deep, 30 in. wide, galv. units. Min. gauge is 28 MSG for corrugated and 22 MSG for fluted units. Spacing of welds attaching units to supports shall not exceed 12 in. O.C. Corrugated units welded to supports through welding washers. Adjacent corrugated units overlapped one corrugation. Adjacent fluted units button-punched or welded together 36 in. O.C. along side joints.**
   United Steel Deck, Inc.--Types B, UFS, UFX.
   Wheeling Corrugating Co.--Types B, BR, BW, BWR, TF-50, TF-75, TF-125.
4. **Steel Joists--Type 10J2 min. size, spaced not over 4 ft. O.C. and welded to end supports.**
5. **Bridging--1/2 in. diam. steel bars welded to top and bottom chords of each joist.**
6. **Furring Channels--No. 16 MSG cold-rolled steel, 3/4 in. deep, spaced 13-1/2 in. O.C., wire-tied to each joist with 16 SWG galv. tie wire. Ends of channels to clear walls by 1/2 in.**
7. **Metal Lath--Diamond mesh, 3.4 lbs. per sq. yd.**
8. **Plaster--Scratch and brown coats: 2 cu. ft. perlite plaster aggregate* to 100 lb. of fibered gypsum. Total thickness, 7/8 in. to face of lath.**
   Airlite Processing Corp. of Florida

   LaHabra Prods., Inc.
   Metro Minerals, Inc.
   Mica Pellets, Inc.
   Pennsylvania Perlite Corp.
   Pennsylvania Perlite Corp. of York
   Perlite of Houston, Inc.
   Perlite Mfg. Co.
   Perlite Products Co.
   Redco, Inc.
   Supreme Perlite Co.
   Zonolite Const. Prods. Div., W. R. Grace & Co.

***Bearing the UL Classification Marking**

Figure 6.33

These roofing system details are taken from the 1981 Underwriters Laboratories Fire Resistance Directory. Several manufacturers get together and devise a standard roof section detail. Figure 6.31 is a good example. A sketch of the roof detail is provided. In this case, a roof covering material is placed over one or more layers of mineral and fiber boards, adhered together. This is adhered to a sheathing material which, in turn, is adhered to precast concrete units. Each of these items:

- Roof covering
- Mineral or fiber board
- Adhesive
- Sheathing
- Precast concrete

is described in depth. Most of these entries list a number of manufacturers who produce an acceptable product. UL permits manufacturers of similar products to defray the expense of the ASTM E119 Fire Test of Building Construction and Materials necessary for the fire resistance ratings by testing their products together. For instance, a 1/2 inch ribbon of adhesive placed 6 inches on center beneath each layer of board insulation can be manufactured by:

. The B. F. Goodrich Company	0.4 gallons/100 Sq.Ft.
. Johns-Manville Corporation	0.4 gallons/100 Sq.Ft.
. Reflecto Barrier Sales Co., Inc.	0.4 gallons/100 Sq.Ft.

This is one form of flexibility that manufacturers have in establishing a national market for a product. Potentially, PV manufacturers may combine resources and put together typical roof sections with other building products manufacturers. For instance, a precast concrete manufacturer, a concrete topping manufacturer and insulation manufacturer may devise a roof section which features a PV array roof covering (see ROOF LOCATIONS: Roof Covering, Section 6.3 for related requirements). Several PV manufacturers may wish to combine products under such a UL Fire Resistance Directory listing.

Figure 6.32 suggests such an option under Design No. P502 utilizing clay tiles as a covering material.

A closer look at Figure 6.32 suggests a possible approach for PV manufacturers interested in developing products to meet the requirements for current listings of "roof covering" as in Figure 6.34. The requirements for roof covering are:

> CLASS A, B OR C BUILT-UP ROOF COVERING MATERIALS CONSISTING ONLY OF FELT AND ASPHALT (OR COAL TAR PITCH) MATERIALS IN ALTERNATE LAYERS. SEE BUILDING MATERIALS DIRECTORY.

Figure 6.34

The Building Materials Directory is also produced by Underwriters Laboratories, Incorporated. This document is described in detail under ROOF LOCATIONS: Roof Coverings (see Page 6-75). However, conceptually; if a PV array could qualify as a rated roof covering material, it could, potentially take the place of or be overlayed on top of roof covering materials already commonly accepted by the building industry.

In the introductory explanatory remarks for the UL Fire Resistance Directory, the Roof-Ceiling Assemblies notes in the General Design Information Section outline some of the underlying assumptions which can be made about the Roof-Ceiling Designs (see Figure 6.35).

ROOF-CEILING ASSEMBLIES

THE RATINGS FOR ROOFS ARE DETERMINED BY THE SAME TEST METHOD USED FOR FLOOR RATINGS. ALL ROOFS ARE TESTED WITH CLASS C, 3-PLY SATURATED TYPE 15 FELT ROOF COVERING APPLIED WITH HOT MOPPING ASPHALT UNLESS SPECIFIED OTHERWISE. HOWEVER, THE RATING IS APPLICABLE WITH CLASS A OR B BUILT-UP ROOF COVERINGS CONSISTING OF ONLY FELT AND ASPHALT IN ALTERNATE LAYERS, ARE SUBSTITUTED. SPECIFICATIONS FOR BUILT-UP ROOF COVERINGS USING FELT AND ASPHALT ARE CONTAINED IN THE BUILDING MATERIALS DIRECTORY.

IN CONTRAST TO THE ROOF COVERING, ROOF INSULATION MUST BE CAREFULLY CONTROLLED AS TO MANUFACTURER, TYPE AND THICKNESS AS SPECIFIED. LESS THAN THE SPECIFIED THICKNESS COULD CAUSE AN EARLY TEMPERATURE END POINT ON THE TOP SURFACE WHILE A GREATER THICKNESS COULD CAUSE EARLIER STRUCTURAL FAILURE.

Figure 6.35

UNLESS SPECIFICALLY DESCRIBED IN A DESIGN, THE ADDITION OF INSULATION IN THE CONCEALED SPACE BETWEEN THE CEILING MEMBRANE AND THE ROOF STRUCTURE MAY REDUCE THE DISRUPTION OF THE CEILING MEMBRANE AND/OR HIGHER TEMPERATURES ON STRUCTURAL COMPONENTS UNDER FIRE EXPOSURE CONDITIONS.

RESISTANCE OF THE ROOF DECK TO UPLIFT BY NEGATIVE PRESSURE ON THE ROOF SURFACE OR OTHER DAMAGE WHICH MAY RESULT FROM HIGH VELOCITY WIND HAS NOT BEEN INVESTIGATED. ROOF DECK CONSTRUCTIONS CLASSIFIED FOR WIND UPLIFT RESISTANCE ARE ILLUSTRATED IN THE BUILDING MATERIALS DIRECTORY.[1]

Figure 6.36

The importance of the specific roof covering is minimum so long as it is a Class A, B or C rated (see Roof Coverings) covering. However, the importance of thermal insulation in altering the resistance of the roof section to fire is clearly indicated. Should the photovoltaic array alter the heat transfer characteristics of the roof markedly, compliance with fire resistance guidelines may be

[1] Fire Resistance Directory January 1981 Edition; Underwriters Laboratories, Inc., Northbrook, Illinois, ©1981, p. 12.

required and leeway in substitution of PV modules for other common building materials may not be permitted.

mounting configuration:

In any instance where building codes require the roof section to be fire resistance rated, code officials may require the roof mounted PV array to be tested along with the roof section on which it is mounted. Rack roof mounted arrays which do not provide poor structural distribution or significant numbers of openings in the assembly may escape this requirement.

HORIZONTAL OPENING FIRESTOPPING:

definition:

Building Codes require that ceiling openings, connections between vertical and horizontal spaces and where attic space exceeding a horizontal area of 3,000 square feet (279 square meters) be fire or draft stopped to prevent the spread of flame or products of combustion from one section of the building to another.

code restrictions:

Part of the requirement for a building permit application may be production of engineering details depicting methods and materials utilized for fire and draft stopping, particularly around openings such as ducts, pipes and conduits. The materials utilized as fire or draft stopping material must be noncombustible according to ASTM E136 - Test for Noncombustibility of Elementary Materials test results. Specific materials permitted by the codes include: brick, concrete, gypsum, iron, steel, asbestos, metal lath, cement or gypsum plaster, mineral wool or rock wool.

mounting configurations:

Roof mounted PV arrays, when hidden air spaces are created either in manufacturing or installation, may be subject to firestopping requirements. The implications of firestopping on heat transfer for the array are discussed in detail under WALL LOCATIONS: VERTICAL PASSAGE FIRESTOPPING (see Page 6-53).

INSULATION:

definition:

Insulation is any material which has the primary function of restricting heat flux or absorbing sound. Insulation in a roof assembly may be utilized in several different ways. The insulation may be exposed to the interior of the space, exposed to the exterior (as is commonly found in "upside-down" roofing systems) or enclosed within the inside and outside surfaces.

code restrictions:

The major concerns of a code official when assessing insulation are outlined under WALL LOCATIONS: INSULATION (see Page 6-40). These concerns are primarily fire safety motivated but have potential for saving energy. Figure 6.26 (see Page 6-44) identifies ten major types of insulation. Some of their combustion characteristics and their suitability for use in building applications are discussed under WALL LOCATIONS (see Page 6-27). A detailed discussion of the differences between foamed plastics and other more "traditional" materials is included.

The amount of insulation is an important consideration for fire resistance ratings. An increase in the quantity of insulation could mean early structural failure (due to poor heat transfer). A decrease in the quantity of insulation could mean an early temperature end point, on the top surface of the roof (for more information, see ASTM E119, Methods of Test of Building Construction and Materials.

Analysis of insulation material as an interior surface material is found under WALL LOCATIONS: INTERIOR SURFACE FINISH (see Page 6-43). Analysis of insulation material as an exterior surface material is found under ROOF COVERINGS (see Page 6-75).

mounting configuration:

Unless the PV panel is a complete roof section in an inside surface to outside surface prefabricated building component, there is little likelihood that PV manufacturers would include insulation materials because of heat transfer restriction.

INTERIOR SURFACE FINISH:

definition:

An interior surface finish is any surface material exposed to the occupants of a building.

code restrictions:

The building code restrictions outlined under WALL LOCATIONS: INTERIOR SURFACE FINISH apply to roof locations as well (see Page 6-43).

mounting configuration:

Only a prefabricated building panel type PV panel which would be integrally mounted would expose its interior surface to building occupants.

MAINTENANCE EQUIPMENT SUPPORT:

definition:

Any form of track, rail, clip or fastening equipment associated with the support or back up safety of maintenance personnel is considered in this section.

code restrictions:

Maintenance equipment support requirements are discussed in detail for WALL LOCATIONS (see Page 6-27). The concern expressed for maintenance staff is applicable in roof mounted locations. (NOTE: Additional consideration must be given to the hazards associated with maintenance personnel or unauthorized personnel having access to the roof of a building. In locations where foot traffic by untrained or unsuspecting persons may be possible, code officials may require fencing, graphic labeling or other means to minimize access. Code officials may be concerned with hazards to maintenance staff people from breakage of PV arrays.)

mounting configuration:

Since maintenance, both periodic preventative maintenace and less frequent replacement maintenance, is necessary for most arrays, the requirements outlined under WALL LOCATIONS for safe access to each module may apply.

MANSARD ROOF:

definition:

A mansard roof or any other sloping overhang may be correlated to roof or wall materials depending upon slope. Both the SBCC Standard Building Code and the BOCA Basic Building Code make a clear distinction between roof and wall construction based upon 60 degrees slope from horizontal.

code restrictions:

Those mansard roofs exceeding 60 degrees slope from horizontal are required to be of noncombustible materials (according to ASTM E136 - Test for Noncombustibility of Elementary Materials) when located over 40 - 50 feet above ground. These roofs must be fire resistance rated at 1 hour according to ASTM E119 - Methods of Fire Test of Building Construction and Materials. At 80 - 85 feet above grade, the fire resistance requirements increase to 1-1/2 hours.

At a slope of less than 60 degrees from horizontal, the primary concern of the code is to prevent fire hazards. This can come from flame spread hazard or from the inability of rescue personnel to traverse the roof surface. Flame spread requirements are identified in the section on ROOF COVERINGS (see Page 6-75). Access to roof and safe passage for rescue personnel are discussed within the same section.

mounting configuration:

Any inclined surface which extends beyond the exterior wall perimeter of a building at roof level may be considered to be a mansard roof according to the building code definition. This may also apply to rack or standoff mounting configurations.

ROOF COVERINGS:

definition:

The roof covering material of the building is commonly the waterproofing membrane of the structure. However, fire resistance requirements associated with roof covering materials give the roof covering the implicit definition of a fire resistance membrane, as well.

code restrictions:

Roof coverings and materials are classified according to ASTM E108 Fire Test for Roof Coverings. This standard test divides sample roof coverings into four classifications; Class A, B, C and Unclassified. Roof coverings correspond to veneers (refer to WALL LOCATIONS, see Page 6-27) in that both categories identify the requirements for exterior surfaces. These classifications are crucial to a number of building industry conventions listed below. As a result, a condensed description of ASTM E84, Standard Test Method for Surface Burning Characteristics of Building Materials, procedures and methods for classification follows.

The Standard Methods of Fire Tests of Roof Coverings (ASTM E108) measure the fire characteristics of roof coverings under simulated fire conditions originating outside the building. There are five subcomponents to this standard test: 1) Intermittent Flame Test, 2) Spread of Flame Test, 3) Burning Brand Test, 4) Flying Brand Test, and 5) Rain Test.

- Intermittent Flame Test

  Flames of specific lengths and temperature are applied in on/off cycles at intervals described in Table 6.1. These are applied to a test sample whose size and mounting configuration are specified. After the completion of cycling, air admitted to promote combustion during intermittent flame cycles is continued until all evidence of flame, smoke or glow, disappears; or a structural collapse occurs.

	INTERMITTENT FLAME TEST SPECIFICATIONS		
Method of Test	Flame On Minutes	Flame Off Minutes	Number of Test Cycles
Class A	2	2	15
Class B	2	2	8
Class C	1	2	3

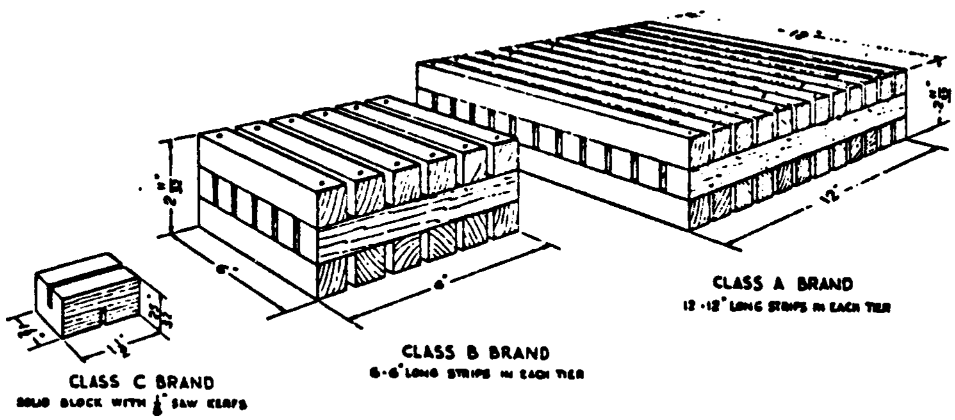
Table 6.1

. Spread of Flame Test

Applying the test flame described in the Intermittent Flame Test to a test deck mounted in the same manner for a fixed length of time. For a Class A or B rating, the flame must be applied for 10 minutes. For a Class C rating, the flame must be applied for 4 minutes. This test must be repeated on at least one other test deck.

. Burning Brand test

Class A rating tests must be peformed on 4 test decks. Class B and C rating tests must be performed on 2 test decks. Figure 6.37 depicts Class A, B and C brands. They are made of heat conditioned douglas fir as specified. The brands are ignited so as to burn freely in still air. The Class A brand is attached to the center of the deck. The Class B test requires two separate burning brands be placed within 30 minutes of each other but not within 6 inches of the sides or 12 inches of top or bottom. The Class C brands are placed at one to two minute intervals in 25 locations on the test deck. Brands must be farther from the sides than six inches, farther from the top and bottom than 12 inches and farther from one another than 4 inches. They will all



Brands for Classes *A*, *B*, and *C* Tests.

Figure 6.37

be burned until fully consumed and each brand will be positioned near a joint in the underlying materials.

- Flying Brand Test

  While applying the same duration of the same flame as in the Spread of Flame Test, maintain a 12 mph wind until all smoke, glowing or flame disappear to determine the likelihood of flying brands developing.

- Rain Test

  Using the same mounting as specified, spray test decks with .7 inches of water per hour for twelve one-week cycles consisting of 96 hours of rain and 62 hours of drying. The final drying should produce moisture content in the deck lumber of 8 to 12%. The intermittent flame, burning brand and flying brand test should each be conducted twice.

The classification of the samples as A, B or C rated roof coverings is contingent upon the flowing test results:

- Intermittent Flame:

  At no time during or after the test is there permitted to be sustained flame on the underside of the deck. The roof deck cannot be exposed and flaming or glowing brands cannot blow off and continue to glow after reaching the floor.

- Spread of Flame Test:

  At no time during or after the test can any portion of the roof deck or flaming or glowing brands blow off and continue to glow upon reaching the floor. The roof deck cannot be exposed. The flame shall not have exceeded the distance spread as described in Table 6.2.

	Class A	Class B	Class C
Distance of Flame Spread	6 feet (1.8m)	8 feet (2.4m)	13 feet (4m) (top of deck)
Lateral Flame Spread from Test Flamepath	No Significant	No Significant	No Significant

Table 6.2

- Burning Brand Test:

  At no time during or after the test can any portion of the roof deck or flaming or glowing brands blow off and continue to glow upon reaching the floor. The roof deck may not be exposed. Flames on the underside of Class A and B, as well as Class C decks with less than 6 or 25 brands in place, are not permitted.

- Flying Brand Test:

  No flying flaming brands, nor debris which continues to glow upon reaching the floor may be produced.

For the purposes of the building codes, roof coverings are separated into two general categories as identified in Figure 6.38 below:

ICBO UNIFORM BUILDING CODE 1976 EDITION
SECTION 3.203 ROOF COVERINGS: DEFINITIONS

BUILT-UP ROOF COVERING: IS TWO OR MORE LAYERS OF ROOFING CONSISTING OF A BASE SHEET, FELTS AND CAP SHEET, MINERAL AGGREGATE SMOOTH COATING, OR SIMILAR SURFACING MATERIAL.

PREPARED ROOFING: IS ANY MANUFACTURED OR PROCESSED ROOFING MATERIAL OTHER THAN UNTREATED WOOD SHINGLES AND SHAKES AS DISTINGUISHED FROM BUILT-UP COVERINGS.

Figure 6.38

As is explained under fire resistance rated assemblies, recent trends in the design profession tend toward the selection of roof section details from the Underwriters Laboratories Fire Resistance Directory. The example from the Fire Resistance Directory listed in Figure 6.39 described roof covering as:

CLASS A, B OR C BUILT-UP ROOF COVERING MATERIALS CONSISTING ONLY OF FELT AND ASPHALT (OR COAL TAR PITCH) MATERIALS IN ALTERNATING LAYERS. SEE BUILDING MATERIALS DIRECTORY.

Figure 6.39

The Building Materials Directory referenced above is an Underwriters Laboratories resource book describing each of the many roofing manufacturers who have subjected their roofing materials to the ASTM E108 Fire Test for Roofing Materials and successfully attained a Class A, B or C rating.

mounting configuration:

Only integral or perhaps direct mounted arrays will be relied upon to be waterproofing membranes on buildings. However, standoff and perhaps even rack mounted arrays will be potential fire spread resistance membranes. Since the traditional materials utilized as

roof coverings have been very flammable, the propensity for code officials to be more concerned with their fire hazard characteristics than their waterproofing characteristics refects a concern for public safety and welfare over comfort.

ROOF SIGN:

definition:

The codes are primarily concerned with roof signs as a structural type, being relatively tall and broad in comparison with thickness with a history of poor maintenance and shoddy construction.

code restrictions:

Code officials are concerned about fire hazard as well as the ability of rescue personnel to traverse the roof of a building quickly. So far as the potential array material and electrical fire safety restrictions are concerned, these can be identified from the following:

BOCA BASIC BUILDING CODE 1981 EDITION:
SECTION 1909.1 ROOF SIGN MATERIALS:

> ALL ROOF SIGNS SHALL BE CONSTRUCTED ENTIRELY OF METAL OR OTHER APPROVED NONCOMBUSTIBLE MATERIALS. PROVISION SHALL BE MADE FOR ELECTRIC GROUND OF ALL METALLIC PARTS. WHERE COMBUSTIBLE MATERIALS ARE PERMITTED (SEE SECTION 1907.4.2 SIGN FACINGS, BELOW) IN LETTERS OR OTHER ORNAMENTAL FEATURES, ALL WIRING AND TUBING SHALL BE KEPT FREE AND INSULATED THEREFROM.

SECTION 1907.4.2 SIGN FACINGS:

> ...SIGN FACINGS MAY BE MADE OF APPROVED COMBUSTIBLE PLASTIC (SEE FIGURE 6.19) PROVIDING THE AREA OF SUCH FACING SECTION IS NOT MORE THAN 120 SQUARE FEET (11.16 M^2) AND THE WIRING FOR ELECTRIC LIGHTING IS ENTIRELY ENCLOSED IN THE SIGN CABINET WITH A CLEARANCE OF NOT LESS THAN 2 INCHES (51 MM) FROM THE FACING MATERIAL.

Figure 6.40

Although the correlation is not really analogous, the implication of such restrictions for PV arrays is understandable. If the PV module cannot qualify according to ASTM E136 Test for Noncombustibility of Elementary Materials as a noncombustible material as in section 1909.1 for Roof Sign Material, the module must satisfy the requirements for section 1907.4.2. Otherwise, such a PV array will not be permitted when a code official interprets the array as a roof sign.

Compliance for a PV array with electrical requirements outlined in section 1907.4.2 for roof signs may be difficult to achieve. Although an area limitation of 120 square feet is not overly restrictive for a PV module, other building codes restrict the total permitted area of plastic covering. The area may be limited to 1100 total square feet. The most difficult restriction may be the two inch clearance between electrical wiring and covering. Although the code specifically references electrical lighting wiring, the code official may be prone to question the proximity of a current-carrying conductor to a combustible cover material.

Building codes restrict the placement of roof signs which may obstruct access for rescue personnel. Six feet may be required between the roof and the base of the roof sign. Five feet may be required between vertical supports. In no case may the path from one side of the roof to any other be completely obstructed by the roof sign. The support structure must be noncombustible according to ASTM E136 - Test for Noncombustibility of Elementary Materials. All metallic parts must be grounded properly as well.

Finally, due to the historic precedence of sign structures to collapse under high wind loading, special structural restrictions are placed on roof signs. Absentee sign owners, who have neglected sign structural upkeep and maintenance, have caused codes to require:

- Sign permits
- Annual inspections
- Conspicuous label of sign's owner

- Submission of engineering drawings as proof of structural safety
- Bond to be filed with the building official

The codes are obviously concerned about accountability for any damages incurred in the collapse of a sign structure. PV arrays can avoid these administrative requirements due to the inherent nature of maintenance responsibility not being in the hands of absentee owners. So long as a proper design transfers loads in an acceptable manner, PV arrays should avoid the code related permit and inspection requirements outlined above.

mounting configuration:

Although there are many reasons for disassociating a PV array and a roof sign assembly, there are two striking similarities between the two. The support structure for a rack mounted PV roof array and a roof sign maybe similar. Also, the inherent hazards of electrical service to the sign as well as from the PV array may be perceived as being similar.

ROOF STRUCTURE:

definition:

BOCA BASIC BUILDING CODE 1981 EDITION
SECTION 201.2 DEFINITIONS:

ROOF STRUCTURE: AN ENCLOSED STRUCTURE ON THE ROOF FOR WEATHER RESISTANCE, FIRE RESISTANCE OR APPEARANCE.

code restrictions:

There are a wide assortment of common elements found on roofs which fall under the requirements associated with the generic term Roof Structures. Among items mentioned include water towers, cooling towers, cupolas. Codes may require the materials utilized above 12 - 40 feet in height above the roof to be noncombustible according to ASTM E136 Test for Noncombustibility of Elementary Materials.

On buildings where combustible construction types are permitted, roof structures are also permitted to be of combustible materials. However, they must have a one hour fire resistance rating for exterior wall enclosures as well as an approved fire covering material.

Any time a structure exceeds 85 feet above grade, and exceeds a horizontal area of 200 square feet, it must be supported on fire resistive, noncombustible supports. Fire retardant wood may be utilized for supports when achieving a flame spread rating of 25 or less when tested for at least 30 minutes according to ASTM E84 Test for Surface Burning Characteristics of Building Materials.
mounting configuration:

Due to the enclosed nature of the roof structure, there is no exact correlation with PV roof mounted configurations. The closest fit may be with rack roof mounted PV arrays such as may be found in a sawtooth configuration. Under such circumstances, the assembly would tend to have an enclosure wall of sorts and, as such, appear to correlate with the "roof structure" definition above.

SLOPED GLAZING:

definition:

Sloped glazing functions as a light transmitting medium which is generally constructed of transluscent or transparent material mounted in a structural framing system.

code restrictions:

Since the mid-1970's, designers have been working in concert with code officials for regulatory reform in the utilization of broad architectural expanses of sloped glazing. Over the years, the constraints developed for sloped glazing have been many and fairly severe. The framing materials were required to be noncombustible as determined by ASTM E136-73 Test for Noncombustibility of Elementary Materials. One-fourth inch glass was required to be either wired glass or protected above and below by wire mesh to protect the glass from impact and to protect the occupants below from falling glass. The area of a skylight unit was restricted to 720 square inches and the width restricted to 24 - 48 inches. The area of roof coverage may have been restricted to 40%.

It is difficult to adapt a new technology item such as a photovoltaic array to this set of regulatory constraints. However, it should be noted that the SBCC Standard Building Code, 1979 Edition, features some attitude changes toward sloped glazing utilized over low fire hazard areas such as walkways, office areas, recreation areas, lobbies and other public areas. Besides wire glass; laminated glass, fully tempered glass and glass with protective wire screens beneath are permitted. The ICBO and BOCA codes are expected to consider such revisions in the near future. The current attitude expressed in BOCA is:

BOCA BASIC BUILDING CODE 1981 EDITION
SECTION 1426.3.4 GLAZING MATERIALS:

SKYLIGHTS MAY BE GLAZED WITH ANY OF THE FOLLOWING MATERIALS, SUBJECT TO NOTED LIMITATIONS: LAMINATED GLASS, WIRED GLASS, ANNEALED GLASS, HEAT STRENGTHENED GLASS, TEMPERED GLASS, AND LIGHT TRANSMITTING PLASTIC. ANNEALED, HEAT STRENGTHENED AND TEMPERED GLASS SHALL BE PROTECTED BY SCREENS. LIGHT TRANSMITTING PLASTICS SHALL MEET THE REQUIREMENTS [OUTLINED BELOW].

SECTION 1426.3.5 SCREENS:

ANNEALED GLASS SKYLIGHTS SHALL BE PROTECTED FROM FALLING OBJECTS BY SCREENS ABOVE THE SKYLIGHT. ANNEALED, HEAT STRENGTHENED AND TEMPERED GLASS SKYLIGHTS SHALL BE EQUIPPED WITH SCREENS BELOW THE SKYLIGHT TO PROTECT BUILDING OCCUPANTS FROM FALLING GLAZING SHOULD BREAKAGE OCCUR. SCREENS SHALL BE OF NONCOMBUSTIBLE MATERIALS AND SHALL HAVE A MESH NOT LARGER THAN 1 INCH BY 1 INCH (25 MM BY 25 MM). THE SCREEN SHALL BE CONSTRUCTED OF NOT LIGHTER THAN NO. 12 B & S GAGE (0.0808 INCHES) MATERIAL. WHEN UTILIZED IN A CORROSIVE ATMOSPHERE, STRUCTURALLY EQUIVALENT NONCORROSIVE MATERIALS SHALL BE USED. SCREENS ABOVE THE SKYLIGHT SHALL BE AT LEAST 4 INCHES (102 MM) ABOVE THE SKYLIGHT AND SHALL PROJECT ON ALL SIDES FOR A DISTANCE OF NOT LESS THAN THE HEIGHT OF THE SCREEN ABOVE THE GLASS. WHEN MULTIPLE LAYER GLAZING SYSTEMS ARE USED AND THE LAYER FACING THE INTERIOR IS LAMINATED GLASS, THE PROTECTIVE SCREEN BELOW THE SKYLIGHT IS NOT REQUIRED.

Figure 6.41

As was seen with vertically mounted glazing, attitudes toward skylighting were formed based on the traditional performance and problems associated with glass. Codes that were written dealt specifically with glass. The coming of age of "plastics" (for a historical accounting and detailed analysis see WALL LOCATIONS: GLAZING MATERIALS CONSIDERATIONS, Page 6-35) meant that sloped glazing was no longer simply light transmitting media. All skylighting regulations applied only to the way glass reacted to fire and impact loading.

Pending further revisions in the building codes, area and dimensional restrictions outlined in the introductory paragraph apply to present sloped glazing applications. A reduction of slope below 45 degrees from horizontal may force individual skylight units to be mounted on four inch noncombustible curbs above the plane of the roof.

Plastics utilized as sloped glazing material can be broken into two subcategories:

- Plastic skylights
- Plastic roof panels

Plastic utilized in a skylight must be "approved" (see the definition in Figure 6.19, Page 6-33). In general, plastic skylights must be mounted on a 4 inch curb with the edges of the plastic being protected by metal. The maximum for a curbed-in area is 100 - 200 square feet while the separation between the skylights must be 4 feet horizontally. The total aggregate area of a plastic skylight can be no greater than 33% for type C1 plastics and 25% for type C2 plastics of the room's floor area below. The use of fire suppression equipment (a mechanical system designed and equipped to detect a fire, actuate an alarm and suppress or control a fire) raises the permissible area within each curb and decreases the required distance between the curbs.

A photovoltaic array would probably need to be both an inside surface to outside surface assembly (only possible in an integral roof mount configuration) to merit this plastic skylight interpretation. Either the inside surface or the outside surface of the module would need to be exposed plastic material. The area restrictions and curbing requirements for the skylight units themselves would be very restrictive. The discontinuity of a four foot horizontal spacing would be even more restrictive than the three to four foot noncombustible horizontal bands found on exterior wall applications due to both the total area restriction implications and electrical detailing problems. This sort of an interpretation would cause unlimited problems, if applied over a broad range of roof mounted installations. By avoiding either through the roof (outside surface to inside surface) modules or the use of plastics as a surface covering material, such an interpretation could be safely avoided.

Plastic Roofing Panels:

BOCA BASIC BUILDING CODE 1981 EDITION
SECTION 201.0 GENERAL DEFINITIONS:

> PLASTIC ROOF PANELS: PLASTIC MATERIALS WHICH ARE FASTENED TO STRUCTURAL MEMBERS, OR TO STRUCTURAL PANELS OR SHEATHING, AND WHICH ARE USED AS LIGHT TRANSMITTING MEDIA IN ROOFS.

Figure 6.42

These panels may be used when any of the following occurs:

- Fire suppression equipment is utilized
- The fire resistance rating for the roof is zero (see Figure 6.9)
- The requirements for a roof covering material are met

In any case, plastic roof panels may not be utilized in Assembly, Institutional or Hazardous Division Occupancies. One story buildings under 1,200 ft.^{2} are exempt from any restrictions.

Plastic utilized for roof panels must be "approved" (for definition, see Figure 6.19, Page 6-33). Plastic roof panels are restricted to areas of 100 square feet for type C2 plastics and 300 square feet for type C1 plastics. The total area of coverge for an enclosed room is 25% for type C1 plastics and 30% for type C2 plastics.

The definition of plastic roof panels (being light transmitting) may reduce the propensity of such an interpretation for PV arrays. However, in an integral mounted application where the module may serve as both exterior roof surface and interior ceiling finish, this interpretation may result. The obvious area restrictions imposed upon plastic roof panels alone would be severely restrictive. There are a significant number of applications where plastic roof panels may be utilized, as noted above. However, the cost of a fire suppression system may exclude that particular item unless secondary safety and economic (reduced insurance premiums, for instance) benefits can be capitalized upon.

Although a PV module may be glass covered, or have both a glass superstrate and substrate with a "plastic" pottant and cells between, thereby resembling laminated glass, the pottant may be significantly greater in thickness than laminated glass. If such a plastic pottant material were to ignite in the presence of Underwriters' Laboratories ASTM E108 Test of Roof Coverings flames as may be expected of plastic glazing rather than laminated glass, the impact on the PV industry may be severe.

The differences between plastic skylights and roof panels and glass skylights are significant in terms of restrictions for both the present time and in the near forseeable future. Therefore, it is in the PV manufacturer's best interest to avoid the correlation with "plastic" materials wherever possible. The restrictions placed on sloped glazing, even for glass glazing material are more extreme than the PV manufacturer may wish to deal with.

mounting configuration:

An interpretation of photovoltaic modules as skylights may only be made when the module serves as both roofing material (see ROOF COVERING) and ceiling finish (see INTERIOR SURFACE FINISH). This could only occur in an integral roof mount configuration, a sandwich module featuring a superstrate sheet, a substrate sheet with a pottant and cells between (with no intervening thermal insulation layers or continuous air spaces) may be necessary before a sloped glazing correlation would be logical. The inclusion of open air spaces and/or thermal insulation material are more typical of fire resistance rated assemblies (see Page 6-60).

ROOF LOCATIONS CONCLUSIONS:

- Fire resistance rated assemblies are selected, when necessary according to Building codes, from the Underwriters' Laboratories Fire Resistance Directory

  PV manufacturers may utilize the similar approach outlined under WALL LOCATIONS CONCLUSIONS (see Page 6-54) in listing typical roof sections which include PV arrays as exterior surface materials.

- PV arrays which classify as A B or C (preferably A or B) rated roof coverings may be permitted to be utilized in all of the roof sections listed in the UL FIRE RESISTANCE DIRECTORY in which surface coverings are itemized as A B or C built up coverings.

  The qualification which may keep PV panels from freely making this exchange is identified in Figure 6.35 (Page 6-67), a part of which is repeated below:

  > "In contrast to the roof covering, roof insulation must be carefully controlled as to manufacturer, type and thickness as specified. Less than the specified thickness could cause early temperature end point on the top surface while a greater thickness could cause earlier structural failure."

  Even if the PV module is not intended to alter the thermal characteristics of the roof section, it may be perceived to somehow adversely affect the fire resistance performance of a typical roof section. Early UL testing of PV panels could be utilized to make a case for the correlation of PV panels with the roof covering materials rather than the roof insulation materials. This would help to convince code officials that PV panels may someday be freely substituted for built up roof coverings when the PV panels themselves are A B or C rated according to ASTM E108 Methods of Fire Tests for Roof Coverings.

- Rack mounted PV arrays have a wide range of categories listed within building codes which have similar attributes (either in appearance or function) with which they may be compared.

  Many of the references listed under ROOF LOCATIONS such as AWNINGS, MANSARD ROOF, ROOF SIGN and ROOF STRUCTURE may only be correlated with rack roof mounted PV arrays. However, due to the secondary nature of these structures and the secondary nature of rack mounted PV arrays, the relatively lenient requirements placed upon such references seem well suited to rack mounted arrays. It is only when the more severe restrictions associated with fire resistance rated assemblies, roof coverings, and sloped glazing are heaped upon rack mounted arrays that any incentive to spend extra money to put PV arrays on rack structures will be lost.

- Sloped glazing restrictions are extremely restrictive and should be avoided.

  Although the exterior surface materials are similar and framing systems may be similar for both sloped glazing and PV roof mounted arrays, the function of one is a light transmitter and the other is a power generator. However, any time that glass is used as a surface covering on a roof, there must be some real questions asked about the ability of fire and rescue personnel to traverse the roof under emergency conditions. This problem may be tackled at the building designed level, however.

6.3.3 GROUND LOCATION:

The following list of building component assemblies may be interpreted as having visual or functional similarities with Ground Rack Mounted PV arrays:

- Canopy
- Ground sign
- Miscellaneous use

Along with sections of the building codes which regulate the use of each assembly, commentary on the impact to the development of PV markets resulting from restrictions imposed by any such correlation is presented. Conclusions are stated addressing how such interpretations should be encouraged or discouraged.

CANOPY:

definition:

For the purpose of this report, a canopy shall be any rooflike structure which is wholly or partially supported on stanchions directly on the ground. It generally overhangs public property.

code requirements:

The canopy is required to be 7 - 9 feet above all sidewalks, at a minimum. The horizontal extension must not extend closer to the curb than 1 to 2 feet, and may not be permitted to extend more than 5 to 7 feet from the building line.

Covering materials may be similar to sloped glazing over walkways as referred to under ROOF LOCATIONS: SLOPED GLAZING (see Page 6-85). Recent trends of lenience toward skylights over such low hazard areas as walkways, office areas, lobbies, recreation and other public spaces provide reasonable guidelines for PV modules having similar structural characteristics.

Fire hazard must be considered along with structural performance. Due to the inherent potential for public hazard from structural collapse or fire, code officials reserve inspection of canopy design and issuance of building permit as a safety check device.
The combustibility of materials are a primary concern, in such an instance. Framing members are required to be noncombustible according to ASTM E136 Test for Noncombustibility of Elementary Materials. Covering materials may be combustible. However, they may be required to be protected with a one hour fire resistance rating according to ASTM E119 Methods of Fire Test of Building Construction and Materials. Plastic canopy covering materials may be required to be restricted in area. Codes cite the example of service station pump canopies for plastic materials. They are restricted to 200 square feet of total area inside fire limits and

1,000 square feet outside fire limits. The plastic material utilized must be approved plastic (see Figure 6.19, Page 6-33).

mounting configuration:

A rack ground mounted array will probably have to overhang a walkway or circulation area where people pass beneath or occupy space beneath the array before the requirements for canopies (for related requirements see WALL LOCATIONS: AWNINGS, Page 6-28) are logically applied.

GROUND SIGN:

definition:

These are relatively tall and broad (compared to their thickness) structures which have been historically constructed of inexpensive materials and poorly maintained.

code requirements:

Although a ground mounted array does not serve the advertising function associated with ground signs, the safety issues pertinent for ground signs, particularly those with electrical service, correlate fairly closely with safety concerns for PV arrays. These issues are structural, fire and electrical hazard related.

Code officials restrict the use of signs without:

- Sign permit
- Bond filed with code agency
- Annual inspections
- Conspicuous label of advertising agency
- Submission of engineering drawings as proof of structural integrity

Historically, absentee advertisers have sacrificed maintenance of signs or abandoned them rather than outlay funds for upkeep. These requirements are intended to force responsibility upon the advertiser to assure structural integrity and upkeep for the sake of public welfare.

The gross area of outdoor signs limits the peril from fire. However, combustibility of materials is of primary concern when in proximity to other occupancies. Therefore, within fire limits, ground sign materials must be noncombustible acording to ASTM E136 Test for Noncombustibility of Elementary Materials. Outside fire limits, combustible materials may be used so long as they are not over 35 feet in height.

When the ground sign has electrical service, care must be taken to protect the public from accidental contact with live parts. Grounding may be necessary, particularly for metal framework.

The interpretation of PV ground mounted arays as ground signs seems to pose few serious probems. The administrative requirements for drawing submissions, permits, bonds, inspections and graphic identification of owner and maintenance responsibility are not applicable, though. PV arrays would be owned and maintained by responsible individuals who would have financial incentive to upkeep the expensive array equipment. Ground mounted arrays located within fire districts may, as ground signs are, be required to be constructed of noncombustible materials. However, due to necessary spacing requirements to avoid shading as well as a desire to utilize inexpensive land for the array, it may not be prone to be located within fire districts. Fire districts are generally densely populated (expensive land) areas where the danger of conflagration may be high.

MISCELLANEOUS USE:

definition:

As is described in the introduction to building codes, one of the very basic variables when assessing regulatory constraint is occupancy type. Figure 6.7 (Page 6-12) outlines maximum floor area as a function of combustibility of construction materials and occupancy. Figure 6.27 (Page 6-44) outlines interior surface finish rating classifications as a function of occupancy. However, a ground mounted array is not easily classified into those occupancy types found commonly in the Commercial/Industrial sectors. Therefore, ground mounted arrays may be classified as temporary or miscellaneous uses.

code restrictions:

Due to the nebulous nature of a Miscellaneous Use Group, the code official is given a tremendous amount of leeway in dealing with the various items classified as such (see Figure 6.43). Code officials may require building owners to file a permit with the building department annually.

BOCA BASIC BUILDING CODE 1981 EDITION
SECTION 514.2 TEMPORARY STRUCTURES - SPECIAL APPROVAL:

> ALL TEMPORARY CONSTRUCTION SHALL CONFORM TO STRUCTURAL STRENGTH, FIRE SAFETY, MEANS OF EGRESS, LIGHT, VENTILATION AND SANITARY REQUIREMENTS OF THIS CODE NECESSARY TO INSURE THE PUBLIC HEALTH, SAFETY AND GENERAL WELFARE.

SECTION 514.3 TERMINATION OF APPROVAL:

> THE BUILDING OFFICIAL IS HEREBY AUTHORIZED TO TERMINATE SUCH SPECIAL APPROVAL AND TO ORDER THE DEMOLITION OF ANY SUCH CONSTRUCTION AT HIS DISCRETION, OR AS DIRECTED BY THE DECISION OF THE BOARD OF APPEALS.

Figure 6.43

As is true of building codes in general (see Figure 6.5) the code official has responsibility to enforce the spirit of the code, however that "spirit" may be interpreted. Figure 6.43 serves as carte blanche authorization to approve or deny ground mounted PV arrays based upon the experience and opinion of the code official, if considered as temporary in nature. Various techniques for isolating the PV array from the public may be utilized to satisfy the health and safety requirements of codes. When miscellaneous uses are located within fire districts (typically, in close proximity to other people) they must be constructed of noncombustible materials to minimize the hazard. Swimming pools may be comparable. Just as a swimming pool may attract curious, although uninvited visitors; a PV array may attract curious, although uninvited visitors. There are hazards associated with each; potential drowning or electrocution, and as a fence may be required around the pool, so may it be required around a PV array. Code officials are left with a great deal of leeway in this regard.

GROUND LOCATION CONCLUSIONS:

Separation from people, buildings and objects which they could endanger is the key variable in assessing the requirements for PV arrays

As was seen under GROUND SIGNS, the materials utilized inside fire limits are to be noncombustible. The logic is to reduce the increased potential for such a sign to be the source of a fire or to propagate flames inside a congested area. As is found with swimming pools, fences are utilized to keep people away from an inherently dangerous item. The electrical hazard associated with accidental contact may necessitate special electrical isolation materials, elevating arrays above harms reach or fencing off arrays.

Code officials will have much more leeway in imposing restrictions upon PV ground mounted arrays which could be interpreted as being Miscellaneous Use Occupancies. Under such an interpretation, code officials will be burdened with providing the public with the same level of protection which the code defines in extreme detail for all other occupancies. In all likelihood, the code officials will fall back on evidence from UL, National Model Code Administrators and the National Electric Code for evidence satisfying electrical and fire safety requirements.

6.4 THE MECHANISMS FOR BUILDING CODE CHANGE:

- BUILDING CODE UPDATING:

Photovoltaic electrical generation is not specifically addressed in the current building codes studied for this report. Exclusion from building codes forces design professionals and code officials to take legal responsibility for PV modules and arrays. As is pointed out in Section 4, assuming the legal responsibility for innovative materials and systems is risky business.

Incorporation into the building codes signifies acceptance as a norm rather than an anomaly in the building industry. The magnitude of the market, which photovoltaic manufacturers have established as being necessary for economies of scale savings required to reach 1986 target costs of $.70 per peak watt, dictates acceptance in the building industry on a widespread basis. This can be most easily accomplished when building codes accept photovoltaic modules as being the norm, rather than an anomaly. The following describes the mechanisms for building code change. Swift incorporation into the codes will signal design professionals and code officials alike that photovoltaic modules and arrays are safe for widespread use, as permitted, in commercial/industrial applications.

Codes evolve as a result of two different stimuli; real or perceived hazard and technological advancement. When codes change as a reaction to real, perceived, natural or man made danger to human life, health or property, it is generally the result of a catastrophic event. Night club fires and ensuing regulatory constraint are an example of this. Urban fires resulted in the establishment of fire districts to reduce the threat of conflagration. These changes in the code tend to be more restrictive in nature. Existing regulations cited in the codes are altered to attenuate the hazard.

Technological advancements, such as photovoltaic power generation equipment, must be soundly scrutinized and tested before even limited experimental use can be expected. The initial step is to obtain variances from code document guidelines. These variances are subjectively granted or denied by the code official. There is an appeal procedure commonly utilized when restrictions are placed on new technology materials and equipment (see Figure 6.44).

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 124.1 APPLICATION FOR APPEAL:

THE OWNER OF A BUILDING OR STRUCTURE OR ANY OTHER PERSON MAY APPEAL TO THE BOARD OF APPEALS FROM A DECISION OF THE BUILDING OFFICIAL REFUSING TO GRANT A MODIFICATION TO THE PROVISIONS OF THIS CODE COVERING THE MANNER OF CONSTRUCTION OR MATERIALS TO BE USED IN THE ERECTION, ALTERATION OR REPAIR OF A BUILDING OR STRUCTURE. APPLICATION FOR APPEAL MAY BE MADE WHEN IT IS CLAIMED THAT THE TRUE INTENT OF THIS CODE OR THE RULES LEGALLY ADOPTED THEREUNDER HAVE BEEN INCORRECTLY INTERPRETED, THE PROVISIONS OF THIS CODE DO NOT FULLY APPLY, OR AN EQUALLY GOOD OR BETTER FORM OF CONSTRUCTION CAN BE USED.

Figure 6.44

Given the dictatorial nature of a code official's interpretational powers, it is reasonable to assume that the Board of Appeals, the appeal option for unfair code official rulings, would serve as a harbinger of new technology. Beyond this option the path for appeal of code rulings leads only to the judicial court system. However, frequently the Board of Appeals is controlled by the same interest groups applying indirect pressure on the code official to resist new technologies (see Section 4, Page 4-1). Analysis of the procedures and politics for building code approval regarding new technologies may be critical for the PV industry defending itself against the judgment of the building industry. After all, there are very few of us who would defend ourselves against personal liability in a jury trial, not knowing the procedures and politics of an arbitrary judicial system.

It is often observed that for various reasons, code documents shield local interests from the unwanted competitive intrusion of innovative technologies. If the code is utilized as an exclusionary tool, the interest of the public is certainly not served. By analyzing the mechanics of code change to accept new technologies, this report seeks to forewarn the photovoltaic manufacturer. With accurate information, the PV industry can begin to plan strategies which will bypass unnecessary barriers which frequently halt the progress of promising new products. The following analysis will identify apparent barriers to new technologies inherent in the code approval process.

The description of the code official, the enforcer of the code document, as an actor in the construction process (see Section 3) revealed several influences and disincentives to an unbiased ruling relative to the application of new products. At the level of the Board of Appeals, the Douglas Commission[1] has this to say:

> "Representatives of the building industry frequently are requested to recommend individuals for appointment to appeal boards, and codes and ordinances frequently require that members of appeal boards be architects, engineers, and contractors. Such practices would not appear to provide adequate protection to the public."

In many cases the propensity of a local code authority to accept a new product is rather closely bound to the vigor of the local construction industry. Abundant employment opportunities and material demand exceeding supply often lead to a relaxation of political pressure on code officials in state and "local" districts. The perception of lost employment opportunity on the part of the actors, no matter what analytic economic evidence may indicate, could mean that short range interests of those temporarily in power supersede the long range good of the public. Plumbers and cast iron pipe manufacturers perceived a redivision of trade when PVC and ABS pipe was introduced, for example. Tremendous sums of money were spent to convince those empowered to deny approval of the product as a danger to public health. Despite a lack of evidence, these anti-plastic pipe interest groups were remarkably able to delay the utilization of plastic pipe.

Definitions and licensing requirements are often the mechanism by which codes preserve employment for interest groups. Many state trade unions have won de facto exclusion of out-of-state prefabrication with requirements for inspection and assemblage of mechanical systems by in-state licensed tradespeople. This is a primary barrier in the ability of a prefabricated builder to flourish. By limiting the ability to market a prefabricated product over a large interstate network, most of the economies of scale are lost. Huge capital outlays cannot be justified for limited in-state markets.

The formal procedure for amending building codes is not as complicated as Figure 6.44 indicates:

BOCA BASIC BUILDING CODE 1981 EDITION

INTRODUCTORY COMMENTS:

THE BOCA BASIC CODES ARE MAINTAINED IN THEIR CURRENT, RESPONSIVE STATE THROUGH A DEMOCRATIC PUBLIC HEARING AND REVISION PROCEDURE WHICH ALLOWS ALL INTERESTED PARTIES THE OPPORTUNITY TO BOTH PROPOSE CHANGES TO CODE PROVISIONS AND TESTIFY REGARDING SUCH CHANGE PROPOSALS. CHANGE PROPOSALS TO THE BOCA BASIC CODES ARE EITHER ACCEPTED OR REJECTED BY VOTE OF THE ORGANIZATION'S ACTIVE MEMBERS, WHO ARE PRACTICING REGULATORY CODE OFFICIALS. VOTING ON CHANGE PROPOSALS IS CONDUCTED AT THE ORGANIZATION'S ANNUAL CONFERENCE, AT WHICH TIME FINAL TESTIMONY IS HEARD. PUBLIC HEARINGS ON PROPOSED CODE CHANGES ARE HELD PRIOR TO THE CONFERENCE AT THE ANNUAL BOCA MID-WINTER MEETING.

EACH OF THE BASIC CODES IS COMPLETELY REVISED AND PUBLISHED IN A NEW EDITION EVERY THREE YEARS. CODE CHANGE ACTIVITY IS CONDUCTED ANNUALLY WITHIN EACH THREE YEAR EDITION CYCLE. THE FIRST AND SECOND YEARS' APPROVED CHANGES ARE PUBLISHED IN SUPPLEMENT FORM, AND THE THIRD YEAR'S REVISIONS ARE INCORPORATED DIRECTLY INTO THE NEXT CODE EDITION. EACH NEW CODE EDITION REFLECTS ALL CHANGES APPROVED BY BOCA'S ACTIVE MEMBERS SINCE ISSUANCE OF THE PREVOUS EDITION.

THIS PROCEDURE IS MAINTAINED FOR RESPONSIVENESS TO OUR RAPIDLY-ADVANCING BUILDING TECHNOLOGY, AND FOR ITS ABILITY TO RETAIN CODE CONTENT IN THE HANDS OF PROFESSIONAL REGULATORY CODE OFFICIALS AND ABOVE THE REACH OF VARIOUS SPECIAL INTERESTS. THE BOCA BASIC CODES ARE DESIGNED TO PROTECT PUBLIC HEALTH, SAFETY AND WELFARE THROUGH EFFICIENT AND EFFECTIVE USE OF AVAILABLE MATERIALS AND CURRENT BUILDING TECHNOLOGY.

Figure 6.45

The codes themselves are amended annually with the exception of the third year of each three year cycle when the entire code is reissued to include all amendments from the current period.

Acceptance into the building codes will only come, however, after adequate testing and assurances guarantee the product is reasonably safe for public utilizaton. This will take a tremendous amount of analytic research as well as public relations work. Both aspects must be seriously considered. History has shown that even the best ideas may sit on the shelf for years due to incorrect marketing strategies. The PV industry may have a good idea, however, in attempting to deal with the building industry, precedence is an important consideration. A brief look at the utilization of plastics in the building industry shows this to be true.

As reviewed under WALL LOCATIONS: GLAZING, Materials Considerations (see Page 6-35), the regulation "plastics" showed some insights into potential problems. Due to the code agencies' need for simplification, the worst properties (as perceived by the code official) caused the restriction of the use of plastics in buildings. A comparison of time versus temperature curves in Figure 6.10 (Page 6-16) also shows how fire resistance ratings are regulated based on the "worst case" fire rather than more "typical" fire depicted in Figure 6.11. The precedence set for "plastics" is very restrictive. Total area and single panel material limitations hamper the widespread utilization of plastics in the building industry. There is a genuine "anti-plastic" sentiment which has propagated throughout the building industry. This sentiment reasonably assures that increased acceptance will only come through public relations efforts to dispel misconceptions.

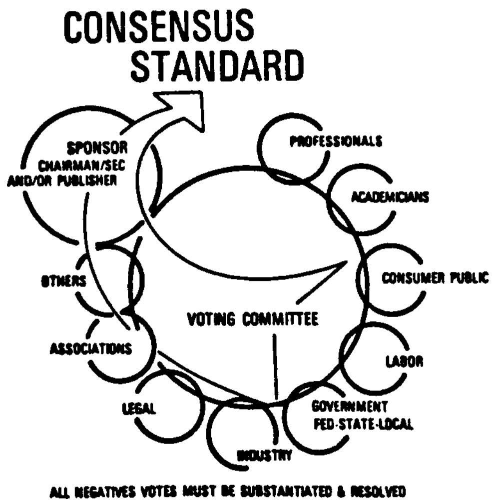
The PV industry must be alert to the dangers of initial over-regulation. There is also a serious question as to whether poorly constructed PV modules, panels or array installed in early experimental applications may alert those writing codes that PV modules and arrays must be seriously restricted to avoid perceived problems. Therefore, the PV industry must take care to only release for potential utilization products which will not gain a reputation as a public health or safety hazard. This will not be easily accomplished considering the propensity of PV modules to contain layers of "plastic" material. The PV industry will be working from a disadvantage simply because of restrictive precedence applied to plastic, a constituant material.

. STANDARD TEST METHOD UPDATING:

Standard Test Methods (Standards) specify the suitability of products, materials and subsystems to meet minimum levels of public health and safety. Standards are found generally in one of two forms: performance or prescriptive (specification). As far as new products and technologies are concerned, it is desirable for all standards to be performance standards. As the name implies, such a standard projects a minimum level of acceptable performance. These favor no particular material but have a minimum acceptable level objective. This kind of a definition is suited to only the most general standards. For example:

> "In the event of a fire, the smoke from the combustion of roofing materials shall not be toxic enough to overcome occupants or fire fighters until sufficient escape time has elapsed."

However, who could determine compliance with this? Instead, code officials refer to specification or prescriptive standards for enforceable definitions. An estimated thirteen thousand standards, originating from some four hundred trade associations representing special interest groups, are currently referenced by code documents. In a "consensus process", a committee of industry and public interest representatives decides upon the suitability of the proposed standards written by trade associations (see Figure 6.46, Page 6-106). The standards are utilized, upon approval, as the reference for product performance. An innovative product which does not react under test conditions as well as a material for which the standard was written, yet which has better reaction to actual in service conditions, may still be denied use by a code official.



CONSENSUS STANDARD DEVELOPMENT PROCESS

Figure 6.46

The building industry may be described as an assurance dependent industry. Performance standards force the manufacturer to take broad marketing and legal product liability risks.

Photovoltaic manufacturers must, through their own trade organization, establish standard test methods which successfully test the performance of PV products for all ranges of electrical, fire and environmental deterioration and hazard. Until such time as the results of these standards provide adequate rationale for code documents to accept PV as a safe societal norm (rather than an anomaly), the PV industry must continue to predict which existing code references (see Section 6.3, Page 6-27) code officials will choose to apply to the PV array.

Nationally recognized testing laboratories conduct these standard tests. There are many laboratories across the nation. The reputation of these testing labs is mixed, both from lab to lab and from the perspective of code jurisdiction. "Approval" from a testing laboratory is a good sign but is not a binding guarantee of code acceptance. Even if one code official accepts the standard test results from a particular testing lab, another official may refuse those results of the same testing laboratory or assign additional testing procedures for code compliance. Although the "police power" empowers the state to enact building codes, the U.S. Supreme Court states that it is "incapable of any very exact definition." The code official is required to impose reasonable and not arbitrary requirements on new products and technologies. What is "reasonable", is left open to a broad range of interpretations.

The photovoltaic manufacturer must deal with these problems in an organized way. National analysis of construction economy in the commercial sector is a good place to start. If political and economic pressure is brought to bear on susceptible building agencies as a function of economic health, the rapidly expanding Southern and Southwestern economies should hold better potential for fair appraisal of innovative products by code officials. In fact, statistics bear this out. The Southern and Southwestern states are utilizing the continuously revised model codes with frequency, while the industrially stagnant Northeast and North Central states utilize locally drafted codes much more frequently.

SECTION 7

NEC REVIEW AND ELECTRICAL REQUIREMENTS

7.1 INTRODUCTION

The purpose of any electrical wiring system is to conduct electricity from one point to another, and to do it in a safe manner. This is accomplished, in part, by isolating the electrical conductors from each other as well as from the building and by providing an appropriate grounding system. Conductor isolation is accomplished through the use of insulation and protective enclosures. In addition, protective enclosures contain disturbances which may occur in a wiring run, such as wire overheat and fire. There are numerous types of wiring schemes available which qualify as one of three characteristic approaches. These three principle types of interior wiring systems are:

1. Exposed insulated cables
2. Insulated cables in cable trays
3. Insulated conductors in raceways

The exposed insulated cables rely upon the construction of the cable itself for protection of the conductors. Because raceways are not required in these "exposed" systems, the conductors are not totally protected from mechanical injury, which could lead to a shock and/or fire hazard. Exposed insulated cables are permitted in most locations where the risk of damage is small. The insulation is rugged; however, where risk of mechanically induced damage is high, protection must be provided. The insulated cables in cable trays are systems whereby safety is offered by both the cable and the supporting tray. This system is specifically intended for industrial application. The insulated conductors in raceways are applicable to all types of wiring in all types of facilities. There are two main subdivisions in this classification:

1. Field Assembled Systems, where usually the conduit or other enclosure is installed first, with the conductors being pulled or laid at a later time. These systems can be either buried into,

attached to, or a part of the structure, and/or any combination of the three.

2. Preassembled Systems, which are either factory-assembled cables or prewired raceways.

A presentation of the major building wiring types which fall into the above mentioned categories is now presented with pertinent comments. It is impossible to succinctly state what wiring types will be required of photovoltaic arrays in the commercial/industrial sector. This is because of the wide variation of construction type and occupancy type encountered in this sector. Furthermore, the mounting placement and wiring exposure will dictate what requirements will need to be satisfied. It is important to realize, however, that certain wiring types and practices which are commonly used in the residential sector are not found in the commercial sector. It can be assumed that the harsher environments accompanied by increased risks of mechanical damage in the commercial/industrial sector will require that a well-protected wiring scheme be utilized.

There is a provision in the NEC which would permit the installation of photovoltaic systems in the near-term. This provision states (NEC 90-6 Examination of Equipment for Safety):

> "It is the intent of this Code that factory-installed wiring or the construction of equipment need not be inspected at the time of installation of the equipment, except to detect alterations or damage, if the equipment has been listed by an electrical testing laboratory that is nationally recognized...and which requires suitability for installation in accordance with this Code."

Therefore, if the module and/or panel electrical wiring interconnects are either factory-installed or field constructed and certified by a national testing facility, e.g. Underwriters Laboratory, then acceptance by the code official who refers to the NEC will be considerably easier. This is analogous to the internal wiring requirements of electrical motors and lighting systems. The acceptance and listing by such a national testing laboratory will be based on the development of the industry standards through the processes referred to at the beginning of this report. It is important, nevertheless, to be cognizant of the present NEC requirements regarding accepted building wiring systems, as the electrical wiring of a photovoltaic system must at some time lend itself to such requirements. These NEC requirements are addressed in detail in the wiring section of this report. The following list of wiring systems and relevant comments are intended to illustrate differences associated with each.

I. Flexible, Metal Clad Cable (NEC type AC)

- trade name "BX"
- must have internal metallic bonding strip in contact with the armor for its entire length.
- must be installed as unit using staples, U-clamps, etc.
- is frequently used in residences and in the rewiring of existing buildings.
- is not allowed in battery storage rooms or certain commercial applications (NEC Article 511)
- is generally restricted to dry locations where not subject to physical damage
- may be exposed and concealed where not subject to physical damage.
- lead covered conductors available (Type ACL) if used where exposed to weather or continuous moisture or underground runs in raceways and embedded in masonry, concrete, or fill in buildings in course of construction, or where exposed to oil or other conditions having a deteriorating effect on the insulation.

II. Nonmetallic Sheathed (Romex)

- is restricted to commercial/industrial buildings not more than 3 floors above grade and residential applications.
- is only for dry locations.

III. Metal Insulated Cable

- is an integral assembly of copper conductors, mineral insulation, and outer copper jacket that serves as a water and gas seal and a continuous ground.
- requires special fittings for termination.
- mineral insulation is flame-proof and cold resistant.
- has an entire construction which is explosion-proof, lightweight, non-aging.
- raceways unnecessary.
- has no application limits.

Note: Because it appears that raceways, e.g. conduit, may be required in the commercial/industrial sector, it may be possible to justify the increased costs associated with MI cable. MI cable with an 85°C rating may permit the use of smaller conductors that would be permitted for a cable with a 60°C rating. Also, the no-conduit, free-air situation with MI should help with temperature control of the conductor. Busways are essentially unimportant here due to the lower current levels associated with PV than with usual busway current levels. Likewise, the Cablebus assemblies are generally available with 3 to 18 cables for sizes 250 through 1500 MCM. These give corresponding electrical ratings from approximately 400-6000 amp and in voltage with ratings of 600, 5000, and 15,000 volts. The current and voltage levels associated with most of the PV systems in the commercial/industrial sector will be less than this and, if encountered, will be found only at the system output terminals. Cablebus and busways are therefore not recommended as serious considerations for wiring systems for the commercial/industrial photovoltaic system.

IV. Flat Cable Assemblies

- NEC Article 363
- may be field installed
- uses AWG 10 conductors

- specially designed cable consisting of 2, 3, or 4 conductors
- allows lights, small motors, unit heaters, and other single phase, light-duty devices to be served without the necessity of conduit and cable wiring.

V. Cable Tray

- NEC Article 318
- is specifically intended for industrial application
- relies upon both the cable and the tray for safety
- is used as a general wiring system that requires that the cables be self-protected, jacketed types such as MI, ALS, and the special tray cable, type TC.
- is used in industrial facilities where only competent maintenance personnel have access to the cable, large size normal building wire can be used.
- advantages are:
  1. free-air rated cables
  2. easy installation and maintenance
  3. relatively low cost
- disadvantages are:
  1. bulkiness
  2. required accessibility

VI. Closed Raceways:

Unlike the residential sector, the commercial/industrial sector involves environments where conductors/cables could receive a direct blow, and thereby suffer mechanical injury. Conduit is often essential when constructing a commercial wiring system. The purpose of the conduit is to:

1. Protect the enclosed wiring from mechanical injury and corrosion.
2. Provide a grounded metal enclosure for the wiring in order to avoid shock hazard.
3. Provide an equipment ground path.
4. Protect surroundings against fire hazard as a result of overheating of the enclosed conductors.
5. Support the conductors.

The three types of steel conduit are seen in Figure 7.1 and qualified as:

1. Heavy-wall or "rigid steel conduit", NEC 346
2. Intermediate metal conduit (IMC), NEC 345
3. Electrical Metallic Tubing (EMT), NEC 348

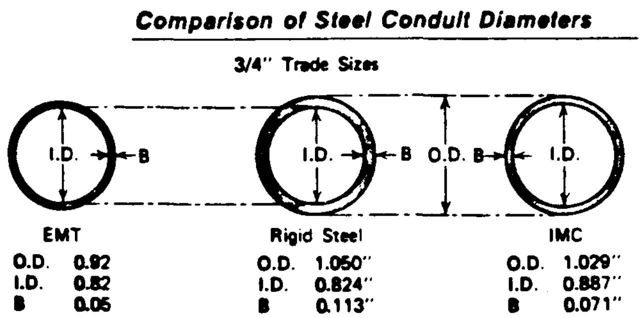


Figure 7.1

EMT and IMC have a larger inner diameter than the rigid conduit and, therefore, allow for easier wire pulling. The reduced weights are also an attractive characteristic of the EMT and IMC. A large amount of field bending would enhance this reduced labor associated with these 2 types of steel conduit. A 1/2" standard size conduit diameter is usually the smallest encountered. Special considerations must be made when conduit is embedded in concrete slabs.

What may prove even more attractive than the 3 steel conduits mentioned above is the Aluminum conduit. With a weight per unit length less than the EMT, there can be considerable labor cost savings with the Aluminum conduit in some cases. Its other advantages:

1. Better corrosion resistance in most atmospheres
2. Non-magnetic, giving lower voltage drop
3. Nonsparking
4. Doesn't require painting usually.

Of the few disadvantages associated with Aluminum is the sometimes unsatisfactory performance when embedded in concrete.

A flexible metal conduit known as "Greenfield" can be used where vibrations might be expected, or where physical obstructions make it difficult to use solid, rigid conduit. This may be the case in some PV installations; and if so, the flexible conduit would suffice in offering the assets of metal conduit while allowing for flexible wiring design. A liquid-tight flexible conduit is also available and is generally referred to by the trade name "Sealtite".

Non-metallic rigid conduit is also available. Typical materials used in these conduits are: fiber, asbestos-cement, soapstone, rigid polyvinyl chloride, and high density polyethylene. They are resistant to moisture and chemical corrosion. In general, there are no restrictions to the use of non-metal conduit within the limitations of the material, e.g. the lower temperature limitation associated the plastic conduits. The selection of a non-metallic conduit for use in a photovoltaic system would be based on calculations of temperature, mechanical stress, (and other parameters).

Surface raceways are covered in NEC Article 352. They are further classified as either "metal surface" or "non-metallic surface" raceways. This type of wiring system can be looked upon as a limited rigid conduit. However, a few characteristics of surface raceways makes them attractive for use in photovoltaic wiring systems. The most important characteristics is the resultant accessibility of the equipment within the raceway. This would offer an alternative to the rigid metal conduit, which makes access within the enclosure very difficult. Shared limitations for both metallic and non-metallic raceways are that they cannot be used:

- in damp locations (unless properly gasketed and accepted for such use)
- in concealed locations (2 exceptions for the metallic raceway)
- where subject to severe physical injury
- in hoistways
- in hazardous locations

Furthermore, non-metallic raceways are limited to an ambient temperature of 50°C with conductors whose insulation temperatures do not exceed 75°C, and a maximum voltage of 300 volts. The advantages of non-metallic over metallic raceways lie within its insensitivity to moisture and to corrosive atmospheres (including battery storage rooms). The advantages of metallic over non-metallic lie within its improved voltage capability (based on metal thickness) and ability to withstand injury.

The ability to integrate a raceway wiring system into the design and fabrication of the module/panel mounting framework could be advantageous. Properly designed, this system could offer physical protection, watertight enclosure, accessibility to conductors and/or terminals for testing and maintenance, and improved conductor carrying capacity due to nonderating of conductors (see NEC 352-4). The use of raceways must depend on many specific requirements of the particular photovoltaic system. An integrally mounted PV system might encounter code problems unless the raceway system is left exposed and accessible or has previously been approved for the purpose. This also requires that the raceway is capable of resisting physical damage to the extent required of it, especially in the commercial/industrial sector. A combination involving raceways and laboratory-accepted quick connect terminals appears to be attractive for many systems. This system would offer the flexibility and ease of maintenance of a plug-receptacle connector and the environmental protection of a properly designed raceway. A locking mechanism could be incorporated into the raceway system if accidental contact and/or vandalism is a potential problem with an array.

In conclusion, the above wiring systems can be used in PV applications where they have been identified as acceptable for use. At this time, the fact that photovoltaics is part of the system has no direct bearing on which wiring system is acceptable. Other than the lack of knowledge about PV, the code official will base his judgment of applicability on application, building type and occupancy.

7.2 WIRING

As the National Electrical Code does not address photovoltaics directly, the designer, as well as the code official, must interpret the code and its intent as it will or may apply to the installation and use of photovoltaic wiring systems. In light of this, the code official may view parts of the wiring system as resembling conventional wiring systems.

According to the NEC, a premises wiring system can consist of three parts:

1. Service
2. Feeders (and subfeeders)
3. Branch circuits

The NEC defines these three components as follows:

1. Service Conductor - The supply conductors that extend from the street main or from transformers to the service equipment of the premises supplied.

   Where service equipment is defined as the necessary equipment, usually consisting of a circuit breaker or switch and fuses and their accessories, located near the point of entrance of supply conductors to a building or other structure, or an otherwise defined area and intended to constitute the main control and means of cutoff of the supply.
2. Feeders - all circuit conductors between the service equipment, or the generator switchboard of an isolated plant and the final branch-circuit overcurrent device.
3. Branch Circuit - the circuit conductors between the final overcurrent device protecting the circuit and the outlet(s).

However, it is important to note that these definitions were established for use end, while the photovoltaic array is the source end. It will be necessary, as well as desirable, for the PV industry to avoid the use of these terms -- service conductor, feeders and branch circuits -- so as not to have imposed the requirements as currently outlined by the NEC. New terms, definitions and requirements must be generated which properly describe the wiring systems for PV.

Indeed, it is the intent of this study to analyze the related NEC requirements as pertains to its potential interpretation and discuss their relevancy as concerns photovoltaic power systems in this report. Many sections of the NEC apply specifically to areas of electrical power distribution which are primarily a characteristic of a conventional AC power source (utility lines); and therefore, many areas of the code will not be discussed due to this obvious inapplicability to on-site, DC photovoltaic systems. The approach used in interpreting the NEC as a precursor of photovoltaic electrical code requirements centers on the synthesis of a general electrical philosophy as exhibited by the code. The development of this electrical philosophy is most important. At this stage in the establishment of future photovoltaic electrical requirements as concerns wiring, termination and grounding, a clear understanding of presently accepted codes should involve more than a simple interpretation of what the code requires. The importance of the development, marketing and utilization of the photovoltaic module/array/system based on safe electrical characteristics cannot be overstated. To have photovoltaics marked early in their conception by electrical failure (in the sense of shock, fire, or other directly resulting hazards) would substantially impair any hopes for a rapid market development. It is, therefore, hoped that this section will supply photovoltaic electrical guidelines as interpreted through a very well-developed and well-used code - the National Electrical Code (NEC).

A previously published document (Residential Photovoltaic Module and Array Requirement Study, JPL/DOE #955149-79/1) that researched the electrical requirements of photovoltaics (based on the NEC) considered only the residential sector. The NEC makes a clear categorization of codes based on the level of voltage encountered. The three voltage groups addressed in the NEC and believed applicable to PV systems are:

1. Less than 30 V
2. 30 V to 600 V, inclusive
3. Greater than 600 V

Due to the larger electrical demands exhibited by commercial/industrial buildings over those of residential, the inclusion of the 600 volt (and greater) codes will appear in this study. The amount of voltage encountered in any one photovoltaic system will depend entirely on the choice of series/paralleling made by the engineer in order to reach a required power output in wattage. The decision of a system array voltage will depend on many factors, among which include:

1. Desired system power output
2. Location of the array
   a. With respect to load
   b. With respect to human access
3. Load requirements
4. System performance considerations involving shadowing, cell short-circuiting, etc.
5. Wiring, grounding and termination requirements

With regard to wiring type, the NEC definitions will be used when assessing the type of wire for a given location -- underground, dry or wet. The NEC Table 310-13, Conductor Application and Insulations, supplies further information about conductor types and application. This table appears as Table 7.1.

The wiring in a photovoltaic system (intermodule, inter-subarray and array) is inherently different from that of the branch or feeder in that it is not subject to overcurrent (if the system is properly designed to limit reverse current flow). The purpose of photovoltaic wiring is not to distribute power to various loads, but rather to supply appropriate (series/parallel) modular electrical continuity so that the array output can be provided to a particular load which will most likely be a power conditioning unit. The output of the PCU will then "supply" the premises. In addition to wiring type, other code sections will apply by virtue of their similarity to PV wiring system. When circuits enter or exit a building, compliance with Article 225-11 will be required.

> **225-11. Circuit Exits and Entrances.** Where outside branch and feeder circuits leave or enter a building, the requirements of Sections 230-43, 230-52, and 230-54 shall apply.

Table 310-13. Conductor Application and Insulations

Trade Name	Type Letter	Max. Operating Temp.	Application Provisions	Insulation	AWG or MCM	Thickness of Insulation Mils	Outer Covering
Heat-Resistant Rubber	RH	75°C 167°F	Dry locations	Heat-Resistant Rubber	**14-12 10 8-2 1-4/0 213-500 501-1000 1001-2000	30 45 60 80 95 110 125	*Moisture resistant, flame retardant, non-metallic covering
Heat-Resistant Rubber	RHH	90°C 194°F	Dry locations				
Moisture and Heat-Resistant Rubber	RHW	75°C 167°F	Dry and wet locations For over 2000 volts insulation shall be ozone-resistant	Moisture and Heat-Resistant Rubber	14-10 8-2 1-4/0 213-500 501-1000 1001-2000	45 60 80 95 110 125	*Moisture-resistant, flame-retardant, non metallic covering
Heat Resistant Latex Rubber	RUH	75°C 167°F	Dry locations.	90% Un-milled, Grainless Rubber	14-10 8-2	18 25	Moisture resistant, flame-retardant, non-metallic covering

* Outer covering shall not be required over rubber insulations which have been specifically approved for the purpose

** For 14-12 sizes RHH shall be 45 mils thickness insulation

For insulated aluminum and copper-clad aluminum conductors, the minimum size shall be No. 12. See Tables 310-16 through 310-19.

Trade Name	Type Letter	Max. Operating Temp.	Application Provisions	Insulation	AWG or MCM	Thickness of Insulation Mils	Outer Covering
Moisture-Resistant Latex Rubber	RUW	60°C 140°F	Dry and wet locations	90% Un-milled, Grainless Rubber	14-10 8-2	18 25	Moisture-resistant, flame-retardant, non-metallic covering
Thermoplastic	T	60°C 140°F	Dry locations	Flame-Retardant, Thermo-plastic Compound	14-10 8 6-2 1-4/0 213-500 501-1000 1001-2000	30 45 60 80 95 110 125	None
Moisture-Resistant Thermoplastic	TW	60°C 140°F	Dry and wet locations	Flame-Retardant, Moisture-Resistant Thermo-plastic	14-10 8 6-2 1-4/0 213-500 501-1000 1001-2000	30 45 60 80 95 110 125	None
Heat Resistant Thermoplastic	THHN	90°C 194°F	Dry locations	Flame-Retardant, Heat-Resistant Thermo-plastic	14-12 10 8-6 4-2 1-4/0 250-500 501-1000	15 20 30 40 50 60 70	Nylon jacket or equivalent
Moisture- and Heat-Resistant Thermoplastic	THW	75°C 167°F 90°C 194°F	Dry and wet locations Special applications within electric discharge lighting equipment. Limited to 1000 open circuit volts or less. (Size 14-8 only as permitted in Section 410-31.)	Flame-Retardant, Moisture and Heat-Resistant Thermo-plastic	14-10 8-2 1-4/0 213-500 501-1000 1001-2000	45 60 80 95 110 125	None
Moisture- and Heat-Resistant Thermoplastic	THWN	75°C 167°F	Dry and wet locations	Flame-Retardant, Moisture-and Heat Resistant Thermo-plastic	14-12 10 8-6 4-2 1-4/0 250-500 501-1000	15 20 30 40 50 60 70	Nylon jacket or equivalent
Moisture- and Heat-Resistant Cross Linked Synthetic Polymer	XHHW	90°C 194°F 75°C 167°F	Dry locations. Wet locations.	Flame-Retardant Cross Linked Synthetic Polymer	14-10 8-2 1-4/0 213-500 501-1000 1001-2000	30 45 55 65 80 95	None
Moisture-, Heat- and Oil-Resistant Thermoplastic	MTW	60°C 140°F 90°C 194°F	Machine tool wiring in wet locations as permitted in NFPA Standard No. 79 (See Article 670.) Machine tool wiring in dry locations as permitted in NFPA Standard No. 79 (See Article 670.)	Flame-Retardant, Moisture-, Heat- and Oil-Resistant Thermo-plastic	 22-12 10 8 6 4-2 1-4/0 213-500 501-1000	(A) (B) 30 15 30 20 45 30 60 30 60 40 80 50 95 60 110 70	(A) None (B) Nylon jacket or equivalent

For insulated aluminum and copper-clad aluminum conductors, the minimum size shall be No. 12. See Tables 310-16 through 310-19.

Table 7.1 (Cont.)

Table 310-13 (Continued)

Trade Name	Type Letter	Max. Operating Temp.	Application Provisions	Insulation	AWG or MCM	Thickness of Insulation Mils	Outer Covering
Perfluoro-alkoxy	PFA	90°C 194°F 200°C 392°F	Dry locations Dry locations — special applications	Perfluoro-alkoxy	14-10 8-2 1-4/0	20 30 45	None
Perfluoro-alkoxy	PFAH	250°C 482°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus. (Nickel or nickel-coated copper only.)	Perfluoro-alkoxy	14-10 8-2 1-4/0	20 30 45	None
Extruded Polytetra-fluoroethylene	TFE	250°C 482°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus, or as open wiring. (Nickel or nickel-coated copper only.)	Extruded Polytetra-fluoro-ethylene	14-10 8-2 1-4/0	20 30 45	None
Thermoplastic and Asbestos	TA	90°C 194°F	Switchboard wiring only	Thermo-plastic and Asbestos	14-8 6-2 1-4/0	Th pl: 20, 30, 40 Ash: 20, 25, 30	Flame-retardant, nonmetallic covering
Thermoplastic and Fibrous Outer Braid	TBS	90°C 194°F	Switchboard wiring only	Thermo-plastic	14-10 8 6-2 1-4/0	30 45 60 80	Flame-retardant, nonmetallic covering
Synthetic Heat-Resistant	SIS	90°C 194°F	Switchboard wiring only	Heat-Resistant Rubber	14-10 8 6-2 1-4/0	30 45 60 80	None
Mineral Insulation (Metal Sheathed)	MI	85°C 185°F 250°C 482°F	Dry and wet locations For special application	Magnesium Oxide	16-10 9-4 3-250	36 50 55	Copper
Underground Feeder & Branch-Circuit Cable Single Conductor (For Type UF cable employing more than one conductor see Article 339.)	UF	60°C 140°F	See Article 339	Moisture-Resistant	14-10 8-2 1-4/0	*60 *80 *95	Integral with insulation
		75°C** 167°F		Moisture- and Heat-Resistant			
Underground Service-Entrance Cable Single Conductor (For Type USE cable employing more than one conductor see Article 338.)	USE	75°C 167°F	See Article 338	Heat- and Moisture-Resistant	12-10 8-2 1-4/0 213-500 501-1000 1001-2000	45 60 80 95 110 125	Moisture-resistant non-metallic covering [See 338-1 (2).]

* Includes integral jacket

** For ampacity limitation, see 339-1(a)

The nonmetallic covering over individual rubber-covered conductors of aluminum-sheathed cable and of lead-sheathed or multiconductor cable shall not be required to be flame retardant. For Type MC cable, see Section 334-20. For nonmetallic-sheathed cable, see Section 336-2. For Type UF cable, see Section 339-1.

For insulated aluminum and copper-clad aluminum conductors, the minimum size shall be No. 12. See Tables 310-16 through 310-19.

Trade Name	Type Letter	Max. Operating Temp.	Application Provisions	Insulation	AWG or MCM	Thickness of Insulation Mils	Outer Covering
Silicone-Asbestos	SA	90°C 194°F 125°C 257°F	Dry locations For special application	Silicone Rubber	14-10 8-2 1-4/0 213-500 501-1000 1001-2000	45 60 80 95 110 125	Asbestos or glass
Fluorinated Ethylene Propylene	FEP or FEPB	90°C 194°F 200°C 392°F	Dry locations Dry locations — special applications	Fluorinated Ethylene Propylene	14-10 8-2	20 30	None
				Fluorinated Ethylene Propylene	14-8	14	Glass braid
					6-2	14	Asbestos braid
Modified Fluorinated Ethylene Propylene	FEPW	75°C 90°C	Wet locations Dry locations	Modified Fluorinated Ethylene Propylene	14-10 8-2	20 30	None
Modified Ethylene Tetrafluoro-ethylene	Z	90°C 194°F 150°C 302°F	Dry locations Dry locations — special applications	Modified Ethylene Tetrafluoro-ethylene	14-12 10 8-4 3-1 1/0-4/0	15 20 25 35 45	None
Modified Ethylene Tetrafluoro-ethylene	ZW	75°C 167°F 90°C 194°F 150°C 302°F	Wet locations Dry locations Dry locations — special applications	Modified Ethylene Tetrafluoro-ethylene	14-10 8-2	30 45	None

Table 310-13 (Continued)

Trade Name	Type Letter	Max. Operating Temp.	Application Provisions	Insulation	AWG or MCM	Thickness of Insulation Mils	Outer Covering
Asbestos	A	200°C 392°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus. Limited to 300 volts	Asbestos	14 12-8	30 40	Without asbestos braid
Asbestos	AA	200°C 392°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus or as open wiring. Limited to 300 volts	Asbestos	14 12-8 6-2 1-4/0	30 30 40 60	With asbestos braid or glass
Asbestos	AI	125°C 257°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus. Limited to 300 volts	Impregnated Asbestos	14 12-8	30 40	Without asbestos braid
Asbestos	AIA	125°C 257°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus or as open wiring	Impregnated Asbestos	 14 12-8 6-2 1-4/0 213-500 501-1000	Sol Str 30 30 30 40 40 60 60 75 90 105	With asbestos braid or glass
Paper		85°C 185°F	For underground service conductors, or by special permis	Paper			Lead sheath

Trade Name	Type Letter	Max. Operating Temp.	Application Provisions	Insulation	AWG or MCM	Thickness of Insulation Mils	Outer Covering
Asbestos	A	200°C 392°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus. Limited to 300 volts.	Asbestos	14 12-8	30 40	Without asbestos braid
Asbestos	AA	200°C 392°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus or as open wiring. Limited to 300 volts	Asbestos	14 12-8 6-2 1-4/0	30 30 40 60	With asbestos braid or glass
Asbestos	AI	125°C 257°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus. Limited to 300 volts	Impregnated Asbestos	14 12-8	30 40	Without asbestos braid
Asbestos	AIA	125°C 257°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus or as open wiring	Impregnated Asbestos	 14 12-8 6-2 1-4/0 213-500 501-1000	Sol Str 30 30 30 40 40 60 60 75 90 105	With asbestos braid or glass
Paper		85°C 185°F	For underground service conductors, or by special permission	Paper			Lead sheath

For insulated aluminum and copper-clad aluminum conductors, the minimum size shall be No. 12. See Tables 310-16 through 310-19

This code refers to 3 codes under Section F of Article 230 titled "Installation of Service Conductors". Therefore, no matter what the wiring classification (branch or feeder), if the circuit leaves or enters the building, it must comply with the requirements of a service conductor as stated in Article 230(F).

Furthermore, the entrance requirements are described in Article 230-52.

> **230-52. Individual Conductors Entering Buildings or Other Structures.** Where individual open conductors enter a building or other structure, they shall enter through roof bushings or through the wall in an upward slant through individual, noncombustible, nonabsorbent insulating tubes. Drip loops shall be formed on the conductors before they enter the tubes.

Thus, if individual conductors from a photovoltaic array enter the building through the roof, roof bushings must be used. If they enter through the wall, then nonabsorbent insulating tubes must be used in such a manner that rain is prevented from entering. Procelain is a common material used for such tubes, and drip loops are also required for prevention of water entering the building.

It appears that the photovoltaic wiring not entering the building must be installed as stated in 225-10.

> **225-10. Wiring on Buildings.** The installation of outside wiring on surfaces of buildings shall be permitted for circuits of not over 600 volts, nominal, as open wiring on insulators, as multiconductor cable, as Type MC cable, as Type MI cable, in rigid metal conduit, in intermediate metal conduit, in rigid nonmetallic conduit as provided in Section 347-2, in busways as provided in Article 364, or in electrical metallic tubing. Circuits of over 600 volts, nominal, shall be installed as provided for services in Section 230-202.

For circuits not over 600 volts, it can be seen from 225-10 that a number of options exist. The application of Article 225-10 to photovoltaics is based on the physical placement of the array wiring, as opposed to similarity of electrical function. This might very well be the case for the individual module interconnects. If only one set of conductors from the array enters the building, then it must be installed by one of the methods listed in 230.43. It should be noted that 230.43 is only applicable to circuits under 600 volts.

It will likewise be required that any photovoltaic conductor (whether it be individual conductors as covered in 230-52 or what might be the primary array conductors carrying the entire system current across the system voltage) will also need to meet Article 230-54 requirements. Subsection (e) in 230-54 should also be considered in the photovoltaic wiring scheme, as it requires that the opposite polarity leads be separated from one another as they pass through the service head.

230-54. Connections at Service Head.

(a) Raintight Service Head. Service raceways shall be equipped with a raintight service head.

(b) Service Cable Equipped with Raintight Service Head or Gooseneck. Service cables, either (1) unless continuous from pole to service equipment or meter, shall be equipped with a raintight service head, or (2) formed in a gooseneck and taped and painted or taped with a self-sealing, weather-resistant thermoplastic.

(c) Service Heads Above Service-Drop Attachment. Service heads and goosenecks in service-entrance cables shall be located above the point of attachment of the service-drop conductors to the building or other structure.

Exception: Where it is impracticable to locate the service head above the point of attachment, the service head location shall be permitted not farther than 24 inches (610 mm) from the point of attachment.

(d) Secured. Service cables shall be held securely in place.

(e) Opposite Polarity Through Separately Bushed Holes. Service heads shall have conductors of opposite polarity brought out throug separately bushed holes.

(f) Drip Loops. Drip loops shall be formed on individual conductors. To prevent the entrance of moisture, service-entrance conductors shall be connected to the service-drop conductors either (1) below the level of the service head, or (2) below the level of the termination of the service-entrance cable sheath.

(g) Arranged that Water Will Not Enter Service Raceway or Equipment. Service-drop conductors and service-entrance conductors shall be arranged so that water will not enter service raceway or equipment.

An additional concern of the photovoltaic wiring system involves the protection of open conductors and cables against damage. (Note: This is for aboveground cases.) This concern is addressed in 230-50 as follows:

230-50. Protection of Open Conductors and Cables Against Damage — Aboveground. Service-entrance conductors installed aboveground shall be protected against physical damage as specified in (a) or (b) below.

(a) Service-Entrance Cables. Service-entrance cables, where subject to physical damage, such as where installed in exposed places near driveways or coal chutes, or where subject to contact with awnings, shutters, swinging signs, or similar objects, shall be protected in any of the following ways: (1) by rigid metal conduit; (2) by intermediate metal conduit; (3) by rigid nonmetallic conduit suitable for the location; (4) by electrical metallic tubing; (5) by Type MC cable; or (6) by other approved means.

(b) Other than Service-Entrance Cable. Individual open conductors and cables other than service-entrance cables shall not be installed within 10 feet (3.05 m) of grade level or where exposed to physical damage.

Note that if the photovoltaic wiring does not qualify as a service-entrance cable, then individual open conductors and cables must be 8 feet or more above grade level. Any commercial or industrial situation where physical damage may be imposed on the conductor restricts their use, unless the appropriate steps (as mentioned in (a)) are taken to protect them.

As previously noted, the above section pertains to voltage levels less than or equal to 600 volts. Articles 230 (k) identify the requirements for systems in excess of 600 volts. Again, an interpretation of existing code article will dominate the code official's decisions until PV is specifically addressed in the NEC. Therefore, Article 230-200 may be utilized for the entrance of the PV system bus.

K. Services Exceeding 600 Volts, Nominal

230-200. General. Service conductors and equipment used on circuits exceeding 600 volts, nominal, shall comply with all applicable provisions of the preceding sections of this article and with the following sections, which supplement or modify the preceding sections. In no case shall the provisions of this article apply to equipment on the supply side of the service-point.

Definition: Service-point is the point of connection between the facilities of the serving utility and the premises' wiring.

For clearances of conductors of over 600 volts, nominal, see National Electrical Safety Code (ANSI C2-1977).

As mentioned previously, a potential difference between the residential and the commercial photovoltaic system is the power output. It was, therefore, decided that high voltage (>600) requirements be studied and presented so as to inform interested parties as to what additional considerations have to be made in the event of high voltage photovoltaic implementation. Even in large commercial/industrial applications, it is unlikely that voltages in excess of 600 volts will be found below that of the subarray voltages, and will more likely be found only at the primary array conductor level. Before the acceptable wiring methods for high voltage services are discussed, it is necessary that a clarification of service conductor definition be made. This is done in 230-201 as follows:

230-201. Classification of Service Conductors.

(a) Secondary Conductors. The secondary conductors shall constitute the service conductors where the step-down transformers are located as follows: (1) outdoors; (2) in a separate building from the building or other structure served; (3) inside the building or other structure served where in a vault complying with Part C of Article 450; (4) inside the building or other structure served where in a locked room or other locked enclosure and accessible to qualified persons only; or (5) inside the building or other structure where in metal-enclosed gear.

(b) Primary Conductors. In all cases not specified in (a) above, the primary conductors shall be considered the service conductors.

Exception: Either the primary or the secondary conductors shall be permitted to constitute the service conductors for an industrial complex where both the primary and secondary voltages are over 600 volts, nominal.

Note: This definition may not apply to any portion of the PV wiring system directly, but the interpretation is possible. Efforts must be made by the PV industry to properly define each of the portions of the wiring system.

In light of the above note and the potential for service entrance conductor interpretation, Article 230-202 addresses requirements for service in excess of 600 volts.

230-202. Service-Entrance Conductors. Service-entrance conductors to buildings or enclosures shall be installed to conform to the following:

(a) Conductor Size. Service conductors shall be not smaller than No. 6 unless in cable. Conductors in cable shall not be smaller than No. 8.

(b) Wiring Methods. Service-entrance conductors shall be installed by means of one of the following wiring methods: (1) in rigid metal conduit; (2) in intermediate metal conduit; (3) in rigid nonmetallic conduit where encased in not less than 2 inches (50.8 mm) of concrete; (4) as multiconductor cable identified as service cable; (5) as open conductors where supported on insulators and where either accessible only to qualified persons or where effectively guarded against accidental contact; (6) in cablebus; or (7) in busways.

Underground service-entrance conductors shall conform to Section 710-3(b).

Cable tray systems shall be permitted to support cables identified as service-entrance conductors. See Article 318.

See Section 310-6 for shielding of solid dielectric insulated conductors.

(c) Open Work. Open wire services over 600 volts, nominal, shall be installed in accordance with the provisions of Article 710, Part D.

(d) Supports. Service conductors and their supports, including insulators, shall have strength and stability sufficient to ensure maintenance of adequate clearance with abnormal currents in case of short circuits.

(e) Guarding. Open wires shall be guarded to make them accessible only to qualified persons.

(f) Service Cable. Where cable conductors emerge from a metal sheath or raceway, the insulation of the conductors shall be protected from moisture and physical damage by a pothead or other approved means.

(g) Draining Raceways. Unless conductors identified for use in wet locations are used, raceways embedded in masonry or exposed to the weather shall be arranged to drain.

(i) Conductor Considered Outside Building. Conductors placed under at least 2 inches (50.8 mm) of concrete beneath a building, or conductors within a building in conduit or raceway and enclosed by concrete or brick not less than 2 inches (50.8 mm) thick shall be considered outside the building.

However, a high voltage primary extending from a photovoltaic array through the building and into a power conditioning room may not under certain circumstances be considered the service entrance conductor. Two such examples are given in Figures 7.2 and 7.3

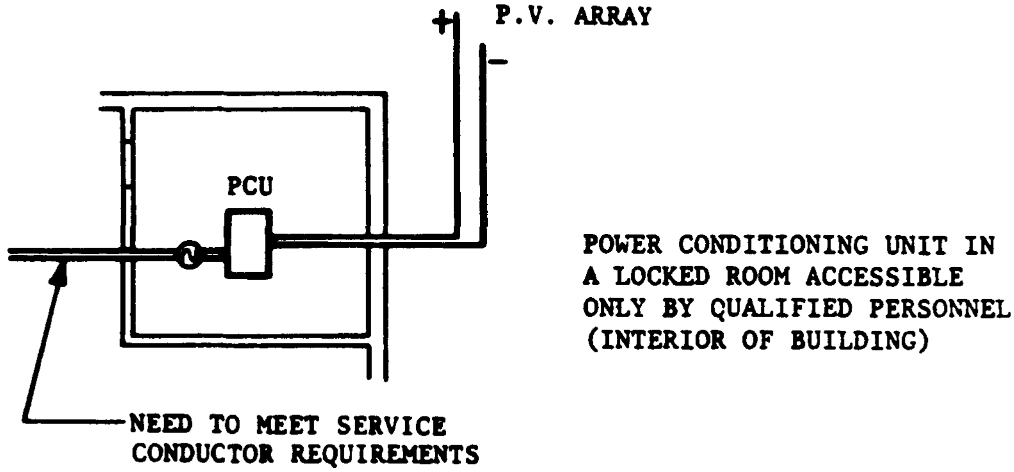


Figure 7.2

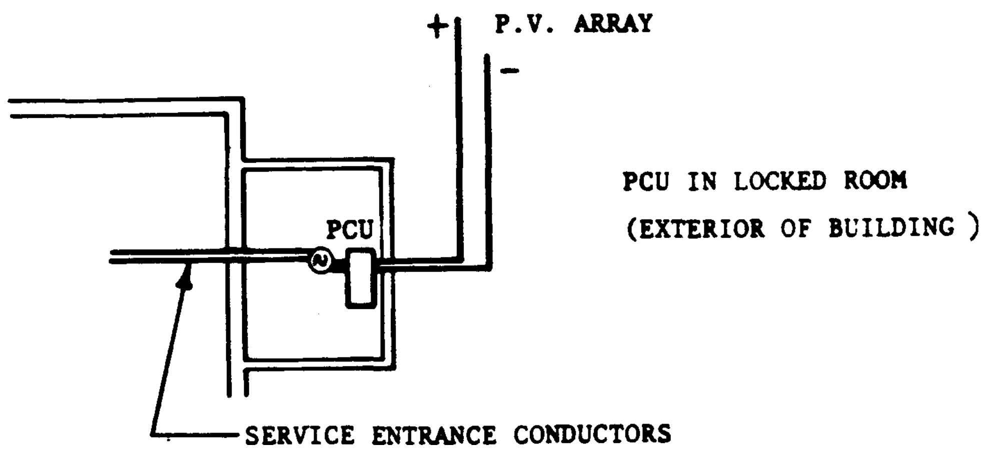


Figure 7.3

In addition to the above code articles, the number of conductors allowed by code in a conduit or a closed raceway will be defined by code and applied to PV wiring systems. It is apparent that code regulation as it currently exists allows for a number of different methods in wiring the photovoltaic module/array as it qualifies as either "wiring on buildings" and "service-entrance conductors". In establishing a wiring scheme, it must be remembered that according to the NEC a maximum number of conductors can be placed in a respective conduit; depending on conductor physical dimensions (cross-sectional area including insulation), the number of conductors of each particular size, and the conduit trade size. The <u>type</u> of conductor is not a factor in this determination.

Tables 2, 3A, 3B and 3C in Chapter 9 of the NEC and Tables 7.2 through 7.5 of this report provide for the maximum allowable number of conductors (new work or rewiring) that may be enclosed in complete systems of conduit or tubing, based on the percentage of fill of Table 1, and do not apply to short sections of conduit or tubing used for the physical protection of conductors and cables. All conductors, including equipment grounding conductors (insulated or bare) and neutral or grounded conductor, must be counted. If the conductors are high-voltage types, the cross-sectional area may be calculated in the following manner, using the actual dimensions of each conductor:

D = outside diameter of a conductor (including insulation)
CM = circular units
1in. = 1,000 mils (or 1 mil = 0.001 in.)
CM = /4 = .7854 of a square mil.

Diam. in mils squared x 0.7854 = cross-sectional area

Table 7.2

Table 1. Percent of Cross Section of Conduit and Tubing for Conductors

(See Table 2 for Fixture Wires)

Number of Conductors	1	2	3	4	Over 4
All conductor types except lead-covered (new or rewiring)	53	31	40	40	40
Lead-covered conductors	55	30	40	38	35

Note 1. See Tables 3A, 3B and 3C for number of conductors all of the same size in trade sizes of conduit ½ inch through 6 inch.

Note 2. For conductors larger than 750 MCM or for combinations of conductors of different sizes, use Tables 4 through 8, Chapter 9, for dimensions of conductors, conduit and tubing.

Note 3. Where the calculated number of conductors, all of the same size, includes a decimal fraction, the next higher whole number shall be used where this decimal is 0.8 or larger.

Note 4. When bare conductors are permitted by other sections of this Code, the dimensions for bare conductors in Table 8 of Chapter 9 shall be permitted.

Note 5. A multiconductor cable of two or more conductors shall be treated as a single conductor cable for calculating percentage conduit fill area. For cables that have elliptical cross section, the cross-sectional area calculation shall be based on using the major diameter of the ellipse as a circle diameter.

Table 7.2 (Continued)

Table 2. Maximum Number of Fixture Wires in Trade Sizes of Conduit or Tubing

(40 Percent Fill Based on Individual Diameters)

Conduit Trade Size (Inches)	½					¾					1					1¼					1½					2				
Wire Types	18	16	14	12	10	18	16	14	12	10	18	16	14	12	10	18	16	14	12	10	18	16	14	12	10	18	16	14	12	10
PTF, PTFF, PGFF, PGF, PFF, PF, PAF, PAFF, ZF, ZFF	23	18	14			40	31	24			63	50	39			115	90	70			157	122	95			257	200	156		
TFFN, TFN	19	15				34	26				55	43				97	76				132	104				216	169			
SF-1	16					29					47					83					114					186				
SFF-1, FFH-1	15					26					43					76					104					169				
CF	13	10	8	4	3	23	18	14	7	6	38	30	23	12	9	66	53	40	21	16	91	72	55	29	22	149	118	90	48	37
TF	11	10				20	18				32	30				57	53				79	72				129	118			
RFH-1	11					20					32					57					79					129				
TFF	11	10				20	17				32	27				56	49				77	66				126	109			
AF	11	9	7	4	3	19	16	12	7	5	31	26	20	11	8	55	46	36	19	15	75	63	49	27	20	123	104	81	44	34
SFF-2	9	7	6			16	12	10			27	20	17			47	36	30			65	49	42			106	81	68		
SF-2	9	8	6			16	14	11			27	23	18			47	40	32			65	55	43			106	90	71		
FFH-2	9	7				15	12				25	19				44	34				60	46				99	75			
RFH-2	7	5				12	10				20	16				36	28				49	38				80	62			
KF-1, KFF-1, KF-2, KFF-2	36	32	22	14	9	64	55	39	25	17	103	89	63	41	28	182	158	111	73	49	248	216	152	100	67	406	353	248	163	110

Table 7.3

Table 3A. Maximum Number of Conductors in Trade Sizes of Conduit or Tubing

(Based on Table 1, Chapter 9)

Conduit Trade Size (Inches)		½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
Type Letters	Conductor Size AWG, MCM													
TW, T, RUH,	14	9	15	25	44	60	99	142						
RUW,	12	7	12	19	35	47	78	111	171					
XHHW (14 thru 8)	10	5	9	15	26	36	60	85	131	176				
	8	2	4	7	12	17	28	40	62	84	108			
RHW and RHH	14	6	10	16	29	40	65	93	143	192				
(without outer	12	4	8	13	24	32	53	76	117	157				
covering),	10	4	6	11	19	26	43	61	95	127	163			
THW	8	1	3	5	10	13	22	32	49	66	85	106	133	
TW,	6	1	2	4	7	10	16	23	36	48	62	78	97	141
T,	4	1	1	3	5	7	12	17	27	36	47	58	73	106
THW,	3	1	1	2	4	6	10	15	23	31	40	50	63	91
RUH (6 thru 2),	2	1	1	2	4	5	9	13	20	27	34	43	54	78
RUW (6 thru 2),	1		1	1	3	4	6	9	14	19	25	31	39	57
FEPB (6 thru 2),	0		1	1	2	3	5	8	12	16	21	27	33	49
RHW and	00		1	1	1	3	5	7	10	14	18	23	29	41
RHH (with-	000		1	1	1	2	4	6	9	12	15	19	24	35
out outer	0000			1	1	1	3	5	7	10	13	16	20	29
covering)	250			1	1	1	2	4	6	8	10	13	16	23
	300			1	1	1	2	3	5	7	9	11	14	20
	350				1	1	1	3	4	6	8	10	12	18
	400				1	1	1	2	4	5	7	9	11	16
	500				1	1	1	1	3	4	6	7	9	14
	600					1	1	1	3	4	5	6	7	11
	700					1	1	1	2	3	4	5	7	10
	750					1	1	1	2	3	4	5	6	9

Table 7.4

Table 3B. Maximum Number of Conductors in Trade Sizes of Conduit or Tubing

(Based on Table 1, Chapter 9)

Conduit Trade Size (Inches)		½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
Type Letters	Conductor Size AWG, MCM													
	14	13	24	39	69	94	154							
	12	10	18	29	51	70	114	164						
THWN,	10	6	11	18	32	44	73	104	160					
	8	3	5	9	16	22	36	51	79	106	136			
THHN, FEP (14 thru 2),	6	1	4	6	11	15	26	37	57	76	98	125	154	
FEPB (14 thru 8),	4	1	2	4	7	9	16	22	35	47	60	75	94	137
PFA (14 thru 4/0)	3	1	1	3	6	8	13	19	29	39	51	64	80	116
PFAH (14 thru 4/0)	2	1	1	3	5	7	11	16	25	33	43	54	67	97
Z (14 thru 4/0)	1		1	1	3	5	8	12	18	25	32	40	50	72
XHHW (4 thru	0		1	1	3	4	7	10	15	21	27	33	42	61
500MCM)	00		1	1	2	3	6	8	13	17	22	28	35	51
	000		1	1	1	3	5	7	11	14	18	23	29	42
	0000		1	1	1	2	4	6	9	12	15	19	24	35
	250			1	1	1	3	4	7	10	12	16	20	28
	300			1	1	1	3	4	6	8	11	13	17	24
	350			1	1	1	2	3	5	7	9	12	15	21
	400				1	1	1	3	5	6	8	10	13	19
	500				1	1	1	2	4	5	7	9	11	16
	600				1	1	1	1	3	4	5	7	9	13
	700					1	1	1	3	4	5	6	8	11
	750					1	1	1	2	3	4	6	7	11
XHHW	6	1	3	5	9	13	21	30	47	63	81	102	128	185
	600				1	1	1	1	3	4	5	7	9	13
	700					1	1	1	3	4	5	6	7	11
	750					1	1	1	2	3	4	6	7	10

Table 7.5

Table 3C. Maximum Number of Conductors in Trade Sizes of Conduit or Tubing

(Based on Table 1, Chapter 9)

Conduit Trade Size (Inches)		½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
Type Letters	Conductor Size AWG, MCM													
	14	3	6	10	18	25	41	58	90	121	155			
	12	3	5	9	15	21	35	50	77	103	132			
RHW,	10	2	4	7	13	18	29	41	64	86	110	138		
	8	1	2	4	7	9	16	22	35	47	60	75	94	137
RHH	6	1	1	2	5	6	11	15	24	32	41	51	64	93
	4	1	1	1	3	5	8	12	18	24	31	39	50	72
(with	3	1	1	1	3	4	7	10	16	22	28	35	44	63
outer	2		1	1	3	4	6	9	14	19	24	31	38	56
covering)	1		1	1	1	3	5	7	11	14	18	23	29	42
	0		1	1	1	2	4	6	9	12	16	20	25	37
	00			1	1	1	3	5	8	11	14	18	22	32
	000			1	1	1	3	4	7	9	12	15	19	28
	0000			1	1	1	2	4	6	8	10	13	16	24
	250				1	1	1	3	5	6	8	11	13	19
	300				1	1	1	3	4	5	7	9	11	17
	350				1	1	1	2	4	5	6	8	10	15
	400				1	1	1	1	3	4	6	7	9	14
	500				1	1	1	1	3	4	5	6	8	11
	600					1	1	1	2	3	4	5	6	9
	700					1	1	1	1	3	3	4	6	8
	750						1	1	1	3	3	4	5	8

Notes to Tables

1. Tables 3A, 3B and 3C apply only to complete conduit or tubing systems and are not intended to apply to short sections of conduit or tubing used to protect exposed wiring from physical damage.

2. Equipment grounding conductors, when installed, shall be included when calculating conduit or tubing fill. The actual dimensions of the equipment grounding conductor (insulated or bare) shall be used in the calculation.

3. When conduit nipples having a maximum length not to exceed 24 inches (610 mm) are installed between boxes, cabinets, and similar enclosures, the nipple shall be permitted to be filled to 60 percent of its total cross-sectional area, and Note 8 of Tables 310-16 through 310-19 does not apply to this condition.

4. For conductors not included in Chapter 9, such as compact or multiconductor cables, the actual dimensions shall be used.

5. See Table 1 for allowable percentage of conduit or tubing fill.

Table 1 is based on common conditions of proper cabling and alignment of conductors where the length of the pull and the number of bends are within reasonable limits. It should be recognized that for certain conditions a larger size conduit or a lesser conduit fill should be considered.

Table 1. Percent of Cross Section of Conduit and Tubing for Conductors

(See Table 2 for Fixture Wires)

Number of Conductors	1	2	3	4	Over 4
All conductor types except lead-covered (new or rewiring)	53	31	40	40	40
Lead-covered conductors	55	30	40	38	35

Note 1. See Tables 3A, 3B, and 3C for number of conductors all of the same size in trade sizes of conduit ½ inch through 6 inch.

Note 2. For conductors larger than 750 MCM or for combinations of conductors of different sizes, use Tables 4 through 8, Chapter 9, for dimensions of conductors, conduit and tubing.

Note 3. Where the calculated number of conductors, all of the same size, includes a decimal fraction, the next higher whole number shall be used where this decimal is 0.8 or larger.

Note 4. When bare conductors are permitted by other sections of this Code, the dimensions for bare conductors in Table 8 of Chapter 9 shall be permitted.

Note 5. A multiconductor cable of two or more conductors shall be treated as a single conductor cable for calculating percentage conduit fill area. For cables that have elliptical cross section, the cross-sectional area calculation shall be based on using the major diameter of the ellipse as a circle diameter.

There are other considerations, beyond the number of accepted conductors in a conduit, which have to be made. The greater the number of conductors in the conduit, the lower the rated ampacity which can be applied to the particular conductor. Therefore, a conduit system design which attempts to save space and material costs will impose restrictions on the accepted minimum size of conductor which can be safely used.

If exposed, the conduit should be raintight with means of draining. This is specifically addressed in the following NEC article.

225-22. Raceways on Exterior Surfaces of Buildings. Raceways on exterior surfaces of buildings shall be made raintight and suitably drained.

A section of the NEC which might have application to large commercial/ industrial photovoltaic systems concerns underground transmission. A rack-mounted ground array which is located apart from the load site by any appreciable distance (where poles would be required for power transmission above ground) might appear favorable to underground transmission. However, it should be expected that proper consideration of wiring needs (e.g., protection from the environment and vandals, mounting, grounding, and termination) be made by both the manufacturer and the systems designer. Good engineering sense is the prerequisite for the development of a successful wiring scheme for this rack-mounted array. If the voltages involved in underground power transmission are less than 600 volts, the following, Article 230 Section D, applies.

Furthermore, wiring systems or portions thereof which are placed underground will be required to follow Article 230-30 if voltage levels are 600 volts or less.

230-30. Insulation. Service lateral conductors shall be insulated for the applied voltage.

Exception: A grounded conductor shall be permitted to be uninsulated as follows:

a. Bare copper used in a raceway.

b. Bare copper for direct burial where bare copper is judged to be suitable for the soil conditions.

c. Bare copper for direct burial without regard to soil conditions when part of a cable assembly identified for underground use.

d. Aluminum or copper-clad aluminum without individual insulation or covering when part of a cable assembly identified for underground use in a raceway or for direct burial.

230-31. Size and Rating. Conductors shall have sufficient ampacity to carry the load. They shall not be smaller than No. 8 copper or No. 6 aluminum or copper-clad aluminum. The grounded conductor shall not be less than the minimum size required by Section 250-23(b).

Again, the No. 8 copper and No. 6 aluminum or copper-clad aluminum conductors are a minimum size acceptable. It should be emphasized that they are minimums under any circumstances for underground wiring. Proper sizing considerations for a photovoltaic array of any considerable array of any considerable size (>25KW) will place requirements on the conductor size in excess of these stated minimums. For voltages in excess of 600 volts, underground conductors need to meet the NEC requirements as given in 710-3 Wiring Methods, which follows.

(b) Underground Conductors. Underground conductors shall be suitable for the voltage and conditions under which they are installed.

Direct burial cables shall comply with the provisions of Section 310-7.

Underground cables shall be permitted to be direct buried or installed in raceways identified for the use and shall meet the depth requirements of Table 710-3(b).

Nonshielded cables shall be installed in rigid metal conduit, in intermediate metal conduit, or in rigid nonmetallic conduit encased in not less than 3 inches (76 mm) of concrete.

Table 710-3(b)
Minimum Cover Requirements
(Cover Means the Distance in Inches Between the Top Surface of Cable or Raceway and the Grade)

Circuit Voltage	Direct Buried Cables	Rigid Nonmetallic Conduit Approved for Direct Burial*	Rigid Metal Conduit and Intermediate Metal Conduit
Over 600-22kV	30	18	6
Over 22kV-40kV	36	24	6
Over 40kV	42	30	6

For SI units: one inch = 25.4 millimeters.

* Listed by a qualified testing agency as suitable for direct burial without encasement. All other nonmetallic systems shall require 2 inches (50.8mm) of concrete or equivalent above conduit in addition to above depth.

Exception No. 1: The above minimum cover requirements shall be permitted to be reduced 6 inches (152 mm) for each 2 inches (50.8 mm) of concrete or equivalent above the conductors.

Exception No. 2: Areas subject to heavy vehicular traffic, such as thoroughfares or commercial parking areas, shall have a minimum cover of 24 inches (610 mm).

Exception No. 3: Lesser depths are permitted where cables and conductors rise for terminations or splices or where access is otherwise required.

Exception No. 4: In airport runways, including adjacent defined areas where trespass is prohibited, cable shall be permitted to be buried not less than 18 inches (457 mm) deep and without raceways, concrete enclosement, or equivalent.

Exception No. 5: Raceways installed in solid rock shall be permitted to be buried at lesser depth when covered by 2 inches (50.8 mm) of concrete which may extend to the rock surface.

(1) Protection from Damage. Conductors emerging from the ground shall be enclosed in approved raceway. Raceways installed on poles shall be of rigid metal conduit, intermediate metal conduit, PVC Schedule 80 or equivalent extending from the ground line up to a point 8 feet (2.44 m) above finished grade. Conductors entering a building shall be protected by an approved enclosure from the ground line to the point of entrance. Metallic enclosures shall be grounded.

The following section deals specifically with sizing conductors based on minimum ampacity as permitted by the NEC. Though the required size for photovoltaic wiring cannot be directly inferred from the NEC, a certain exhibited philosophy regarding conductor sizing, coupled with certain knowledge of the electrical characteristics of photovoltaic systems is sufficient for establishing an initial set of requirements. Minimum branch wiring size is generally ascertained by the NEC to be No. 14 AWG. This is due primarily to the fact that the code recognizes five branch-circuit ratings: 15, 20, 30, 40 and 50 amps. The total load connected to a branch circuit may not exceed the branch-circuit rating (as stated in 210.19 below). For example, although a 15 amp branch circuit may be loaded to 15 amps, continuous loads shall not exceed 80 percent of the circuit rating. Furthermore, additional maximum ampacity ratings must be developed with consideration of the type of loading. If a circuit supplies an individual load (e.g., a range), the wiring is sized according to the current requirement of that particular load. Although the following articles are applied to the load end of a system, important inferences may be drawn. A discussion of these follows.

B. Branch-Circuit Ratings

210-19. Conductors — Minimum Ampacity and Size.

(a) General. Branch-circuit conductors shall have an ampacity of not less than the rating of the branch circuit and not less than the maximum load to be served. Cable assemblies with the neutral conductor smaller than the ungrounded conductors shall be so marked.

210-22. Maximum Loads. The total load shall not exceed the rating of the branch circuit, and it shall not exceed the maximum loads specified in (a) through (c) below under the conditions specified therein.

(c) Other Loads. Continuous loads, such as store lighting and similar loads, shall not exceed 80 percent of the rating of the branch circuit.

Exception No. 1: Motor loads having demand factors computed in accordance with Article 430.

Exception No. 2: Circuits that have been derated in accordance with Note 8 to Tables 310-16 through 310-19.

Exceptions (1) and (2) exist so that a double derating doesn't occur in determining maximum loads.

Exception No. 3: Circuits supplied by an assembly together with its overcurrent devices that is listed for continuous operation at 100 percent of its rating.

This article exemplifies the dependency of wire sizing on the load type. The concern here is for determining how the load type will be classified for photovoltaic systems, and how that will affect the wire sizing requirements.

The photovoltaic cell acts as a current source when illuminated, where the current is primarily dependent on:

1. Size of cell (cm^2)
2. Intensity and wavelength of radiation reaching the cell
3. Temperature of the cell (°C)
4. Type of cell (material, manufacturing process used, etc.)

Furthermore, the module/array current output is a function of the number of cells/modules connected in a parallel arrangement, as well as the operating point on the voltage-current curve (determined by load resistance). The four initial parameters are all to be determined on the selection of a cell manufacturer and on the site where the system will operate. The number of cells/modules connected in parallel is not to be determined until detailed specifications relating to system design have been established. Furthermore, the insolation reaching the cell is a function of system orientation as well. The operating point on the V-I curve is also due to system design decisions, e.g. the loading characteristics of the service equipment.

Once these design decisions have been made, the magnitude of the maximum system operating current for any time during the year should be attainable.

*Continuous loads: defined by the NEC as a load where the maximum circuit current is expected to continue for three hours or more.

If we normalize this time dependent (diurnal) current curve, it will take on a shape quite similar to that of the following figure (for a clear day).

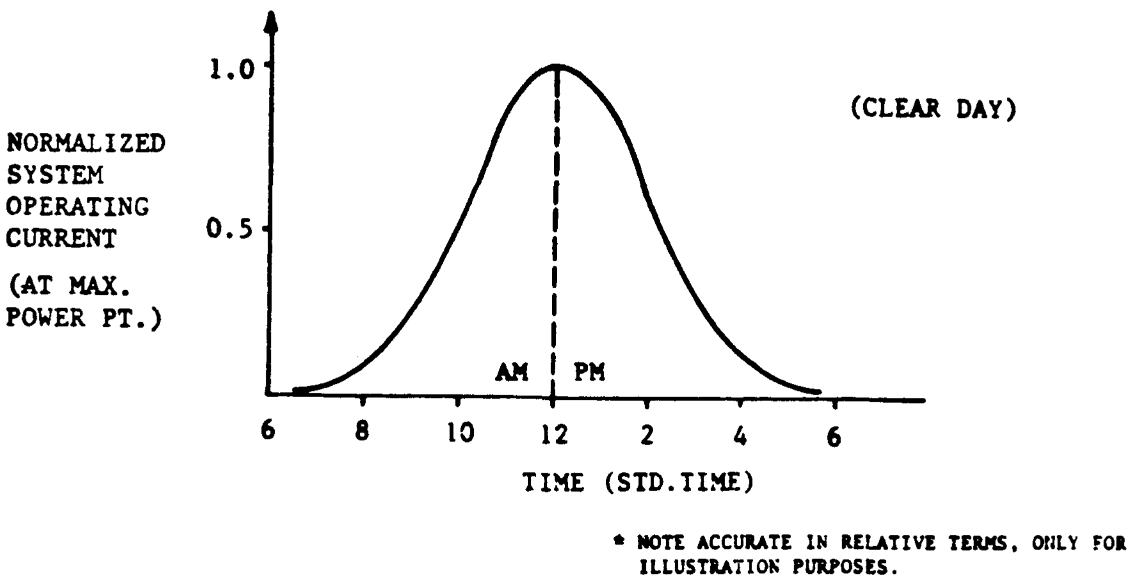


Figure 7.4

The NEC (210-22(c)) considers circuit requirements where the loads are characterized by a maximum current which continues for 3 hours or more. The bell-shaped curve above illustrates the fact that in nearly all cases, the photovoltaic array's operating current will not maintain a maximum output of such duration. Theoretically, it is feasible for a system to maintain a continuous current level (based on cloud cover variation causing an increase or decrease in insolation) for three hours or more; however, this level will almost never be any higher than the current value found either 1-1/2 hour before or 1-1/2 hour after solar noon on a perfectly clear day (true only if the array is oriented so that maximum diurnal radiation reaches the cell at solar noon). To make the determination of this "maximum continuous current" of the array such that the NEC safety factor of 1.25 applies is quite unnecessary in light of a clearer and more appropriate method. This method is now presented.

Table 310-16. Allowable Ampacities of Insulated Conductors Rated 0-2000 Volts, 60° to 90°C

Not More Than Three Conductors in Raceway or Cable or Earth (Directly Buried). Based on Ambient Temperature of 30°C (86°F)

Size	Temperature Rating of Conductor. See Table 310-13								Size
	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	
AWG MCM	TYPES RUW, T, TW, UF	TYPES FEPW, RH, RHW, RUH, THW, THWN, XHHW, USE, ZW	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †FEP, †FEPB, †RHH, †THHN, †XHHW*	TYPES RUW, T, TW, UF	TYPES RH, RHW, RUH, THW, THWN, XHHW, USE	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †RHH, †THHN, †XHHW*	AWG MCM
	COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM				
18				21					
16			22	22					
14	15	15	25	25					
12	20	20	30	30	15	15	25	25	12
10	30	30	40	40	25	25	30	30	10
8	40	45	50	50	30	40	40	40	8
6	55	65	70	70	40	50	55	55	6
4	70	85	90	90	55	65	70	70	4
3	80	100	105	105	65	75	80	80	3
2	95	115	120	120	75	90	95	95	2
1	110	130	140	140	85	100	110	110	1
0	125	150	155	155	100	120	125	125	0
00	145	175	185	185	115	135	145	145	00
000	165	200	210	210	130	155	165	165	000
0000	195	230	235	235	155	180	185	185	0000
250	215	255	270	270	170	205	215	215	250
300	240	285	300	300	190	230	240	240	300
350	260	310	325	325	210	250	260	260	350
400	280	335	360	360	225	270	290	290	400
500	320	380	405	405	260	310	330	330	500
600	355	420	455	455	285	340	370	370	600
700	385	460	490	490	310	375	395	395	700
750	400	475	500	500	320	385	405	405	750
800	410	490	515	515	330	395	415	415	800
900	435	520	555	555	355	425	455	455	900
1000	455	545	585	585	375	445	480	480	1000
1250	495	590	645	645	405	485	530	530	1250
1500	520	625	700	700	435	520	580	580	1500
1750	545	650	735	735	455	545	615	615	1750
2000	560	665	775	775	470	560	630	630	2000

CORRECTION FACTORS

Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.								Ambient Temp. °F
31-40	.82	.88	.90	.91	.82	.88	.90	.91	86-104
41-50	.58	.75	.80	.82	.58	.75	.80	.82	105-122
51-60		.58	.67	.71		.58	.67	.71	123-141
61-70		.35	.52	.58		.35	.52	.58	142-158
71-80			.30	.41			.30	.41	159-176

Table 310-17. Allowable Ampacities of Insulated Conductors Rated 0-2000 Volts, 60° to 90°C

Single conductors in free air, based on ambient temperature of 30°C (86°F)

Size	Temperature Rating of Conductor. See Table 310-13								Size
	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	
AWG MCM	TYPES RUW, T, TW	TYPES FEPW, RH, RHW, RUH, THW, THWN, XHHW, ZW	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †FEP, †FEPB, †RHH, †THHN, †XHHW*	TYPES RUW, T, TW	TYPES RH, RHW, RUH, THW, THWN, XHHW	TYPES V, MI	TYPES TA, TBS, SA, AVB, SIS, †RHH, †THHN, †XHHW*	AWG MCM
	COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM				
18				25					
16			27	27					
14	20	20	30	30					
12	25	25	40	40	20	20	30	30	12
10	40	40	55	55	30	30	45	45	10
8	55	65	70	70	45	55	55	55	8
6	80	95	100	100	60	75	80	80	6
4	105	125	135	135	80	100	105	105	4
3	120	145	155	155	95	115	120	120	3
2	140	170	180	180	110	135	140	140	2
1	165	195	210	210	130	155	165	165	1
0	195	230	245	245	150	180	190	190	0
00	225	265	285	285	175	210	220	220	00
000	260	310	330	330	200	240	255	255	000
0000	300	360	385	385	230	280	300	300	0000
250	340	405	425	425	265	315	330	330	250
300	375	445	480	480	290	350	375	375	300
350	420	505	530	530	330	395	415	415	350
400	455	545	575	575	355	425	450	450	400
500	515	620	660	660	405	485	515	515	500
600	575	690	740	740	455	545	585	585	600
700	630	755	815	815	500	595	645	645	700
750	655	785	845	845	515	620	670	670	750
800	680	815	880	880	535	645	695	695	800
900	730	870	940	940	580	700	750	750	900
1000	780	935	1000	1000	625	750	800	800	1000
1250	890	1065	1130	1130	710	855	905	905	1250
1500	980	1175	1260	1260	795	950	1020	1020	1500
1750	1070	1280	1370	1370	875	1050	1125	1125	1750
2000	1155	1385	1470	1470	960	1150	1220	1220	2000

CORRECTION FACTORS

Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.								Ambient Temp. °F
31-40	.82	.88	.90	.91	.82	.88	.90	.91	86-104
41-50	.58	.75	.80	.82	.58	.75	.80	.82	105-122
51-60		.58	.67	.71		.58	.67	.71	123-141
61-70		.35	.52	.58		.35	.52	.58	142-158
71-80			.30	.41			.30	.41	159-176

Table 310-18. Allowable Ampacities for Insulated Conductors Rated 110 to 250°C

Not More Than Three Conductors in Raceway or Cable Based on Ambient Temperature of 30°C (86°F)

Size	Temperature Rating of Conductor. See Table 310-13								Size
	110°C (230°F)	125°C (257°F)	150°C (302°F)	200°C (392°F)	250°C (482°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	
AWG MCM	TYPES AVA, AVL	TYPES AI, AIA	TYPE Z	TYPES A, AA, FEP, FEPB, PFA	TYPES PFAH, TFE	TYPES AVA, AVL	TYPES AI, AIA	TYPES A, AA	AWG MCM
	COPPER				NICKEL OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM			
14	30	30	30	30	40				
12	35	40	40	40	55	25	30	30	12
10	45	50	50	55	75	35	40	45	10
8	60	65	65	70	95	45	50	55	8
6	80	85	90	95	120	60	65	75	6
4	105	115	115	120	145	80	90	95	4
3	120	130	135	145	170	95	100	115	3
2	135	145	150	165	195	105	115	130	2
1	160	170	180	190	220	125	135	150	1
0	190	200	210	225	250	150	160	180	0
00	215	230	240	250	280	170	180	200	00
000	245	265	275	285	315	195	210	225	000
0000	275	310	325	340	370	215	245	270	0000
250	315	335				250	270		250
300	345	380				275	305		300
350	390	420				310	335		350
400	420	450				335	360		400
500	470	500				380	405		500
600	525	545				425	440		600
700	560	600				455	485		700
750	580	620				470	500		750
800	600	640				485	520		800
1000	680	730				560	600		1000
1500	785					650			1500
2000	840					705			2000

CORRECTION FACTORS

Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.								Ambient Temp. °F
31-40	.94	.95	.96			.94	.95		87-104
41-45	.90	.92	.94			.90	.92		105-113
46-50	.87	.89	.91			.87	.89		114-122
51-55	.83	.86	.89			.83	.86		123-131
56-60	.79	.83	.87	.91	.95	.79	.83	.91	132-141
61-70	.71	.76	.82	.87	.91	.71	.76	.87	142-158
71-75	.66	.72	.79	.86	.89	.66	.72	.86	159-167
76-80	.61	.69	.76	.84	.87	.61	.69	.84	168-176
81-90	.50	.61	.71	.80	.83	.50	.61	.80	177-194
91-100		.51	.65	.77	.80		.51	.77	195-212
101-120			.50	.69	.72			.69	213-248
121-140			.29	.59	.59			.59	249-284
141-160					.54				285-320
161-180					.50				321-356
181-200					.43				357-392
201-225					.30				393-437

Table 310-19. Allowable Ampacities for Insulated Conductors Rated 110 to 250°C, and for Bare and Covered Conductors

Single Conductors in Free Air Based on Ambient Temperature of 30°C (86°F)

Size	Temperature Rating of Conductor. See Table 310-13										Size
	110°C (230°F)	125°C (257°F)	150°C (302°F)	200°C (392°F)	Bare and covered conductors	250°C (482°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	Bare and covered conductors	
AWG MCM	TYPES AVA, AVL	TYPES AI, AIA	TYPE Z	TYPES A, AA, FEP, FEPB, PFA		TYPES PFAH, TFE	TYPES AVA, AVL	TYPES AI, AIA	TYPES A, AA		AWG MCM
	COPPER					NICKEL OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM				
14	40	40	40	45	30	60					
12	50	50	50	55	40	80	40	40	45	30	12
10	65	70	70	75	55	110	50	55	60	45	10
8	85	90	95	100	70	145	65	70	80	55	8
6	120	125	130	135	100	210	95	100	105	80	6
4	160	170	175	180	130	285	125	135	140	100	4
3	180	195	200	210	150	335	140	150	165	115	3
2	210	225	230	240	175	390	165	175	185	135	2
1	245	265	270	280	205	450	190	205	220	160	1
0	285	305	310	325	235	545	220	240	255	185	0
00	330	355	360	370	275	605	255	275	290	215	00
000	385	410	415	430	320	725	300	320	335	250	000
0000	445	475	490	510	370	850	345	370	400	290	0000
250	495	530			410		385	415		320	250
300	555	590			460		435	460		360	300
350	610	655			510		475	510		400	350
400	665	710			555		520	555		435	400
500	765	815			630		595	635		490	500
600	855	910			710		675	720		560	600
700	940	1005			780		745	795		615	700
750	980	1045			810		775	825		640	750
800	1020	1085			845		805	855		670	800
900					905					725	900
1000	1165	1240			965		930	990		770	1000
1500	1450				1215		1175			985	1500
2000	1715				1405		1425			1165	2000

CORRECTION FACTORS

Ambient Temp. °C	For ambient temperatures over 30°C, multiply the ampacities shown above by the appropriate correction factor to determine the maximum allowable load current.										Ambient Temp. °F
31-40	.94	.95	.96				.94	.95			87-104
41-45	.90	.92	.94				.90	.92			105-113
46-50	.87	.89	.91				.87	.89			114-122
51-55	.83	.86	.89				.83	.86			123-131
56-60	.79	.83	.87	.91		.95	.79	.83	.91		132-141
61-70	.71	.76	.82	.87		.91	.71	.76	.87		142-158
71-75	.66	.72	.79	.86		.89	.66	.72	.86		159-167
76-80	.61	.69	.76	.84		.87	.61	.69	.84		168-176
81-90	.50	.61	.71	.80		.83	.50	.61	.80		177-194
91-100		.51	.65	.77		.80		.51	.77		195-212
101-120			.50	.69		.72			.69		213-248
121-140			.29	.59		.59			.59		249-284
141-160						.54					285-320
161-180						.50					321-356
181-200						.43					357-392
201-225						.30					393-437

Number of Conductors	Percent of Values in Tables 310-16 and 310-18
4 thru 6	80
7 thru 24	70
25 thru 42	60
43 and above	50

Where single conductors or multiconductor cables are stacked or bundled without maintaining spacing and are not installed in raceways, the maximum allowable load current of each conductor shall be reduced as shown in the above table.

Exception No. 1: When conductors of different systems, as provided in Section 300-3, are installed in a common raceway the derating factors shown above shall apply to the number of power and lighting (Articles 210, 215, 220, and 230) conductors only.

Exception No. 2: The derating factors of Sections 210-22(c), 220-2(a) and 220-10(b) shall not apply when the above derating factors are also required.

Exception No. 3. For conductors installed in cable trays, the provisions of Section 318-10 shall apply.

9. Overcurrent Protection. Where the standard ratings and settings of overcurrent devices do not correspond with the ratings and settings allowed for conductors, the next higher standard rating and setting shall be permitted.

Exception: As limited in Section 240-3.

10. Neutral Conductor.

(a) A neutral conductor which carries only the unbalanced current from other conductors, as in the case of normally balanced circuits of three or more conductors, shall not be counted when applying the provisions of Note 8.

(b) In a 3-wire circuit consisting of 2-phase wires and the neutral of a 4-wire, 3-phase wye-connected system, a common conductor carries approximately the same current as the other conductors and shall be counted when applying the provisions of Note 8.

(c) On a 4-wire, 3-phase wye circuit where the major portion of the load consists of electric-discharge lighting, data processing, or similar equipment, there are harmonic currents present in the neutral conductor and the neutral shall be considered to be a current-carrying conductor.

11. Grounding Conductor. A grounding conductor shall not be counted when applying the provisions of Note 8.

12. Voltage Drop. The allowable ampacities in Tables 310-16 through 310-19 are based on temperature alone and do not take voltage drop into consideration.

Notes to Tables 310-16 through 310-19

1. Explanation of Tables. For explanation of Type Letters, and for recognized size of conductors for the various conductor insulations, see Section 310-13. For installation requirements, see Sections 310-1 through 310-10, and the various articles of this Code. For flexible cords, see Tables 400-4 and 400-5.

2. Application of Tables. For open wiring on insulators and for concealed knob-and-tube wiring, the allowable ampacities of Tables 310-17 and 310-19 shall be used. For all other recognized wiring methods, the allowable ampacities in Tables 310-16 and 310-18 shall be used, unless otherwise provided in this Code.

3. Three-Wire, Single-Phase Dwelling Services. In dwelling units, conductors, as listed below, shall be permitted to be utilized as three-wire, single-phase, service-entrance conductors and the three-wire, single-phase feeder that carries the total current supplied by that service.

Conductor Types and Sizes
RH-RHH-RHW-THW-THWN-THHN-XHHW

Copper	Aluminum and Copper-Clad AL	Service Rating in Amps
AWG	AWG	
4	2	100
3	1	110
2	1/0	125
1	2/0	150
1/0	3/0	175
2/0	4/0	200

4. Type MC Cable. The ampacities of Type MC cables are determined by the temperature limitation of the insulated conductors incorporated within the cable. Hence the ampacities of Type MC cable may be determined from the columns in Tables 310-16 and 310-18 applicable to the type of insulated conductors employed within the cable.

5. Bare Conductors. Where bare conductors are used with insulated conductors, their allowable ampacities shall be limited to that permitted for the insulated conductors of the same size.

6. Mineral-Insulated, Metal-Sheathed Cable. The temperature limitation on which the ampacities of mineral-insulated, metal-sheathed cable are based is determined by the insulating materials used in the end seal. Termination fittings incorporating unimpregnated, organic, insulating materials are limited to 85°C operation.

7. Type MTW Machine Tool Wire. The ampacities of Type MTW wire are specified in Table 200-B of the Standard for Electrical Metalworking Machine Tools and Plastics Processing Machinery (NFPA 79-1980).

8. More than Three Conductors in a Raceway or Cable. Where the number of conductors in a raceway or cable exceeds three, the ampacity shall be as given in Tables 310-16 and 310-18, but the maximum allowable load current of each conductor shall be reduced as shown in the following table:

This method would simply be to determine what the magnitude of the system short-circuit current would be under conditions of highest insolation for the year at the site. Code officials would require substantiating documentation when the designer seeks code approval for a system design. Because the photovoltaic module is a current limiting device, such a determination should supply the maximum expected current under any conditions (extraneous to that of lightning strike on an unprotected array where the path to ground becomes the conductor - see section on lightning). Conductors sized such that they can safely handle this maximum system short-circuit current should be sufficient for acceptance by the code official. The tables which supply this information are given in Tables 310-16 through 310-19 of the NEC which are given on the previous page.

It can be seen in Notes to NEC Tables 310-16 through 310-19 that there are additional considerations which must be made that will affect the accepted conductor size. As mentioned previously, the number of conductors in a raceway affects the maximum allowable load current acceptable. The magnitude of this consideration is discussed in Note 8 and quantified in the accompanying table.

A second consideration involves the operating temperatures to which the wiring will be exposed. Table 7.10 gives typical ambient temperatures and the minimum rating of required conductor insulation. Because photovoltaic wiring has the potential for high temperature exposure (relative to the 30°C base used in the establishment of Tables 310-16 through 310-19), the designer must take into consideration such factors as:

1. exposure of conduit/wiring to direct sunlight
2. the thermal coupling of the conduit/wiring to components which are exposed to direct sunlight
3. general system physical layout where extraneous energy input will affect conduit/wiring temperatures.

This temperature factor cannot be neglected. In a closed conduit exposed to direct solar radiation, a dramatic temperature increase can be expected. From Table 13 it can be seen that a 50°C (122°F) temperature environment would limit a 60°C rated conductor to nearly one-half its accepted ampacity at 30°C environment. This trend of reduced allowable ampacity with increasing conductor ambient temperature is graphically illustrated in Figure 7.5.

Table 7.10

Typical Ambient Temperatures

Location	Temperature	Minimum Rating of Required Conductor Insulation
Well ventilated, normally heated buildings	30° C (86° F)	(See note below)
Buildings with such major heat sources as power stations or industrial processes	40° C (104° F)	75° C (167° F)
Poorly ventilated spaces such as attics	45° C (113° F)	
Furnaces and boiler rooms (min.)	40° C (104° F)	75° C (167° F)
(max.)	60° C (140° F)	90° C (194° F)
Outdoors in shade in air	40° C (104° F)	75° C (167° F)
In thermal insulation	45° C (113° F)	75° C (167° F)
Direct solar exposure	45° C (113° F)	75° C (167° F)
Places above 60° C (140° F)		110° C (230° F)

NOTE. 60° C for up to and including No. 8 AWG copper and 75° C for over No. 8 AWG copper.

A second electrical consideration which should be made (according to the NEC) before a conductor is selected concerns the voltage drop across conductors. The NEC's recommended practice is to reduce voltage drop in branch circuits to 3%, and in branch and feeders combined to 5%. Note that this is not a mandatory requirement, but rather a recommendation of good engineering practice. It is primarily important to maintain a low voltage drop across the photovoltaic conductors due to the useful power lost with this decrease in system electrical potential. With a required voltage across the load (whether it be a set of batteries at nearly a constant voltage, or an inverter with a particular voltage input "window"), the greater the voltage drop across conductors, the more photovoltaic cells and area needed to meet this requirement. Minimizing voltage drop by using lower resistance conductors thus reduces the area of photovoltaic cells and

REDUCTION IN ALLOWABLE AMPACITY

VS. CONDUCTOR AMBIENT TEMPERATURE

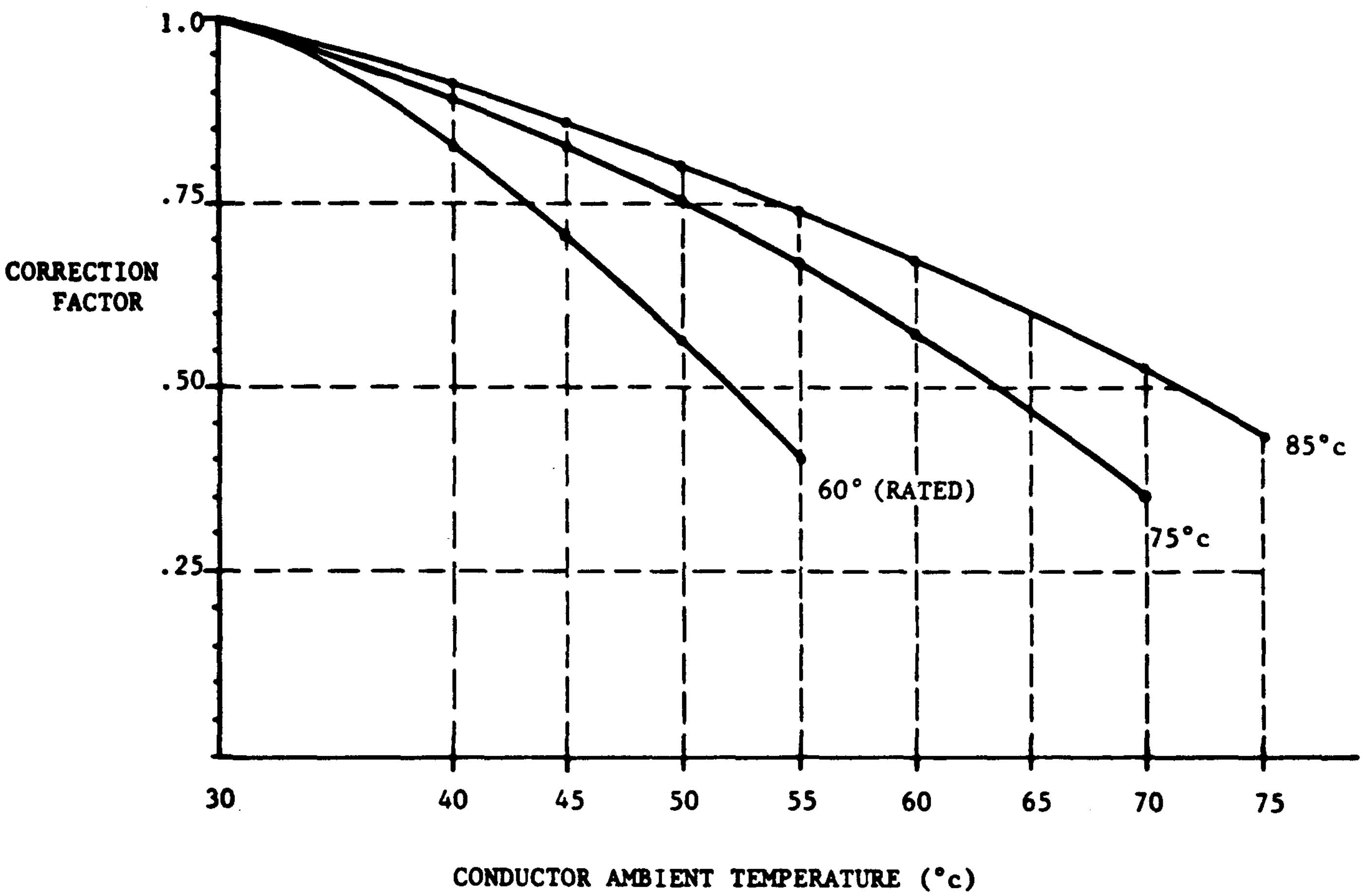


Figure 7.5

the resulting costs. The trade-off, of course, is with the increased costs associated with the larger conductor.

In calculating the total voltage drop, the module/subarray interconnects as well as the primary leads should be considered. Because the photovoltaic current is a function of many parameters, and the voltage drop is a linear function of this current, this calculation should be made for a steady-state, maximum current operating condition. To maintain a total voltage drop at this current to 5% or less would be consistent in magnitude to that recommended by the NEC for total branch and feeder circuits.

7.3 GROUNDING

In the establishment of an overall grounding philosophy for photovoltaic systems it is essential that one takes the entire system into consideration, not just the array. The photovoltaic system grounding considerations should not only include the module/panel/array, but the leads, conduit, lightning protection, and load equipment as well. As the system complexity increases, for example, when the photovoltaic system is interfaced with a utility AC power supply, additional considerations for grounding must be made. It is the overall system approach which is presented here. The various grounding schemes are presented to permit the reader to examine the logical development of an effective grounding system. It should be initially understood that a photovoltaic array presents a very unique electrical power system, and that grounding for such a system can be approached in many ways. It is hoped that this section will offer a clear understanding of the reasons for the establishment of an electrically safe photovoltaic system.

A major difficulty in developing a grounding philosophy for photovoltaic systems is due to the wide variety of photovoltaic system designs. Design specific characteristics of these systems should focus on the inherent safety offered by the grounding system used. Furthermore, a potential for shock and/or fire exists for all systems, thereby requiring that proper grounding and user insulation from ground be maintained.

At this point in time, the development of grounding systems for PV systems continues. Studies are currently being performed by UL which will result in grounding philosophies and systems for photovoltaic systems.

It is recommended that the reader review the UL work for information on grounding systems. In addition, the remainder of this section will identify NEC articles related to grounding techniques, grounding conductors and conductor sizes.

This combination of a solidly based electrical grounding philosophy and present applicable NEC grounding requirements should give the reader a well-defined path to follow with regards to system/user safety.

Article 250-3 addresses grounding of direct-current systems.

B. Circuit and System Grounding

250-3. Direct-Current Systems.

(a) Two-Wire Direct Current Systems. Two-wire dc systems supplying premises wiring shall be grounded.

Exception No. 1: A system equipped with a ground detector and supplying only industrial equipment in limited areas.

Exception No. 2: A system operating at 50 volts or less between conductors.

Exception No. 3: A system operating at over 300 volts between conductors.

Exception No. 4: A rectifier-derived dc system supplied from an ac system complying with Section 250-5.

Exception No. 5: DC fire protective signaling circuits having a maximum current of 0.030 amperes as specified in Article 760, Part C.

COMMENT: The first exception might be a consideration for photovoltaic arrays in industrial applications, where access is limited to qualified people only, e.g. a roof mounted array with access only through normally locked doors. This, however, overlooks the fact that individuals other than "qualified" people will probably have access. It seems unlikely that the cleaning person would be sufficiently versed in electricity to be considered "qualified" enough for safe activity around such ungrounded equipment. (The additional usage of a ground detector is something which will be discussed later in this section.)

The second and third exceptions, as mentioned in a previous report (JPL #955149, RPMS), are based on one readily understandable consideration, and the other on an outdated and inappropriate consideration. The former, low voltage exception is based merely on the reduced hazards associated with the low potential. The latter exception, #3, is the result of a very old code which addressed permanent equipment that operated at above 300 volts DC. In this case the equipment was grounded and the system was not. It is felt that neither of these exceptions should be applied to photovoltaic arrays. Though exception #2 is a low voltage exclusion, from the previous discussion of hazardous conditions (e.g., height) which frequently accompany these arrays, it is evident that the minimization of shock of any perceptable magnitude should be pursued. The high voltage exception is obviously not of any application with regard to these DC power systems. Exception #4 is a case where a PV inverter runs backwards. Evaluation of this exception is being undertaken by UL at this date. Exception #5 is likewise not of any value in this study.

In addition, the NEC identifies the proper methods for grounding of enclosures and equipment in Articles 250(D) and 250(E) respectively.

D. Enclosure Grounding

250-32. Service Raceways and Enclosures. Metal enclosures for service conductors and equipment shall be grounded.

250-33. Other Conductor Enclosures. Metal enclosures for other than service conductors shall be grounded.

Exception No. 1: Metal enclosures for conductors added to existing installations of open wire, knob-and-tube wiring, and nonmetallic-sheathed cable, if in runs of less than 25 feet (7.62 m), if free from probable contact with ground, grounded metal, metal lath, or other conductive material, and if guarded against contact by persons shall not be required to be grounded.

Exception No. 2: Metal enclosures used to protect cable assemblies from physical damage shall not be required to be grounded.

E. Equipment Grounding

250-42. Equipment Fastened in Place or Connected by Permanent Wiring Methods (Fixed). Exposed noncurrent-carrying metal parts of fixed equipment likely to become energized shall be grounded under any of the conditions in (a) through (f) below.

(a) Vertical and Horizontal Distances. Where within 8 feet (2.44 m) vertically or 5 feet (1.52 m) horizontally of ground or grounded metal objects and subject to contact by persons.

(b) Wet or Damp Locations. Where located in a wet or damp location and not isolated.

(c) Electrical Contact. Where in electrical contact with metal.

(d) Hazardous (Classified) Locations. Where in a hazardous (classified) location as covered by Articles 500 through 517.

(e) Metallic Wiring Methods. Where supplied by a metal-clad, metal-sheathed, or metal-raceway wiring method, except as permitted by Section 250-33 for short sections of raceway.

(f) Over 150 Volts to Ground. Where equipment operates with any terminal at over 150 volts to ground.

Exception No. 1: Enclosures for switches or circuit breakers used for other than service equipment and accessible to qualified persons only.

Exception No. 2: Metal frames of electrically heated appliances, exempted by special permission, in which case the frames shall be permanently and effectively insulated from ground.

Exception No. 3: Distribution apparatus, such as transformer and capacitor cases, mounted on wooden poles, at a height exceeding 8 feet (2.44 m) above ground or grade level.

Finally, the following sections of the NEC are areas of concern once a grounding system has been established. These codes concern themselves with: methods of grounding, effective grounding paths, bonding, grounding electrode system, grounding electrode conductor, grounding conductor size, and equipment grounding conductor size. The following relevant NEC sections are not listed in their entirety.

250-51. Effective Grounding Path. The path to ground from circuits, equipment, and conductor enclosures shall: (1) be permanent and continuous, (2) have capacity to conduct safely any fault current likely to be imposed on it; and (3) have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit.

J. Grounding Conductors

250-91. Material. The material for grounding conductors shall be as specified in (a) and (b) below.

(a) Grounding Electrode Conductor. The grounding electrode conductor shall be of copper, aluminum, or copper-clad aluminum. The material selected shall be resistant to any corrosive condition existing at the installation or shall be suitably protected against corrosion. The conductor shall be solid or stranded, insulated, covered, or bare and shall be installed in one continuous length without a splice or joint.

Exception No. 1: Splices in busbars shall be permitted.

Exception No. 2: Where a service consists of more than a single enclosure as permitted in Section 230-45, it shall be permissible to connect taps to the grounding electrode conductor. Each such tap conductor shall extend to the inside of each such enclosure. The grounding electrode conductor shall be sized in accordance with Section 250-94, but the tap conductors shall be permitted to be sized in accordance with the grounding electrode conductors specified in Section 250-94 for the largest conductor serving the respective enclosures.

250-93. Size of Direct-Current System Grounding Conductor. The size of the grounding conductor for a dc system shall be as specified in (a) through (c) below.

(a) Not Be Smaller than the Neutral Conductor. Where the dc system consists of a 3-wire balancer set or a balancer winding with overcurrent protection as provided in Section 445-4(d), the grounding conductor shall not be smaller than the neutral conductor.

(b) Not Be Smaller than the Largest Conductor. Where the dc system is other than as in (a) above, the grounding conductor shall not be smaller than the largest conductor supplied by the system.

(c) Not Be Smaller than No. 8. In no case shall the grounding conductor be smaller than No. 8 copper or No. 6 aluminum.

7.4 LIGHTNING PROTECTION

A lightning strike to earth is a statistical event which is dependent on changing weather patterns, thunderstorm electrification, nature of the strike progression to the earth, and the highly local nature of the geography. In general, the determination of the need for lightning protection is based on the following factors:

1. Occupant safety
2. Nature of building and contents (value)
3. Relative exposure
4. Thunderstorm frequency and severity
4. Indirect losses
6. Availability of firefighting apparatus

A very large percentage of the damage caused by lightning occurs in rural areas. A building among many other buildings of similar height is less prone to a lightning strike than a similar building placed alone in a rural setting. A photovoltaic array atop a 3 or 4 story complex that is situated in a flat, open space may need lightning protection. Due to the space required for a ground mounted array (solar access) and the conductive nature of such an array, proper lightning precaution is essential here as well. In considering lightning protection for photovoltaic systems, one should be aware of the potential damage associated with both the roof mounted and the ground mounted system.

The ground mounted array may exhibit both an affinity for lightning as well as an adverse reaction to a strike; however, the major difference to that of the roof or wall mounted array is the obvious segregation of array and building. Therefore, the ground mounted array becomes less of a direct hazard to the safety of the building and its occupants. For instance, a fire within a module resulting from lightning proposes, in all likelihood, only a risk to the remainder of the array and not to the building. However, line surges from the array leads still create a potential building fire hazard if load equipment failure occurs. In any case, the potential damage resulting from a lightning strike to an array is reduced by having the array separate from the building. The need for lightning protection for the array must take this reduced potential loss into consideration.

To better determine the need for lightning protection, it is essential that thunderstorm frequency as well as severity be established. The frequency of thunderstorms vary in the U.S. from a minimum of five days/year to a maximum of over 90 days/year, e.g. in Florida. Though New England may have only 20 thunderstorm days per year, the severity of the storms makes that region a high risk area. Figure 7.6 illustrates the regional propensity for thunderstorms on an annual basis.

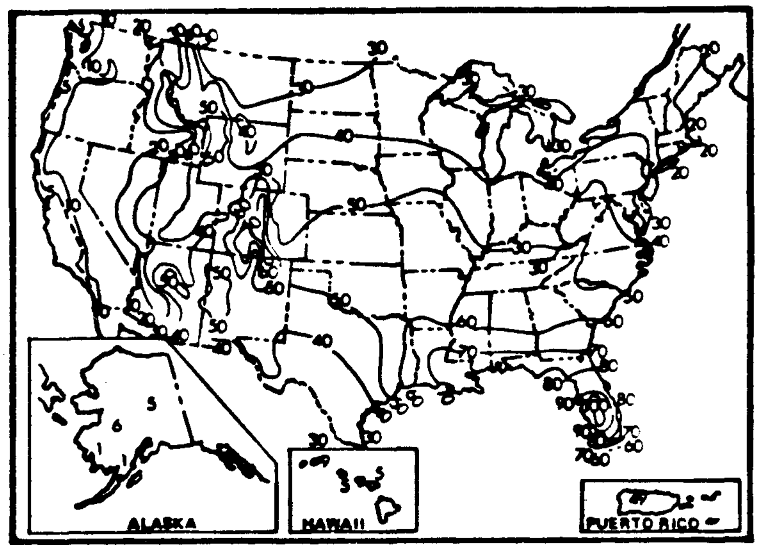


Figure 7.6

This map is referred to as an isokeraunic map which is published at intervals by the U.S. Weather Bureau. This isokeraunic level fluctuates widely from year to year; and furthermore, it fails to distinguish between cloud-cloud and cloud-earth lightning. Power engineers concerned with lightning strikes to high power transmission lines use a very simple relationship to estimate the number of strikes to the earth per square mile per year. This is given as:

$$N_a = 0.25\ k$$

Where: N_a = # stroke to earth/sq. mile/year

K = isokeraunic level

This value of N_a can be readily altered when considering local geography and the nature of the thunderstorms (e.g., tropical, frontal, etc.).

It is not the intent of this report to expound on the electrical complexities involved with lightning induced phenomena. However, the development of safe photovoltaic lightning protection systems requires the basic understanding of certain lightning related problems. Lightning protection systems are typically used on commercial/industrial buildings as their height and size makes them more prone to lightning strikes than a residence. It is important to understand the purpose of lightning protection itself. Upon the realization that lightning cannot be stopped from traveling to ground, we must provide a path of least resistance to reduce its potential for damaging property. This can be accomplished by one of two means, or a combination of both.

The first of these techniques is <u>shielding</u>, which is simply the correct placement of a conductor so as to intercept the strike and safely conduct it to ground. This is commonly done to protect buildings, transmission lines, trees, etc. In the vicinity of the shield there will be a zone in which lightning is not likely to strike because the leader (lightning strike) either approaches close enough to the shielding arrangement to be attracted to it or else too far away to be influenced, and thus is outside of this protective zone. In very rough terms, a single mast or rod will offer protection in a cone shaped volume with the apex at the top of the rod and the surface making an angle of 30° with the vertical. The exposure within the cone is said to be 0.1 percent or, in other words, out of 1,000 strikes to the shield, only one will terminate on the protected object. Multiple masts or rods increase the shielded zone between them to a greater extent than the sum of the protected cones of each individual rod.

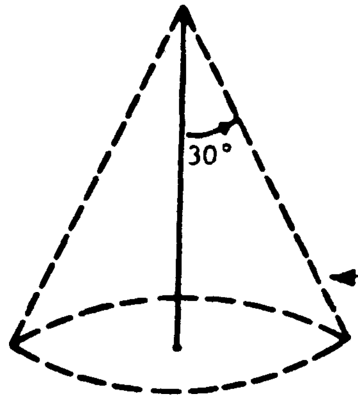


Figure 7.7

Even with extensive shielding of an object such as a photovoltaic array, a potential hazard still exists with "side-flashes". This phenomenon occurs when the lightning rod/conductor system is poorly grounded, and is, therefore, of high resistance, which produces high voltages. An additional effect which increases this voltage is due to the inductive nature of the conductor. The magnitude of this voltage due to inductance is determined by the rate of increase of current. Because of the probable exposed-metallic nature of photovoltaic arrays, this problem of "side-flashes" needs to be addressed. One technique to eliminate this phenomenon is to metallically bond the exposed photovoltaic array member(s) to the lightning conductors.

The NEC addresses this issue in Article 250 as:

> **250-46. Spacing from Lightning Rods.** Metal raceways, enclosures, frames, and other noncurrent-carrying metal parts of electric equipment shall be kept at least 6 feet (1.83 m) away from lightning rod conductors, or they shall be bonded to the lightning rod conductors.
>
> See Sections 250-86 and 800-31(b)(5). For further information see the Lightning Protection Code, NFPA 78-1977 (ANSI), which contains detailed information on grounding lightning protection systems.

Therefore, if the roof or wall mounted array is located such that the application of a lightning shield system reduces the spacing from the array to the lightning conductor to within 6 feet, then the array must be electrically bonded to the lightning rod conductors. This does not, however, allow the lightning protection system to become a replacement for the photovoltaic system's grounding conductors. This is per requirement of the NEC as shown:

> **250-86. Use of Lightning Rods.** Lightning rod conductors and driven pipes, rods, or other made electrodes used for grounding lightning rods shall not be used in lieu of the made grounding electrodes required by Section 250-83 for grounding wiring systems and equipment. This provision shall not prohibit the required bonding together of grounding electrodes of different systems.

This last provision allows the common bonding of electrodes from various systems and is addressed further in the NEC in Sections 800-31 (b)(7) and 820-22 (h). This practice is recommended because it causes all the grounding electrodes to reach the same potential, eliminating any current flow from one electrode to another. For an extensive presentation of shielding systems one should refer to the National Fire Protection Association's NFC (National Fire Code) Volume 7, Section 78, concerned with lightning protection. This code covers lightning protection requirements for ordinary buildings, miscellaneous structures and special occupancies, heavy-duty stacks, and structures containing flammable liquids and gases. It does not cover lightning protection requirements for explosives manufacturing buildings and magazines or electric generating, transmission, and distribution systems. An "ordinary" building is "one of common or conventional design and construction used for ordinary purposes, whether commercial, farm, industrial,....". Therefore, even though this code does not cover electrical generating systems as such, it is an invaluable reference in the design of photovoltaic lightning protection systems. Its inapplicability to electrical generating systems is in reference to the high power distribution systems associated with conventional utility companies, and is, therefore, of little concern. Section 78 of the NFC addresses many of the concerns on which the proper design of a lightning shield system centers, such as: acceptable rod placement as a function of building shape, acceptable materials, grounding electrode requirements as a function of soil type, bonding of metal masses, and much more. It is interesting to note that the NFC Section 78, Paragraph 3-24, Metal Bodies, states that, "Metal bodies of conductance shall be protected if not within the zone of protection of an air terminal (rod). All metal bodies of conductance having an area of 400 square inches (0.26 m^2) or greater or a volume of 1,000 cubic inches (0.016 m^3) or greater shall be bonded to the lightning protection system." This requires that the photovoltaic array must be bonded to the lightning protection system if it is not within the zone of protection offered by the lightning rod. This NFC 78.3-24 combined with the NEC 250-46 will require bonding of the array to the air terminal conductor in every case, except where the entire array lies within the zone of protection and is greater than 6 feet from any lightning ground conductor.

Having discussed shielding as one technique of reducing the potential for lightning related damage, another protective technique is now presented which is of most importance concerning photovoltaic systems. Because the photovoltaic array is an exposed object which is connected via electrical conductors to load equipment, the phenomenon of abnormal voltage surges due to lightning discharge must be considered. Lightning can cause these high voltage surges in the conductors by induction due to a nearby strike, as well as by a direct strike to the conductor. A direct strike usually creates a higher potential; however, severely damaging voltages are attainable by induction phenomenon. On relatively low voltage systems, induced voltages are a hazard. It is through the use of "arrestors" that these dangerous transient overvoltages are drained off the line and safely to ground. Without the use of such protective equipment the photovoltaic array would be prone to one or more of the following if high transient voltages are created in the array conductors by a lightning strike:

1. Destruction of conductor insulation
2. Destruction of conductor(s)
3. Destruction of load equipment insulation
4. Destruction of load equipment

An indirect result of either conductor or load equipment insulation failure is a high potential for shock and/or fire. The arrestor offers the high voltage a low resistance, alternative path to ground, thus avoiding the above-mentioned hazards. The proper placement of these arrestors on a photovoltaic system should reduce module/panel/array, as well as load equipment damage due to lightning surges. The roof and wall mounted arrays will, in most cases, be free of a potential direct strike to the leads because of close proximity to load and because of direct strike shielding from proper air terminal placement. Induced overvoltages, however, still need to be considered. The ground mounted array where overhead transmission lines are utilized offers potential for both direct and induced surges. Protection must be offered to both the load equipment and the array. The NEC addresses lightning arrestors in Article 280.

> **280-3. Number Required.** Where used at a point on a circuit, a surge arrester shall be connected to each ungrounded conductor. A single installation of such surge arresters shall be permitted to protect a number of interconnected circuits provided that no circuit is exposed to surges while disconnected from the surge arresters.

From the previous section on grounding (where a nongrounded lead approach is recommended) it is seen that an arrestor for each lead is required. These arrestors should be placed both at the exit from the array as well as at the entrance to the building. Under Section C, Other Occupancies, of the NEC Article 280, this placement is further elaborated on:

> **B. Installation**
>
> **280-11. Location.** Surge arresters shall be permitted to be located indoors or outdoors and shall be made inaccessible to unqualified persons.
>
> *Exception: Surge arresters listed for installation in accessible locations.*

Further NEC requirements concerning installation and conductor size and material are also available. In the most limiting case, a minimum of four lightning arrestors should be used on any photovoltaic system. They should appear in the system circuit in the following locations:

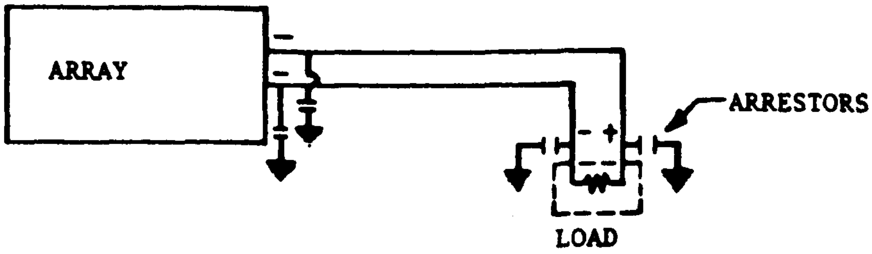


Figure 7.8

If the array is ground mounted accompanied by relatively long overhead transmission lines, increased application might be considered appropriate.

7.5 ELECTRICAL TERMINATION

A photovoltaic module electrical termination study was recently completed (Motorola Inc./ITT Cannon JPL #955367) which developed information to assist in the selection of "life-cycle cost-effective electrical termination for photovoltaic modules and arrays." This report developed and identified: design requirements; selection criteria for four application sectors (remote, residential, commercial/industrial, and large industrial/central station); existing candidate termination hardware and their attributes; and cost drivers. It is not intended that a critical review of this extensive work be presented here. Rather it is felt that certain areas, which appear relevant to the termination requirements of the commercial/industrial sector as seen in this report, be highlighted. Furthermore, due to the high degree of similarity between the termination requirements in both the residential sector and commercial/industrial sector, pertinent information will be drawn from another publication: Residential Photovoltaic Module and Array Study (JPL #955149). It is the intent of this study to present the previously published information concerning photovoltaic wiring termination along with the most recent developments in this area. Additionally, specific considerations will be discussed as they pertain to problems that may be encountered in the commercial/industrial sector.

Independent of the application sector and/or module/panel/array size(s) are certain fundamental requirements for termination hardware. The first of these are electrically based and need little, if any, supporting material:

1. Adequate current capacity
2. Adequate electrical insulation (voltage requirement)
3. Low ohmic contact

It is in the area of current and voltage where a particular terminal will need to meet certain performance requirements as dictated by industry standards (see following section on standards). The successful completion of tests, e.g. the dielectric voltage-withstand test as defined in Underwriter Laboratory's UL310 Quick-Connect Terminals, will be necessary before approval and acceptance is possible. The low ohmic contact is more a performance requirement than a safety requirement; and therefore, an acceptable level will be determined by the terminal designer considering economics and accepted standards.

Two additional and fundamental requirements for photovoltaic terminals are:

1. Adequate weatherization
2. Low life-cycle cost

Because of the uncertainty associated with an optimum photovoltaic mounting design, the severity of environmental conditions to which a terminal connection will be exposed will differ considerably from one design to another. An environmentally-exposed terminal on a rack-ground mounted array will experience a much greater exposure to water, ultraviolet radiation, and ambient temperature than a concealed terminal used for the wiring of an integrally mounted system. Last but not least is the most important economic consideration -- a low life-cycle cost. This cost is reflected in many of the performance characteristics through the ability to maintain and replace the terminals while in service. A terminal which is not capable of meeting the durability requirements for its particular environment will need to be characterized by:

1. Easy access for testing
2. Easy access for maintenance
3. Quick replacement time
4. Low level of labor skill involvement

These are necessary if a low life-cycle cost is to be expected. It should be noted that of the nine generic termination types investigated in the ITT Cannon/Motorola report, all were found to have MTBF's (Mean Time Between Failures) that exceeded the module design life of 20 years. This determination, however, was not based on the quality control and/or termination specifications which are typical of commercially available termination hardware. Therefore, the above-mentioned terminal design characteristics need to be considered so as to keep life-cycle cost reduced.

7.5.1 STANDARDS AND CODES APPLICABLE TO ELECTRICAL TERMINATION OF PHOTOVOLTAIC SYSTEMS

In the area of electrical terminations, an obvious source of information is the National Electrical Code. However, this source offers only a very general guideline in this area. One major concern of the NEC is the proper selection of a connector when conductors of dissimilar metals are joined (NEC 110-14), e.g. copper and aluminum. These codes are not likely to be of major value to the photovoltaic termination study. The listing of a terminal by an independent testing laboratory, e.g. Underwriters' Laboratory, should be sufficient for acceptance by the NEC; and therefore, a better estimate of a connector's usability can be made based on certain UL test standards. Three important UL standards which will affect terminal/termination acceptance are:

1. UL 310 — Quick Connect Terminals
2. UL 486 A/B — Wire Connectors and Soldering Lugs
3. UL 514 — Outlet Boxes and Fittings

Each of these standards address a number of performance criteria. The first two standards, UL 310 and UL 486, address termination techniques which are not accompanied by a terminal box. Certain performance criteria evaluated with these testing procedures are:

- Secureness
- Heating and Heat Cycling (due to I^2R loss in connection)
- Pull-out
- Dielectric Voltage Withstand
- Secureness of Insulation
- Flexing

In addition to these performance criteria, there are additional criteria which apply indirectly through the establishment of DOE/JPL test specifications (DOE/ JPL #5101-138 1982 Technical Readiness Module and Test Specification - Intermediate Load Applications). This is a document that establishes the requirements for the design and test of terrestrial solar cell modules. Due to the physical proximity and integration of terminal connections with the module, the same criteria will apply to each. An applicable document which is referenced in this technical readiness report is a military standard, MIL-STD-810-C, Environmental Test Methods, March 10, 1975. The criteria which are addressed in this module design and test requirement include:

- Thermal Shock (externally generated temperature cycling)
- Humidity Cycling

UL 514, Outlet Boxes and Fittings, is a more extensive standard than UL 310 or UL 486. This is primarily due to the requirement for specific fittings of the various cable and cable enclosure types, e.g. Mineral-Insulated Cable and rigid metal conduit. This standard dictates such requirements for terminal boxes as:

- Material
- Thickness
- Protection against corrosion
- Assembly
- Dimension
- Raintightness

These are accompanied by performance criteria such as:

- Water absorption
- Flame-retardant properties
- Heat distortion
- Resistance to crushing
- Resistance to impact
- Flexural strength

Though these lists are not complete, it is evident the extent to which a device must be designed and tested before this critical UL acceptance takes place.

There are additional standards which have application to photovoltaic electrical termination. These standards are the Military Standards, and they address many of the same performance specifications for electrical connections as does U.L. These specifications address specifically:

- Accelerated temperature cycling (MIL-STD-202, Method 107)
- Insulation resistance (MIL-STD-202, Method 302)
- Dielectric withstand voltage (MIL-STD-202, Method 301)
- Contact resistance (MIL-STD-202, Method 307)

Depending on the material(s) used in the connector(s), further testing is needed to establish performance data for accelerated weathering as addressed by the American Society for the Testing of Materials (ASTM). Two such standards are:

ASTM D-1435-65 Recommended Practice for Outdoor Weathering of Plastic

ASTM D-1149 Accelerated Ozone Cracking of Vulcanized Rubber

As can be seen, many requirements need to be met by the particular electrical connection. The acceptance by the National Electric Code will center on the connector's ability to be qualified by an "electrical testing laboratory which is recognized as being, properly equipped and qualified for experimental testing." NEC acceptance will be further based on "inspections on the run of goods at factories and service-value determination through field inspections." Therefore, the successful listing by Underwriter's Laboratories coupled with high quality control and acceptable field-service performance will yield a photovoltaic electrical termination that is institutionally accepted. However, the consideration of wiring connection flexibility, access for testing and maintenance, replacement cost, and design-specific problems needs to be made before a life-cycle cost effective termination is determined.

7.5.2 ELECTRICAL TERMINATION DESIGN REQUIREMENTS

The Motorola Inc./ITT Cannon report concluded that the three most attractive generic connections in the intermediate sector were:

1. Plug/receptacle
2. Screw
3. Crimp

These selections were based on the addressing of two basic questions:

- Does the particular connector meet the particular criteria selected?

- Does the particular criteria play an important role in the application sector?

Certain design factors are felt to be important in the selection of a wiring termination technique as mentioned above. Among these factors is that the selection of a certain connector should be made with a strong consideration for the photovoltaic wiring system used. The development of a suitable connector should be concurrent with the development of a wiring system that meets the stated requirements of the module/panel/array. The wiring system as well as the connectors need to conform to the physical restraints imposed by the mounting type and associated hardware. Furthermore, the electrical flexibility of such a combination should be a critical parameter in any successful design. The Motorola Inc./ITT Cannon report essentially neglected these requirements by assuming:

- Free access to module output(s)
- No restrictions on cable routing

These assumptions were not detrimental to the successful completion of that termination study; however, from a systems standpoint the inclusion of these considerations is most important. The difficulties associated with the design of a connection/wiring system for a direct or stand-off photovoltaic array exhibits the need for these considerations. The restrictions further imposed by the NEC as well as accessibility for testing and maintenance supports this concern.

Standardization of the positioning of terminations on modules and panels would significantly assist in the development of an electrical connector; however, it appears that a truly universal terminal(s) location might not be in the best interest of either the manufacturer or the user. Of the four generic mounting types, the problems associated with electrical termination appear to create two divisions. These divisions are delineated by their termination accessibility.

The first category includes the integral and the rack mounted arrays, where electrical termination and wiring access can be gained from both the front and the back of the module. The second category encompasses the direct and stand-off arrays where access is limited to the front of the array. To design an electrical termination system that caters only to front accessibility might overlook the far superior back accessible approach applicable to the integral and rack arrays. The larger arrays found in the commercial/industrial sector might present considerable difficulty and cost involved with troubleshooting and maintenance if the termination/wiring system is not readily accessible.

The electrical flexibility that a termination offers is an important consideration for any photovoltaic system. The ability to accept a range of conductor sizes as well as the ability to series/parallel connect modules and panels is of primary concern. A termination that offers a "pigtail" connection would offer considerable series/parallel flexibility over the single conductor connector. A design that illustrates this connector characteristic is shown below.

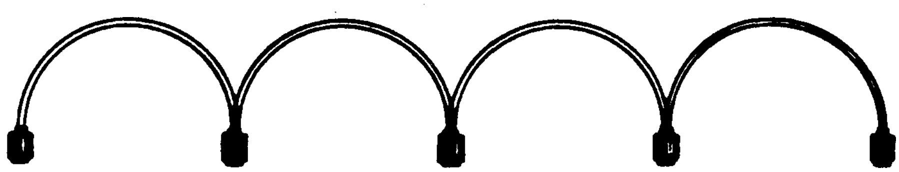


Figure 7.17

From a cost standpoint, the Motorola Inc./ITT Cannon report presented evidence that cost for the crimp and the screw type connectors lies mainly in labor cost incurred while in the field. The environmental sealing of these connectors requires in-the-field labor involvement, which occurs at a much higher rate than factory labor. Contrastingly, most of the cost associated with plug-receptacle connectors lies in factory labor. Additionally, the initial costs for the three connector types are given as:

Table 7.11

Initial Cost

Connector	In Quantities of:	10^4	10^7
Crimp		$0.90	$0.076
Screw		$0.985	$0.788
Plug/Receptacle		$0.322	$0.232

Because the crimp and screw type connectors have been available for a long time, potential for cost reduction is small. The plug/receptacle, however, is relatively new, and many opportunities exist for cost reduction. Summarily, this cost information leads to the conclusion that the plug/receptacle offers the greatest chance of cost reduction. The fact that automated manufacturing techniques could displace a present, relatively low labor cost further enhances this termination technique.

One manufacturer has addressed this connector and has two preliminary designs as well as a receptacle/junction box that facilitates the use of conduit. These products are illustrated below.

AMP® SOLARLOK CONNECTOR SYSTEM

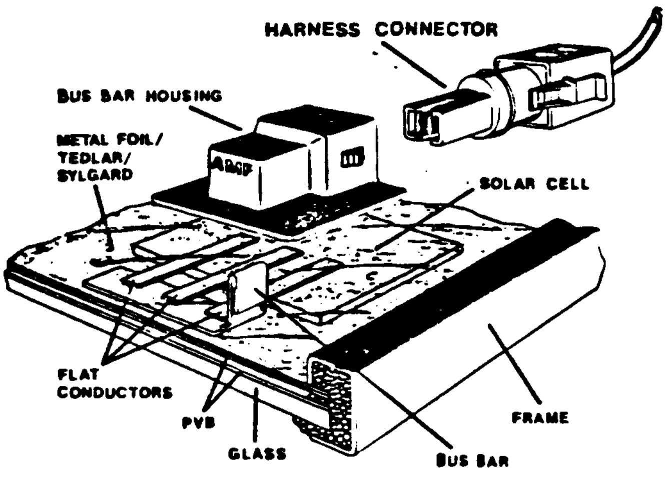


Figure 7.9

AMP® SOLARLOK

DUAL LEAD CONNECTOR

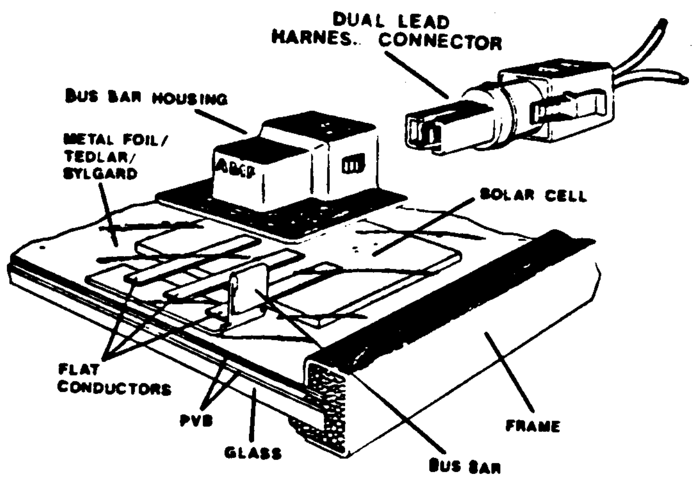


Figure 7.10

AMP® SOLARLOK

J-BOX RECEPTACLE

ADL AMP

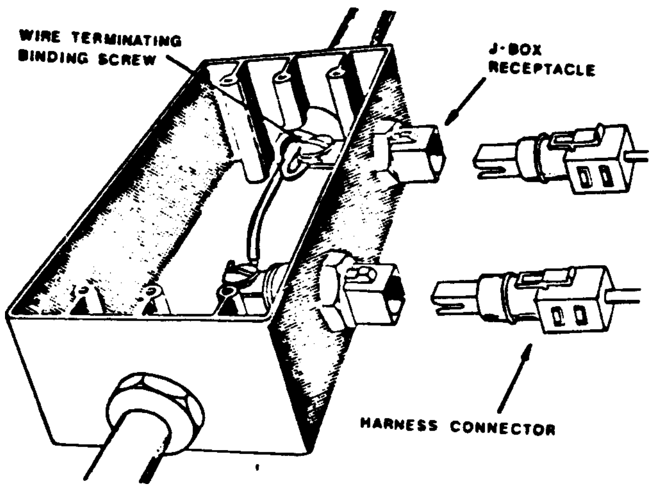


Figure 7.11

No additional requirements exist for photovoltaic electrical termination in the industrial sector (as opposed to the residential) in the area of electrical interconnection. There may be an increased desire for reliability in circumstances where the power produced by the photovoltaic system is used in a critical process that cannot experience power interruption. This dependency should be avoided in the system design if at all possible, considering the transient output characteristics of the array. Depending on many parameters, the current and voltage levels experienced in this sector may be substantially higher than those experienced in the residential sector. Proper voltage and current ratings would be required in every application.

7.5.3 CONCLUSION

A substantial amount of performance standards exist that are applicable to connectors which can be used in photovoltaic wiring termination. The acceptance by the NEC will require that they be recognized and listed by a testing laboratory, which will subject the connectors to the conditions dictated by these standards. Furthermore, a successful termination design will allow for the electrical and physical flexibility as demanded by the system. Termination design should recognize that direct and stand-off will not allow ready access to the rear of the module/panel/array. Additionally, inaccessible electrical terminations will present problems with acceptance by the NEC. Series/parallel wiring interconnects will need a junction which facilitates such an application. It is felt that a photovoltaic electrical termination be developed concurrently with a wiring system. This total electrical system approach would be developed with the specific requirements associated with the four generic mounting types in mind. This would allow for the submittal of a complete system to a testing laboratory. Listing of such a system would resultantly lessen the burden of interpretation placed on the local code official.

SECTION 8

STRUCTURAL/MECHANICAL REQUIREMENTS

8.1 INTRODUCTION

The objective of this section is to assess the structural and mechanical limitations placed on photovoltaic modules and panels to be introduced into the commercial/industrial sector of the building industry. Structural limitations of building elements are highly dependent on the type, size, and configuration of materials. The approach was to identify the limitations and standards for prefabricated building elements currently marketed in this sector. It was also necessary to investigate the historical development, proposed conventions, and developing trends of these elements in order to make reasonable assumptions about the future limitations and standards of the industry.

8.2 HISTORICAL BACKGROUND

The present day practices of the commercial/industrial building industry have evolved over thousands of years of trial and error of new materials, processing techniques, and construction techniques. Until relatively recent times, this evolutionary process was very gradual with little impact over one lifetime. Rule of thumb methods for analyzing the structural and mechanical limitations of building materials were passed from generation to generation. Buildings were essentially constructed by hand, each material cut to fit the context of its use. Material selection was limited to those materials indigenous to the site. Fabrication techniques were limited to cutting, and occasionally molding these materials to a usable form. The Industrial Revolution accelerated this evolutionary process rather rapidly. Machines automated the processes required for building material fabrication, reducing the energy, materials, and time involved. Reapplication and modification of these and other processes as well as the development of new processing techniques have led to the introduction of many new materials and components to the building industry. Each new component was found to have structural and mechanical characteristics unique to the material and configuration of that material. These characteristics improved with each refinement in material processing and with additives to raw materials.

Trial and error has remained the ultimate test of the structural and mechanical capabilities of material components although these capabilities can be calculated, within tolerable limits, through the use of formulas, charts, and tables which have developed from the analysis of recurring mechanical and structural behavior.

Today, the success of a building hinges on the ability of its factory made parts to be assembled in a consistent and predictable pattern with the least amount of effort. The controlling factors for minimizing this effort are essentially based on making the parts as large as possible, making the joints as simple as possible, and to minimize the length of the joints, without disturbing the performance of the part or its ability to integrate into the building system. By producing the parts as large as possible a manufacturer can reduce the length of joints required but material restrictions set limits on the maximum manufacturable part or component.

. The material restrictions place limitations on a product based on raw material sizes, fabrication of the raw material into a particular building component, and market requirements for that component relative to the economy of the finished products made from that component.

. Available raw material sizes affect only those materials which are used as they are found in nature, without undergoing processing. Wood and stone are typical examples of such materials used in their raw form. Wood, for example, must be cut from a tree of a given diameter. It is the usable diameter of the tree which establishes the maximum possible size of a solid wood building component.

. Fabrication techniques define a second generation of size limitations for a particular building component. Most materials used by the commercial building industry are processed by rolling, stamping, extruding, molding or any other similar fabrication procedures.

Few limitations, if any, are placed on second generation processing by the available sizes of raw material. The limitations are based on the particular processes such as: roll widths for rolling mills, presses for stamping, dies for extruding, and forms for molding. Even material formed on site must conform modularly to these dimensional limitations since the formwork used to define the outer skin of the formed materials is processed by these automated techniques. Stamped metal and molded fiberglass pans are typical examples of modular prefabricated formwork used extensively in the construction industry for poured concrete.

- Market requirements for materials of certain sizes and shapes are by far the most difficult restrictions to quantify. They not only rely on the usefulness of a product but also on public attitudes towards a product and the adaptability of the fabricated components of that product with other products in related or unrelated industries.

- Combining all the restrictions placed on various building materials, including manufacturing limitations, some standard sizes have been developed. Current limitations and standards for selected processed materials are listed in Table 8.1. These change constantly as demand increases for larger components and/or new fabrication techniques are developed.

Table 8.1

	Thickness In.	Width of Sheet Size	Lbs./Ft.^{2} Weight
• Metal Sheets	Varies	80" Max. 48" Standard	Varies
• (Self Supporting) Plastics	Other sizes available 0.125 - 0.25 (for glazing purposes)	48" Standard	Varies
• Thin Film Plastics	1 mil - 7 mils	58", 64", 108" Standard Widths	0.029-0.77
• Aluminum Extrusions	0.60 avg. wall	6" Circumference Maximum Standard	Varies
• Tempered Glass	0.125	48"	1.60

8.3 INDUSTRIAL BUILDING SYSTEMS

Industrial building systems utilize prefabricated components, to develop subsystems which integrate to form the "whole" of a building. Within the commercial/industrial sector of the building industry, there are many areas that have had a great deal of difficulty with the integration of industrialized building subsystems. The difficulties associated with the integration of subsystems can be attributed to the diversity of the building program, the functional variations required of each subsystem, and/or, the lack of coordination between the manufacturers of a given subsystem.

Subsystem Coordination

Subsystems of buildings, found in the commercial/industrial sector, can be listed under the following generic categories:

- Structure
- HVAC
- Lighting
- Interior Space
- Vertical Skin
- Plumbing
- Electric
- Furniture
- Roofing
- Interior Finishing

The coordination between these categories is hierarchal in nature. For instance, the furniture used in a building has very little to do with the roofing of that building while an interface between the structure and the roofing of a building is critical for each to meet their individual performance requirements.

In 1965, an industrialized building system was developed for school construction in Ontario, Canada--the S.E.F. system. Within the studies needed to develop the system, a comprehensive analysis of mandatory and optional interfaces for building subsystems was performed. Listed in Table 8.2 are the results of that analysis.

Table 8.2

SUBSYSTEM		MANDATORY INTERFACES
1	Structure	2, 3, 4, 5, 9
2	HVAC	1, 3, 4, 5, 10
3	Lighting (Cooling System)	1, 2, 4, 5
4	Interior Space	1, 2, 3, 5
5	Vertical Skin	1, 3, 4, 9
6	Plumbing	8, 9
7	Electrical	3, 4
8	Furniture	4, 5, 6, 7, 10
9	Roofing	1, 2, 5, 6
10	Interior Finishing	4, 5, 8

The mandatory interfaces insured the compatibility of each subsystem with the remaining subsystems. For example, the roofing subsystem required interfacing with the structure, HVAC, vertical skin, and plumbing subsystems. A further interpretation of this analysis could determine secondary interfaces by listing the additional mandatory interfaces required by the primary interfaces and so on until a complete hierarchal arrangement of all the subsystems is determined. For roofing subsystems, the following hierarchy has been developed:

Mandatory Interfaces

- Structural Subsystems
- Vertical Skin Subsystems
- HVAC Subsystems
- Plumbing Subsystems

Secondary Interfaces

- Lighting
- Interior Space
- Furniture

Tertiary Interfaces

- Electrical
- Interior Finishing

This arrangement is of particular importance to a manufacturer developing a modular product to obtain the highest degree of interfaces compatible with all other building subsystems. It is important to note that the product must first and foremost have compatibility with the subsystem of which it is a part.

In order to illustrate the requirements for subsystem compatibility, a number of commonly used building systems will be discussed. As these subsystems (structural) are typically found on construction sites, it is felt that these examples will demonstrate the sizes which photovoltaic manufacturers must address if a viable product is to penetrate the building industry. The two systems studied are metal building systems and space frame structural systems.

Metal Building Systems

The metal buildings sector of the Commercial/Industrial Building Industry has had some success with subsystem coordination and industrialized building components. Although the metal buildings industry got its start in the early 1900's, it did not have a major impact on the building industry until the Metal Building Manufacturers Association (MBMA) was formed in 1956. Its purpose was to "conduct research on building materials and methods; review building codes, construction practices and safety regulations as they apply to the metal building industry; and to compile and publish recommended design standards that would insure high quality metal buildings".[1]

Presently, twenty-five percent of the buildings constructed in the Commercial/Industrial Sector are constructed from metal building systems. Recent patterns indicate a current growth rate near three times that of the commercial/industrial sector.[1] This rate is essentially due to the increased architectural capabilities of the systems along with the ever present functional and cost considerations.

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[1] Metal Buildings Systems Fact Book, Metal Building Manufacturers Association, Washington, D.C., 1977.

The designs for most metal building systems are in essence a direct expression of structural function. The recent advances in the architectural capabilities have resulted from the combination of two or more separate structures, or through the integration of conventionally constructed components to the systems by employing an architect to organize the variations. A typical selection of standard structural systems and the modular range of each are listed in Table 8.3 and diagrammed in Figure 8.1.

Of particular importance in Table 8.3 is the building module consistency of the spans and the bay spacing. All the dimensions listed for spans and bay spacing are some multiple of 5'-0". Photovoltaic modules designed to integrate with all of these metal building systems must be dimensioned to fit within a 5'-0" module in at least one direction if filler panels are to be avoided.

Space Frames

A space frame is the most stable and efficient frame structure that can be built because it transfers loads to the supports three dimensionally while bracing itself and because all members participate in carrying primarily axial loads (compression and tension) in proportion to their strength. The simplicity of its components permits the ultimate mix of factory and field labor with no special joinery and with no decrease of structural performance of the overall structure or any of its components.

The modular shape of the top and bottom chords may be square, rectangular, triangular or even geodesic (Figure 8.2). The shape of the system may be planar, multi-planar, or curved; and the shape of the edge conditions may be square, sloped-out, or sloped-in (Figure 8.3).

Table 8.3

1.	Single-span tapered beam:	eave height–10'to 26'
		spans–20'to 80'
		bay spacing–20'to 25'
2.	Single-span rigid frame:	eave height–12'to 24'
		spans–30'to120'
		bay spacing–20'to 25'
3.	Single-span truss:	eave height–10'to26'
		spans–30'to140'
		bay spacing–20'to 25'
4.	Two-span tapered beam:	eave height–10'to 26'
		spans–60'to 160'
		bay spacing–20'to 25'
5.	Two-span rigid frame:	eave height–12'to 24'
		spans–100'to 160'
		bay spacing–20'to 25'
6.	Three-span tapered:	eave height–14'to 20'
		spans–90'to 240'
		bay spacing–20'to 25'
7.	Three-span rigid:	eave height–12'to 24'
		spans–150'to 240'
		bay spacing–20'to 25'
8.	Multi-span, tapered: (four-span, five span)	eave height–14'to 20'
		spans–120'to 400'
		bay spacing–20'to 25'
9.	Post and beam: (one and two storey construction)	eave height–12'to 26'
		spans–120'to 480'
		bay spacing–40', 50', or 60'

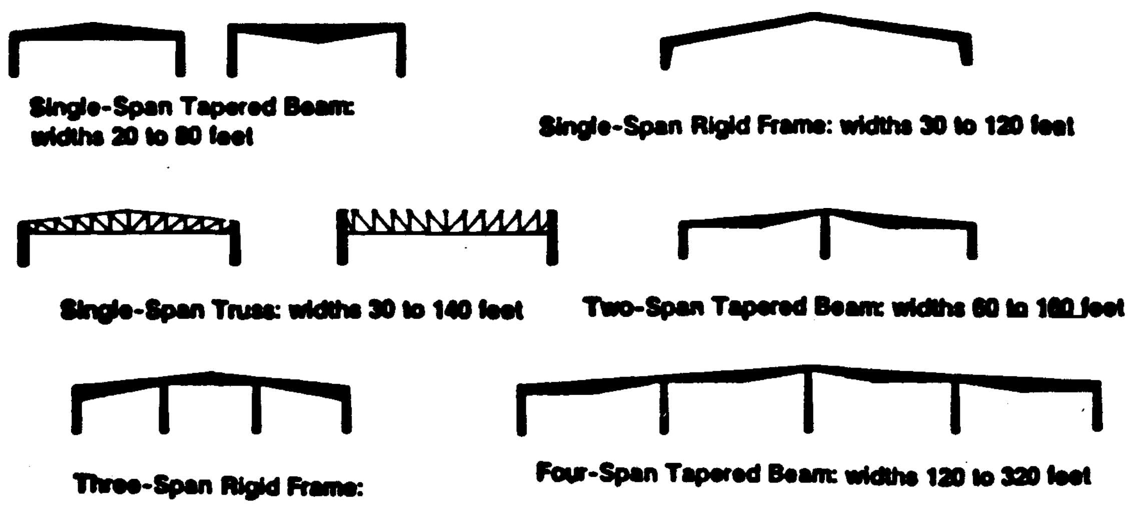


Figure 8.1

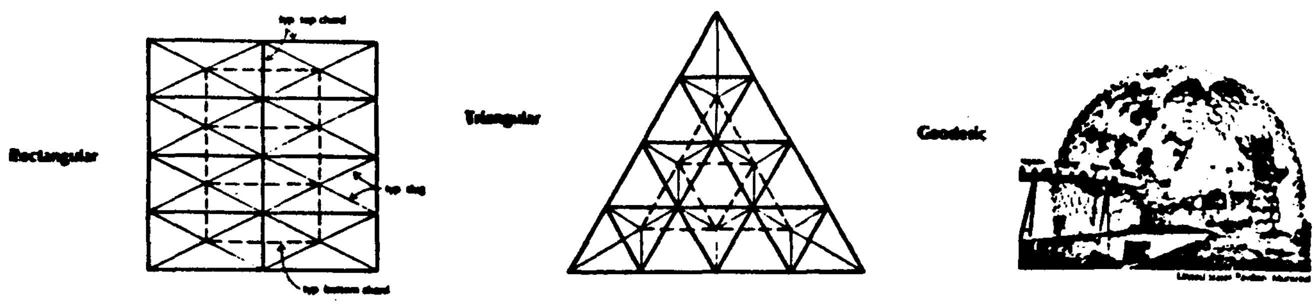


Figure 8.2

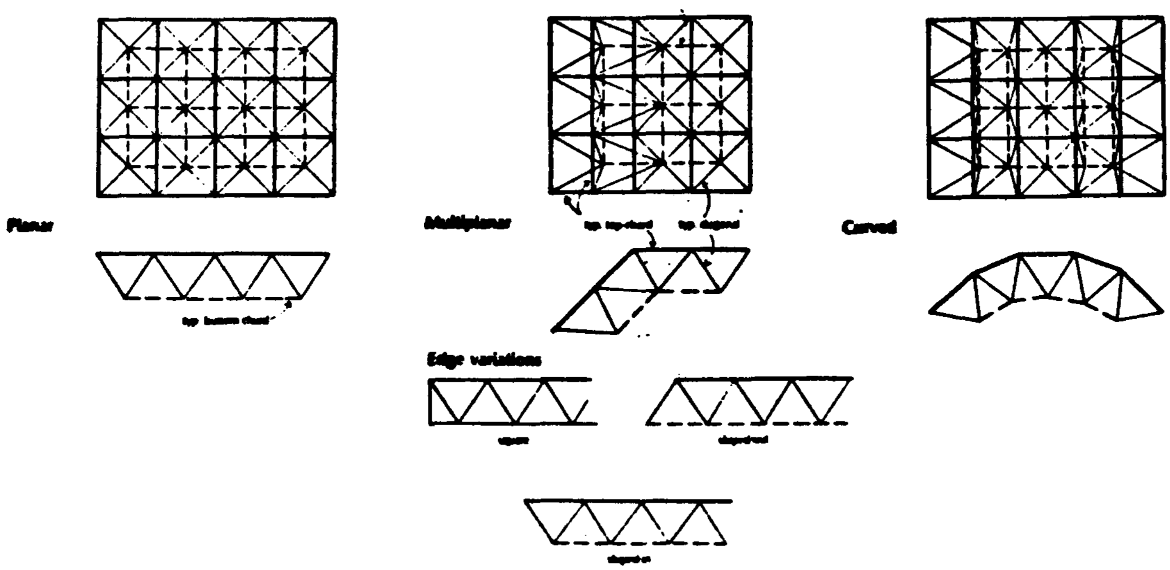


Figure 8.3

Standard space frames which are currently marketed are constructed from 4'-0" square modules or 5'-0" square modules for short span conditions and 10'-0" square modules for long spans to optimize structural efficiency. As with any other building material or subsystem, special-sized modules could be produced at no additional charge to the purchaser if orders are large enough for the manufacturer to absorb the added cost for retooling. It is unlikely that the number of photovoltaic systems constructed at one time using space frames for support would warrant a manufacturer's retooling, unless rational and demand dictated a cost effective change in size. Therefore, a photovoltaic module designed to integrate with space frame systems must be designed, in at least one dimension, to modulate with 4'-0", 5'-0", and/or 10'-0" nominal center to center dimensions. Joints and tolerances must also be taken into account when determining the actual size of the module.

8.4 MODULAR CONVENTION

Principle

Modular Convention is the standardization of modular sizes and shapes in order to facilitate modular coordination between building subsystems, elements, and components. Its purpose in the building industry is to enable prefabricated parts of unrelated origin or purpose to be fitted together without the need for site alteration of the parts or the need for variable joint dimensions and/or infill panels. Standard dimensions could be fixed arbitrarily, without regard for the structural and mechanical requirements; but this would require a complete redefinition of existing building systems. A more logical approach to the problem has developed through analysis of common sizes and shapes of semi-finished products currently marketed. For instance, a width of four feet (approximately 1200 mm) is very common for materials produced in sheet form; however, for a variety of aesthetic, functional and/or economical reasons, building elements do not maintain this dimension as a standard. Table 8.5 lists the common sizes of prefabricated elements currently used by the building industry in the United States. Common to the majority of these sizes is a submodular dimension of four inches (approximately 100 mm).

Practice

The precedence, within this report, for addressing metric units of measure is two fold; the U.S. Metic Conversion Act, Public Law 94-168, adopted in 1975, and that work done on modular convention has been done essentially for metric units in anticipation of a worldwide system of measure based on metric units.

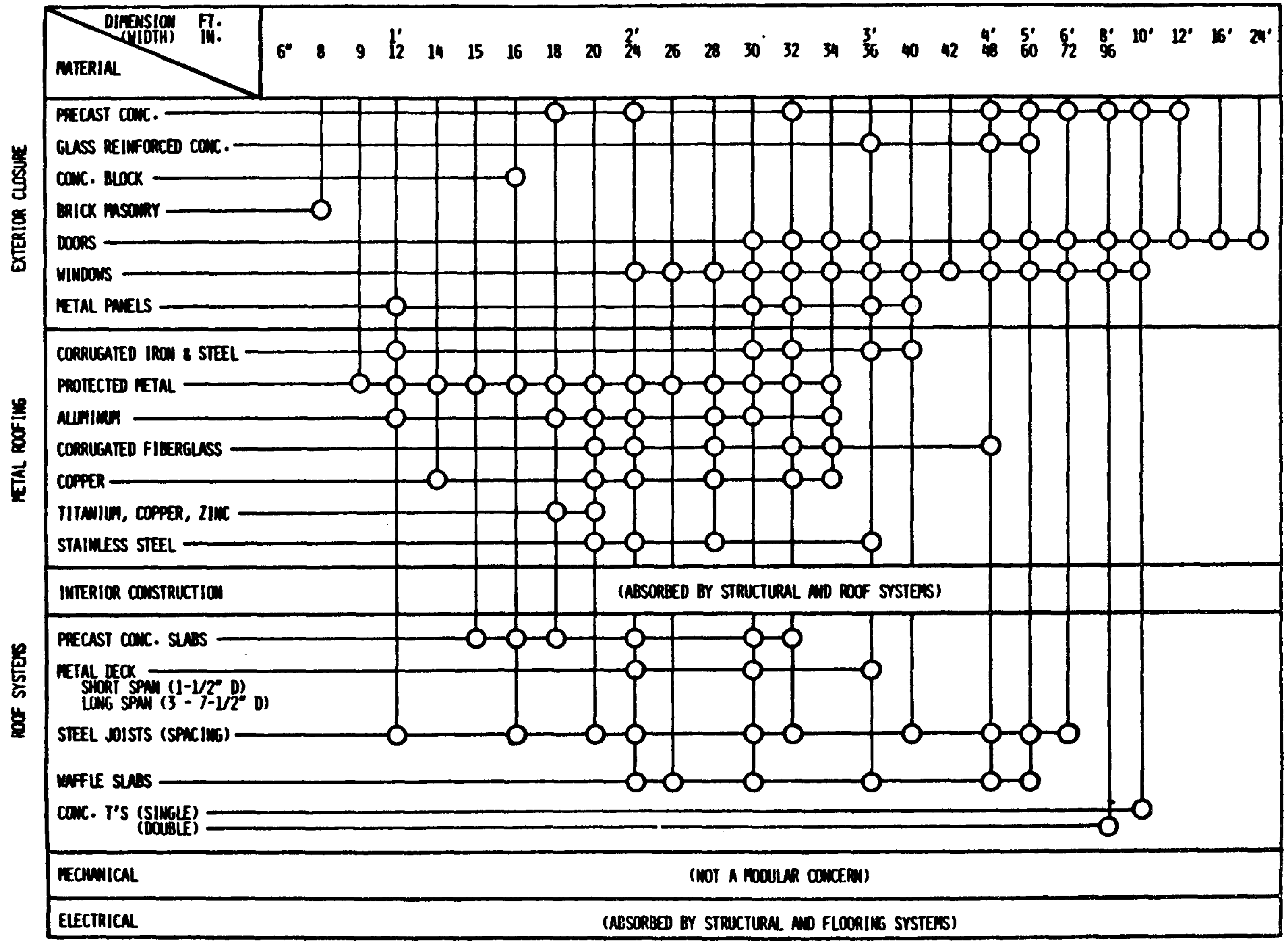

DIMENSION (WIDTH) FT. IN.
MATERIAL
6" 8 9 1' 12 14 15 16 18 20 2' 24 26 28 30 32 34 3' 36 40 42 4' 48 5' 60 6' 72 8' 96 10' 12' 16' 24'
EXTERIOR CLOSURE
PRECAST CONC.
GLASS REINFORCED CONC.
CONC. BLOCK
BRICK MASONRY
DOORS
WINDOWS
METAL PANELS
METAL ROOFING
CORRUGATED IRON & STEEL
PROTECTED METAL
ALUMINUM
CORRUGATED FIBERGLASS
COPPER
TITANIUM, COPPER, ZINC
STAINLESS STEEL
INTERIOR CONSTRUCTION
(ABSORBED BY STRUCTURAL AND ROOF SYSTEMS)
ROOF SYSTEMS
PRECAST CONC. SLABS
METAL DECK
SHORT SPAN (1-1/2" D)
LONG SPAN (3 - 7-1/2" D)
STEEL JOISTS (SPACING)
WAFFLE SLABS
CONC. T'S (SINGLE)
(DOUBLE)
MECHANICAL
(NOT A MODULAR CONCERN)
ELECTRICAL
(ABSORBED BY STRUCTURAL AND FLOORING SYSTEMS)

Table 8.4

The Metric Conversion Act implemented a voluntary conversion process which had little effect on the U.S. construction industry, but it was only one step away from mandatory conversion. Prior to this, in 1972 the American National Standards Institute (ANSI) formed the American National Metric Council (ANMC), representing more than 300 trade, professional, labor, and government organizations and more than 400 major corporations, to develop and organize the conversion process. Since that time a number of special publications concerning metric conversion, dimensional convention, and dimensional coordination have set guidelines for the use of metrics.

Conversion to the metric system of measure may take one of two paths with respect to modularity; Soft Conversion or Hard Conversion.

- Soft Conversion implies a retention of customary sizes with dimensions expressed in metric units of measure.

- Hard Conversion requires the adoption of metric sizes and dimensions.

Table 8.5 lists typical English modules, their metric equivalent, and the corresponding metric module; i.e., the hard metric conversion.

Table 8.5

ENGLISH MODULE		METRIC EQUIVALENT	METRIC MODULE
	1"	25.4 mm	25 mm
	2"	50.8 mm	50 mm
	3"	76.2 mm	75 mm
	4"	101.6 mm	100 mm
	6"	152.4 mm	150 mm
	8"	203.2 mm	200 mm
	10"	254.0 mm	250 mm
(1')	12"	304.8 mm	300 mm
	16"	406.4 mm	400 mm
	20"	508.0 mm	500 mm
(2')	24"	609.6 mm	600 mm
	28"	711.2 mm	700 mm
	30"	762.0 mm	750 mm
	32"	812.8 mm	800 mm
(3')	36"	914.4 mm	900 mm
	40"	1,016.0 mm	1,000 mm
	44"	1,117.6 mm	1,100 mm
(4')	48"	1,219.2 mm	1,200 mm
	52"	1,320.8 mm	1,300 mm
	56"	1,422.4 mm	1,400 mm
(5')	60"	1,524.0 mm	1,500 mm
	64"	1,625.6 mm	1,600 mm
	68"	1,727.2 mm	1,700 mm
(6')	72"	1,828.8 mm	1,800 mm
	76"	1,930.4 mm	1,900 mm
	80"	2,032.0 mm	2,000 mm
(7')	84"	2,133.6 mm	2,100 mm
	88"	2,235.2 mm	2,200 mm
	92"	2,336.8 mm	2,300 mm
(8')	96"	2,438.4 mm	2,400 mm
	100"	2,540.0 mm	2,500 mm
	104"	2,641.6 mm	2,600 mm
(9')	108"	2,743.2 mm	2,700 mm
	112"	2,844.8 mm	2,800 mm
	116"	2,946.4 mm	2,900 mm
(10')	120"	3,048.0 mm	3,000 mm
	128"	3,251.2 mm	3,200 mm
(11')	132"	3,352.8 mm	3,300 mm
	136"	3,454.4 mm	3,400 mm
(12')	144"	3,657.6 mm	3,600 mm
(14')	168"	4,267.2 mm	4,200 mm
(15')	180"	4,572.0 mm	4,500 mm
(16')	192"	4,876.8 mm	4,800 mm
(20')	240"	6,096.0 mm	6,000 mm
(22')	264"	6,705.6 mm	6,600 mm
(24')	288"	7,315.2 mm	7,200 mm
(25')	300"	7,620.0 mm	7,500 mm
(26')	312"	7,924.8 mm	7,800 mm
(28')	336"	8,534.4 mm	8,400 mm
(30')	360"	9,144.0 mm	9,000 mm
(32')	384"	9,753.6 mm	9,600 mm
(34')	408"	10,363.2 mm	10,200 mm
(35')	420"	10,668.0 mm	10,500 mm
(36')	432"	10,972.8 mm	10,800 mm
(38')	456"	11,582.4 mm	11,400 mm
(40')	480"	12,192.0 mm	12,000 mm

The International Standards Organization (ISO) has adopted the 100 mm dimension as the international standard submodule for all non-technical dimensions. "Technical dimensions", such as wall, column, and floor thicknesses, have no standard submodule. Within the building industry, a 100 mm submodule is restrictively small. Therefore, larger dimensional standards were developed to economize the size of building elements. Horizontal submodules of 300 mm (approximately 12") were adopted for the residential construction industry and 600 mm (approximately 24") for commercial construction. From these submodules preferred sizes for building components, elements, and assemblies have resulted and are listed in Table 8.6.

Table 8.6

PREFERRED SIZES FOR BUILDING COMPONENTS, ELEMENTS AND ASSEMBLIES

CATEGORY	EXAMPLES	1ST PREFERENCE	2ND PREFERENCE	
SMALL 25 MM - 500 MM (4" - 20")	BRICK, BLOCK, TILE, PAVING UNITS	100 MM (4") 200 MM (8") 300 MM (12") 400 MM (16")	25 MM (1") 50 MM (2") 75 MM (3") 150 MM (6") 250 MM (10")	
MEDIUM 500 MM - 1,500 MM (20" - 60")	PANELS, PARTITIONS, DOOR SETS, WINDOWS, SLABS	600 MM (24") 800 MM (32") 900 MM (36") 1,200 MM (48")	500 MM (20") 700 MM (28") 1,000 MM (40") 1,400 MM (56") (SEE NOTE 1)	
LARGE 1,500 MM - 3,600 MM (60" - 144")	PRECAST FLOORS, PRECAST WALLS, PANELS, DOORS, WINDOWS, STAIRS	1,800 MM (72") 2,400 MM (96") 3,000 MM (120") 3,600 MM (144")	(N X 300) 1,500 MM (60") 2,100 MM (84") 2,700 MM (108") 3,300 MM (132")	(N X 200) 1,600 MM (64") 2,000 MM (80") 2,200 MM (88") 2,600 MM (104") 2,800 MM (112") 3,200 MM (128") 3,400 MM (136")
			(SEE NOTE 2)	
VERY LARGE OVER 3,600 MM (OVER 144")	PREFABRICATED BUILDING ELEMENTS, PRECAST FLOOR AND ROOF SECTIONS	4,800 MM (16') 6,000 MM (20') 7,200 MM (24') 8,400 MM (28') 9,600 MM (32') 10,800 MM (36') 12,000 MM (40')	(N X 600) 4,200 MM (14') 6,600 MM (22') 7,800 MM (26') 9,000 MM (30') 10,200 MM (34') 11,400 MM (38')	(N X 1,500) 4,500 MM (15') 7,500 MM (25') 10,500 MM (35')
			(SEE NOTE 3)	

Notes:

1) 1100 and 1300 may also be included in this preference group when smaller components require 100 mm flexibility.

2) Multiples of 200 mm are more appropriate for vertical dimensions of non-masonry construction while multiples of 300 mm are better suited for integration with masonry construction.

3) For some projects, especially large open plan offices, schools and large spans where structure dominates, it will be more appropriate to size large components or assemblies in multiples of 1500 mm (5').

As a result of 4'-0" dimensional restriction for building materials, a 5'-0" recommended module for metal building systems, standard 4'-0", 5'-0" and 10'-0" modules used in space frames, the existing modular sizes for building components listed in Table 8.4, and the preferred sizes for building components, elements and assemblies listed in Table 8.6, a modular dimension, based on conventional building structural systems, of 4'-0" x 5'-0" is strongly suggested for photovoltaic modules. This implies modules and panel be some multiple of 4' x 5' nominal.

8.5 MODULAR ORDERING SYSTEMS

The goals of modular ordering systems within the commercial/industrial sector are essentially to minimize waste of materials and construction labor, improve productivity of building elements, and to simplify on-site construction procedures. Modular ordering systems result from both theoretical and practical investigations of measurements, measuring methods, the determination of proportions and the dimensioning of everything from the smallest building components to the building as a whole.

The basis of a modular ordering system is a modular unit of measure, from which any component dimension, area, or volume within the system may be derived through some geometric order. The size and shape of the basic modular unit is determined by the parallels between the following restrictions and requirements:

- Structural
- Performance
- Handling/Transportation
- Geometry
- Joints
- Tolerance

It will be seen that these requirements apply to all modular systems, including photovoltaic modules, panels and arrays.

Structural Requirements

Structural requirements for buildings have been clearly defined by the building codes discussed earlier in this document. The building codes give requirements for structural loading maximums; dead, live, wind, snow, and earthquake load as they would occur over 25, 50 and 100 year intervals. As these intervals increase in length of time, the structural loading requirements also increase. Effective loads for all permanent structures are based on maximum loading recurrences for 50 or 100 year intervals.

Theoretically, this interval is based on the permanence of the structure. For structures having no human occupants, or where there is negligible risk to human life, a 25 year mean recurrence interval may be used.

Although photovoltaic panels may very well be classified as permanent structures, their design life is only 20 years. It is also probable that their structural failure would create a situation of negligible risk to personnel or property. For these reasons a 25 year mean recurrence interval may be used to determine the structural loading requirements for photovoltaic modules. Figures 8.4 and 8.5 show the wind speed and snow load, respectively, for a 25 year mean recurrence interval. Loads imposed on structures due to earthquakes are assumed to be similar to those that have occurred in the past. As a result, earthquake risk zones have been developed and are shown in Figure 8.6.

The following example illustrates the structural requirements imposed on a building. Similar requirements will be necessary for P.V. hardware based on year mean recurrence interval and desired markets. If a prefabricated building element is marketed nationally, it must be capable of resisting the ultimate loading condition projected to occur within that market over the design life of the element. From the windloading map, it is clear that 100 mph wind on the east coast is the maximum wind speed. The snow loading maximums occur in Maine and the highest risk zone for earthquakes occur in California, Montana, Alaska, and near the tip of Illinois. Preliminary calculations showed the east coast of Maine as the area that would experience the highest combined loading conditions. Alaska was excluded, due to undeterminable snow loading conditions. From the maps, the following ultimate loading conditions were taken for the realistic worst case, the east coast of Maine:

Wind	=	70 mph
Earthquake	=	Zone 2
Snow	=	52 lbs./ft^2

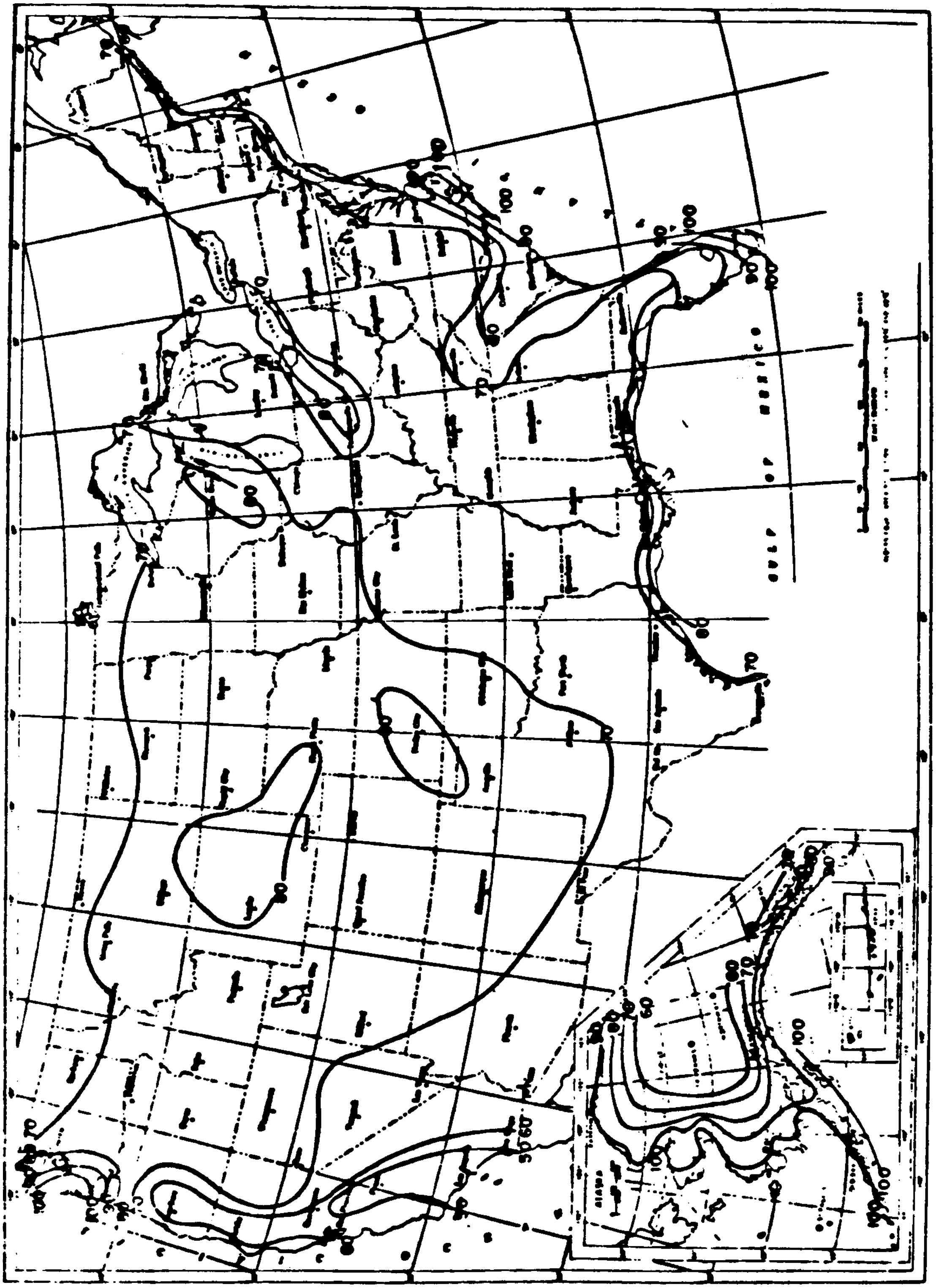


Figure 8.4
Basic Wind Speed in Miles per Hour
Annual Extreme Fastest-Mile Speed 30 Feet Above Ground,
25-Year Mean Recurrence Interval

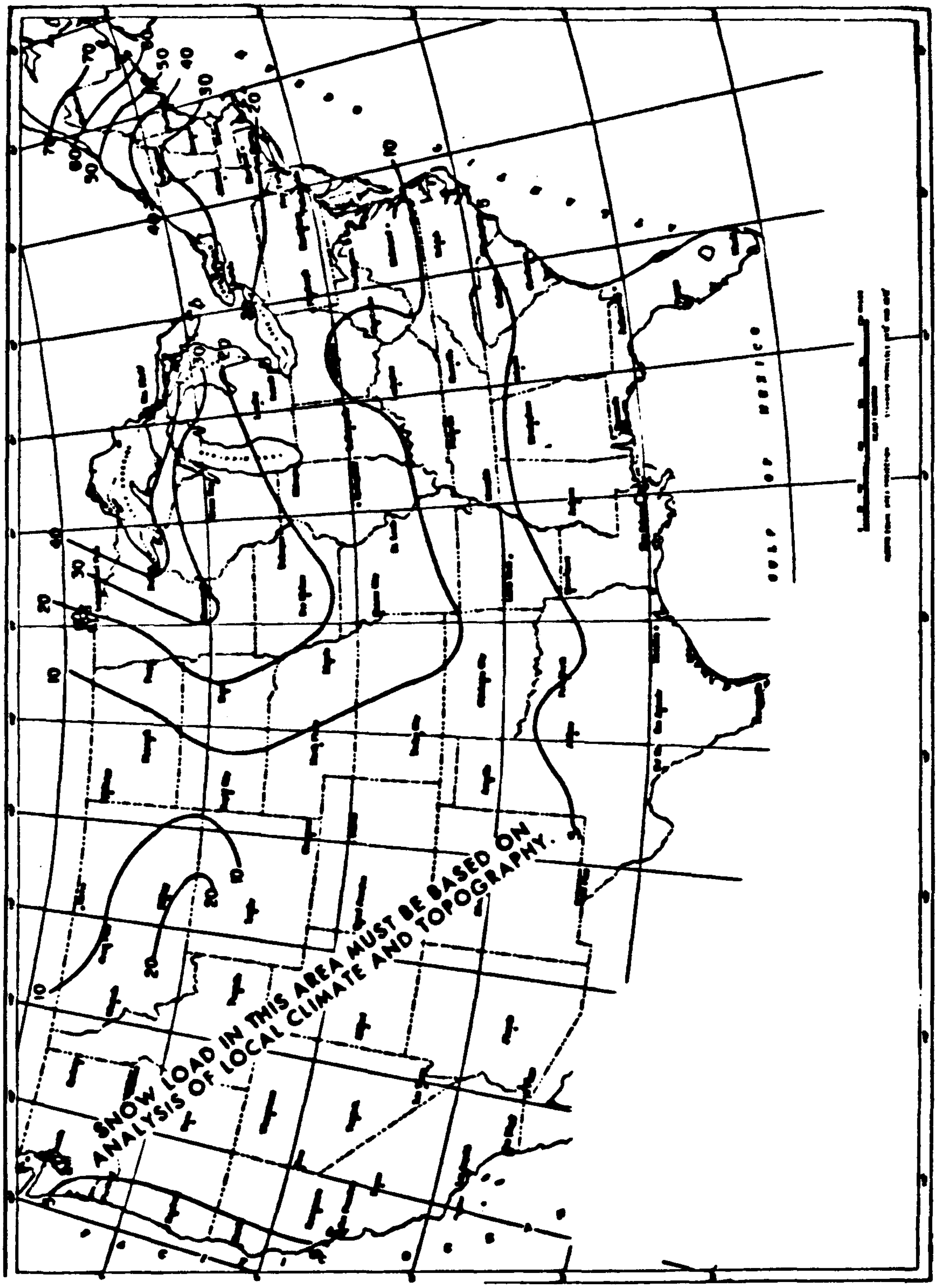


Figure 8.5
Snow Load in Pound-Force per Square Foot on the Ground,
25-Year Mean Recurrence Interval

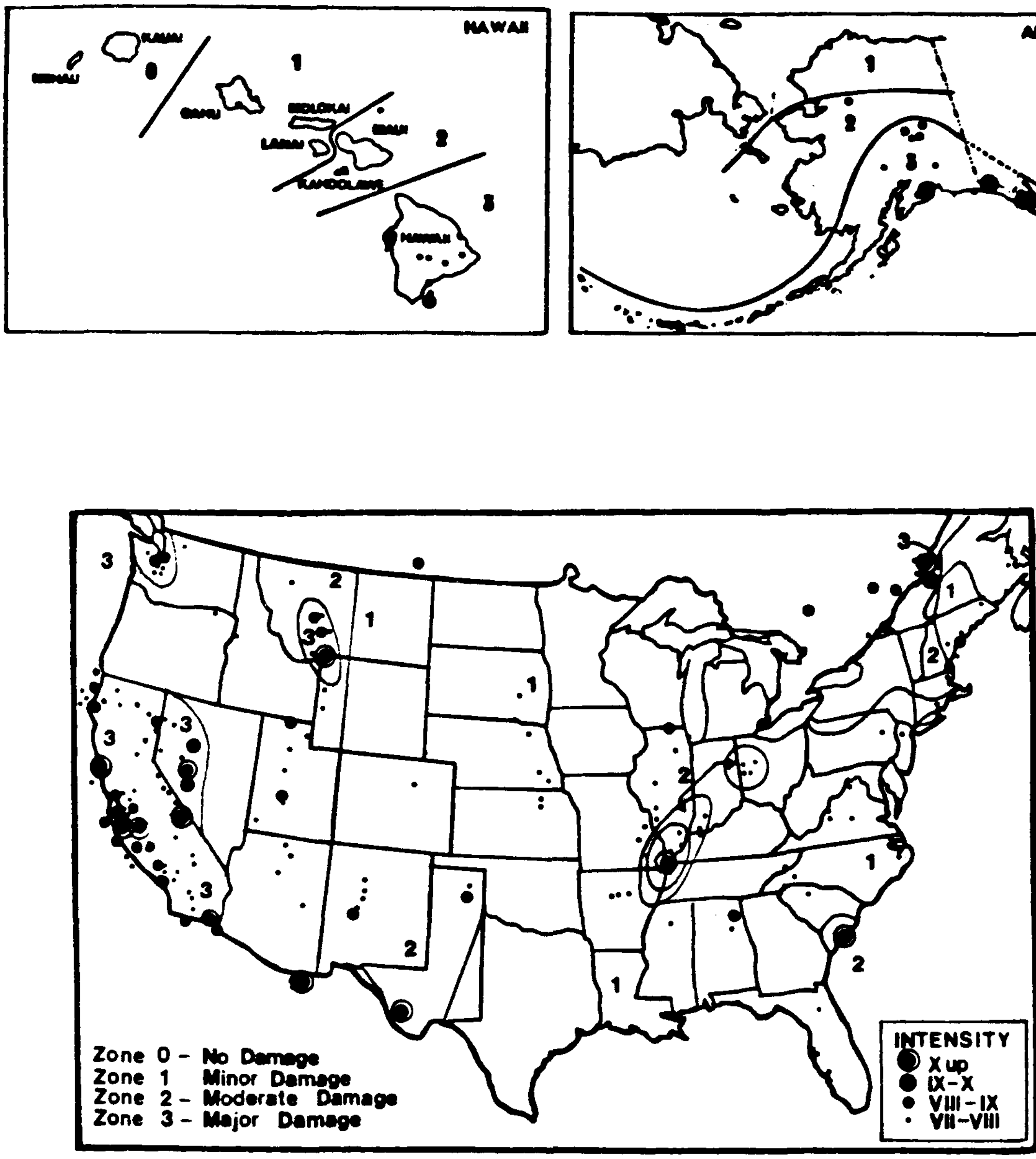


Figure 8.6
Risk Zones and Damaging Earthquakes of the United States
Through 1968

Other structural loads placed on a building and/or building element are based on additional live loading conditions specific to the application of that building or element and to the dead weight of the materials. In order to analyze the impact of these ultimate loading conditions, it is necessary to identify the materials and the application.

The structural requirements for photovoltaic modules are based on the assumption that their market be restricted to those locations with combined structural loading conditions equal to or less than those experienced in Bangor, Maine. It was also necessary to assume a typical composite of materials for the photovoltaic module. A photovoltaic module consisting of a 0.125" (3 mm) tempered glass superstrate, 0.080" PVB or EVA encapsulation and a 0.06" mylar back cover was chosen based on the assumption that it is the most structurally restrictive composite of the candidate composites, as well as one of the most cost effective composites identified. Ordinary soda-lime window glass was not addressed on the grounds that it would not meet code requirements at any thickness.

Performance Requirements

The performance requirements of a component, element or device are those necessary for it to fulfill its intended function, within the context of its use, and its design life. Any element located on the exterior of a building may be required to perform any or all of the functions listed in Table 8.8. (See Page 8-24)

Any element located between the exterior and interior of a building may also be required to perform any or all of the functions listed in Table 8.7 as well as Table 8.8.

Table 8.7

To control passage of insects and vermin
To control passage of plants, leaves, roots, seeds and pollen
To control passage of dust and inorganic particles
To control passage of heat
To control passage of sound
To control passage of light
To control passage of radiation
To control passage of air and other gases
To control passage of odors
To control passage of water, snow and ice
To control passage of water vapour
To control condensation
To control generation of sound
To control generation of odors

Table 8.8

To resist in one or more directions due to:

- compression
- tension
- bending
- shear
- torsion
- vibrations (or any other type of stress which may induce fatigue)
- impact
- abrasion (indicate, for each particular case, the type of wear)
- shrinkage or expansion
- creep
- dilation or contraction due to temperature variations

To control passage of fire, smoke, gases, radiation and radioactive materials
To control sudden positive or negative pressures due to explosion of atmospheric factors
To avoid generation of toxic gases and fumes in case of fire
To avoid harbouring or proliferation of dangerous micro-organisms
To have acceptable appearance
To avoid promotion of plant growth
To avoid discoloration due to biological, physical or chemical action
To avoid all or part of the internal structure showing
To avoid dust collection
To have specified minimum life, taking into account cyclic factors
To resist damage or unauthorized dismantling by man
To resist action of animals and insects
To resist action of plants and micro-organisms
To resist action of water, water vapour or aqueous solutions or suspensions
To resist action of polluted air
To resist action of light
To resist action of radiation (other than radiation of light)
To resist action of freezing of water
To resist action of extremes of temperatures
To resist action of airborne or structure-borne vibrations, shock waves or high-intensity sound
To resist abrasive action

To permit partial or complete dismantling and reassembly

To perform required functions over a specified range of temperatures
To perform required functions over a specified range of atmospheric humidity
To perform required functions over a specified range of air or liquid pressure differentials
To perform required functions over a specified range of joint clearance variations

Handling/Transportation

Handling places limitations on a product based on transportation, site erection, and factory production in the sense of moving a component from place to place within a factory. The capacity of cranes and lifting devices within the factory seldom affect the dimensions of a building element or component. Restrictions on size are much more often the result of transportation or site erection limitations.

The Federal Transportation Commission (FTC) of the United States recently increased the weight limitation for major arteries from 72,000 pounds to 80,000 pounds maximum for the truck, trailer and load combined. A typical truck and trailer weighs approximately 24,000 pounds empty leaving roughly a 48,000 pound load capacity. The maximum allowable width of a truck or trailer is 8'-0". Standard trailers vary in height up to 12'-6". The average height of the floor of a trailer from the road surface is 4'-3" allowing approximately 8'-3" from the floor to the top of the trailer. The standard length of a trailer varies from 22'-0" to 45'-0". The largest panel size which could be carried in a trailer is approximately 8'-0" in width by slightly less than 45'-0" in length, or approximately 360 square feet. If these panels are packed six inches apart, one tractor trailer could carry 15 panels or approximately 5,400 square feet of panels weighing a total of 15,000 lbs. It follows that three trailer trucks could carry enough panels to construct a 15,000 square foot array with 600 cubic feet of space left over for any additional mounting hardware. Most states allow trailer widths of 14'-0" and lengths of up to 70'-0" for mobile homes provided they are clearly marked "wide load" and accompanied by another vehicle warning other vehicles of the presence of the "wide load". If we can assume equal consideration would be given to the transportation of photovoltaic panels, a specially designed trailer could carry an entire photovoltaic array (15,000 square feet weighing approximately 40,000 lbs.), if it is found economically favorable.

Site erection limitations, for the most part, are based on the lifting capacity of the machinery found on the job site. Most larger commercial buildings warrant the use of a tower crane capable of lifting 24,000 pounds at a maximum reach of 90 feet. Photovoltaic panels range in weight from approximately 2-15 pounds per square foot. Since the largest easily transportable panel is roughly 320 square feet, the lifting capacity of the crane required is only 640-4,800 pounds (far less than the 24,000 pound capacity).

Size, however, may be a problem with respect to the wind resistance of large panels during erection, requiring special guying precautions and/or good weather allowances for erection.

Of equal importance are the limitations placed on handling by module replacement operations, when tower cranes are no longer on the site. Very often replacement of modular building components must be accomplished by hand. The lifting capacity of an individual is between 50 and 60 pounds while a comfortable hand-to-hand grip span is between 36 and 40 inches. It follows that the lifting capacity of two individuals working simultaneously is between 100 and 120 pounds while no dimensional limitations are required for a comfortable hand grip. A 4' x 5' module weighing less than 6 pounds per square foot would satisfy the 120 pound weight restriction and could easily be installed or removed by hand employing a two man crew. A typical 1/8" thick glass module weighs approximately 2.3 pounds per square foot. Size and weight of a module may be increased under different repair/replacement scenario. In other words, if replacement were made only when a large number of modules were in need of replacement, a crane or lift could be justified. This would permit the use of modules which cannot be handled by one or two men. Similarly, if mechanized maintenance hardware is installed with the array, larger modules may be used.

The module replacement implication coupled with the desires to maximize panel size lead to the logical conclusion that the panel may be a permanent installation while the modules are easily replaceable by a small one or two man crew without the aid of heavy equipment. This is a standard building industry practice.

Geometry Requirements

The geometry requirements define the proportional system governing the relationship between the two adjacent sides of a module, the relative size or area of one module to the next, and/or the sequential order of position or placement of modules of varying sizes. This is achieved by proportional enlargement or reduction systems. Four systems of proportional variation have been reduced to numerical series based on proportional growth found in nature. These include repetitive growth, additive growth, multiple growth, and exponential growth.

Relative to the current status of photovoltaic modules, the relationship between the two adjacent sides of the modules is limited to a repetitive series or a multiple series. The relative size between modules or between panels is strictly repetitive as is the sequential order between them. This lack of geometric diversity presently exists in most industrialized building elements as well, but as the potential for visual relief increases as the market for industrialized building elements matures, the demand for geometric diversity of photovoltaic modules and panels will also increase.

The geometry of sloped roofs of buildings is also important to the geometry requirements, but it is often overlooked due to the fact that few inclined roof surfaces are modular. Current practice within the building industry is to special order or cut to fit roofing materials for inclined surfaces. The materials used by the commercial building industry for sloped roofs include various types of shingles and rolled metals and other similar materials which allow a variety of slant heights by trimming excess material. Since photovoltaic panels cannot be trimmed, it is not possible for photovoltaic modules to maintain the same dimension as the trimmable materials currently used for roofing if three dimensional order is to be maintained. To maintain geometric integrity with the plan view module, the slant height of the photovoltaic module must vary proportionately so that the plan view dimension of both modules is equal. The relationship of the slant height to the planning module is the secant of the angle formed between the two modules. This consideration is important when the PV array must integrate with the building structural system directly, such as in the case of an integral array.

Although three-dimensional modularity within a building is an optimal result, it is seldom necessary. It is necessary, however, to maintain integrity between the horizontal dimensions of the wall and roof panels. The planning module establishes this dimension. Planning modules of either 4'x4' or 5'x5' are typically used to generate commercial buildings. It follows that a module nominally sized to 4'x5' could satisfy both of these dimensions. In order to accommodate variations in slope and slant height, one or more of the following dimensional modifiers must be employed:

- Install filler panels at the top and/or bottom of the array ignoring the modularity of the individual components.

- Design the horizontal joints to vary with the slope by increasing the width of the joint and/or joint material.

- Install filler panels between each module or panel.

- Vary the size of the module by increasing or decreasing the length of the substrate and superstrate without changing the dimensions of the electrical module.

- Standardize the slopes used, choosing one or two dimensions that satisfy the resulting slant heights.

Joints

The performance of an element depends on the performance of its joints as well as the performance of the components it joins. The performance of a joint depends on its location, material composition and form, and the external forces to which it is subject. The material composition and form of the joint are dependent on the external forces acting on the joint. These forces are determined by the location of the joint. Therefore, the functions required of a joint are to a large extent determined by the location of the joint. When the location is known, the joint may then be designed to fulfill the requirements of that location. Location can be divided into location within a particular microclimate, within the building, and within or between building components. For example, a joint in an industrial atmosphere will be required to withstand the chemical pollutants of such a microclimate while a joint located in a "clean" atmosphere, removed from industrial centers, may have less stringent requirements placed on it. The location of the joint within the building will determine the exposure of the joint to the microclimate inside or outside the building. The location of the joint within or between two components of a building affects the required compatibility between the joint and the components being joined with respect to material composition and shape.

Combining all locational requirements, a list of possible functions of joints was developed by the International Standards Organization and is the combination of Tables 8.7 and 8.8.

The principle concerns with joints in relation to modular construction lie within the physical constraints of the gap between adjacent components, normal to the plane of the building surface, and the geometrical relationship between the structural and architectural components. The functional attributes of a joint will identify the possible locations of that joint with respect to the building surface.

The joint becomes critical when dealing with prefabricated building components. Joints are an absorber of error associated with the manufacturing of a product and the construction of a building. It is, therefore, important for the designer of building components to thoroughly understand joinery and allowable tolerances. The following section will describe tolerance requirements in the building industry.

Tolerance Requirements

Tolerance, as it relates to the building industry, is the allowable degree of inaccuracy, by design, for the manufacture and installation of a building component, element, and/or the overall building system. Tolerance requirements are necessary because nothing can be manufactured and assembled with absolute precision. Until the development of modular building systems, "known" tolerances were not critical to the design of industrialized building products, since these tolerances could be absorbed by the material surrounding the component. Modular building systems, however, place industrialized components side by side, forcing the tolerances of the adjacent components to be absorbed by a joint between them.

Tolerance requirements for building elements are based on manufacturing inaccuracies, thermal expansion of materials, installation inaccuracies, and joint tolerances.

. Tolerances based on manufacturing inaccuracies are commonly termed size tolerances. These may be a function of machinery capabilities, or deviations inherent to the type of processing or the number and size of components necessary to form a building element.

. Tolerances required to allow thermal expansion and contraction are a function of the properties of materials, and components of those materials used. These tolerances must be used to design a component or element that will permit erection with the expansion joints almost fully open in cold weather and nearly closed in hot weather. Table 8.14 shows the comparison of coefficients of thermal expansion for four materials commonly used in the construction industry and the actual maximum expansion of these materials over 48", 60", 96" and 480".

Table 8.9

Material	Expansion Coefficient (inches/inch/°F)	Expansion @ 400°			
		48"	60"	96"	480"
Lucite/Lexan	0.0000390	0.75"	0.94"	1.50"	7.50
Aluminum	0.0000129	0.25"	0.31"	0.50"	2.50
Steel	0.0000630	1.21"	1.51"	2.42"	12.10
Float Glass	0.0000050	0.10"	0.12"	0.20"	0.96

- Installation tolerances are due to the squareness and plumbness inaccuracies associated with positioning a building component or element. A commonly accepted, rule of thumb, value for these dimensions is roughly 0.78 inches (20 mm) over the length of a room or a bay. The fallacies with this standard lie with its lack of regard for the component size and the variations in room and bay sizes. A more logical system for determining these tolerances is based on the size and common fastening procedures required by the specific components. Listed below are standard tolerances, based on this system, which are accepted by the commercial/industrial building industry.

Excavation	=	$\pm$ 0.2 feet
Concrete Foundations	=	$\pm$ 0.25 inches
Masonry Work	=	$\pm$ 0.06 inches
Windows < 6'-0"	=	$\pm$ 0.06 inches
Windows > 6'-0"	=	$\pm$ 0.125 inches
Door Hardware	=	$\pm$ 0.015 inches

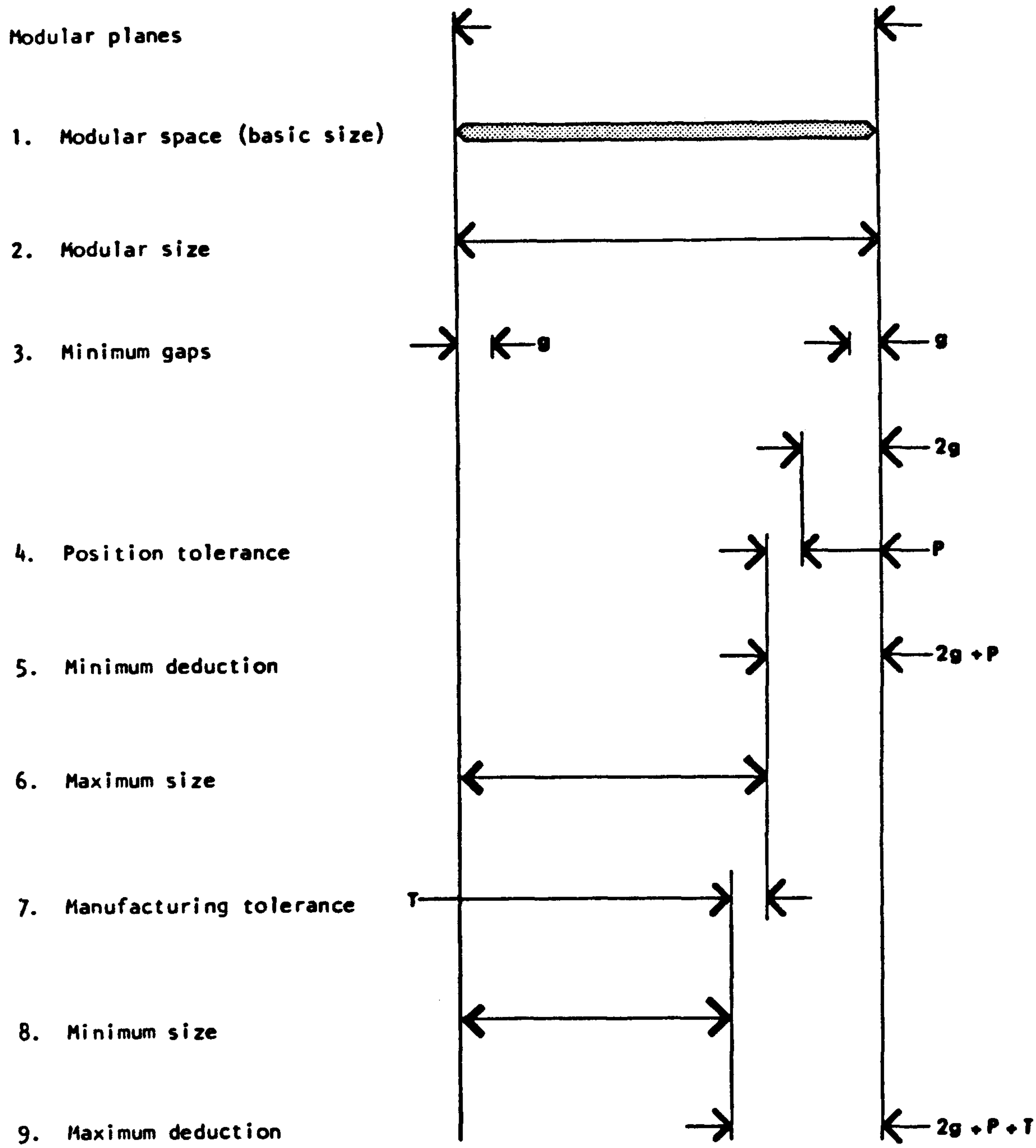
- The joint tolerance is entirely a function of the design of the framing system. The joint tolerance is also commonly referred to as the gap. The maximum and minimum gap widths are determined by the performance requirements of the joint. The width of the gap may vary from 0 to 30 mm but rarely exceeds 3 mm.[1]

[1] Joints in Buildings, Bruce Martin, George Godwin Limited, London, 1977.

The installation of glass photovoltaic modules into a panel or glass panels into an array may utilize procedures similar to the installation of a typical glazing system. It follows that the tolerance requirements for typical glazing systems may also be used for glass photovoltaic modules and/or panels.

Two categories for attaching glass panels to buildings are presently used. The first category employs factory applied channels to frame the glass. These channels act as an intermediate between the glass and the structural support. The second category merely requires a frameless glass module/panel to be attached at the site utilizing common glazing techniques. Each of the two categories would require a different set of tolerances for sizing a glass module, resulting in varying maximum and minimum size for their glass if both are designed to fit the same nominal dimension or modular plane. Figure 8.7 illustrates the process used to determine the overall system dimension.

The development of tolerance requirements is essential to determining the size of photovoltaic modules and panels. These tolerances are the primary modifiers necessary to determine the actual size of photovoltaic modules and panels from nominal dimensions. Required tolerances will vary in accordance with the manufacturing tolerance associated with the materials and processes used to assemble a panel, variations in thermal expansion between the photovoltaic panel and its support framing, installation inaccuracies, and the minimum gaps required by the particular framing system used.



APPLICATION OF THE SYSTEM OF TOLERANCES TO A MODULAR COMPONENT

Figure 8.7

8.6 PHOTOVOLTAIC MODULE AND PANEL SIZE AND SHAPE

Photovoltaic modules and panels and array mounting hardware cannot be designed independently. The dimensional and tolerance requirements must be considered simultaneously for the system is a unit. For example, a common glazing system may be used as a mounting system for a PV array with a requirement for 3/4" of bare glass on the PV module edges; but currently no such module exists, as the two have been designed independently. Again, the need to understand the industry which will be the end user of PV modules arises.

Based on the previous discussions, a module with 4' x 5' nominal dimensions provides the greatest flexibility in its ability to interface with standard building structural systems and dimensions. It is important to note these dimensions are nominal and not absolute; actual dimensions of the module will depend on the specific design of the mounting hardware, module to module interface and panel requirements.

A specific panel size is more difficult to define. As seen above, the maximum panel size is based on shipping and handling and is limited to 8' x 40' when using conventional trucking techniques. This provides the manufacturer with a wide range of possibilities - 4' x 5' to 8' x 40' panels. It will be shown in Section 11 that there is an optimum panel size based on installation costs. However, the architect would hope for a broader range of panel sizes or flexibility in the panel internal joints to give the illusion of smaller panels. This flexibility is necessary as size and scale of the building and its skin define the building aesthetic. In order to eliminate the need for the manufacturing of many different panel sizes, care must be taken in the proper design of the intra-panel joints.

SECTION 9
ECONOMIC CONSIDERATIONS

9.1 INTRODUCTION

The economic concerns in this section will be characterized by a qualitative approach as opposed to that of a more specific, quantitative methodology. An extensive economic analysis has been performed (Research Triangle Inc. - Application Analysis and Photovoltaic System Conceptual Design for Service/Commercial/Institutional and Industrial Sectors) in a previous study, with several generalizations resulting. Most important among these economic conclusions were:

1. Achievement of DOE array cost goals is necessary to make applications in the SCII sector viable.[1]
2. Increasing system efficiency to 15% or more would be very significant in increasing viability.
3. Economic viability is highly dependent on the rate of escalation of conventional electricity as compared to the general inflation rate.

It can be noted that economic viability in the commercial/industrial sector relies heavily on predicted, future technical performance and the accompanying cost reductions. Coupling these two potential accomplishments with a correct interpretation of the present economic indicators, an accurate economic feasibility study might be possible. Based on proprietor ownership (as opposed to utility ownership) the above mentioned study found that economic viability for a high school (SIC 82) may occur anytime from the year 1978 to 2010, depending on which combination of economic variables is chosen. It is not the intention of this study to attempt to verify or refute such a determination. Instead, relevant economic topics are presented and discussed such that a more complete understanding of their potential influence on the future economic viability of photovoltaic power generation in the commercial/industrial sector can be attained. Among these topics are: insurance; depreciation; tax deductions related to purchase, operation, maintenance; and utility rate structure. An actual quantitative comparison is presented in Section 11 where cost data relevant to material and labor installation costs are presented.

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[1] SCII: Service, Commercial, Institutional, and Industrial sectors which consumes approximately 2/3 of the electricity generated.

9.2 INSURANCE

The question of insurance for the potential commercial (and residential as well) photovoltaic user is still much unanswered. Essential to the development of premiums in the insurance world is precedence. With an extensive data base, statistical information is available such that undue risk is avoided in underwriting a policy. Such statistical resources likewise offer the insured a fair premium as defined by the inherent risks involved with the use of a photovoltaic power system. However, with the lack of information concerning actual in-field performance of such systems, the present state of affairs in the insurance world can most effectively be described as uncertain.

Of the various companies contacted with regard to solar photovoltaic systems insurance, only one was capable of addressing any of the concerns. The vast majority of insurance companies were unable to respond to related questions with any specifics whatsoever. For these companies, the word "solar" evoked a cautious apprehensiveness caused by the lack of certain established policies. To date, no established policy has been created such that underwriters are capable of referring to a written document in search of answers pertaining to the coverage of these systems. In general, the approach to policy writing is characterized by a "wait and see" attitude.

This attitude is appropriate in two senses. First, until these systems are installed, a lack of performance information will lead to a policy written as an endorsement to an existing policy. The cost of the system will be added to the worth of the existing property, and an appropriate premium established. Secondly, this "wait and see" attitude is appropriate not only for empirical data accrual, but for competitive policy trends as well. As mentioned previously, one company contacted has written a specific policy guideline with regard to an all-risk coverage for solar energy systems. It is this type of free-market precedence in the insurance world which will initiate established, written policies for solar system coverage. Thus, it appears that sufficient impetus is beginning to surface which will direct the insurance companies to a comprehensive system coverage.

A pioneer in the insurance field with regard to solar thermal system coverage is St. Paul Fire and Maine Insurance Company in St. Paul, Minnesota. The following is a series of questions and answers related to the policy as presented in a fact sheet supplied by St. Paul's regional underwriting manager for commercial property, Mr. Roger P. Carlson:

The St. Paul Solar Energy System Policy
Fact Sheet

What is the Solar Energy System Policy?

It is a broad, all-risk policy designed to insure against physical loss of or damage to the components of a commercially-employed solar energy system.

What is its basic coverage?

We'll cover the insured's solar energy system including but not limited to collector units or devices, conductor panels, heat transfer and exchange mechanisms, plumbing, piping, duct work, circulating medium, control and safety devices, and storage units.

What is excluded from coverage?

-- Loss or damage from wear and tear, gradual deterioration, extremes in temperature, and atmospheric or climatic conditions.

-- Loss or damage from discoloration, deterioration, or corrosion of solar absorption panels.

-- Loss or damage due to inherent vice.

-- Loss or damage due to any dishonest and/or illegal act on the part of the insured or any others to whom the property may be entrusted.

What is unique about the policy?

The St. Paul Solar Energy System Policy is a pioneer in its field. Designed specifically to cover solar installations, it picks up where more limited commercial property policies leave off and treats the solar energy system as a separate entity requiring specialized comprehensive coverage. The St. Paul Solar Energy Equipment Protection can be written either as a separate policy or as an endorsement to an existing policy. This approach permits The St. Paul to insure the solar energy system without having to insure the rest of the property as well.

What perils are covered?

-- Glass breakage

-- Water damage to the system

-- Leakage and/or overflow damage to the system

-- Mechanical breakdown

-- Collapse of the absorbing surface

-- Flood and earthquake

Does the policy apply to both passive and active systems?

Yes, and insurance protection is not restricted to new units planned for new construction projects. Coverage includes existing systems and newly installed systems in existing buildings.

Who qualifies for coverage?

Every commercial property which utilizes sun-generated power for its primary or supplementary heating/cooling system would quality.

Where is the policy available?

The policy is now being filed with state insurance departments. It will be available through independent agents representing The St. Paul in all states <u>except</u> Mississippi, Texas and Hawaii.

The following is additional information based on a phone conversation with Mr. Carlson:

> The above mentioned policy applies not only to solar-thermal systems but solar-electric systems as well; provided that the additional costs of the system are registered with the company. This policy holds for all standard buildings and content. It was emphasized that a common approach may be to write a coverage for the system with two exclusionary items: mechanical breakdown and electrical energy. The area of mechanical breakdown would refer to additional elements in the system which are extraneous to the collector or array. This might be analogous to that of a separate policy being written for a boiler/heating system in an insured building.
>
> In the case of electrical energy coverage, such an item as the battery storage might qualify. Because of the potential hazard associated with improper lead-acid battery venting, certain precautionary action would be needed before coverage could be established. Among these requirements might be a separate, totally enclosed battery storage room, coupled with an approved ventilation system. At this point in time, however, it was felt that the electrical energy generated by a photovoltaic array offers no greater danger than the electricity which is supplied by conventional generation techniques and means.
>
> Due to the lack of quantitative, statistical data on the performance of photovoltaic arrays, most of the information that St. Paul has thus far relied upon is available in trade journal publications and other sources which are readily available to the general public. The policy is written as a multiple-peril form, and some of the factors affecting the premiums are:
>
> 1. Building
> 2. Location
> 3. Occupancy
>
> Concerned with the Building Category are such items as fire exposure (nearest water supply, construction type, etc.), extended coverage (hail, snow load, and five other indigenous phenomena), and all-risk exposure (earthquake, flood, criminal activity, etc.). Mr. Carlson remarked that the NFPA's (National Fire Protection Association) National Fire Code supplies them with much of their information concerning codes and standards. Their policy regarding potential damage due to hail relies heavily on the slant angle designed for the collector. It is felt that an angle from the horizontal of more than 45° reduces the chance of hail related damage to essentially zero in any region of the country.

In summary, the St. Paul policy appears to be a pioneering effort in the area of insurance coverage. As the market develops, the need for insurance will concurrently increase, and in most likelihood, policy revision will be prevalent. The evolution of events surrounding market penetration will have significant effect on the ability of the potential user to locate reasonably priced insurance policies. As stressed previously, performance history will play a major role in establishing the underwriting of necessary insurance coverage. The development of standards for the use of photovoltaic arrays and the resulting code adoption and testing will help alleviate the chance of early failures in the field. This in turn will keep the insurance costs low, helping to reduce the life-cycle costs associated therein.

It should be noted that any insurance costs associated with photovoltaic systems in the commercial/industrial sector are a deductible business expense. This does not apply, however, to amounts periodically credited to a reserve for self-insurance equal to the estimated premiums that would have otherwise been paid to an insurance company.

9.3 TAX DEDUCTION*

There are certain tax deductions which may accompany the purchase and use of a photovoltaic system in commercial applications. The amount of the various tax deductions will depend on such factors as:

- Type of business (corporate or private)
- Location (municipality and state)
- Amount of annual profit (dictating tax bracket)
- Size of system (determining: annual power output, maintenance costs, operating costs)
- Interest attached to the borrowed capital (if any)
- Salvage value
- System useful life (obsolescence included)
- Method of determining depreciation (e.g., straight-line, declining balance, sum-of-the-years-digits, etc.)

*NOTE: Changes in the tax code will influence the consideration outlined in this section. The reader must review current tax laws. The Recovery Tax Act of 1981 is not addressed.

This is not a comprehensive listing; however, it should offer an idea of the complexity involved in determining an actual quantitative amount associated with tax deductions. Some of the more important deductions will be highlighted and discussed as they apply to solar photovoltaic systems.

I. SIZE OF SYSTEMS

A. Maintenance

The Internal Revenue Service differentiates between a "repair" and a "replacement" in the following manner:

Repair: Repairs do not add to the value or utility of the property, nor do they appreciably lengthen its life. They merely maintain the property in an ordinarily efficient operating condition over its estimated useful life for the purposes for which it was acquired. The cost of repairs, including labor, supplies, and certain other items, is a deductible expense.

Replacements: ...may not deduct the cost of a replacement that stops deterioration and appreciably lengthens the life of the property.

The following is a list of certain array failures which would require corrective action qualifying as a repair:

1. Disconnected leads
2. Mounting failure (collector building interface)
3. Internal shorting of cell (due to cracking)
4. Broken glazing
5. Collector failure which jeopardizes lifetime drastically (general)

Similarly, developments most likely to qualify as being of the replacement type:

1. U.V. Degradation of components
    a. Glazing
    b. Cell
    c. Pottant/bonding material
2. Environmental alteration of glazing
    a. Crazing
    b. Scratching

A photovoltaic array offers potential for discrepancy in categorizing certain procedures as either repair or replacement, as defined by the IRS. For example, if a module in a series or parallel string has been adversely affected by what would be considered "normal conditions", then according to the above definitions, a compensating action might be considered as a replacement, and thus, not a deductible expense. However, this affected module might appreciably alter the array output; and without proper corrective action, the collector is not maintained "in an ordinary, efficient operating condition". Thus, the action should be classified as a repair and a deductible expense. This type of problem will most easily be handled by those trained in such areas of taxation.

B. Operating Costs

The Internal Revenue Service states:

> "Heat, light and power are ordinary and necessary expenses common to almost all businesses. You may deduct the full amount of these expenses if paid or incurred in carrying on your trade or business."

Because the photovoltaic system produces electricity, the displacement of this ordinarily induced expense results in a lower tax deduction for the user. This may adversely affect the life-cycle cost of the system.

II. LOCATION OF SYSTEM

The location of the photovoltaic application is quite important in determining the magnitude of the following deductions.

A. Property Tax

Ordinarily, you may deduct all taxes imposed on real property. Thus, the higher assessment and resulting increase in property tax that a particular structure and/or property (utilizing a photovoltaic power system) would experience can be considered as a deduction, thus helping to retrieve a portion of the additional capital outlay. The size of this deduction would depend on: initial cost of system, assessed value of property with the system as opposed to without the system, rate of taxation (usually in dollars per thousand dollars assessed value), and the tax bracket of the owner. This is an annually reoccurring cost.

B. Sales Tax

Sales tax imposed on sales of property or services at retail and measured gross sales price or gross receipts may be deductible. The magnitude of this sales tax is based on the state and/or municipality for which the sales tax is imposed. In the United States, this sales tax could range anywhere from zero to eight percent. Considering the high initial cost of photovoltaic systems, this range of taxation could have some impact on the first year's cash flow determination. This initial tax-related cost and the resulting deduction should not play a major role in the life-cycle cost analysis or any other technique used in determining economic viability. The amount of the tax deduction due to the sales tax will depend on: cost of system, rate of taxation (if any), and the tax bracket of the owner.

It appears that in these above-mentioned economic factors lie a great potential for state and local government to assist in the establishment of photovoltaic power systems in the commercial/ industrial sectors. The potentially high initial investment associated with systems of the size required in this sector could lead to substantial increases in property value assessment and, therefore, high property and sales taxes. Tax breaks in these two areas would help improve the economic attractiveness associated with photovoltaic systems. Care must be taken, however, in the use of the federal, state, or local programs that subsidize financing, as Section 203 of the Crude Oil Windfall Profits Tax Act of 1980 prohibits so-called "double benefits". Reduction or elimination of the Federal 40 percent tax credit will occur if such subsidized financing is utilized for some renewable energy source expenditures. A closer examination is required when such a situation exists.

9.4 UTILITY RATE STRUCTURE

In any analysis concerning the economic feasibility of photovoltaic systems, a most crucial variable is the cost of conventionally generated power. This variable is highly dependent on the location of concern. Recent data substantiates this [U.S. DOE Electric Power Monthly, July 1980, DOE/EIA-0226 (80/07)]:

Geographic Variation of Rate: (Data for July, 1980)

Commercial Sector 40 KW (representative amount of consumption)
10,000 KWH

City	Rate [$/KWH]
Seattle, Washington	0.0163
New York City	0.1164

Out of a sample of 26 cities: MEAN = 0.064 $/KWH
Sample Standard Deviation = 0.0195 $/KWH

Industrial Sector 50 KW (representative amount of consumption)
200,000 KWH

City	Rate [$/KWH]
Seattle, Washington	0.008
New York City	0.0916

Out of a sample of 26 cities: MEAN = 0.0466 $/KWH
Sample Standard Deviation = 0.016 $/KWH

As can be seen, the amount of variation between locations can be significant. Typically, New York City will represent an upper limit on rates, and Seattle, with its abundant hydro sources, will represent a lower limit. To use a mean rate for the particular sector (commercial or industrial) would most likely result in either an overestimation or an underestimation of system viability based on the representative standard deviations. Approximately 68% of the sample in the commercial sector has rates ranging from 0.045 to 0.084 dollars per kilowatt-hour; and likewise in the industrial sector, the rates range from 0.031 to 0.063 $/KWH. This exhibits the need for specific data in determining system economies.

This oversimplified presentation, however, overlooks many other critical factors. One of these factors is the rate structure. The structure by which costs are determined varies significantly with the utility company and, therefore, the location. The implementation of a peak loading rate is peculiar to location, and depending on such items as load profile and electrical storage, economic viability of photovoltaic systems may differ considerably among regions with the same "average" cost per kilowatt-hour as given in the above figures.

The following illustrates the complexities involved in determining the worth of displaced utility company power when performing a life-cycle cost analysis of a photovoltaic system in the commercial/industrial sector. This information was supplied by the Boston Edison Utility Company and is for illustrative purposes only.

The rate structure for the commercial/industrial sector is primarily a function of demand. Boston Edison has established three categories:

<u>Classification G-1</u>:	Monthly demand is less than 20 KW
<u>Classification G-2</u>:	Service voltage is less than 5000 volts and monthly demand is greater than 20 KW
<u>Classification G-3</u>:	14,000 volts nominal and customer furnishes, installs, owns, and maintains at his own expense all the protective devices, transformers, and other equipment required by the company

The rates experienced by the above users are determined from:

- Demand charge (KW or .80 KVA from G-2 and G-3)
- Energy charge (KWH)
- Additional energy charge (1.40 cents/KWH for direct current energy in the G-1 and G-2 classifications)
- Fuel and purchased power adjustment (applicable to all KWH)

The demand charge for the user who is classified as G-2 is determined monthly over a 15 minute interval, while it's determined over a 30 minute interval if a G-3. Furthermore, this <u>demand charge</u> is a function of:

- Utility rate classification (G-1, G-2, or G-3)
- Time of the year
- Day of the week
- Time of day
- Amount of demand (a decreasing charge with increased demand after an initial fixed cost per classification)

<u>The energy charge is a function of</u>:

- Utility rate classification
- Amount of energy (decreasing charge with increased usage)
- Time of year

It should be noted that an additional energy cost of 1.4 cents/KWS is levied in the G-1 and G-2 classes for purchase of direct current energy. This makes the displacement of direct current energy with photovoltaic systems that much more economically attractive. In the G-2 class there is also a 2% "primary credit" allowed to those users of only alternating current. Therefore, if a G-2 classified user can displace his DC requirement with a photovoltaic system, an inflated energy usage rate can be alleviated, as well as a 2% reduction on the total electrical bill.

The point should be made from these rate structure guidelines that the factors involved in determining photovoltaic life-cycle cost in the commercial/industrial sector are many and varied. An accurate determination of such a cost relies on the appropriate, site-specific, utility rate structure. It is the existence of this type of complexity which incurs substantial difficulties for the optimum system sizing for a particular application in this sector. Though other limiting factors may eventually govern this decision (e.g., limited capital to invest), any determination of life-cycle cost rests heavily on the above-mentioned service rate parameters.

Furthermore, it should be realized that these rates are not static, but dynamic, time-dependent variables susceptible to the economic forces which act on them. These forces differ in make-up and magnitude depending not only on time, but place. The percent change in cost associated with electrical rates for 3 United States cities from July 1979 to July 1980 illustrates this dependence[1].

Commercial (40 KW; 10,000 KWH)

City	Percent Change
Long Beach, California	54.9%
Louisville, Kentucky	- 2.4%

MEAN: 19.05%

Sample Standard Deviation: 13.27%

[1] U.S. DOE Electric Power Monthly, July 1980, DOE/EIA-0226 (80-07)

Industrial (500 KW; 200,000 KWH)

City	Percent Change
Long Beach, California	67.1%
Cleveland, Ohio	- 0.5%

MEAN: 25.97%

Sample Standard Deviation: 18.53%

The wide spectrum of annual percentage change represented by the maximums and minimums in these two sectors suggests a large nonuniformity in rate changes. This nonuniformity is further substantiated by the relatively large standard deviations accompanying these two sets of data. Predicted escalation rates, as supplied by the Department of Energy, supports this trend. The following information gives the yearly range for the associated escalation prediction and the region for which it applies.

DOE PREDICTED ESCALATION RATES FOR ELECTRICITY

Commercial	Period	Percent Increase*	Region
	1980 - 1984	5.4%	6 (max.)
		-0.67%	3 (min.)
	1985 - 1989	1.42%	10 (max.)
		-1.28%	1 (min.)
	1990 - 1995+	1.09%	10 (max.)
		-0.79%	9 (min.)

Industrial	Period	Percent Increase*	Region
	1980 - 1984	8.94%	6 (max.)
		0.63%	7 (min.)
	1985 - 1989	2.66%	10 (max.)
		-1.74%	8 (min.)
	1990 - 1995+	1.89%	10 (max.)
		-1.21%	2 (min.)

*NOTE: % increases are in addition to present rate of inflation

First, it should be mentioned that the data set is characterized by ten regions, and that only the maximum and minimums associated with the predicted escalation rates are shown. An important factor is not where these represented regions lie, but rather that they do not show any trends in relation to escalation rates. Only region 10 appears twice in both the commercial and industrial sectors. This data implies further that regional influences will play a significant role in determining system economics.

Based on these three factors (rate, rate structure, and escalation rate), it becomes apparent that specific site/system/load analysis is needed before economic viability can be accurately determined. An illustrated 67.1% annual increase in rates could reverse an expected unattractive rate of return of an earlier economic analysis of a photovoltaic system that was based on a lower, predicted escalation rate. If the analysis is based on a high, predicted escalation rate, a low or negative annual percent change could accordingly construct a scenario of reverse consequences. Though these factors are widely known as being important economic consideration, it must be stressed that because the displacement energy with photovoltaics is of a single type (electricity) and is highly micro-geographically dependent, then site and design specific details are essential to an accurate cost analysis.

9.5 DEPRECIATION

Depreciation is a tax deduction allowed by the IRS for an asset's exhaustion, wear and tear, and obsolescence. The property to be depreciated must have a useful life of more than one year and "be used in your trade or business or held for the production of income" (IRS Tax Guide for Small Business). It is also required that the asset not be depreciated below a reasonable salvage value under any method. The subject of depreciation of an asset is a well-established one in the area of taxation. However, it does involve concepts whose values are not easily determined prior to implementation, e.g. obsolescence and salvage value. This is especially true with new technologies for which there is an insufficient amount of empirical data with relation to long-term exposure of actual load conditions.

Obsolescence is a concept which considers the extent to which the expected useful life of the property will be shortened by technological improvements, progress in the arts, reasonably foreseeable economic changes, shifting of business centers, prohibitory laws, and other causes apart from wear and tear that diminish the value of the property or shorten its useful life. Determination of the useful life is considered to be the first step in computing depreciation. The IRS says, "No useful life for an item is applicable in all businesses. The useful life of any item depends upon such things as the frequency with which you use it; its age when you acquired it; your policy as to repairs, renewals and replacements; the climate in which it's used; the normal progress of the art, economic changes, inventions, and other developments within the industry and your trade or business."

In well-established technologies the determination of useful life is made easier and with more accuracy by the use of statistical data gathered on actual performance history. Such graphic tools as survivor curves and retirement-frequency curves allow for the accurate prediction of the asset's "service life."[1] A series of such statistical analyses over a period of years would illustrate trends as to the lengthening or shortening of the "service lives".

These curves will be useful in the area of photovoltaics as they will reflect retirements for all causes, not just deterioration. In the initial years due to the lack of such retirement data for photovoltaic systems, the useful lives must be determined by other less specific criteria. It should be noted that "useful life" and "service life" are not the same, and that "useful life" as used in depreciation accounting is usually shorter than average "service life".

It is said by the IRS that the useful life should be determined "on the basis of your particular operating conditions and experience." Additionally, <u>for cases where there is an inadequacy of experience</u>, "you

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[1] Service life reflects the expected life of a specific component.

may use the general experience in the industry until your own experience forms an adequate basis for making the determination." Therefore, it appears that the initial photovoltaic systems will be given a useful life as seen by the manufacturers of the equipment throughout the industry. A clear knowledge of the particular components used, and their performance in the environment in which they are placed (based on past, analogous exposure situations and accelerated testing) should give a good indication of system life-time. This type of useful life prediction will have to be sufficient until the systems have undergone actual exposure. However, a change in useful life during service is permitted, but only if "change is significant, and there is a clear and convincing basis for re-determination." This clause could play a significant role for early users of photovoltaic systems where actual life-times, due solely to the dearth of long-range performance data, have not been determined.

Due to the nature of photovoltaic systems, the most costly element (the array) is exposed to the natural environment. The deterioration of the array itself will depend entirely on the severity of the conditions to which it is exposed in its natural surroundings (excluding the quality of the array's components). Some of the factors affecting the type and rate of deterioration are:

1. Amount of insolation striking the array
2. Amount of precipitate (and type, e.g., snow, rain, hail)
3. Frequency, magnitude, and relative direction of wind
4. Mounting orientation of array (vertical, horizontal, etc.)
5. Air pollution, including airborne pollutants, e.g. sand
6. Vibrational stresses due to activity in close proximity to array

Thus, it can be seen that the actual useful lifetime of the system (and the array specifically) depends highly on location. Even with careful design, it may not be possible or practical to consider a single accepted useful life for systems installed randomly throughout the country. As information is gained and designers make the appropriate modifications, it may be possible for arrays throughout the country to approach a uniform average life; however, until then geographic considerations should play a part in determining useful life. Another factor used in depreciating accounting is salvage value, which is defined as, "the amount that you estimate will be realized upon sale or other disposition of an asset when it is no longer useful in your business or in the production of your income and is to be retired from service." If the asset is used for the full inherent useful life, then the salvage value may be zero. However, if the asset is retired while in relatively good working condition, the salvage value may be considerable. It is most likely that a photovoltaic system would be purchased with intent to use the system continuously from the time of purchase until degradation of output and/or increase in operation and maintenance costs makes further use uneconomical. The relatively high installation costs associated with replacement would probably deter an early retirement of the system. The IRS does offer some assistance in the area of salvage value by allowing a reduction in the salvage value by any amount up to 10% of the full adjusted basis of the property when acquired. Photovoltaic systems would meet the greater than three year useful life requirement as stipulated by this clause.

The subject of depreciation is an important concern in the establishment of economic viability for photovoltaic systems. This is due in part to the capital intensiveness associated with systems of the size required in the commercial sector. Most importantly, however, is the effect that depreciation has on economic attractiveness in periods of high inflation. It can be safely assumed that revenues associated with the use of photovoltaic systems (the cost of displaced, conventionally generated electricity) will remain responsive to inflation in the immediate future. Depreciation deductions, however, are not responsive to inflationary trends, as they are based on the original value of the system; as inflation increases, investment decisions become less attractive because depreciation is not fully recovered in real or constant money dollars.

This is due to the fact that taxes are paid on a current money value basis. With a fixed deduction over the useful life of the system and an inflationary response of revenue, an overstatement of taxable income occurs; and after the remaining "profit" is deflated back to the time of the asset's purchase, the amount left is less than what the current money income would show.

To counter this disadvantageous situation, the IRS needs to allow for rapid depreciation methods. This would improve the chance of getting more of the capital investment returned in money of purchasing power similar to that used to obtain the asset in order to reinvest it and keep pace with inflation. There is presently an additional first-year depreciation in which 20% of the cost up to $10,000 may be deductible, or $2,000 maximum. The property qualifying for this deduction must have a useful life of at least 6 years. This additional depreciation allowance coupled with the use of a rapid method of depreciation (e.g., the double declining balance, which is twice the straight line rate) would retrieve this investment early in the life of the system and thus helping to combat this problem of depreciation and inflation.

The potential for accelerated technical and economic obsolescence with photovoltaic systems in the next decade is high. This fear in most likelihood will act as a major deterrent to the potential user who sees himself/herself not only as a pioneer, but a guinea pig as well. Unless specific economic advantage can be pointed out initially, this accelerated obsolescence potential will most certainly retard initial field installations. This situation is somewhat analogous to the rapidly progressing technical trends exhibited by the electronics industry; specifically calculators, micro-processors, and computers. The precipitous fall in price accompanied by an improvement in quality does not lend itself to an early investment decision. This apparent problem will be augmented by the relatively high capital expenditure required for such systems. Some form of government assistance is necessary in the early marketing thrust, as the rate of development will depend heavily on the performance of installed systems.

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SECTION 10

BUILDING OCCUPANCIES

10.1 INTRODUCTION

Buildings addressed within building codes are broken down according to categories of use. Building codes refer to a number of separate use groups which have different safety requirements. These classifications are:

BOCA BASIC BUILDING CODE 1981 EDITION

SECTION 301.1 USE GROUP CLASSIFICATION AND GENERAL:

ALL BUILDINGS AND STRUCTURES SHALL BE CLASSIFIED WITH RESPECT TO USE IN ONE OF THE USE GROUPS LISTED BELOW.

1. USE GROUP A ASSEMBLY
2. USE GROUP B BUSINESS
3. USE GROUP F FACTORY AND INDUSTRIAL
4. USE GROUP H HIGH HAZARD
5. USE GROUP I INSTITUTIONAL
6. USE GROUP M MERCANTILE
7. USE GROUP R RESIDENTIAL
8. USE GROUP S STORAGE
9. USE GROUP T TEMPORARY AND MISCELLANEOUS

Figure 10.1 expounds upon these Use Group classifications, giving typical examples of each and correlating each Use Group classification to the nomenclature of both the ICBO Uniform Building Code and the SBCC Standard Building Code.

When analyzing a Use Group for potential PV utilization, dozens of concerns must be considered. In previous studies concerns have centered on economic and electrical considerations only. Through the review of those concerns, which must be considered as crucial design criteria for the PV array design professional, top prospects for early utilization of photovoltaic modules and arrays have been identified.

A review of Use Groups based on economic and electrical-usage-compatibility considerations has been conducted by the Research Triangle Institute (RTI) for the United States Department of Energy under the supervision of Sandia Laboratories under Contract Number 07-6936.

Building Officials Conference of America, Inc. Code Based Classification Nomenclature	BOCA Code Classification Title	Typical Examples:	Uniform Building Code Alternate Classification Designation	Standard Building Code Alternate Classification Designation
A1A	Assembly	Raised stage proscenium, loft, lights and fixed seating. Theatrical and operatic production.	A 1 A 2	A
A1B	Assembly	Fixed seating without stage. Motion picture performance.	A 2.1	A
A2	Assembly	Public assembly without stage or fixed seating. Night clubs and dance halls.	A	A
A3	Assembly	Public assembly without stage or fixed seating. Educational, art, incidental movie or dramatic presentation, libraries, museums and restaurants over 100 persons.	A	A
A4 *	Assembly	Religious and educational. Churches, elementary and <u>SECONDARY SCHOOLS</u>, colleges, academies and universities.	E 1 E 2 E 3	E A church
B *	Business	Offices, <u>REAL ESTATE OFFICES</u>, banks, civic administration, service stations, testing and research labs, greenhouses, radio stations and telephone exchanges.	B 2	B
F *	Factory / Industrial	<u>MACHINERY MANUFACTURE</u>, mills, processing plants, power production, bakeries, breweries, canneries, tanneries, electrolytic reducers, sugar refiners, refrigeration, ice production, textile mills, upholsterers, and woodworking mills.	B 2 B 4	F
H	High Hazard	Artificial flower, acetylene gas, ammunition, celluloid, cotton, matches, kerosene and bulk paint producers, spray paint shops, sodium nitrate users, flammable solvent drycleaning and grain elevators.	H	H
I 1	Institutional / Restrained	Jails, insane asylums, prisons, reformatories and houses of correction.	I 3	I restraine
I 2 *	Institutional / Incapacitated	<u>DENTIL CLINICS</u>, day nurseries, hospitals, sanitariums, clinics, infirmaries, orphanages, homes for the aged, fire houses and police stations.	I 1 I 2	I
M *	Mercantile	Retail stores, <u>SHOPPING CENTER</u>, shops, salesrooms and markets.	B 2	M
R 1	Residential / Non-Housekeeping	Hotel, boarding house, lodging houses, motels, dormitories, convents and monasteries.	R 1	R
S 1	Storage / Moderate Fire Hazard	Public garages, burlap, baskets, books, cardboard, clothing, furniture, furs, glue, leather, linoleum, livestock, petroleum warehouse, photo engraving, silk, sugar, tobacco, upholstery and wax candles.	B 3	S
S 2	Storage / Low Fire Hazard	Aesbestos, chalk, crayons, food products, glass, ivory, metals, pottery, talc and soapstone.	B 4	S
T	Temporary / Miscellaneous	Private garages, sheds and fences.	M	none
	*	Examples to be expounded upon are listed in CAPITALS.		

Figure 10.1

The RTI study analyzes the potential for photovoltaic utilization as a function of Standard Industrial Classification (SIC) categories. These SIC categories are themselves use groups just as are the Occupancy Use Groups found in building codes. However, each building code Occupancy Use Group can be broken down into many SIC categories. Analyzing USE Group F-Factory/Industrial, outlined in Figure 10.1 as described in the 1981 Edition of the BOCA BASIC BUILDING CODE, it can be seen that specific examples of uses falling under this occupancy type are machinery manufacturing, mills, processing plants, power production, bakeries, breweries, canneries, tanneries, electrolytic reducers, sugar refiners, refrigeration, ice production, textile mills, upholsterers and wood working mills. This list produced by the code administration is not intended to be complete but only to give an idea of the types of uses falling under such a category. Upon review of the RTI Study, the prime candidates for early PV use, based on electric load matching, will not include all of the SIC categories which fall under Use Group F-Factory/Industrial, as an example. However, if a photovoltaic module is designed to be utilized on any one of these buildings, it can be used on all of the above mentioned occupancies. Therefore, by identifying the early users of PV by SIC categories and by subsequently identifying the code Use Group classification under which the PV user's application falls, many other specific SIC categories are addressed.

Standard Industrial Classifications (SIC) were established as a tool for statistical comparison by the U.S. government. The Economy is broken into divisions - Agriculture, Mining, Construction, Manufacturing, Transportation, Wholesale Trade, Retail Trade, Finance, Services and Public Administration. For a comparison with the above outlined Use Group F-Factory/ Industrial, the comparable SIC division is manufacturing - Division D. Major Division D-Manufacturing encompasses codes 20-39, or twenty different coded subsections. For instance, Group 20 is Food and kindred products, Group 33 is the primary metals industry and Group 35 is machinery other than electrical. Although these have been addressed as separate entities by the RTI study, they, along with the other seventeen coded subsections are lumped together in the eyes of the code official.

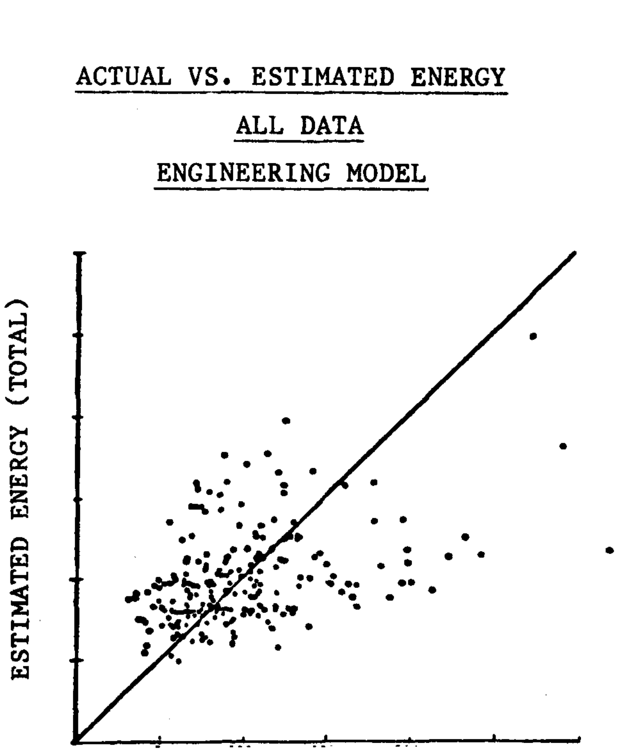
Any code requirements which apply to primary metals industry factories also apply to food processing plants as well as to all of the other industries which fall under this USE Group. Figure 6.10 depicts construction type as a function of occupancy, building area and building height. Construction type for a primary metal manufacturers factory is the same as for a machinery manufacturer with the same building area. Similarly, the fire resistance rating for that particular construction type will be the same for the same building area and height for a food processing plant and a machinery manufacturing plant as depicted in Figure 6.7. Therefore, so far as building codes are concerned, the same requirements imposed upon a PV array on the food processing plant (SIC 20) will be imposed upon the primary metals production facility (SIC 33) and the machinery manufacturing plant (SIC 35). Therefore, from a code standpoint, the specific application type is not important. What is critical is addressing the code Use Group when designing a PV module, thus providing a product which can find use in many of the SIC categories, i.e. all of those which fall under the code Use Group addressed.

The RTI study selects five SIC categories: SIC 80, a dental clinic; SIC 58, a fast food restaurant; SIC 35, a machinery manufacturing plant; SIC 53, a shopping center and SIC 82, a high school. These are derived on the basis of national statistics for each SIC category. However, as is pointed out in a study of energy use characteristics for commercial buildings (Presentation of Data of Energy Use Characteristics of Commercial Buildings for Passive Commercial Building Program Performance Evaluation Meeting, San Francisco, California, December 1980, BHKRA Associates), specific building projects <u>must</u> be evaluated on an individual basis for photovoltaic potential. See Figure 10.2 on Page 10-5.

ACTUAL VS. ESTIMATED ENERGY

ALL DATA

ENGINEERING MODEL



ACTUAL ENERGY (TOTAL)
(MBTU/SF/YR)

Figure 10.2

As Figure 10.2 shows, even when analytic estimates are compared to actual energy utilization, the correlation is poor.

The five selections made within the RTI study fall within several different Use Group occupancies (as is illustrated by asterisked items in Figure 10.1). The study of building codes in Section 6, however, illustrates that certain items (see, for example, Fire Resistance Rated Assembly and Interior Surface Finish) are restricted as a function of Occupancy Use Groups.

Rather than specific occupancies standing out as being of great potential concern for PV module and array designer, certain occupancies stand out as being of relatively low potential for PV modules and arrays because of restrictions on materials and assemblies. Among these are: Institutional (incapacitated and restrained), hotels, hazardous, and assembly Use Groups. When consideration is given to the increased concern of code officials and design professionals for the safety and welfare of the occupants of these groups, it seems unwise to depend upon these categories for extensive market potential.

It should be noted that the five selections made in the RTI study do not take into account the many critical institutional issues which are highlighted in this report. Because of an increased potential for vandalism, maintenance and/or financial considerations (to name a few), specific types of occupancies may be inappropriate for early PV array applications. Fast food restaurants may be eliminated, and have been for this study, from early consideration for institutional reasons. A relatively high propensity for vandalism, grease from exhaust and typically high land cost may eliminate most fast food applications.

If consideration is given to similar SIC classifications being combined into use group occupancies as outlined in Figure 10.1, a replacement for fast food restaurants may be selected. Based upon the broad variety of SIC codes which would qualify as examples of Business Occupancies (as found in Figure 10.1), office buildings as a generic type must be considered as an alternate choice to that of fast food restaurants as an application with high potential for PV utilization.

By choosing the business office and adding it to the remaining RTI choices, the following SIC categories are addressed:

- Secondary Schools
- Real Estate Offices
- Machinery Manufacturing
- Dental Clinics
- Shopping Center

This provides the greatest flexibility as each of these fall under different code classification groups, i.e.:

. Assembly	A4
. Business	B
. Factory/Industrial	F
. Institutional/Incapacitated	I2
. Mercantile	M

The code issues addressed previously, therefore, consider the requirements for the above classifications for the broadest possible range of design requirements.

SECTION 11

INSTALLATION COST ANALYSIS

11.1 INTRODUCTION

The objective of this section is to estimate the labor and material costs for photovoltaic panels installed within the commercial/industrial sector of the building industry. The approach was to identify several mounting details currently used in the building industry for exterior cladding, then to modify those details so as to accommodate photovoltaic panels. The material costs for these modified details were developed from cost estimates for similar materials and material processing. Labor costs required further definition in order to integrate equipment and labor. The common denominator between equipment rental and labor is time. All estimated labor costs were therefore reduced to the hours required to perform each task, then multiplied by the cost per hour for the crew and equipment required to complete the task.

Material and labor costs provided in this Section are detail specific. It is important to note if details are changed, costs will change. The base labor rates will apply to other details if crew types are not changed. The per hour labor rates for each individual can be applied for individual crew requirements if details are changed.

11.2 ARRAY COSTING

As mentioned in Section 8, the commercial construction industry employs a wide variety of construction techniques, materials and equipment. Construction costs will rise and fall in accordance with the complexity of the task required, the familiarity of the labor force with that task, the structural, mechanical and electrical efficiency of the building components, and the size, shape and number of components installed. Trends indicate a shift to the utilization of factory labor and processes for labor intensive tasks in order to automate the fabrication of building components, thus reducing the field labor required to erect the building. The increased use of factory labor tends to limit the versatility of size of building components creating an increasing need for the standardization of the size of building components. Otherwise, filler panels and substructure required to install components that do not integrate dimensionally with the rest of the building will increase costs. It follows that photovoltaic panels must interface with typical construction industry materials and dimensions and must be fabricated and erected with an optimal mix of factory and field labor. The ability to interface with typical construction material increases proportionately with a decrease of panel size. Unfortunately, the cost of factory and field labor tends to increase as the panel size decreases.

The size of photovoltaic modules does not affect the labor cost for installation panels but will affect panel material, fabrication, and electrical wiring/termination costs as well as the total installed array cost. It is assumed that finished panels are received at the job site; thus no additional installation materials or labor costs are incurred. If the module size changes, internal to the panel, panel installation costs will not change. Modules do, however, require the panel size to be some multiple of the module. The maximum size of photovoltaic panels as determined in Section 8 was primarily restricted to 40 feet x 8 feet, the maximum size transportable by a common carrier. Therefore, maximum panel size used for the costing analysis was also limited to this dimension. As a result of a detailed study of module and panel size and shape, as discussed in Section 8, a module with nominal dimensions of 4' x 5' yields the greatest amount of flexibility in its ability to interface with structural systems used in commercial/industrial buildings. Figure 11.1 illustrates the flexibility this module provides in the form of the possible panel sizes.

Having established a standard 4' x 5' module size, it is now appropriate to develop assumptions for the four established mounting locations with respect to a building in order to fully analyze the effects that each will have on the installed system cost. The following assumptions have been made:

1. Rack Mount (ground or roof support)

- Suitable site characteristics and soil conditions to accept ground mounted PV array configuration.
- Above ground lifting to be accomplished by tower crane.
- Arrays must comply with local zoning laws with regard to height, property line setback and obstruction of views or visual access from adjacent buildings.
- 14,400 $ft.^2$ array was costed utilizing rack of 8' x 120' or 16' x 120'.

2. Standoff Mount

- Above ground lifting to be accomplished by tower crane.
- Panels must be easily handled by one or two men and one crane.
- Panel must present favorable aspect ratio for convenient inclusion in a 14,400 $ft.^2$ array.
- Approaches closely the considerations of a roof support, rack mounted array.

3. Direct Mount

- Panels must be easily handled by one or two men and one crane.
- No limitation of size to total area as a function of flammability of PV panel materials as stipulated by building code(s).
- Panel must present favorable aspect ratio for efficient inclusion in a 14,400 $ft.^2$ array.
- Mildew and rot under panel may be a problem. Panels can be directly fastened and flashed to the roof deck.

4. Integral Mount

- Panels will be mounted on purlins spaced on 5'-0" centers.
- Waterproofing of array will be a major factor.
- Panels must be easily handled by one or two men and one crane.
- Panels which for 14,400 $ft.^2$ array were investigated.

Using these asumptions and the above generated discussion on the standard module size, considerations can now be given to the individual mounting techniques.

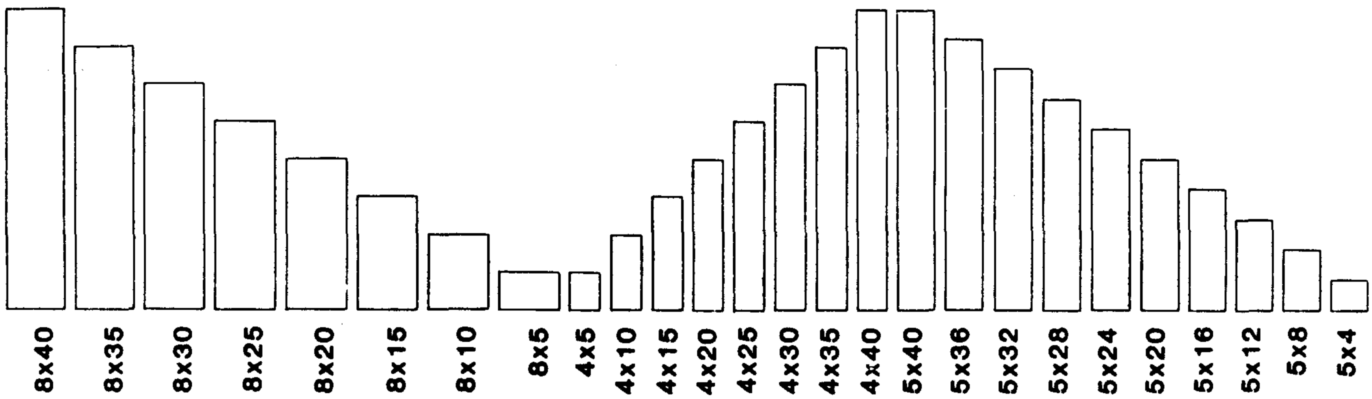


Figure 11.1

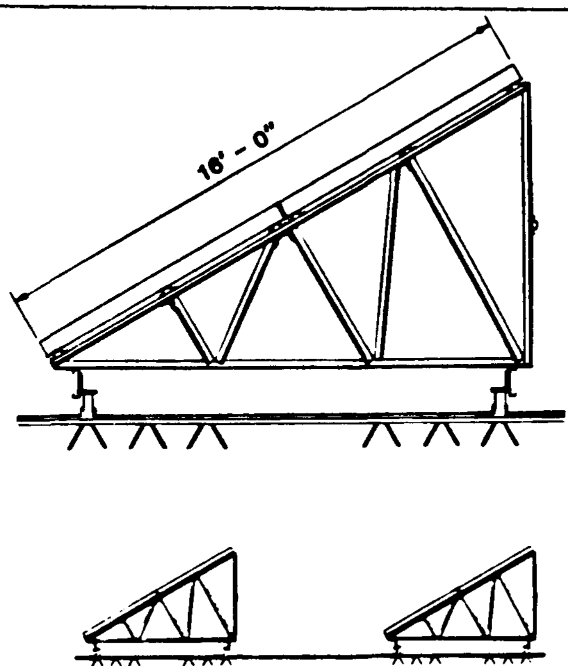
Rack Mount

Commercial framing materials most closely associated with the mounting of photovoltaic panels on a rack are those used for Mansard roof used to screen mechanical equipment. Various manufacturers have developed complete systems for this purpose. For the most part, the framing systems are built of factory-made trusses of galvanized steel rolled sections. The frames have been strictly designed for structural performance and optimal economy of material. The years of research that have gone into the development of these frames have led to a frame that is the most economical structure available for rack mounting photovoltaic panels. Therefore, the cost analysis is based on the cost of these frames. The particular standard frames used were slightly modified for panel sizes ranging from 4' x 5' to 8' x 40'. The rack sizes costed were 8' x 120' and 16' x 120' (see figures on Table 11.1). The erection procedure is as follows:

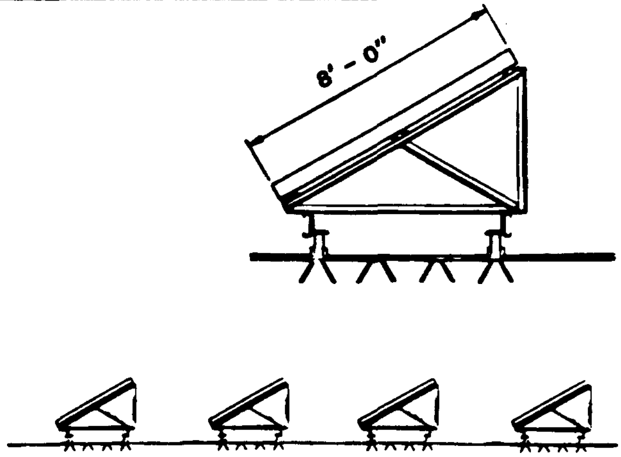
- Space and weld pipe supports to metal roof joists.
- Bolt steel C-Channels to pipe supports.
- Raise premanufactured trusses to the roof and screw in place.
- Screw purlins to trusses.
- Raise photovoltaic panels to the roof and screw in place.

Table 11.1

STEEL RACK LABOR AND MATERIAL COST



MOUNTING LOCATION MATERIAL SECTION	QUANTITY	MATERIAL RATE	MATERIAL COST	LABOR RATE	LABOR COST	TOTAL COST
Roof Mount (120' x 16')						
Pipe Column Welded	22 pcs.	4.45 ea.	$ 97.90	$1.75 ea.	$ 38.52	$ 136.42
2x10 14 ga. C Channel	240 lin. ft.	$2.05/lin. ft.	492.00	$0.41/lin. ft.	98.40	590.40
Hat Section (Truss)	31	$15.18 ea.	470.58	$17.61 ea.	547.77	1,018.35
Hat Section (Purling)	840 lin. ft.	$0.19/lin. ft.	159.60	$0.27/lin. ft.	226.80	386.40
Pipe Flashing	22 pcs.	$8.40 ea.	184.80	$1.10 ea.	24.20	209.00
Total			$1,404.88		$935.69	$2,340.57



MOUNTING LOCATION MATERIAL SECTION	QUANTITY	MATERIAL RATE	MATERIAL COST	LABOR RATE	LABOR COST	TOTAL COST
Roof Mount (120' x 8')						
Pipe Column Welded	22 pcs.	$4.45 ea.	$ 97.90	$1.75 ea.	$ 38.52	$ 136.42
2x8 14 ga. C Channel	240 lin. ft.	$1.78/lin. ft.	427.20	$0.36/lin. ft.	86.40	513.60
Hat Section (Truss)	31	$5.12 ea.	158.72	$8.94 ea.	268.20	426.92
Hat Section (Purling)	360 lin. ft.	$0.19/lin. ft.	68.40	$0.27/lin. ft.	97.20	165.60
Pipe Flashing	22 pcs.	$8.40 ea.	184.80	$1.10 ea.	24.20	209.00
Total			$ 937.02		$514.52	$1,451.54

Table 11.2

RACK MOUNT COST SUMMARY

DETAIL	PANEL SIZE	MATERIAL COSTS	LABOR COSTS	TOTAL COSTS*
C	4' x 5'	$12,139.20	$ 6,591.15	$18,730.35
	4' x 10'	12,283.20	5,464.50	17,747.70
	4' x 20'	11,115.00	4,704.00	15,819.00
	8' x 20'	9,529.20	4,225.05	13,754.25
	8' x 40'	10,767.60	3,774.45	14,542.05
C w/ (Rack 8' x 120')	4' x 5'	26,194.50	14,308.95	40,503.45
	4' x 10'	26,338.50	13,182.30	39,520.80
	4' x 20'	25,170.30	12,421.80	37,592.10
	8' x 20'	23,584.50	11,942.85	35,527.35
	8' x 40'	24,822.90	11,492.25	36,315.15
C w/ (Rack 16' x 120')	4' x 5'	22,675.80	13,608.83	36,284.63
	4' x 10'	22,819.80	12,482.18	35,301.98
	4' x 20'	21,651.60	11,721.68	33,373.28
	8' x 20'	20,065.80	11,242.73	31,308.53
	8' x 40'	21,304.20	10,792.13	32,096.33

*ELECTRICAL INTERCONNECTION NOT INCLUDED.

Panel details for rack mounting do not need to provide the array with waterproof integrity but are merely required to securely fasten the panels to the rack. Detail C shown on Table 11.3 has been designed specifically for rack mounting. It should be noted that in Detail C, the panel frames are fastened from the back with sheet metal screws. Because rack mounted arrays are easily accessible from both the front and the back from a stable working position and since the connections are not required to be waterproof, the panel mounting cost is low (see Tables 11.3, and 11.4). However, this cost is greatly increased when the cost of the rack materials and installation are included. Table 11.3 illustrates two rack concepts with their associated materials and installation costs on a per unit basis, 8' x 120' and 16' x 120'. Non-determinable costs for rack mounting are the cost savings for not wasting valuable interior space to accommodate the required slope of the array and the visual cost or effect the racks have on the building.

Finally, a summary of installation costs for the rack mounted array are seen in Table 11.2. <u>It must be noted that these costs are detail specific</u> and will change for mounting and rack details other than those illustrated.

Standoff Mount

Like rack mounting, standoff mounting may also share the cost advantages of not waterproofing the array. However, the size of the panel and the panel's structural capacities determines the number of roof penetrations required for adequate support. Shipping/handling requirements allow panels to withstand environmental loads of approximately 60 p.s.f. if they are supported every twelve feet. Pipe columns similar to those used to attach the rack to the joist were used in the costing analysis. Access to the back of standoff mounted arrays is highly dependent on the distance the panels stand away from the roof. Panel sizes ranging from 4' x 5' to 8' x 40' were costed. The material and labor costs for standoffs are listed in Table 11.5. These may be coupled with the panel installation cost for Detail C in Tables 11.3 and 11.4 to attain an overall cost for panels mounted on standoffs. A summary of costs for standoff installations is seen in Table 11.6.

Direct Mount

Panels mounted directly to a roof deck require no supplemental structural support. However, this mounting type does require that the panels be detailed to provide the building with a continuous waterproof membrane. Both Detail A and B provide such waterproof integrity. (See figures on Tables 11.7 and 11.8.)

Detail A is intended for use with large panels. It provides waterproof integrity to the array by mounting the panels mechanically in a manner similar to that employed in standing seam roofing.

Detail B limits the size of panels to the size of the module used, but it also eliminates panel fabrication costs, which are not addressed in detail in this costing analysis. Detail B provides waterproof integrity to the array by mounting the module/panels with an adhesive, silicone. This type of mounting has been used extensively for mounting glazing when a clean, flush appearance is required.

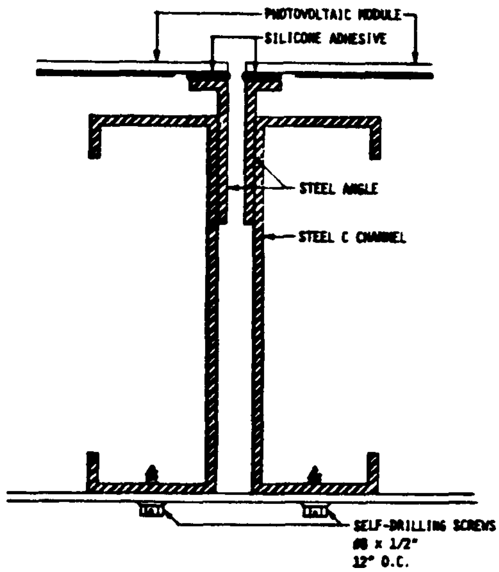
Due to the wide fluctuations in cost for roofing used by the commercial industrial sector, roofing credits could not be addressed in the costing analysis. It is also beyond the scope of this report to determine a dollar value for the lack of cell cooling from the back of the array. It is critical that a designer assess these costs when comparing the mounting costs. Costs for direct mounted panels utilizing Detail A and B are listed in Table 11.7 and 11.9, and Tables 11.8 and 11.10 rspectively. Cost summaries for installations can be seen in Table 11.11.

Integral Mount

Panels mounted integrally are required to become the roofing composite. This composite is required to provide a continuous waterproofing membrane. As with direct mounted panels, Details A or B may be used to provide this

Table 11.3

DETAIL C



DETAIL	MATERIAL SECTION	QUANTITY	MATERIAL RATE	MATERIAL COST
C (4' x 5')				
	C Channel 20 ga. 3-5/8"	12,960 lin. ft.	$0.62/lin. ft.	$ 8,035.20
	L Channel 20 ga.	12,960 lin. ft.	$0.30/lin. ft.	$ 3,888.00
	Screws #10 x 3/4"	5,400 pcs.	$0.04 ea.	$ 216.00
	Total (120' x 120' array)			$12,139.20
C (4' x 10')				
	C Channel 18 ga. 3-5/8"	10,080 lin. ft.	$0.72/lin. ft.	$ 7,257.60
	L Channel 20 ga.	10,080 lin. ft.	$0.30/lin. ft.	$ 3,024.00
	Screws #10 x 3/4"	5,400 pcs.	$0.04 ea.	$ 216.00
	Horizontal 20 ga.	1,440 lin. ft.	$0.47/lin. ft.	$ 676.80
	Adhesive 1/8" x 1/2"	10,080 lin. ft.	$0.11/lin. ft.	$ 1,108.80
	Total (120' x 120' array)			$12,283.20
C (4' x 20')				
	C Channel 20 ga. 6"	8,640 lin. ft.	$0.82/lin. ft.	$ 7,084.80
	L Channel 20 ga.	8,640 lin. ft.	$0.30/lin. ft.	$ 2,592.00
	Screws #10 x 3/4"	5,400 pcs.	$0.04 ea.	$ 216.00
	Horizontal 20 ga.	2,160 lin. ft.	$0.47/lin. ft.	$ 1,015.20
	Adhesive 1/8" x 1/2"	10,080 lin. ft.	$0.11/lin. ft.	$ 216.00
	Total (120' x 120' array)			$11,123.00
C (8' x 20')				
	C Channel 18 ga. 6"	5,040 lin. ft.	$0.98/lin. ft.	$ 4,939.20
	L Channel 20 ga.	5,040 lin. ft.	$0.30/lin. ft.	$ 1,512.00
	Screws #10 x 3/4"	5,400 pcs.	$0.04 ea.	$ 216.00
	Horizontal 18 ga.	1,080 lin. ft.	$0.84/lin. ft.	$ 907.20
	Hat Section 20 ga.	1,800 lin. ft.	$0.47/lin. ft.	$ 846.00
	Adhesive 1/8" x 1/2"	10,080 lin. ft.	$0.11/lin. ft.	$ 1,108.80
				$ 9,529.20
C (8' x 40')				
	C Channel 16 ga. 6"	4,320 lin. ft.	$1.20/lin. ft.	$ 5,184.00
	L Channel 20 ga.	4,320 lin. ft.	$0.30/lin. ft.	$ 1,296.00
	Screws #10 x 3/4"	5,400 pcs.	$0.04 ea.	$ 216.00
	Horizontal 18 ga.	2,520 lin. ft.	$0.84/lin. ft.	$ 2,116.80
	Hat Section 20 ga.	1,800 lin. ft.	$0.47/lin. ft.	$ 846.00
	Adhesive 1/8" x 1/2"	10,080 lin. ft.	$0.11/lin. ft.	$ 1,108.80
				$10,767.60

Table 11.4

HOURLY LABOR RATE

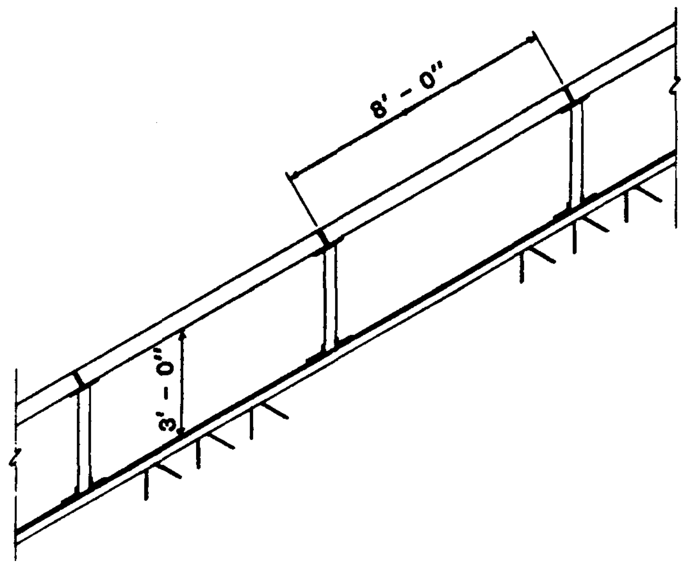
QUANTITY	LABOR TYPE	COST/HR	DESCRIPTION	SOURCE
1	Crane Rental	$ 38.08	= $6,600/month ÷ 173.33 hr./mo. (based on 8 hr. days, 5 day weeks)	Means 1980
1	Crane Operator	21.05	= $14.65 (base rate) + $6.40 (Sub's overhead and profit)	Means 1980
3	Sheet Metal Workers	65.85	= [$15.40 (base rate) + $6.55 (Sub's overhead and profit)] x 3	Means 1980
4	Building Laborers	62.80	= [$11.15 (base rate) + $4.55 (Sub's overhead and profit)] x 4	Means 1980
	Total Crew	$ 187.78	= $38.08 + $21.05 + $65.85 + $62.80	

LABOR COST

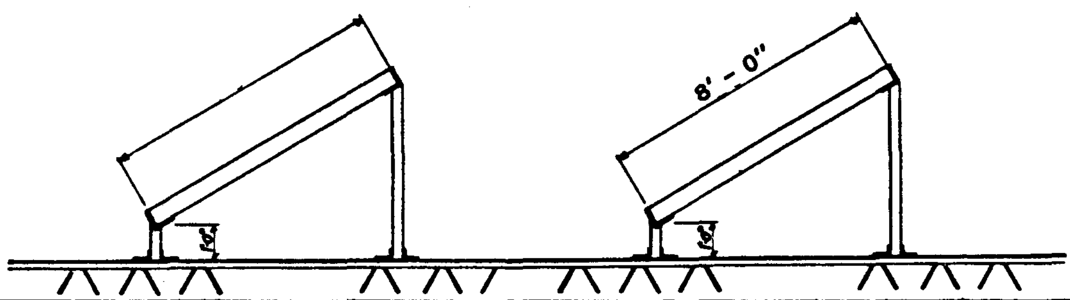
DETAIL	TIME REQUIRED	AVE.COST	OPERATION	COMMENTS
C (8x40 panels)	5.00 Hrs.	$ 938.90	= Position and set panels (20 min./panel x 45 panels) ÷ 60 min./hr. ÷ 3 crews	Estimate
	15.00 Hrs.	2,816.70	= Screw panels to purlins [(0.5 min./screw x 5,400 screws) ÷ 60] ÷ 3	Estimate
120'x120' array	20.00 Hrs.	$3,755.60	= Total	Does not include electrical costs
C 8'x20' panels	7.50 Hrs.	$1,408.35	= Position and set panels [([15 min./panel] x 90 panels) ÷ 60] ÷ 3	Estimate
8'x20' panels	15.00 Hrs.	2,816.70	= Screw panels to purlins [(0.5 min./screw x 5,400 screws) ÷ 60] ÷ 3	Estimate
120'x120' array	22.50 Hrs.	$4,225.05	= Total	Does not include electrical costs
C 4'x20' panels	10.00 Hrs.	$1,877.80	= Position and set panels [([10 min./panel] x 180 panels) ÷ 60 min./hr.] ÷ 3 crews	Estimate
	15.00 Hrs.	2,816.70	= Screw panels to purlins [(0.5 min./screw x 5,400 screws) ÷ 60 min./hr.] ÷ 3 crews	Estimate
120'x120' array	25.00 Hrs.	$4,694.50	= Total	Does not include electrical costs
C 4'x10' panels	14.00 Hrs.	$2,628.92	= Position and set panels [([7 min./panel] x 360 panels) ÷ 60 min./hr.] ÷ 3 crews	Estimate
	15.00 Hrs.	2,816.70	= Screw panels to purlins [(0.5 min./screw x 5,400 screws) ÷ 60 min./hr.] ÷ 3 crews	Estimate
120'x120' array	29.00 Hrs.	$5,445.62	= Total	Does not include electrical costs
C 4'x5' panels	20.00 Hrs.	$3,756.60	= Position and set panels [([5 min./panel] x 720 panels) ÷ 60 min./hr.] ÷ 3 crews	Estimate
	15.00 Hrs.	2,816.70	= Screw panels to purlins [(0.5 min./screw x 5,400 screws) ÷ 60 min./hr.] ÷ 3 crews	Estimate
120'x120' array	35.00 Hrs.	$6,572.30	= Total	Does not include electrical costs

Table 11.5

STEEL POST STANDOFF LABOR AND MATERIAL COST



MOUNTING LOCATION MATERIAL SECTION	QUANTITY	MATERIAL RATE	MATERIAL COST	LABOR RATE	LABOR COST	TOTAL COST
Sloped Roof (120' x 120')						
8' x 40', 8' x 20' Panels						
3" Pipe Column x 3'	208 pcs.	$13.45 ea.	$ 2,797.60	$2.00 ea.	$ 416.00	$ 3,213.60
Pipe Flashing	208 pcs.	$8.40 ea.	$ 1,747.20	$1.10 ea.	$ 228.80	$ 1,976.00
	Total		$ 4,544.80		$ 644.80	$ 5,189.60
4' x 20', 4' x 10' Panels						
3" Pipe Column	403 pcs.	$13.45 ea.	$ 5,420.35	$2.00 ea.	$ 806.00	$ 6,226.35
Pipe Flashing	403 pcs.	$8.40 ea.	$ 3,385.20	$1.10 ea.	$ 443.30	$ 3,828.50
	Total					$10,054.85
4' x 5' Panels						
3" Pipe Column	775 pcs.	$13.45 ea.	$10,423.75	$2.00 ea.	$1,550.00	$11,973.75
Pipe Flashing	775 pcs.	$8.40 ea.	$ 6,510.00	$1.10 ea.	$ 852.50	$ 7,362.50
	Total		$16,933.75		$2,402.50	$19,336.25



MOUNTING LOCATION MATERIAL SECTION	QUANTITY	MATERIAL RATE	MATERIAL COST	LABOR RATE	LABOR COST	TOTAL COST
Flat Roof (8' x 120')						
8' x 40', 8' x 20' Panels						
3" Pipe Column x 1'	11 pcs.	$4.45	$ 48.95	$1.75 ea.	$ 19.25	$ 68.20
3" Pipe Column x 8'	11 pcs.	$32.45	$ 356.95	$3.75 ea.	$ 41.25	$ 398.20
Pipe Flashing	22 pcs.	$8.40	$ 184.80	$1.10 ea.	$ 24.20	$ 209.00
	Total		$ 590.70		$ 84.70	$ 675.40

Table 11.6

STANDOFF MOUNT COST SUMMARY

DETAIL	PANEL SIZE	MATERIAL COSTS	LABOR COSTS	TOTAL COSTS*
C	4' x 5'	$12,139.20	$ 6,591.15	$18,730.35
	4' x 10'	12,283.20	5,464.50	17,747.70
	4' x 20'	11,115.00	4,704.00	15,819.00
	8' x 20'	9,529.20	4,225.05	13,754.25
	8' x 40'	10,767.60	3,774.45	14,542.05
C w/ Sloped Roof	4' x 5'	29,072.95	8,993.65	38,066.60
	4' x 10'	21,088.75	6,713.80	27,802.55
	4' x 20'	19,920.55	5,953.30	25,873.85
	8' x 20'	14,074.00	4,869.85	18,943.85
	8' x 40'	15,312.40	4,419.25	19,731.65
C w/ Flat Roof	4' x 5'	-----	-----	-----
	4' x 10'	-----	-----	-----
	4' x 20'	-----	-----	-----
	8' x 20'	18,389.70	5,495.55	23,885.25
	8' x 40'	19,628.10	5,044.95	24,673.05

*ELECTRICAL INTERCONNECTIONS NOT INCLUDED.

waterproof integrity. Since integrally mounted panels replace the roof decking as well as the roofing membrane, cost credits for the material and labor required to install the elements are important for comparative reasons, but could not be addressed due to cost fluctuations. However, it should be noted that with adequate ventilation behind an array, cooling the back of the array is not a problem. Costs for integrally mounted panels utilizing Detail A and B are equal to those for direct mounted panels and are listed in Tables 11.7 through 11.10, with summaries found in Table 11.11. It is imperative that the module/panel manufacturer understand the potential problems associated with integral mounted panels as addressed in the code analysis section. The added cost necessary for compliance with assembly requirements must be added to the costs given in this section for integral mount.

11.3 ELECTRICAL WIRING/TERMINATION COST

11.3.1 INTRODUCTION

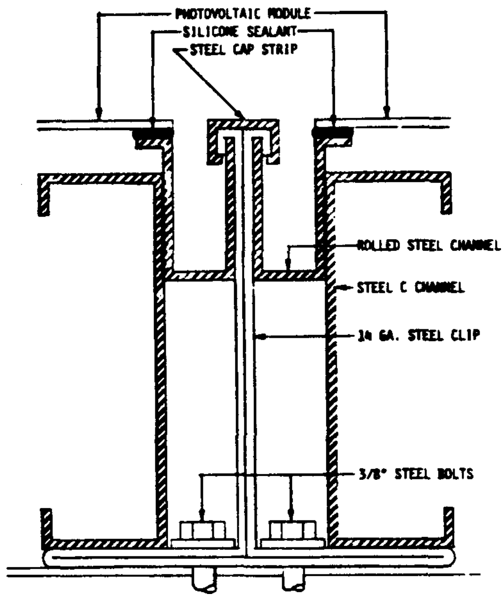
This electrical wiring/termination cost analysis was developed around a number of system-related parameters. These parameters were allocated values that were felt to be realistic in scope for the year 1986. It should be realized that to present an accurate cost analysis for a photovoltaic system and its electrical components, many details need to be known about the system design and characteristics. This cost analysis is based upon the following assumptions:

- Packing Efficiency (cells only) = 94%
- Array Efficiency = 10.1%
- Peak Electrical Output Based on Insolation = 800 w/m^2
- Array Area = 1,338 m^2
- Array Peak Power = 145,000 Watts

Furthermore, this electrical wiring/termination cost study considered the panel the prewired electrical device that is to be

Table 11.7

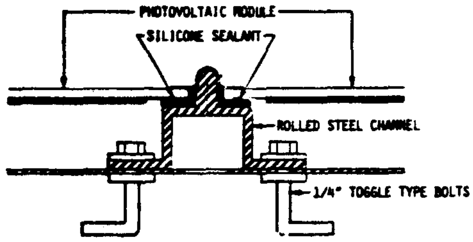
DETAIL A



DETAIL	MATERIAL SECTION	QUANTITY	MATERIAL RATE	MATERIAL COST
A (4' x 5')				
20 ga. 3-5/8	C Channel	13,440 lin. ft.	$0.62/lin. ft.	$ 8,332.80
14 ga.	Anchor Clip	775	$0.44 ea.	$ 341.00
3/8" x 1"	Bolts	775	$0.25 ea.	$ 193.75
20 ga.	Gutter	13,440 lin. ft.	$0.50 lin. ft.	$ 6,720.00
20 ga.	Cap Strip	3,720 lin. ft.	$0.16 lin. ft.	$ 595.00
	Total			$16,182.55
A (4' x 10')				
18 ga. 3-5/8	C Channel	10,560 lin ft.	$0.72/lin. ft.	$ 7,603.20
14 ga.	Anchor Clip	775	$0.44 ea.	$ 341.00
3/8" x 1"	Bolts	775	$0.25 ea.	$ 193.75
20 ga.	Gutter	10,560 lin. ft.	$0.50/lin. ft.	$ 5,280.00
20 ga.	Cap Strip	3,720 lin. ft.	$0.16/lin. ft.	$ 595.00
20 ga.	Horizontal Tie	1,440 lin. ft.	$0.47/lin. ft.	$ 676.80
1/8" x 1/2"	Adhesive	12,960 lin. ft.	$0.11/lin. ft.	$ 1,425.60
	Total (with 4 x 5 modules			$16,115.35
A (4' x 20')				
20 ga. 6"	C Channel	9,120 lin. ft.	$0.82/lin. ft.	$ 7,478.40
14 ga.	Anchor Clip	775	$0.44 ea.	$ 341.00
3/8" x 1"	Bolts	775	$0.25 ea.	$ 193.75
20 ga.	Gutter	9,120 lin. ft.	$0.50/lin. ft.	$ 4,560.00
20 ga.	Cap Strip	3,720 lin. ft.	$0.16/lin. ft.	$ 595.00
	Horizontal Tie	2,160	$0.47/lin. ft.	$ 1,015.20
	Adhesive	12,960 lin. ft.	$0.11/lin. ft.	$ 1,425.60
	Total (with 4 x 5 modules			$15,608.95
A (8' x 20')	C Channel	5,520 lin. ft.	$0.98/lin. ft.	$ 5,409.60
14 ga.	Anchor Clip	400	$0.44 ea.	$ 176.00
	Bolts	400	$0.25 ea.	$ 100.00
20 ga.	Gutter	5,520 lin. ft.	$0.50/lin. ft.	$ 2,760.00
20 ga.	Cap Strip	1,920 lin. ft.	$0.16/lin. ft.	$ 307.20
18 ga.	Horizontal Tie	2,160 lin. ft.	$0.84/lin. ft.	$ 1,814.40
20 ga.	Hat Section	1,800 lin. ft.	$0.47/lin. ft.	$ 846.00
1/8" x 1/2"	Adhesive	12,960 lin. ft.	$0.11/lin. ft.	$ 1,425.60
	Total (with 4 x 5 modules)			$12,838.20
A (8' x 40')				
16 ga. 6"	C Channel	4,800 lin. ft.	$1.20/lin. ft.	$ 5,760.00
14 ga.	Anchor Clip	400	$0.44 ea.	$ 176.00
3/8" x 1"	Bolts	400	$0.25 ea.	$ 100.00
20 ga.	Gutter	4,800	$0.50/lin. ft.	$ 2,400.00
20 ga.	Cap Strip	1,920	$0.16/lin. ft.	$ 307.20
18 ga.	Horizontal Tie	2,520 lin. ft.	$0.84/lin. ft.	$ 2,116.80
20 ga.	Hat Section	1,800	$0.47/lin. ft.	$ 846.00
1/8" x 1/2"	Adhesive	12,960	$0.11/lin. ft.	$ 1,425.60
	Total (with 4 x 5 modules			$13,131.60

Table 11.8

DETAIL B



DETAIL	MATERIAL SECTION	QUANTITY	MATERIAL RATE	MATERIAL COST
B (4' x 5')	Hot Section	3,000 lin. ft.	$0.76/lin. ft.	$ 2,280.00
20 ga.	Horizontal Tie	3,720	$0.47/lin. ft.	$ 1,748.40
3/8" x 1"	Bolts	775	$0.25/lin. ft.	$ 193.75
1/4" x 1/2"	Adhesive	12,960 lin. ft.	$0.21/lin. ft.	$ 2,592.00
	Total			$ 6,814.15
B (4' x 10')				
20 ga.	Hat Section	3,000 lin. ft.	$0.76/lin. ft.	$ 2,280.00
18 ga.	Horizontal Tie	1,560 lin. ft.	$0.52/lin. ft.	$ 811.20
	Bolts	775	$0.25 ea.	$ 193.75
	Adhesive	10,080 lin. ft.	$0.21/lin. ft.	$ 2,116.80
	Total			$ 5,400.75

Table 11.9

HOURLY LABOR RATE

QUANTITY	LABOR TYPE	COST/HR	DESCRIPTION	SOURCE
1	Crane Rental	$ 38.08	= $6,600/month ÷ 173.33 hr./mo. (based on 8 hr. days, 5 day weeks)	Means 1980
1	Crane Operator	21.05	= $14.65 (base rate) + $6.40 (Sub's overhead and profit)	Means 1980
3	Sheet Metal Workers	65.85	= [$15.40 (base rate) + $6.55 (Sub's overhead and profit)] x 3	Means 1980
4	Building Laborers	62.80	= [$11.15 (base rate) + $4.55 (Sub's overhead and profit)] x 4	Means 1980
	Total Crew	$ 187.78	= $38.08 + $21.05 + $65.85 + $62.80	

LABOR COST

DETAIL	TIME REQUIRED	AVE.COST	OPERATION	COMMENTS
A (8'x40')	2.58 Hrs.	$ 484.48	= Additional cost to set purlins [([3 x 775] ÷ 60) ÷ 3] x 20%	Cost for sloped application is 20% greater than that found in typical construction.
	5.00 Hrs.	939.00	= Position and set panels (20 min./panel) x 45 panels ÷ 60 ÷ 3	Estimate
	4.45 Hrs.	835.62	= Bolt Panels to purlins [([2 min./bolt] x 400 bolts) ÷ 60] ÷ 3	Estimate
	1.53 Hrs.	287.31	= Install Cap Strips [([1,920 lin. ft.] ÷ 420) ÷ 60] ÷ 3	Estimate
	13.56 Hrs.	$2,546.41	= Total excluding electrical connections	
A (8'x20')	2.58 Hrs.	$ 484.48	= Additional cost to set purlins [([3 x 775] ÷ 60) ÷ 3] x 20%	Cost for sloped application is 20% greater than that found in typical construction.
	7.50 Hrs.	1,408.50	= Position and set panels (15 min./panel) x 90 panels ÷ 3 crews	Estimate
	4.45 Hrs.	835.62	= Bolt Panels to purlins (2 min./bolt) x 400 bolts	Estimate
	1.53 Hrs.	287.31	= Install Cap Strips (1,920 lin. ft.)	Estimate
	16.06 Hrs.	$3,015.91	= Total excluding electrical connections	
A (4'x20')	2.58 Hrs.	$ 484.48	= Additional cost to set purlins	Cost for sloped application is 20% greater than that found in typical construction.
	10.00 Hrs.	1,877.80	= Position and set panels [([10 min./panel] x 180 panels) ÷ 60] ÷ 3	Estimate
	8.62 Hrs.	1,618.67	= Bolt Panels to purlins [([2 min./bolt] x 775 bolts) ÷ 60] ÷ 3	Estimate
	2.96 Hrs.	555.83	= Install Cap Strips [([3,720 lin. ft.] ÷ 420) ÷ 60] ÷ 3	Estimate
	24.16 Hrs.	$4,536.78	= Total excluding electrical connections	
A (4'x10')	2.58 Hrs.	$ 484.48	= Additional cost to set purlins [([3 x 775] ÷ 60) ÷ 3] x 20%	Cost for sloped application is 20% greater than that found in typical construction.
	14.00 Hrs.	2,628.92	= Position and set panels [([7 min./panel] x 360 panels) ÷ 60] ÷ 3	Estimate
	8.62 Hrs.	1,618.67	= Bolt Panels to purlins (2 min./bolt) x 775 bolts	Estimate
	2.96 Hrs.	555.83	= Install Cap Strips [([3,720 lin. ft.] ÷ 420) ÷ 60] ÷ 3	Estimate
	28.16 Hrs.	$5,287.90	= Total excluding electrical connections	
A (4'x5')	2.58 Hrs.	$ 484.48	= Additional cost to set purlins [([3 x 775] ÷ 60] ÷ 3	Cost for sloped application is 20% greater than that found in typical construction.
	20.00 Hrs.	3,794.60	= Position and set panels [([5 min./panel] x 720 panels) ÷ 60] ÷ 3	Estimate
	8.62 Hrs.	1,618.67	= Bolt panels to purlins [([2 min./bolt] x 775 bolts) ÷ 60] ÷ 3	Estimate
	2.96 Hrs.	555.83	= Install Cap Strips [([3,720 lin. ft.] ÷ 420) ÷ 60] ÷ 3	Estimate
	34.16 Hrs.	$6,453.58	= Total excluding electrical connections	

Table 11.10

HOURLY LABOR RATE

QUANTITY	LABOR TYPE	COST/HR	DESCRIPTION	SOURCE
1	Crane Rental	$ 38.08	= $6,600/mo. ÷ 173.33 hrs./mo. (8 hr. day, 5 day week)	Means 1980
1	Crane Operator	21.05	= $14.65/hr. (base rate) + $6.40/hr. (Sub's overhead and profit)	Means 1980
6	Glaziers	114.90	= [$13.80/hr. (base rate) + $5.35/hr. (Sub's overhead and profit) x 6]	Means 1980
1	Common Building Laborer	15.70	= $11.15 (base rate) + $4.55/hr. (Sub's overhead and profit)	Means 1980
	Total Crew	$ 189.73	= $38.08 + $21.05 + $114.90 + $15.70	

LABOR COST

DETAIL	TIME REQUIRED	AVE.COST	OPERATION	COMMENTS
B (4'x10')	2.58 Hrs.	$ 489.51	= Additional cost to set purlins [([3 min./bolt x 775 bolts] ÷ 60) ÷ 3] x 20%	Cost for sloped application is 20% greater than that found in typical construction.
	13.27 Hrs.	2,517.72	= Position and bolt frame to purlins [([2 min./bolt x 775 bolts] + [3 min./40' frame x 93 frames]) ÷ 60] ÷ 3	Estimate
	10.50 Hrs.	1,992.17	= Apply Adhesive to frame [(360 panels x 28 lin. ft./panel) ÷ 320] ÷ 3	Estimate
	14.00 Hrs.	2,656.22	= Position & Set panels [([7 min./panel] x 180 panels) ÷ 60] ÷ 3	Estimate
	12.17 Hrs.	2,309.02	= Seal Array (8,760 lin. ft. ÷ 240 lin. ft./hr.) ÷ 3	Estimate
	52.52 Hrs.	$ 9,964.64	= Total excluding electrical connections	
B (4'x5')	2.58 Hrs.	$ 489.51	= Additional cost to set purlins [([3 min./bolt x 775 bolts] ÷ 60) ÷ 3] x 20%	Cost for sloped application is 20% greater than that found in typical construction.
	13.27 Hrs.	2,517.72	= Position and bolt frame to purlins [([2 min./bolt x 775 bolts] + [3 min./40' frame x 93 frames]) ÷ 60] ÷ 3	Estimate
	13.50 Hrs.	2,561.36	= Apply Adhesive to frame [(720 panels x 18 lin. ft./panel) ÷ 320] ÷ 3	Estimate
	20.00 Hrs.	3,794.60	= Position & Set panels [(5 min./panel x 720 panels) ÷ 60] ÷ 3	Estimate
	14.17 Hrs.	2,688.48	= Seal Array (10,200 lin. ft. ÷ 240 lin. ft./hr.) ÷ 3	Estimate
	63.52 Hrs.	$12,051.67	= Total excluding electrical connections	

Table 11.11

INTEGRAL AND DIRECT MOUNT COST SUMMARY

DETAIL	PANEL SIZE	MATERIAL COSTS	LABOR COSTS	TOTAL COSTS*
A	4' x 5'	$16,182.55	$ 6,453.58	$22,636.13
	4' x 10'	16,115.35	5,287.90	21,403.25
	4' x 20'	15,608.95	4,536.78	20,145.73
	8' x 20'	12,838.20	3,015.91	15,854.11
	8' x 40'	13,131.60	2,546.41	15,678.01
B	4' x 5'	6,814.15	12,051.67	18,865.82
	4' x 10'	5,400.75	9,964.64	15,365.39

transported to the site. Thus, all the conductor costs will exclude the required module to module electrical connection costs. The format of presentation in this study, however, does allow one to consider the panel to be a module, without requiring a modification of the basic conclusions that have resulted. The hierarchical electrical system illustrated in Figure 11.2 presents the structure of cost data development in this section.

11.3.2 CONDUCTOR COST

Conductor costs have been developed around the following:

- All conductors are Type THHN dual rated 90°C for dry locations and 75°C for wet locations (600 volt maximum).

- Allowable ampacity based on ambient temperature of 60°C, and therefore, a derating of 0.71 for 90°C rated conductors is used.

- For voltages in excess of 600 volts, the conductor costed was a medium voltage, MV90, cable.

- All conductor costs are based on a large volume purchase and are, therefore, conservative in nature.

- All are 1980 dollar figures and are presented in $\$/m^2$.

In determining conductor costs ($\$/m^2$) for this prototypical array as shown in Figure 11.2, it was felt that two very important parameters should be allowed to vary. These were:

1. Voltage for all three system levels: panel, sub-array and array.
2. Length of conductor for each system level.

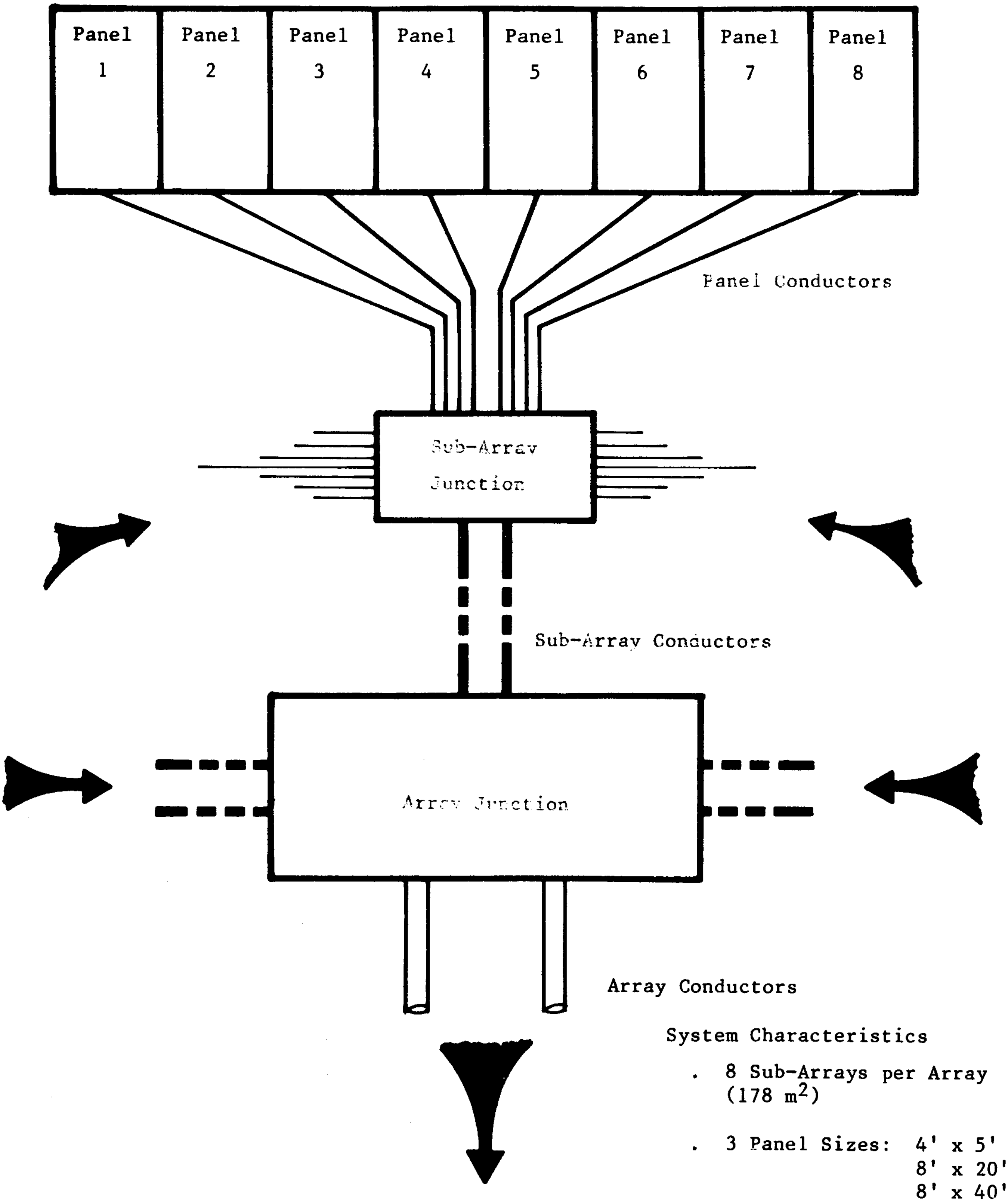

Panel 1
Panel 2
Panel 3
Panel 4
Panel 5
Panel 6
Panel 7
Panel 8
Panel Conductors
Sub-Array Junction
Sub-Array Conductors
Array Junction
Array Conductors
System Characteristics
. 8 Sub-Arrays per Array ($178 m^2$)
. 3 Panel Sizes: 4' x 5'
8' x 20'
8' x 40'

Figure 11.2

Costs were determined for four voltage levels:

1. 30 volts
2. 250 volts
3. 600 volts
4. 1000 volts

Because the NEC addresses three standard voltage regimes (less than 30 volts, between 30 and 600 volts, and greater than 600 volts), it was determined that cost data should be developed around these critical voltage points. At the array level, it was felt that the greater than 600 volt regime should be complimented with costs determined at the 750 volt operational level to facilitate the development of a cost trend in this regime.

Additionally, the second variable that was considered (the length of conductor) involved three variations:

1. 2 feet (.61 m)
2. 10 feet (3.05 m)
3. 40 feet (12.19 m)

Because of the fact that detailed system configuration information was necessary to accurately determine conductor length for the three system levels, an average conductor length was assumed and allowed to vary from 2 to 40 feet. This illustrates the order of magnitude of conductor cost in $\$/m^2$ to other system costs.

Therefore, the cost data for electrical conductors has been developed for a photovoltaic system consisting of three electrical system levels: panel, sub-array, and array. Both systems level operational voltage as well as systems level average conductor length have been allowed to vary to illustrate cost dependency on these two variables.

In performing this analysis it was felt that system power loss due to conductor electrical resistance could play an important role in determining the system economics. Therefore, a determination of I^2R power loss was determined for all of the cases which are presented above. This determination is explained in the following.

11.3.3 DETERMINATION OF I^2R POWER LOSS COSTS

Because resistance increases with temperature, the I^2R power loss was based on the same temperature, 60°C, that was used to determine the allowable conductor size based on ampacity of the conductor. The following equation was applied.

(11.3.1) $$R_{t_2} = R_{t_1} [1 + \alpha_{t_1} (t_2 - t_1)]$$

Where t_1 = 25°C

α_{t_1} = 25° = 0.0038

t_2 = 60°C

R_{t_1} = resistance of copper at 25°C per 1000 feet

R_{t_2} = resistance of copper at 60°C per 1000 feet

Substituting gives:

(11.3.2) $$R_{60°} = (1.133)\ R_{25°}$$

(Standard Handbook for Electrical Engineers, Fink and Beaty, ed.; McGraw-Hill, 1978.)

The determination of the I^2R power loss was based on the peak power output of the array. As mentioned earlier, this peak power output was based on:

- Solar Radiation = 800 w/m^2
- Packing Efficiency = 94%
- Cell Efficiency = 13.5%

The following equations were used in this determination:

(11.3.3) (1.133) R_{25} • (conductor length) • (2 conductors/panel) = Electrical Resistance/Panel

[Ω /Panel]

(11.3.4) (Electrical Resistance/Panel) • (I^2) = $\text{Power Loss/Panel]}_{\text{Peak}}$

[Watts/Panel]

Where I = Peak current output of panel (amps)

(11.3.5) $\text{[Power Loss/Panel]}_{\text{Peak}}$ • No. Panels/Array = $\text{[Power Loss/Array]}_{\text{Peak}}$

[Watts]

The following assumption was made to determine the cost of the "lost" power due to conductor resistance:

System Cost = \$1.50/Watt_p

Therefore, I^2R Power Loss Costs are found by:

(11.3.6) $\text{[Power Loss/Array]}_{\text{Peak}}$ • $\text{\$1.50/W}_{\text{Peak}}$ ÷ Area/Array = Power Loss Costs/Unit Area [\$/m^2]

It was found (as will be presented later) that this I^2R power-loss incurred cost was quite substantial. It should be remembered, however, that the determination of this cost lies directly in the assumption of the monetary worth of the lost power. For this study this value was assumed to be \$1.50 per peak watt. It is quite realistic to think that until system costs reach this level, that the incurred cost is considerably higher, and that the use of small gage, high resistance, conductor will inflict great economic penalties on the system. This subject is addressed in greater detail later in this section.

11.3.4 TERMINATION COST

The three generic termination types that were considered in this study were:

1. Crimp
2. Plug and Receptacle
3. Screw

The material and labor costs associated with these three electrical termination types were taken from a previous report (Photovoltaic Module Electrical Termination Design Requirement Study), Motorola, Inc./ITT Cannon, JPL Contract No. 955367). A tabular presentation of the costs is given in Table 11.12 as a function of current rating. Because voltage is considered to be a variable in this study, a cost dependency on current is therefore a necessary consideration.

Table 11.12

Termination Costs vs Current Rating (Quantities of 10^4)

Termination Type		Total Cost Per Connector [$]
Crimp		
	0-50 amps	0.69
	50-100 amps	0.93
	100-200 amps	1.24
	200-250 amps	1.33
Plugs and Receptacles		
	0-60 amps	0.80
	60-150 amps	1.25
	150-250 amps	1.60
Screw		
	0-50 amps	4.78
	50-175 amps	5.06
	175-250 amps	5.28 (per two connectors)

11.3.5 LABOR COST

Labor cost for the installation of conductor was based on the 1980 MEANS CONSTRUCTION GUIDE. The cost of installing conductor rated up to 600 volts is a function of size, with the larger conductor requiring more cost per linear foot for installation. For the medium voltage, MV90 cable, it was assumed, based on means, that a 20% increase in labor cost would be incurred for the same size conductor. The sensitivity of overall system costs to this assumption is very low because of the negligible labor cost associated with the system electrical level at which this higher voltage conductor is found. The labor cost associated with the three termination types was included in the connector costs in Table 11.12. The field labor rate for the Motorola/ITT Cannon Study was $19.15/hr., and the factory labor rate was $9.70/hr.

11.3.6 RESULTS

Results of the electrical conductor/termination cost analysis are presented in this section. A very large amount of cost data was generated for this section, however, many of the cost-related curves have been excluded due to the expected repetition of trends among the various system configurations. For instance, curves which illustrate the dependency of conductor costs (material and labor) as well as the I^2R power loss costs on the system level voltage are only given for one panel size (see Figures 11.3 and 11.4). Though the curves are quite different for the other two panel sizes (they remain the same for the sub-array and array), it is only important that the cost trends be established. It should be noted that the Conductor Cost vs Voltage Curves shown in Figure 11.3 represent the costs associated with the minimum-size acceptable conductor, based on the assumptions given in Section 11.3.2. It must be noted that the minimum size conductor acceptable for a given application is less code related than economic related. From a system loss standpoint, the minimum conductor size will exceed the code requirements. The type of cable used, however, is code restrictive and the reader should reference Section 7 on the NEC. Because of the magnitude of the costs associated with I^2R power loss (see Figure 11.4) in these smaller conductors, the counter-balancing relationship between the higher cost and the lower resistances associated with larger conductors was investigated. Additionally, the increase in labor costs which accompany larger conductors contributes to the offsetting of the benefits of lower electrical resistance. Only with a complete understanding of the magnitude and relationship of these factors was it possible to approach the selection of an optimum electrical conductor and its cost.

Figure 11.3, Conductor Costs vs Voltage, illustrates the cost ($\$/m^2$) of conductor material and labor versus system level voltage. This is given for the three system levels (panel, sub-array, and array) as well as for three average conductor lengths (2 ft., 10 ft., and 40 ft.). The increase in conductor length, as to be expected, only contributes a simple multiplicative term to the costs. However, it facilitates the understanding that for the lower voltage regions where a rapid increase in costs can occur, that substantial cost penalties can exist for long conductor leads. In addition to this, it can be seen that conductor lead length has a greater or lesser effect on cost, depending on the system level. For instance, a long conductor length for the 4' x 5' panel creates a major cost due to the fact that 768 panels are required to form an array of 1,427 m^2. It should be noted that no consideration for the cost penalty due to I^2R costs has been made in this curve.

One other note of interest for this curve is the voltage level for which the panel conductor costs no longer decrease with increasing voltage. This voltage is approximately 150 volts for the 8' x 20' panel, and it is due to the fact that at this voltage (and greater) the minimum size that is acceptable becomes #18 AWG conductor. Therefore, no improvement in cost reduction occurs at higher voltages. When the I^2R power losses are considered,

Figure 11.3

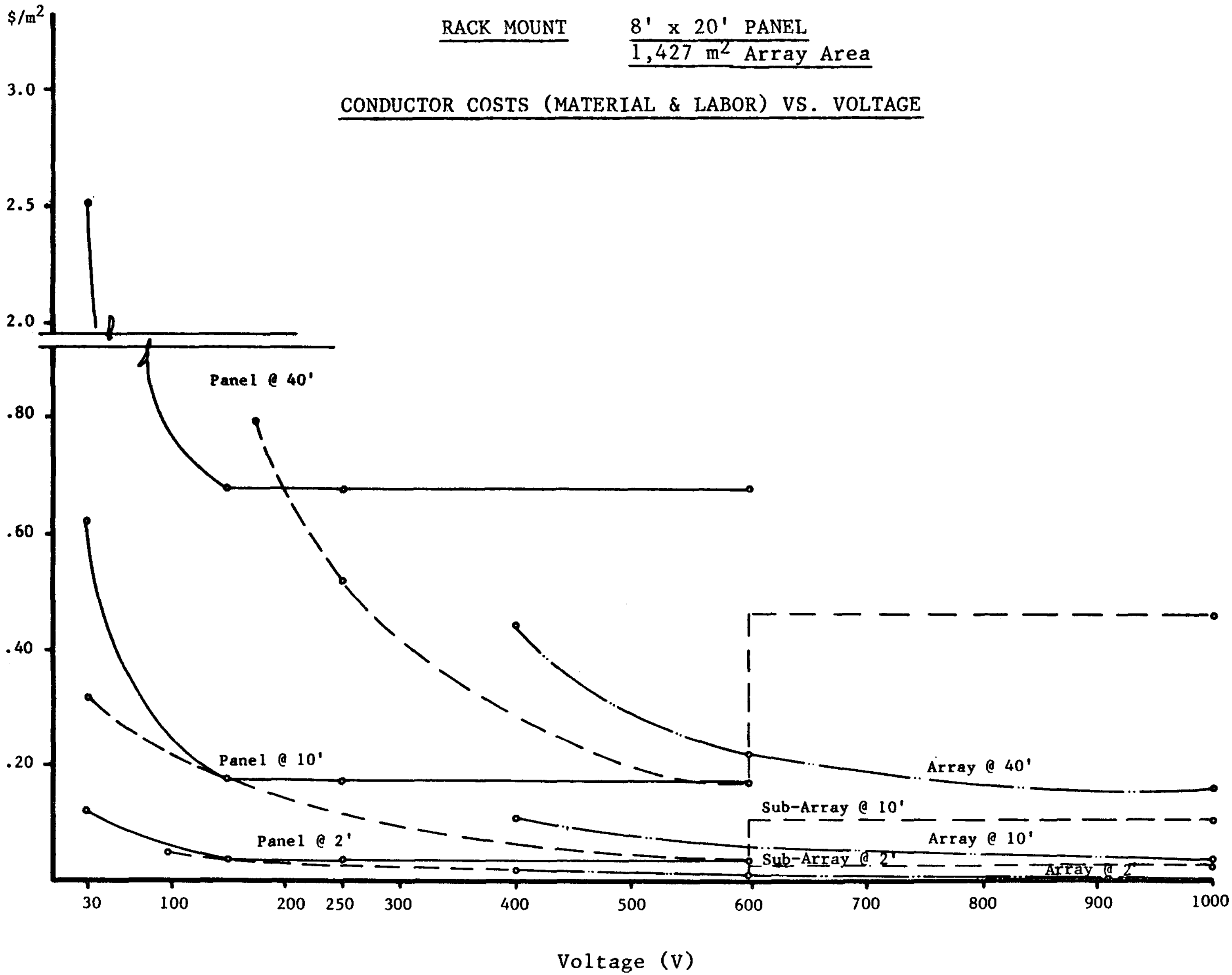
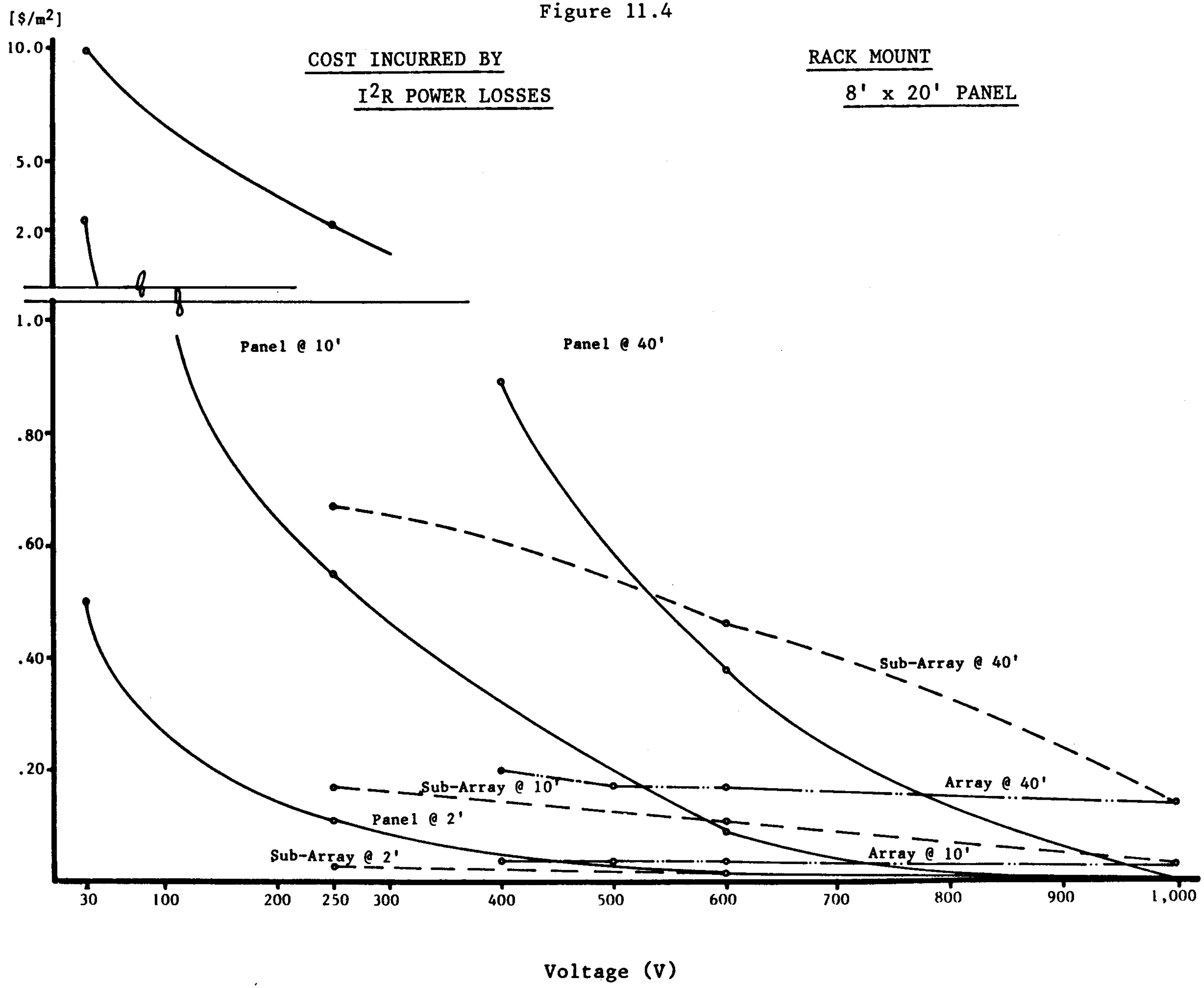

$/m2
3.0
2.5
2.0
.80
.60
.40
.20
RACK MOUNT
8' x 20' PANEL
1,427 m2 Array Area
CONDUCTOR COSTS (MATERIAL & LABOR) VS. VOLTAGE
Panel @ 40'
Panel @ 10'
Panel @ 2'
Array @ 40'
Sub-Array @ 10'
Array @ 10'
Sub-Array @ 2'
Array @ 2'
30
100
200
250
300
400
500
600
700
800
900
1000
Voltage (V)

Figure 11.4


[$/m2]
10.0
5.0
2.0
1.0
.80
.60
.40
.20
COST INCURRED BY
I2R POWER LOSSES
RACK MOUNT
8' x 20' PANEL
Panel @ 10'
Panel @ 40'
Sub-Array @ 40'
Sub-Array @ 10'
Array @ 40'
Panel @ 2'
Sub-Array @ 2'
Array @ 10'
30
100
200
250
300
400
500
600
700
800
900
1,000
Voltage (V)

however, it will be shown that this simple relationship does not hold, and that certain economic incentive exists with operation at higher voltages.

Figure 11.4, Cost Incurred by I^2R Power Losses vs Voltage, illustrates the reason why the conductor costs are not a linear function of voltage for panel voltages greater than 150 volts. These conductor costs in Figure 11.4 are also based upon the smallest acceptable conductor determined from a derated ampacity rating (according to the National Electric Code). Substantial cost penalties are experienced at lower operating voltages if the smallest conductor allowable is used. The reasons that very little array conductor power loss/voltage dependency exists is due to the substantially lower linear footage of conductor used, coupled with the very low electrical resistance experienced with conductors at that current level. The potential danger of large incurred costs due to this Joulean dissipation is found at the system's lower power levels due to:

1. Ability to use smaller but higher resistance conductor.
2. Larger number of conductors and thus increased length of the resistive path.

Again, it should be remembered that an actual cost associated with the power drop encountered in the leads is directly based on the assumed worth of the power produced. In this case, $1.50 per peak watt was used in this determination. A situation in which the life-cycle-cost analysis shows a produced power cost (worth) greater than this amount, places that much more emphasis on the cost of this lost power.

The combined cost of material, labor, and I^2R power loss allows for the determination of an optimum conductor size for a given system area and voltage. A family of curves have been developed which graphically delineate this cost as a function of conductor size. An example of this is given in Figures 11.5 through 11.7.

Figure 11.5

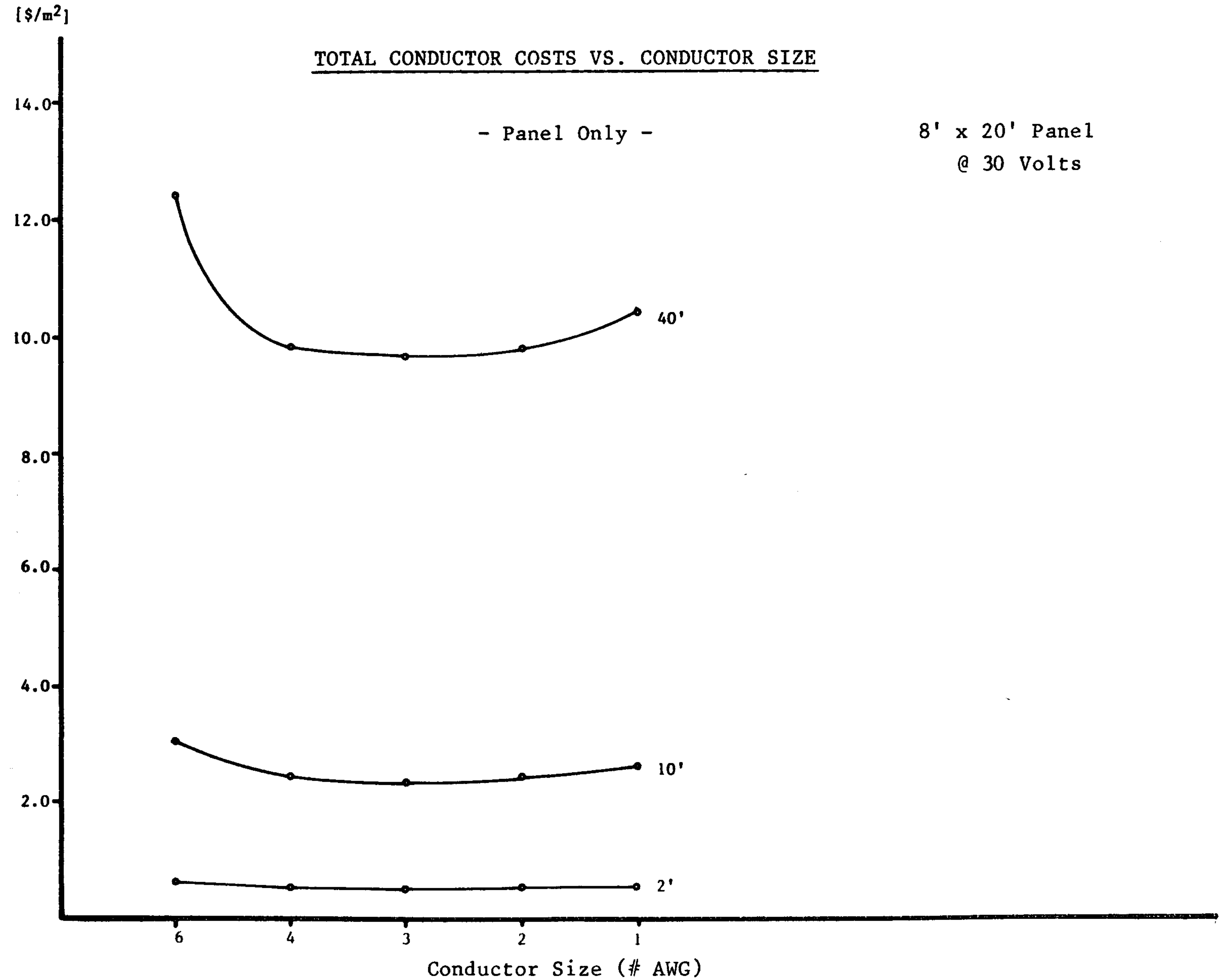
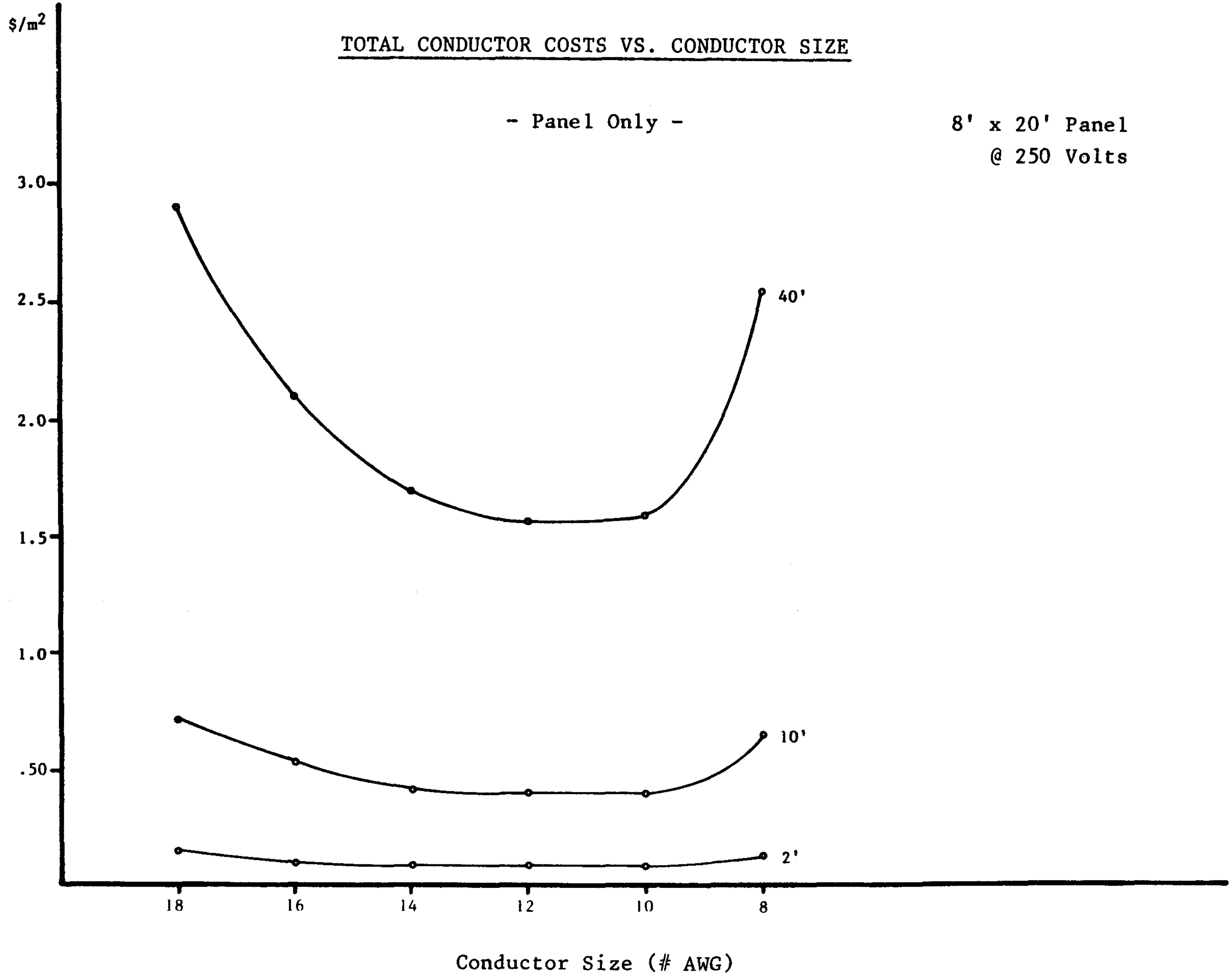
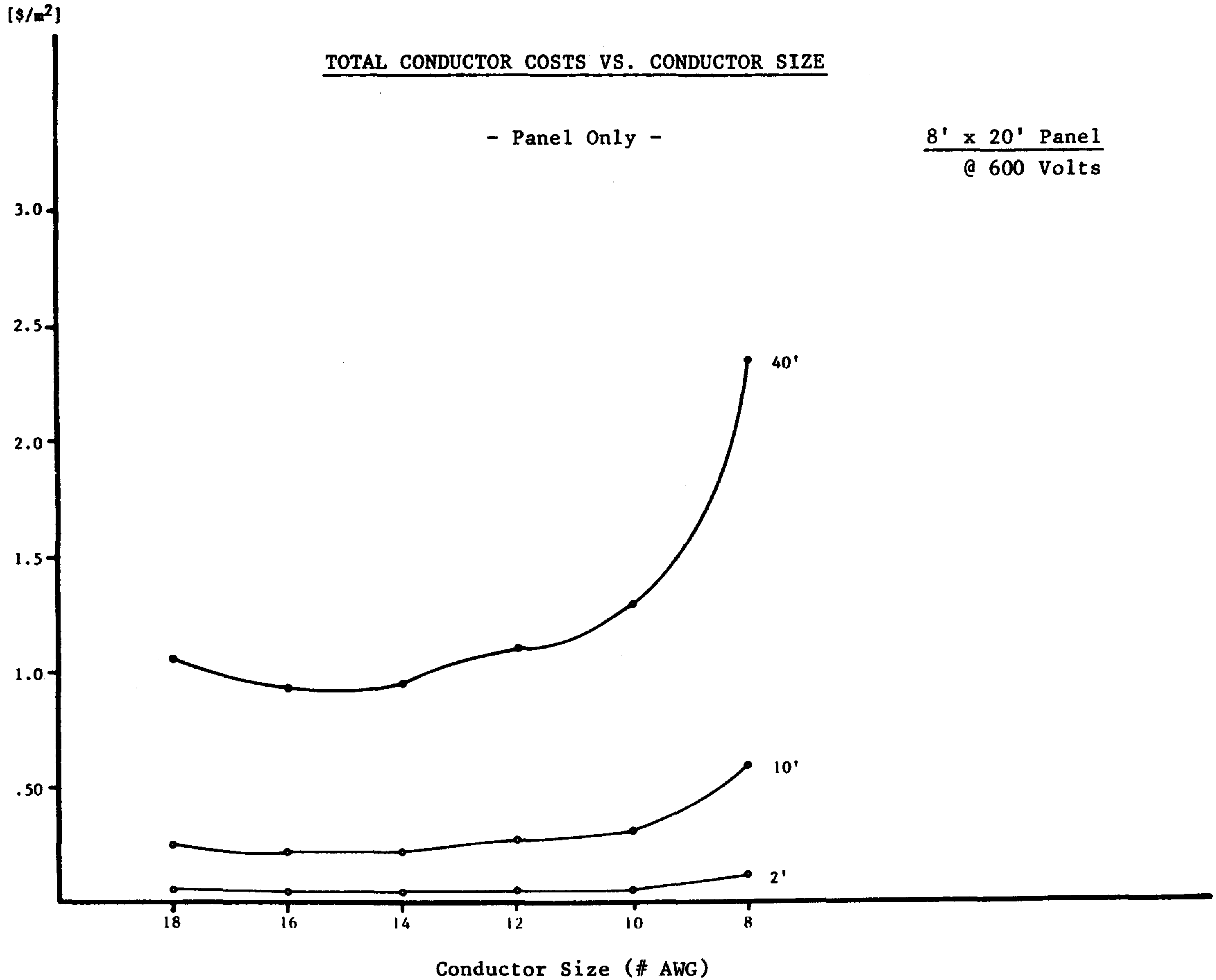

[$/m2]
TOTAL CONDUCTOR COSTS VS. CONDUCTOR SIZE
- Panel Only -
8' x 20' Panel
@ 30 Volts
14.0
12.0
10.0
8.0
6.0
4.0
2.0
40'
10'
2'
6
4
3
2
1
Conductor Size (# AWG)

Figure 11.6



$/m²
TOTAL CONDUCTOR COSTS VS. CONDUCTOR SIZE
- Panel Only -
8' x 20' Panel
@ 250 Volts
3.0
2.5
2.0
1.5
1.0
.50
40'
10'
2'
18
16
14
12
10
8
Conductor Size (# AWG)

Figure 11.7



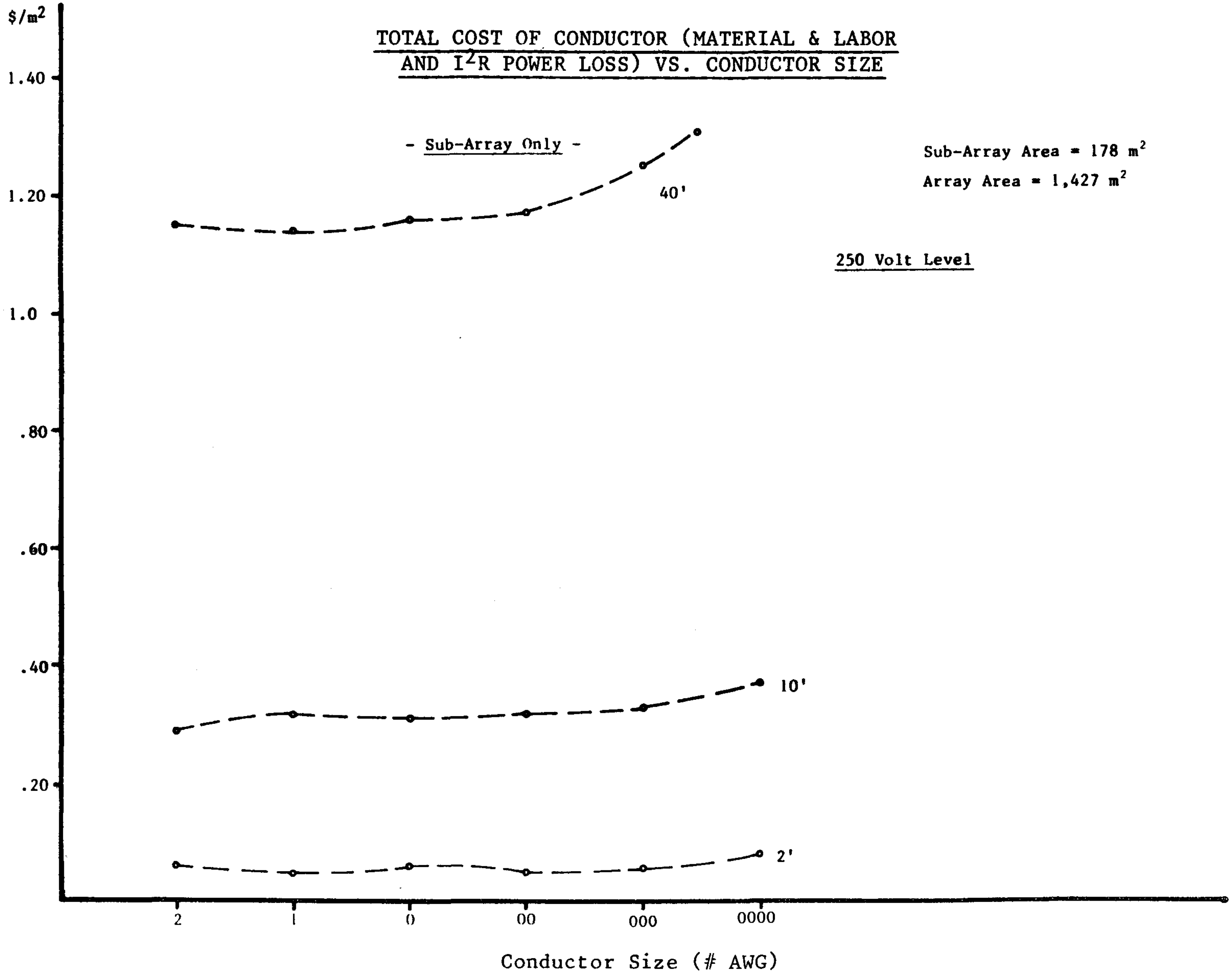
[$/m²]
TOTAL CONDUCTOR COSTS VS. CONDUCTOR SIZE
- Panel Only -
8' x 20' Panel
@ 600 Volts
3.0
2.5
2.0
1.5
1.0
.50
40'
10'
2'
18
16
14
12
10
8
Conductor Size (# AWG)

These show the total conductor costs, as described above, as a function of conductor size for the 8' x 20' panel at three voltage levels and at three conductor lengths. It can be seen that a minimum occurs for all cases, and that only at the larger voltages (lower current) do the costs show the least expensive conductor approaching the smallest allowable conductor. These cost curves are given for the sub-array and the array in Figures 11.8 through 11.13.

Once the minimum conductor cost was determined for the respective system level and voltage, more accurate cost/voltage curves were produced. Unlike Figure 11.3, these curves represent <u>minimum</u> conductor costs as a function of voltage. An example curve is illustrated in Figure 11.14 for the 8' x 20' panel, and curves for the sub-array and array are given in Figure 11.15 and 11.16. The data for the three panel sizes are presented in tabular form along with the minimum-cost-conductor size in Table 11.13.

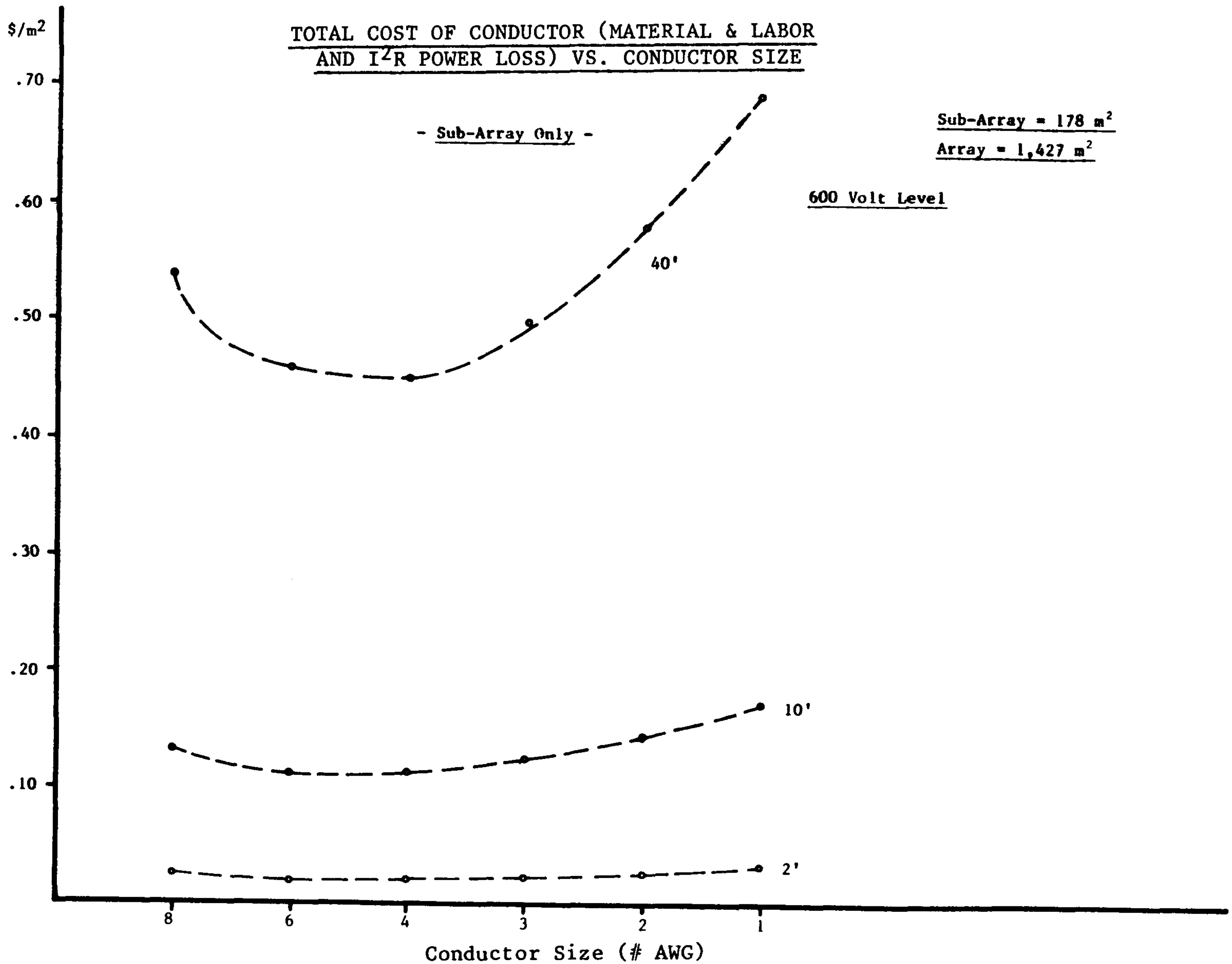
It is interesting to note what occurs in the region above 600 volts for the sub-array and array. For the sub-array there is no dependency of costs on voltage in this region. This is because of the fact that at 600 volts the sub-array current level is relatively small, so that a minimum #6 AWG conductor suffices. The small decrease in current obtained by operating at 1000 volts is not enough to lower the I^2R power loss noticably and thus the costs remain insensitive to voltage. This is not the case for the array level, as seen from Figure 11.17. In the greater than 600 volt region for the array, a conductor cost reduction does appear to occur as voltage increases. However, it appears that unless very long array conductor leads are expected, minimal, if any, savings can be expected from operating at system level voltages in excess of 600 volts. Additionally, extraneous NEC requirements, e.g. fences, may further prove high voltage operation economically uncompetitive in the commercial/industrial sector. It may be possible that systems with power output in excess of 145 kilowatts will show high voltage operation economical; however, systems of

Figure 11.8



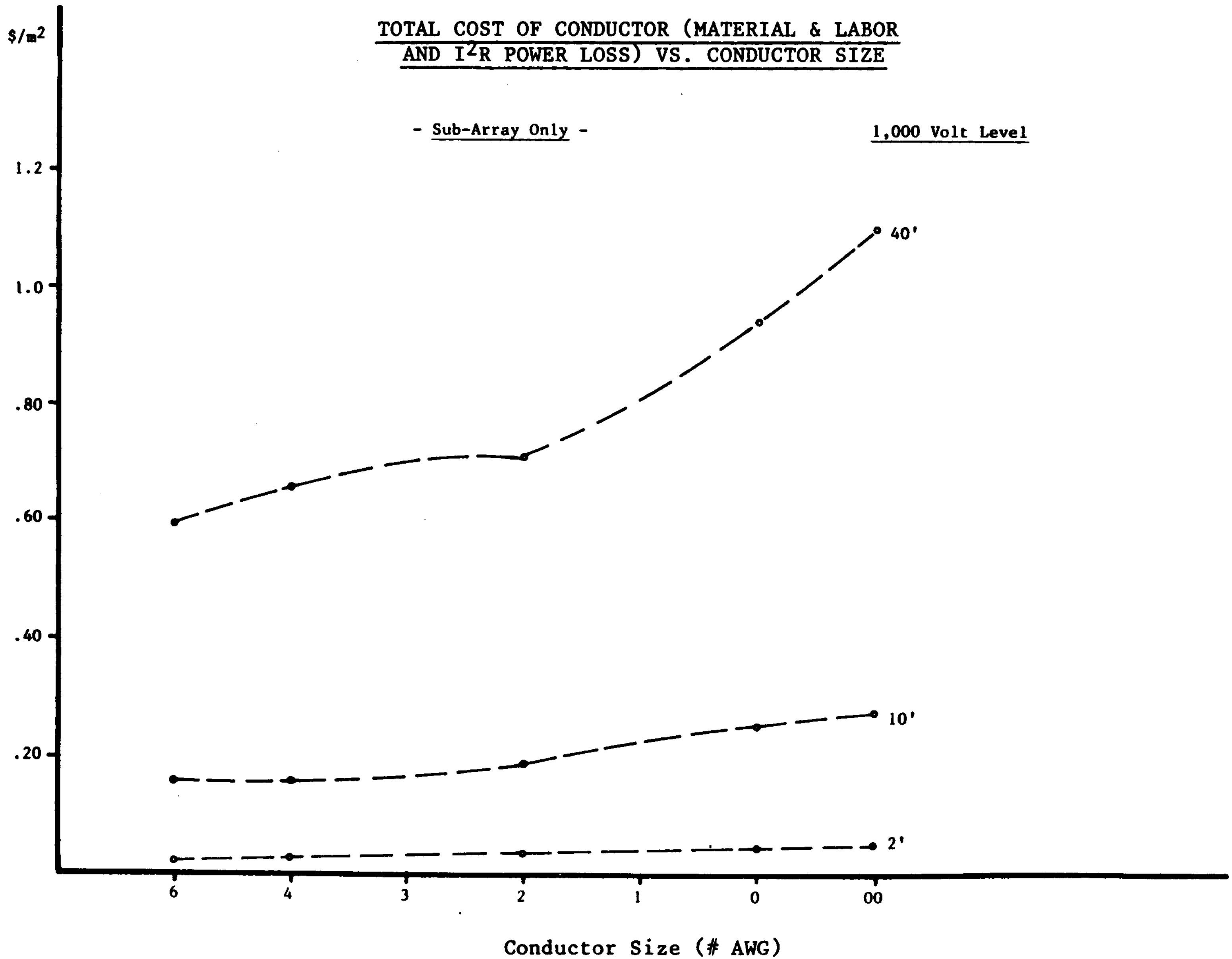
$/m²
1.40
1.20
1.0
.80
.60
.40
.20
TOTAL COST OF CONDUCTOR (MATERIAL & LABOR AND I²R POWER LOSS) VS. CONDUCTOR SIZE
- Sub-Array Only -
Sub-Array Area = 178 m²
Array Area = 1,427 m²
250 Volt Level
40'
10'
2'
2
1
0
00
000
0000
Conductor Size (# AWG)

Figure 11.9



TOTAL COST OF CONDUCTOR (MATERIAL & LABOR AND I^2R POWER LOSS) VS. CONDUCTOR SIZE
- Sub-Array Only -
Sub-Array = 178 m^2
Array = 1,427 m^2
600 Volt Level
$/$m^2$
.70
.60
.50
.40
.30
.20
.10
40'
10'
2'
8
6
4
3
2
1
Conductor Size (# AWG)

Figure 11.10



TOTAL COST OF CONDUCTOR (MATERIAL & LABOR AND I²R POWER LOSS) VS. CONDUCTOR SIZE
- Sub-Array Only -
1,000 Volt Level
$/m²
1.2
1.0
.80
.60
.40
.20
40'
10'
2'
6
4
3
2
1
0
00
Conductor Size (# AWG)

Figure 11.11

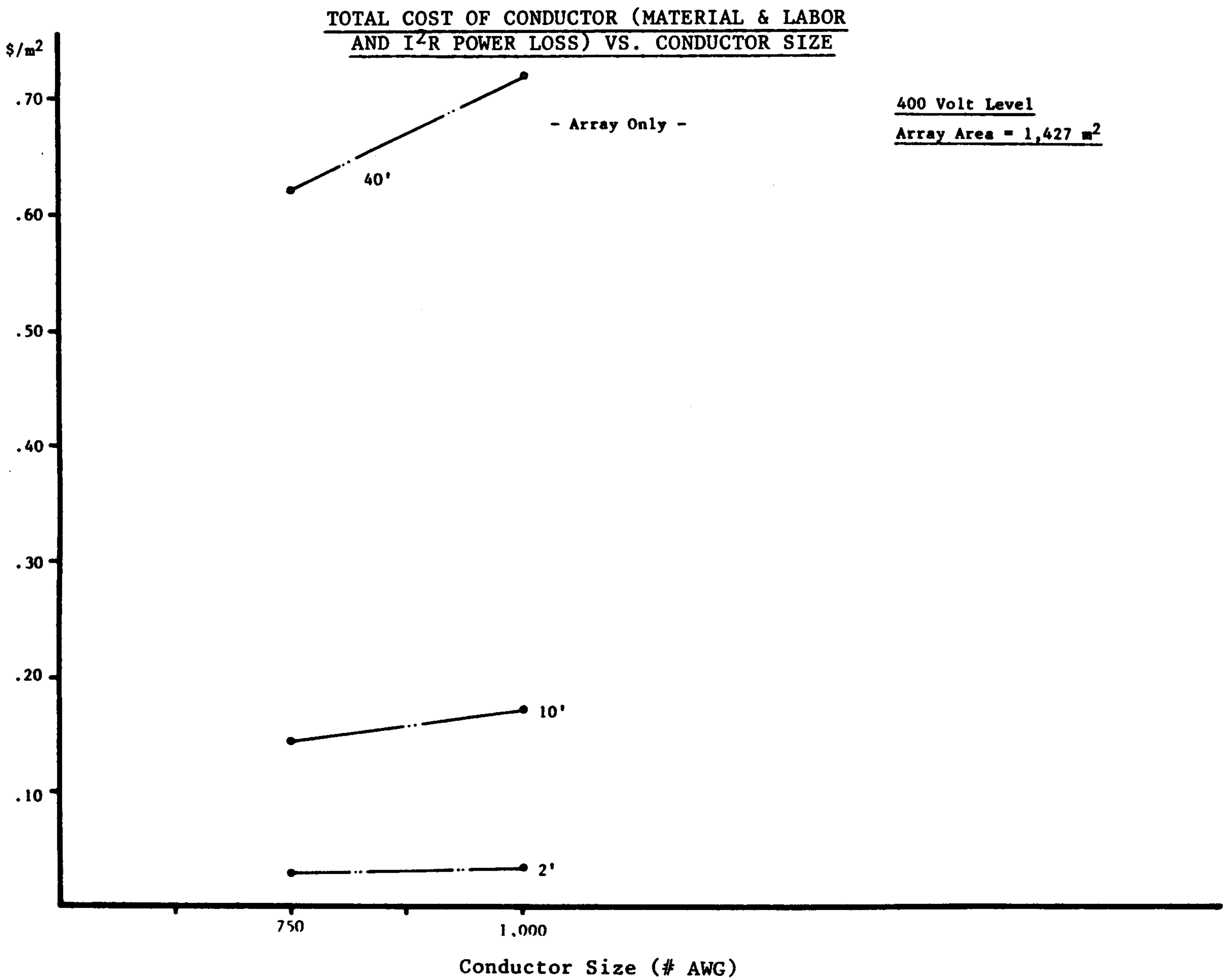

TOTAL COST OF CONDUCTOR (MATERIAL & LABOR
AND I2R POWER LOSS) VS. CONDUCTOR SIZE
$/m2
.70
.60
.50
.40
.30
.20
.10
- Array Only -
400 Volt Level
Array Area = 1,427 m2
40'
10'
2'
750
1,000
Conductor Size (# AWG)

Figure 11.12

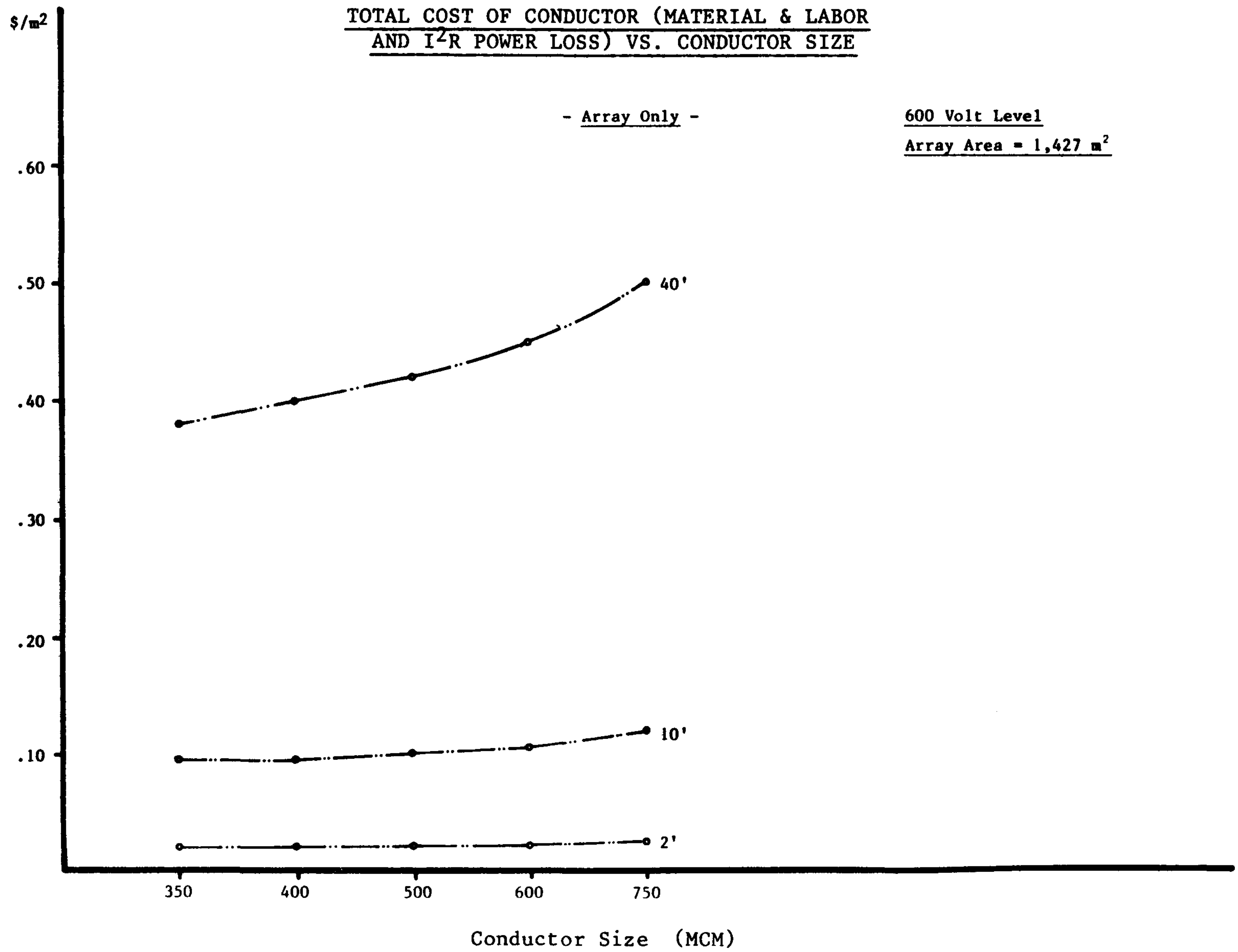
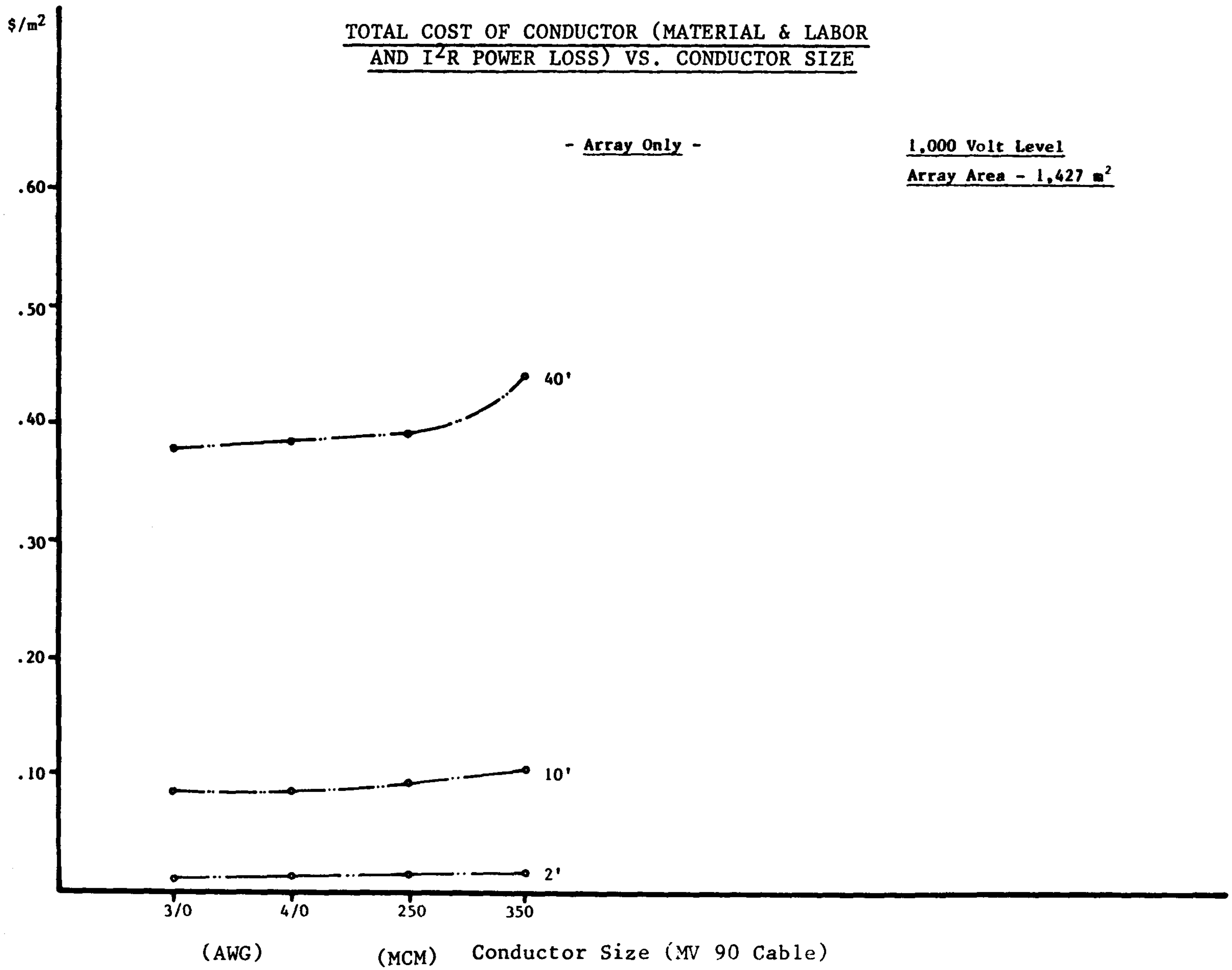
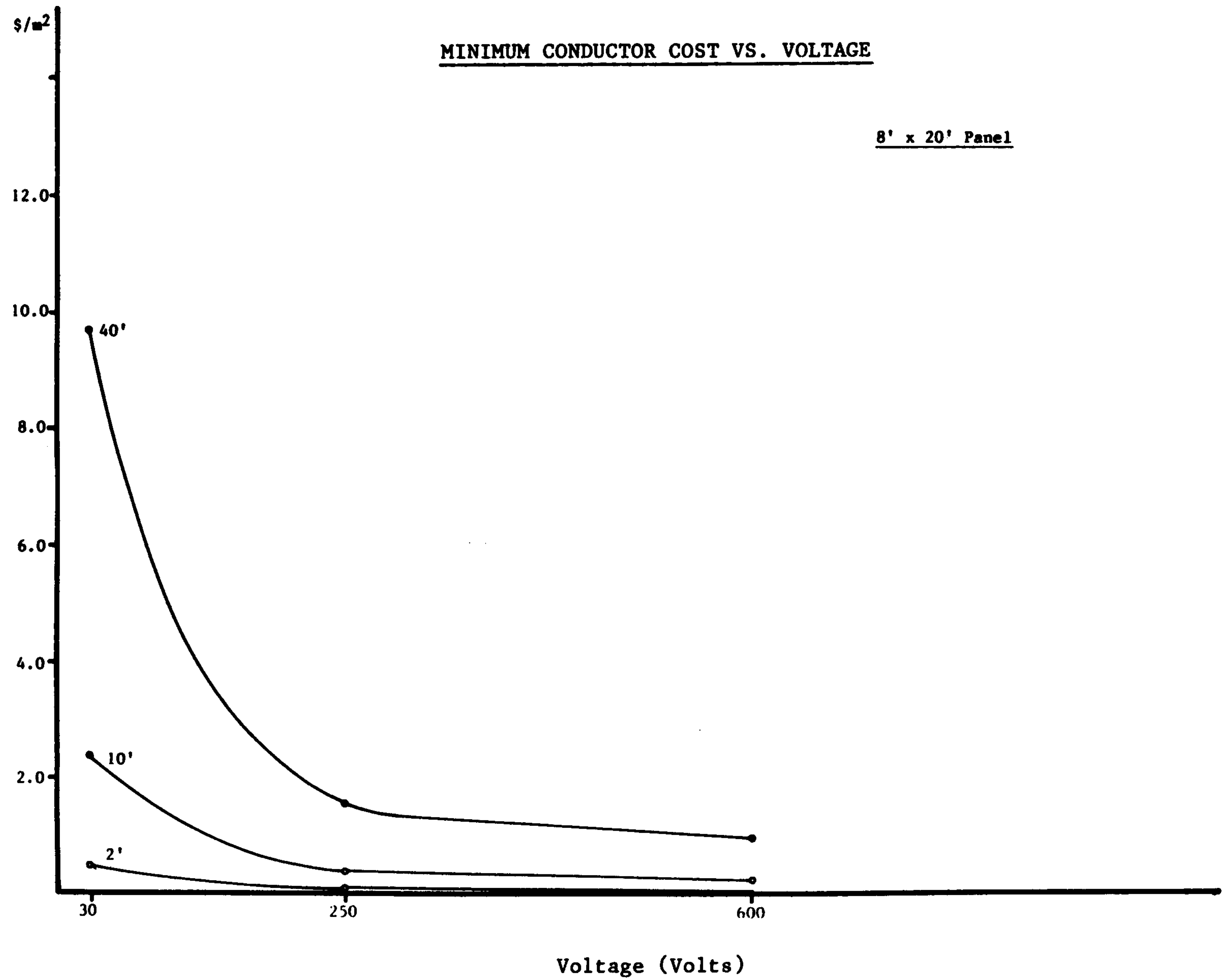

$/m²
TOTAL COST OF CONDUCTOR (MATERIAL & LABOR
AND I²R POWER LOSS) VS. CONDUCTOR SIZE
- Array Only -
600 Volt Level
Array Area = 1,427 m²
.60
.50
.40
.30
.20
.10
40'
10'
2'
350
400
500
600
750
Conductor Size (MCM)

Figure 11.13



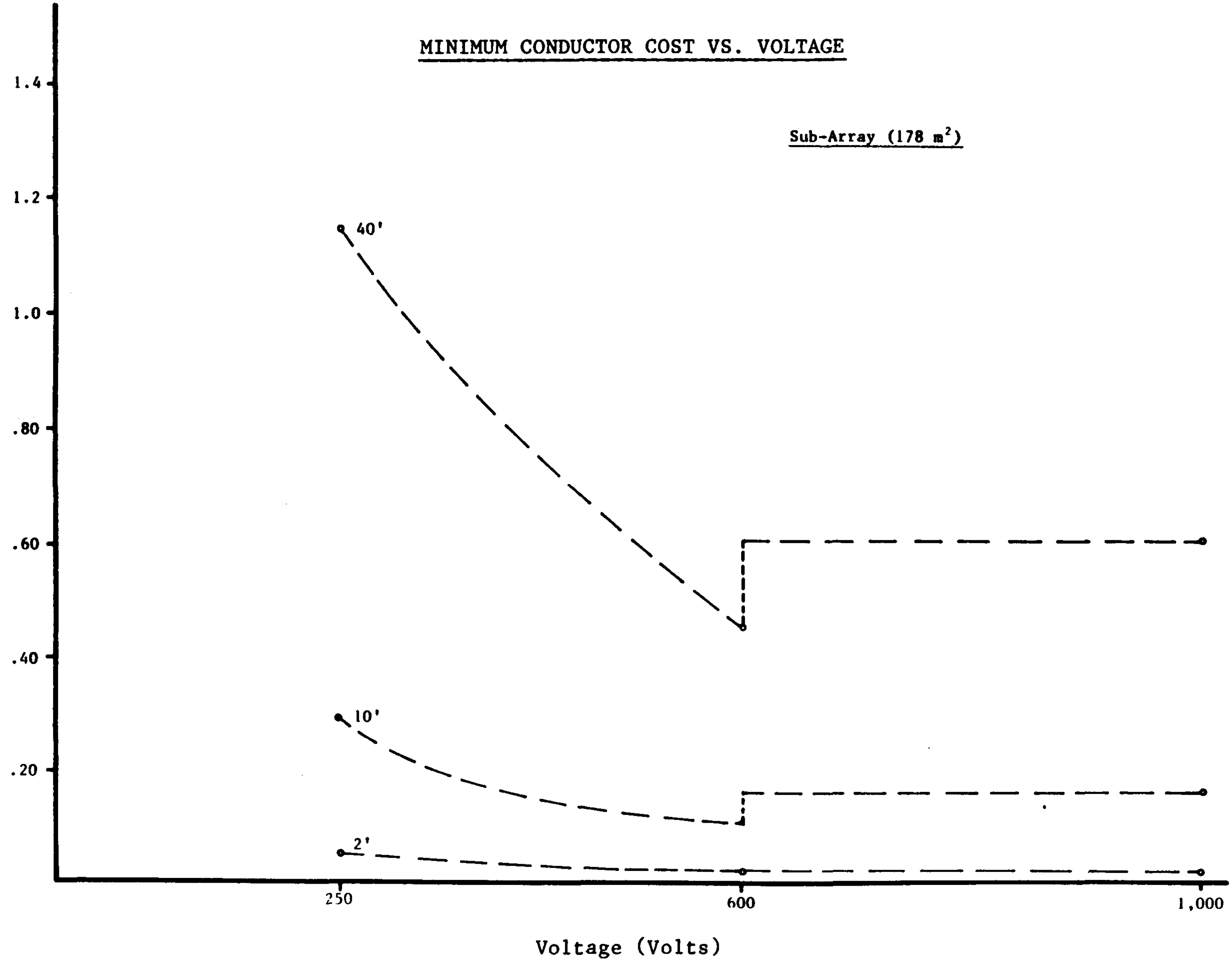
TOTAL COST OF CONDUCTOR (MATERIAL & LABOR AND I²R POWER LOSS) VS. CONDUCTOR SIZE
- Array Only -
1,000 Volt Level
Array Area - 1,427 m²
$/m²
.60
.50
.40
.30
.20
.10
40'
10'
2'
3/0
4/0
250
350
(AWG)
(MCM)
Conductor Size (MV 90 Cable)

Figure 11.14



$/m²
MINIMUM CONDUCTOR COST VS. VOLTAGE
8' x 20' Panel
12.0
10.0
8.0
6.0
4.0
2.0
40'
10'
2'
30
250
600
Voltage (Volts)

Figure 11.15



MINIMUM CONDUCTOR COST VS. VOLTAGE
Sub-Array (178 m²)
1.4
1.2
1.0
.80
.60
.40
.20
40'
10'
2'
250
600
1,000
Voltage (Volts)

Figure 11.16

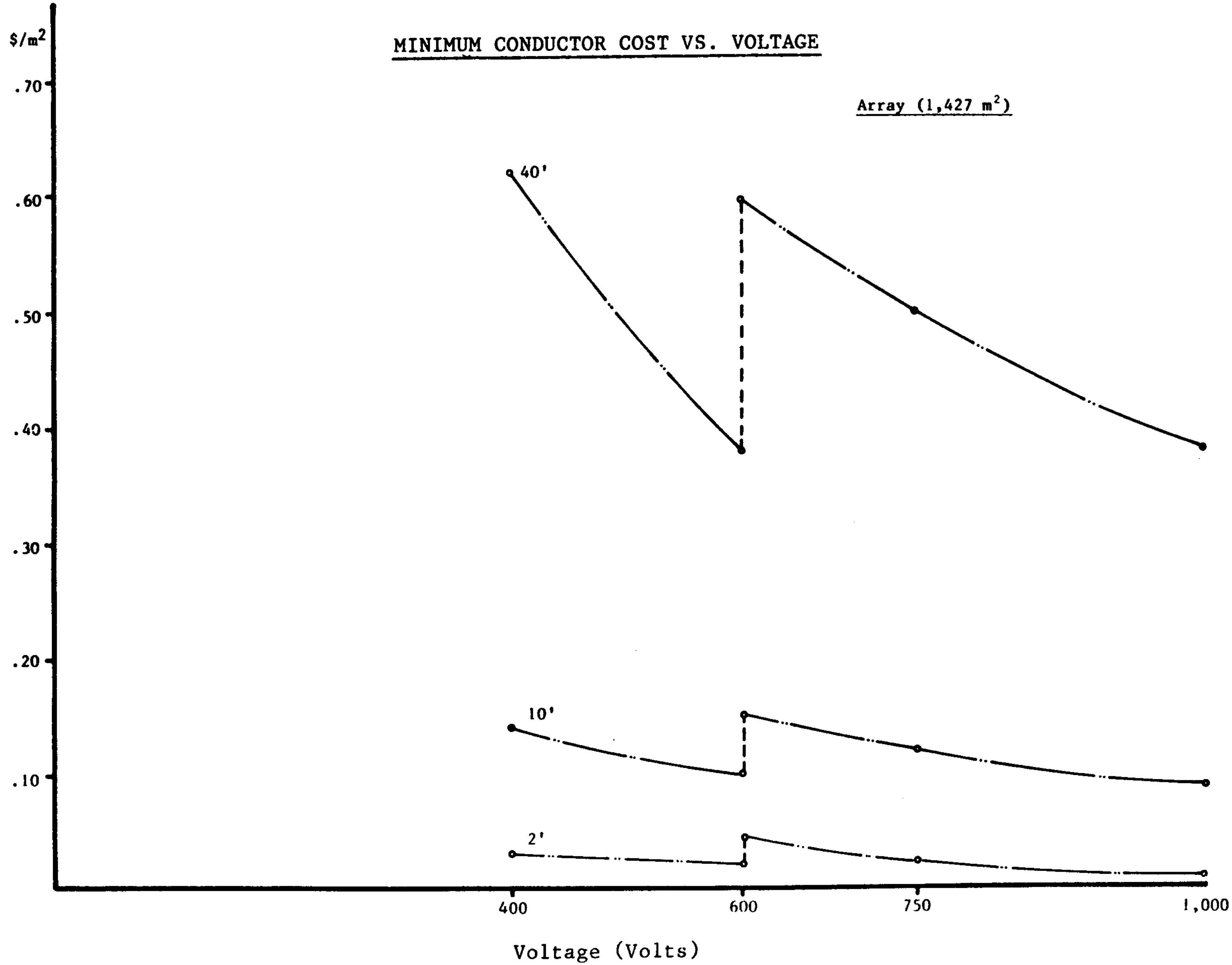

MINIMUM CONDUCTOR COST VS. VOLTAGE
$/m²
.70
.60
.50
.40
.30
.20
.10
Array (1,427 m²)
40'
10'
2'
400
600
750
1,000
Voltage (Volts)

Table 11.13

MINIMUM CONDUCTOR COST AND SIZE

30 VOLTS

Panel Size	Conductor	Minimum Cost ($\$/m^2$)	Size (AWG)
4'x5'	2'	0.64	#10 or #12
	10'	3.22	
	40'	7.28	
8'x20'	2'	0.47	#3
	10'	2.39	
	40'	9.64	
8'x40'	2'	0.45	#2/0
	10'	2.23	
	40'	9.00	

250 VOLTS

Panel Size	Conductor	Minimum Cost ($\$/m^2$)	Size (AWG
4'x5'	2'	0.28	#18 or #16
	10'	1.42	
	40'	5.68	
8'x20'	2'	0.08	#12
	10'	0.39	
	40'	1.56	
8'x40'	2'	0.06	#10
	10'	0.33	
	40'	1.31	

600 VOLTS

Panel Size	Conductor	Minimum Cost ($\$/m^2$)	Size (AWG)
8'x20'	2'	0.05	
	10'	0.23	#16 or #14
	40'	0.93	#16
8'x40'	2'	0.03	#14 or #12
	10'	0.16	#14
	40'	0.69	#12
4'x5'	2'	0.27	#18 or #16
	10'	1.38	#18
	40'	5.44	#18

this size in the commercial/industrial sector will most likely be unusually large and thus infrequently built.

Based on the electrical termination costs as presented in Section 11.3.3, cost curves were produced as a function of voltage. These curves proved to show little cost ($\$/m^2$) dependency at any system level as a function of voltage. However, because of the direct relationship between the panel size and the number of electrical connectors required, the cost does show an important dependency on panel area. This is illustrated in Figure 11..17, Termination Cost vs Area, where costs are determined for three termination types for 250 to 600 volts. It can be seen that electrical termination costs ($\$/m^2$) increase quite dramatically below an area of approximately 15 m^2, with the screw type being the most expensive and the crimp type being the least.

Table 11.14 gives the lowest conductor and termination costs for three system levels for the three panel areas considered in this study. The conductor costs include: material, labor, and I^2R power loss; and the termination costs include: material and labor. These costs were based on the following average conductor lead length for the three system levels:

1. Panel conductor length = 10 ft.
2. Sub-array conductor length = 40 ft.
3. Array conductor length = 10 ft.

These costs show, based upon all of the previously mentioned assumptions used in performing this cost analysis, that system level voltages should be kept as close to 600 volts as possible. However, closer inspection shows little cost sensitivity above certain voltages in some cases; and therefore, further considerations, e.g. safety, may persuade the system designer to operate the system at a lower voltage with a minimum cost penalty. The total costs are plotted in Figure 11.18.

Figure 11.17

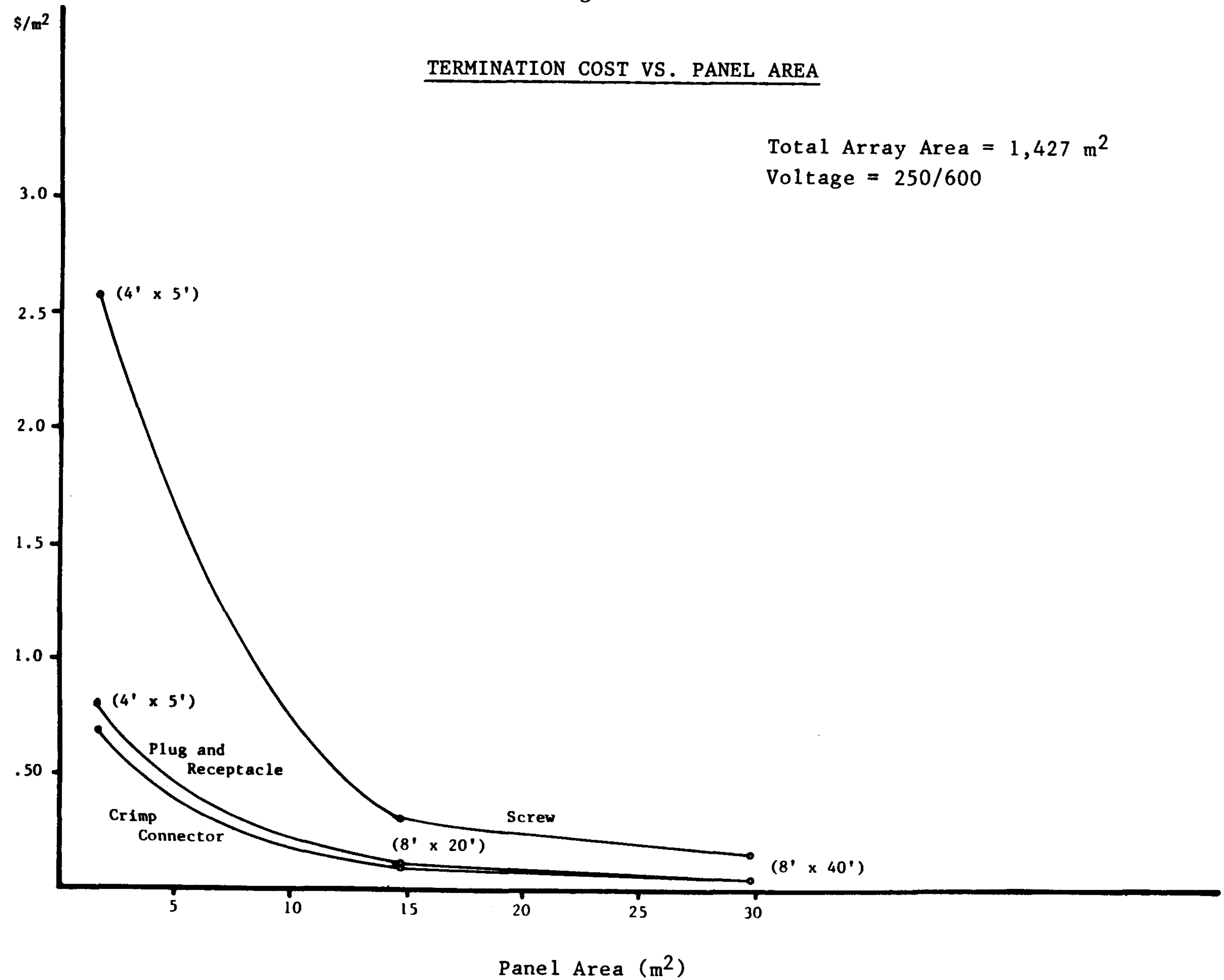

TERMINATION COST VS. PANEL AREA
Total Array Area = 1,427 m2
Voltage = 250/600
$/m2
3.0
2.5
2.0
1.5
1.0
.50
(4' x 5')
(4' x 5')
Plug and
Receptacle
Crimp
Connector
Screw
(8' x 20')
(8' x 40')
5
10
15
20
25
30
Panel Area (m2)

Figure 11.18

TOTAL ELECTRICAL CONDUCTOR & TERMINATION COSTS

VS.

PANEL AREA

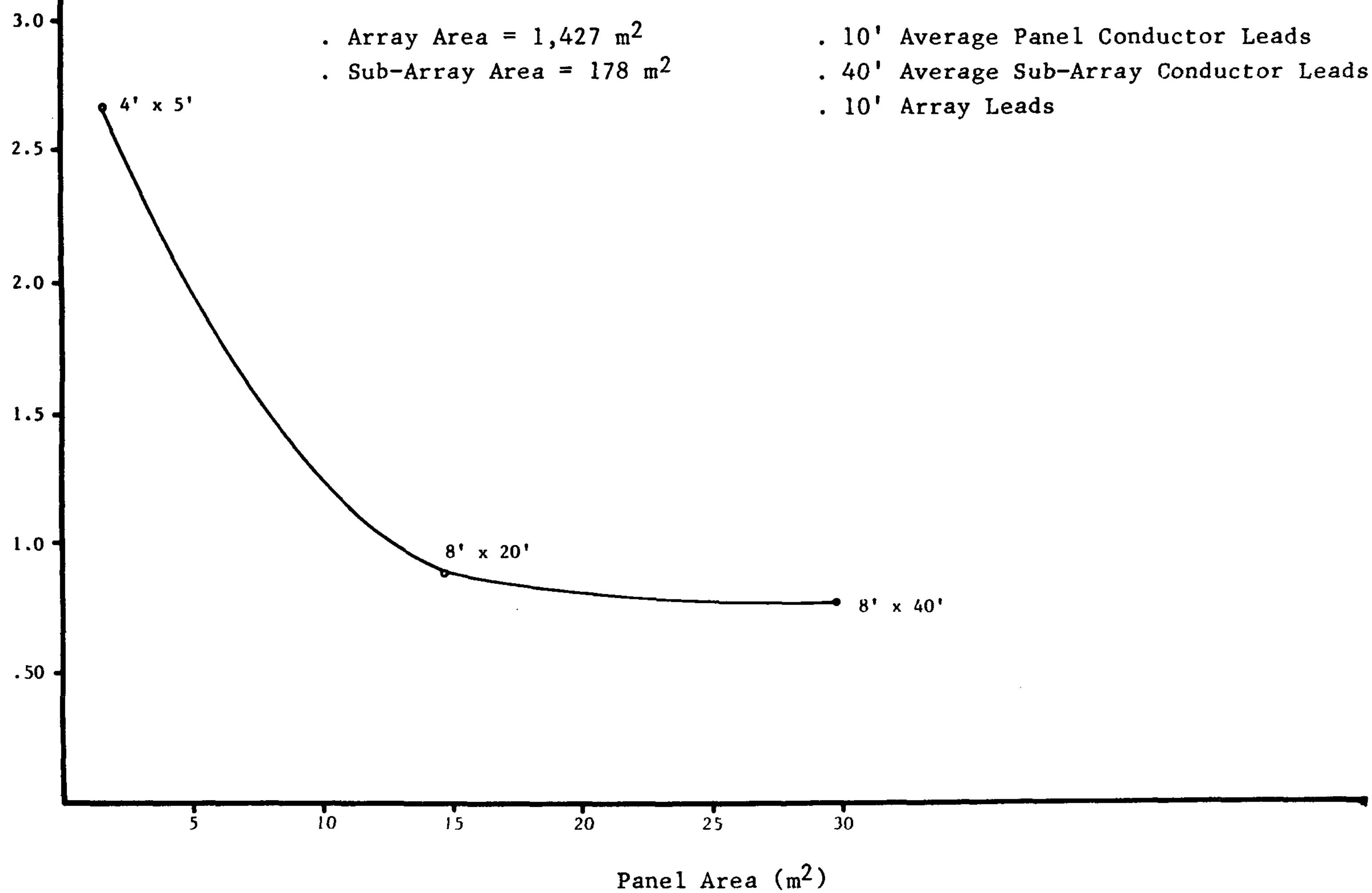


Table 11.14

Total Electrical Costs [Conductor Material & Labor, and Termination]

[$/m²] (BEST CASE)

SYSTEM LEVEL	PANEL SIZE 4'x5' (1.86 m^2)		8'x20' (14.9 m^2)	8'x40' (29.7 m^2)
Panel	Conductor:	1.38 @ 600v	0.23 @ 600v	0.16 @ 600v
	Termination:	0.74 (crimp)	0.09 w/crimp	0.05 w/crimp or P&R
Sub-Array	Conductor:	0.45 @ 600v	0.45 @ 600v	0.45 @ 600v
	Termination:	0.007 w/crimp	0.007 w/crimp	0.007 w/crimp
Array	Conductor:	0.10 @ 600v	0.10 @ 600v	0.10 @ 600v
	Termination:	-----	-----	-----

Assumptions:
1. Average panel conductor length = 10'.
2. Average Sub-Array conductor length = 40'.
3. System leads = 10'.

TOTAL COSTS [$/m²]

Panel Size	4'x5'	8'x20'	8'x40'
	$2.68/m²	$0.88/m²	$0.77/m²

11.3.7 COST DRIVERS

An important aspect of any costing analysis is the determination of the cost drivers. Using the optimized results of Table 11.14 shown previously, the following cost distributions were created. This cost breakdown is given for the three panel sizes that were considered in this analysis.

Panel Size

I. 4' x 5'

Conductor Cost:		Percent of Total
Material	- \$0.56/m^2	21%
Labor	- \$1.17/m^2	44%
I^2R Incurred Cost	- \$0.21/m^2	8%
Termination Cost	- \$0.74/m^2	28%
Total	= \$2.68/m^2	

It can be seen that for the 4' x 5' panel array, a majority of the cost lies in the labor cost of installing the conductors. This occurs due to the large number of panels required to make up the 1,427 m^2 array. It is interesting to note that if the smallest allowable conductor was used instead of the optimum-cost conductor, the total cost would have been \$7.84/m^2 and the I^2R power loss cost would have contributed 72% to this.

Panel Size

II. 8' x 20'

Conductor Cost:		Percent of Total
Material	- (\$0.285/\$0.31)/m^2	32%/35%
Labor	- \$0.24/m^2	27%
I^2R Incurred Cost	- \$0.27/m^2	28%/26%
Termination	- \$0.10/m^2	11%
Total	= \$0.88/m^2	

The two costs given for the material and the I^2R costs above represent #16 and #14 AWG conductor respectively. This larger panel reduces the cost driver of the 4' x 5' (the conductor labor) to 27 percent. A relatively even distribution of cost occurs for this 8' x 20' panel among the conductor material, conductor labor, and I^2R incurred cost. The termination costs contribute only 11 percent to the total.

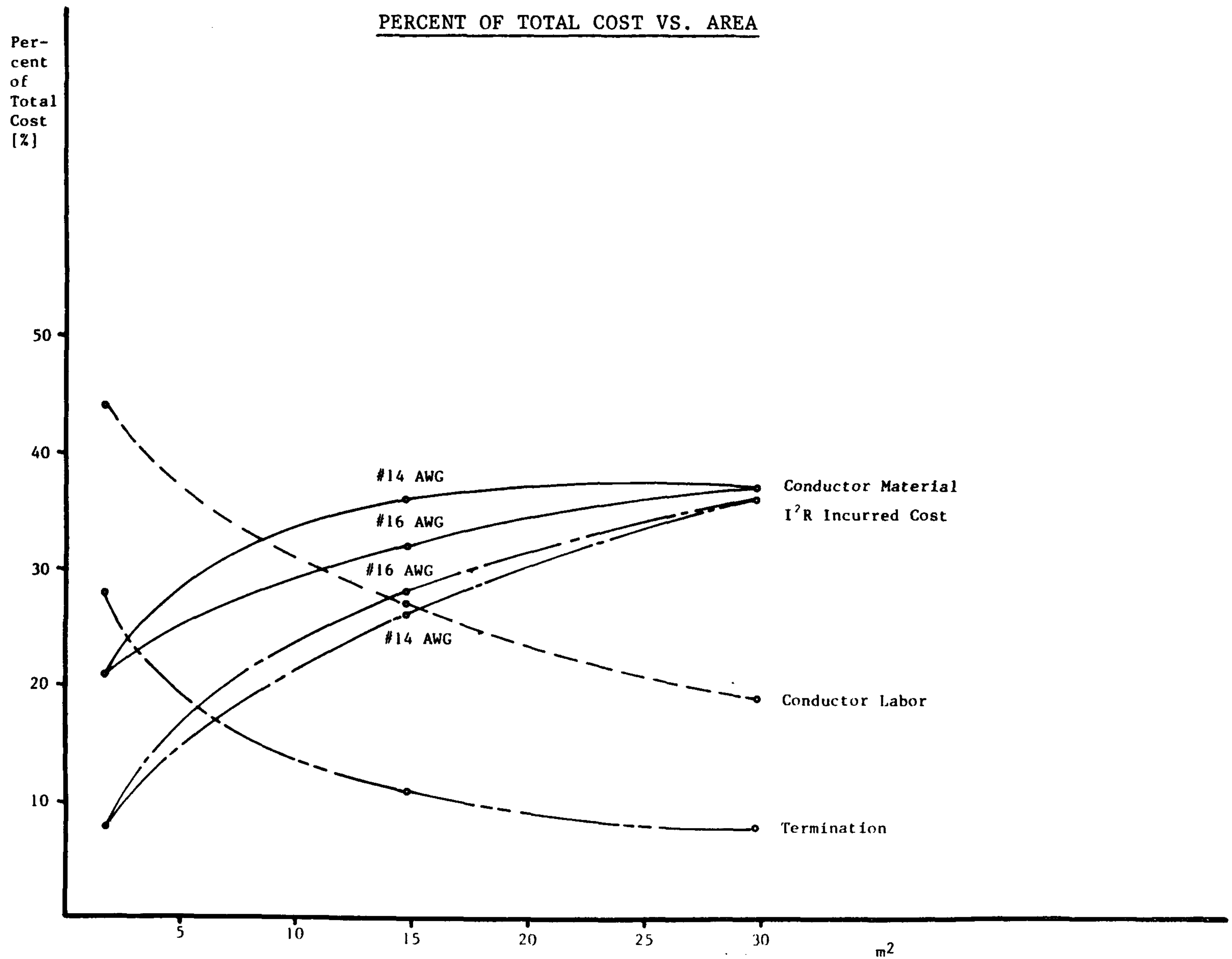
Panel Size

				Percent of Total
III. 8' x 40'	Conductor Cost:			
	Material	-	$0.28/m^2$	37%
	Labor	-	$0.14/m^2$	19%
	I^2R Incurred Cost	-	$0.27/m^2$	36%
	Termination Cost	-	$0.06/m^2$	8%
	Total	=	$0.75/m^2$	

The cost drivers for this large 8' x 40' panel are the conductor material cost and the I^2R incurred cost. Because of the limited number of terminations required, the related costs contribute only 8% of the total.

In summary, the development of cost data has allowed the cost drivers to percipitate out as a function of the panel size. It should first be remembered that the above figures are directly a function of the average conductor lengths assumed in Table 11.14. Any alteration in these lengths would most certainly affect the cost distribution. This "percent of total cost" trend is depicted graphically in Figure 11.19 on the following page. It is clearly shown that conductor labor and termination (material and labor) costs fall off in percent contributed as the panel size increases. The conductor material and the I^2R incurred costs, however, increase as panel area, and thus power, increases.

Figure 11.19



PERCENT OF TOTAL COST VS. AREA
Per-
cent
of
Total
Cost
[%]
50
40
30
20
10
5
10
15
20
25
30
m2
#14 AWG
#16 AWG
#16 AWG
#14 AWG
Conductor Material
I²R Incurred Cost
Conductor Labor
Termination

SECTION 12

OPERATION AND MAINTENANCE

12.1 INTRODUCTION

The objective of this section is to assess the impact of the characteristics of operation and maintenance on photovoltaic modules and panels if they are to be introduced into the commercial/industrial sector of the building industry. The approach used was to identify the general characteristics of commercial maintenance and how they may affect photovoltaic arrays, then determine the positive and negative attributes of specific design criteria with respect to maintenance.

Definitions

- Serviceability is a measure of the degree to which servicing the component can be accomplished under specified conditions within a given amount of time. Servicing is the performance of operations intended to sustain the intended operation of the component; this includes such items as painting and inspecting for mechanical and electrical integrity, but does not include periodic replacement of parts or any corrective maintenance tasks.

- Maintainability is a design and installation characteristic indicating the degree of ease with which a component can be restored to its proper operation condition. Maintainability is generally stated as the quantity of time required to restore or repair failures.

- Periodic maintenance is the action of performing normal maintenance procedures on a systematic basis by scheduling service and replacement of components in order to maintain performance or prevent failure.

- Preventive maintenance programs are planned procedures designed to retain a piece of equipment or a component at a specified level of performance.

- Corrective maintenance is an action taken as a result of failure in order to return an item to a specified level of performance.

- Accessibility is the quality or state of being easy to access.

- Repairability is the quality or state of being easy to repair.

- Cleanability is the quality or state of being easy to clean.

12.2 CHARACTERISTICS OF MAINTENANCE

Maintenance is the general servicing, repair or replacement of a component, system, or piece of equipment. There are basically two phases of any maintenance program: Preventative and corrective maintenance.

Preventative maintenance programs are planned and scheduled procedures which are enacted to retain a component at a specified performance level. They are also a method of budgeting and controlling maintenance expense. This may be accomplished by providing systematic inspections and maintenance for the detection and prevention of impending failures. A preventative maintenance plan for equipment or systems should minimize the frequency and difficulty of servicing, while providing maximum performance and prolonged life. These preventative maintenance programs should be established by the manufacturers of the system's components.

Corrective maintenance programs are procedures performed as a result of failure in order to restore a component or system to its designed level of performance. Tasks included in such programs include testing, failure isolation, and repair/replacement.

Should an owner determine not to implement a planned maintenance program, then the equipment will operate until it fails. This is, however, not a recommended approach. If a general maintenance program is not adhered to, it is recommended that any safety devices in the system be periodically inspected to insure operability.

All maintenance programs include to some degree the following:

1. Management maintenance policy, which consists of the objectives and type of maintenance program, the personnel required, organization, performance schedules, and cost information.

2. Records of the systems, systems components, and associated equipment including:
   a. Construction drawings and specifications
   b. As-built drawings
   c. Shop drawings and equipment catalogs
   d. Servicing instructions, maintenance instructions, troubleshooting checklists and spare parts lists.
   e. Service and spare parts sources.
   f. Systems diagrams.

3. Procedures and Schedules. This is the most important part of the maintenance program and relates to the operation, inspection, servicing, repairing and replacement of components and equipment. At a minimum, it includes the following requirements:
   a. Operating instructions.
      1. Starting and shutdown procedures.
      2. Seasonal adjustments.
      3. Logging and recording.
   b. Inspection
      1. That equipment to be inspected
      2. Points of inspection
      3. Time of inspection
      4. Methods of inspection
      5. Evaluation, recording and reporting
   c. Service and repair
      1. Frequency of service
      2. Service procedures
      3. Repair procedures
      4. Reporting

4. Operating and Maintenance Manuals. Operating and maintenance manuals provide instructions and information pertaining to the overall system. These manuals should be prepared by the system designer in conjunction with and/or including the component manufacturer's appropriate maintenance information. All preventative maintenance procedures should be included with adequate information to perform the necessary procedures. Required routine maintenance actions should also be included in the maintenance manual and are typically incorporated on a permanent label attached to the equipment. However, this label may merely indicate the required procedure which is more greatly explained in the operation and maintenance manual.

   The operation and maintenance manual can be organized in two parts, with Part I containing information on the system, and Part II covering the equipment components in the overall system.

Characteristics of Commercial Maintenance

In the commercial sector, the building owner is most often the principal charged with the responsibility of maintenance. In some cases, however, the tenant may be responsible for part or all of the maintenance. In either case, the party responsible for maintenance must determine:

a. What type of maintenance program to adopt.

b. Whether to provide for operation and maintenance by his own staff, or by contract.

The general skill level of most maintenance personnel retained by commercial organizations allows for the execution of relatively easy and minor maintenance practices. These include such items as cleaning and painting, and in some cases, lubricating and minor adjustments. However, detailed and technical maintenance practices are not typically performed by maintenance personnel employed by commercial organizations. These more complex tasks are carried out by more qualified individuals who are contracted under a short-term or long-term agreement.

There are generally three types of contracted maintenance:

1 Single service call where parts and labor are extra.
2. Periodic service call where parts and labor are extra.
3. Preventative maintenance where parts and labor are included.

The single service call where parts and labor are extra is usually initiated by the owner or tenant contacting the service organization and requesting assistance. Most service organizations charge a service fee for travel time and expenses to and from the site. Labor time spent inspecting, repairing or maintaining equipment is charged in addition to the service fee. Cost of parts required when repairing a system is also an additional charge.

The periodic service call where parts and labor are extra usually includes inspections and maintenance which are part of a preventative maintenance program. The frequency and type of inspections and maintenance are usually specified in a contractual agreement between the owner or tenant and the maintenance organization. The fee for performing the inspections and maintenance is also part of the contractural agreement. Any parts or labor required for repair or maintenance but not included in the contractual agreement are billed in addition to the contract fee.

In preventative maintenance contracts where parts and labor are included, the maintenance organization is solely responsible for maintaining the equipment or system. During the life of the contract, the maintenance organization charges a single fee that covers all inspections, maintenance and repairs on the equipment or system. The fee is specified as part of the contractual agreement between the owner or tenant and the maintenance organization.

Characteristics of Commercial Maintenance Relative to Photovoltaics

The maintenance of photovoltaic panels and arrays in commercial applications requires varying skill levels in order to accomplish the many and varied maintenance tasks associated with these devices. Maintenance tasks which are specifically related to photovoltaic panels include: panel replacement, cleaning, wiring repair, termination repair, and problem detection. There are also many general maintenance procedures which will be performed on the photovoltaic array in order to maintain a specified array output over the life of the system.

Of the above mentioned tasks, only general maintenance procedures, such as painting, partial cleaning, and perhaps visual inspection, will be performed by the typical maintenance staff employed by the commerical organization. The remainder of these tasks will be performed under contract or by arrangement by professionals.

It is important to note the photovoltaic array is not a complex apparatus; it is an electrical generator. To the general building owner, tenant, or the general maintenance personnel, electricity is a dangerous and complex phenomenon. Therefore, in the minds of most of these people, only qualified personnel should perform maintenance tasks on electrical equipment. Special problems arise when dealing with photovoltaic panels, as they are electrically active when exposed to light. This increases the general fear factor related to working on electrical equipment and decreases the likelihood of building owner, tenant, or the general maintenance personnel involvement in maintenance/repair operations. With photovoltaic panels being electrically active during daylight hours, special precautions must be taken before any maintenance tasks can be performed. As several of these procedures are required on the systems level, it is important that the system designer has a good understanding of the potential maintenance procedures required during the life of the system. It is important to measure for leakage current to ground as well as any leakage current through the frame of the system. As an overall precaution, the system should not be considered safe until checked with the appropriate measurement. The array is then ready for any maintenance procedures.

Specific safety procedures must be developed for individual photovoltaic power systems. Each component in a system should be supplied from the manufacturer with an instruction manual which should include a description of all safety precautions and procedures. The system designer or the system supplier should provide a systems maintenance manual describing all maintenance procedures and schedules detailing the necessary safety procedures. By adhering to the guidelines established in the maintenance manual, the array should be in a "safe condition" before maintenance actions are initiated.

For a detailed description of an example safety procedure related to photovoltaic arrays, see "Safe Procedures for the 25kw Solar Photovoltaic Array at Mead, Nebraska" by Massachusetts Institute of Technology Lincoln Laboratory, 7 April 1978. The safety procedures recommended by the manufacturers and the photovoltaic systems designer must be adhered to in order to insure the safe and successful performance of all maintenance actions.

Because of the physical size of commercial photovoltaic arrays, automated service platforms for cleaning and repair of the arrays are often justified. The automated platforms can result in a savings in manpower required to service an array, and when properly designed are more safe than most conventional service structures. By making it more convenient to service the array, the automated service platform may help to insure that service is performed as scheduled, or as required.

12.3 DESIGN CRITERIA AFFECTING MAINTENANCE

The design criteria for commercial photovoltaic arrays which affects the maintainability of those arrays is generally a function of the following characteristics:

- Panel/Array Mounting Type
- Installation/Replacement Type
- Wiring Location
- Termination Type

Panel/Array Mounting Type Description

The four generic mounting types identified and defined in Section 5 of this document and listed below each have unique characteristics. For this reason, they are handled separately in the remainder of this description.

- Rack Mounting
- Standoff Mounting
- Direct Mounting
- Integral Mounting

1. Rack Mounting: Rack mounted photovoltaic arrays can be located on the ground away from the building or on the roof of the building. Of the four mounting types, rack mounted panels are perhaps the easiest to install and maintain. This is due to the relative ease of accessibility to both the front and back surfaces of the panel. This is especially true of ground mounted arrays. Panels can be easily cleaned, wiring systems are easily accessible, and generally, mounting systems are easily reached for panel replacement. Also, as this mounting type does not require array waterproofing, a minimum amount and number of materials are used in this installation. Therefore, during maintenance procedures, such as panel replacement, additional costs are not required for the replacement of expensive materials other than the panel itself; i.e., no expensive gaskets or waterproofing materials are required.

   There are, however, some drawbacks to rack mounting of PV arrays. Structural costs, both initial and maintenance, can be high for this type of mounting technique. As seen in earlier studies, the use of wood, by virtue of its low cost, is recommended for rack mounted arrays. This implies either specially treated woods or the painting of the rack structure. This requires additional maintenance tasks be performed over the life of the array. Another critical problem associated with rack mounted arrays and related to the maintenance of such arrays is the areas around the roof penetration caused by the rack. Special detailing and care must be given to these roof penetrations to insure the watertight integrity of the roof.

2. Standoff Mounting: Elements that separate modules or panels from the roof or wall surface are known as standoffs. By supporting the panel away from the surface, air and water can pass freely behind the module. However, if the panel to roof surface distance is small and does not allow easy access of the rear surface of the panel, all installation and maintenance procedures need to be performed from the easily accessed top surface. This will require specially designed mounting details and electrical integration details.

   However, this mounting type may utilize fewer materials associated with structural support of the array. As with the rack mounted arrays, special attention must be given to the detailing of any roof penetrations. This implies that the overall installation costs for a standoff mounted array may be less than that associated with a rack mounted array. This does not imply that the costs relative to operation and maintenance will be lower. Unless considerable effort is employed in the design of the array, the standoff mounted array will be extremely difficult and costly to maintain.

3. Direct Mounting: Installation of direct mounted panels is accomplished by attaching the panels directly to the roof or wall surface. This mounting type eliminates the need for additional structural supports. Special care must be used in developing and detailing direct mounting modules as they act as a waterproof membrane. If a typical panel is used, perimeter waterproofing is needed; if a simple overlapping technique is used, it will afford a watertight surface. However, the overlapping module may be more expensive to replace, as other modules will be disturbed during such operations.

   Due to the direct mounted system's inherent contact with the roof, several major problems exist. These problems are similar to those experienced when using a standoff mounted system. It is necessary for all installation and electrical terminations to occur on the exposed surface, thus allowing easy installation, maintenance and repair procedures.

With overlap type modules, special consideration must be given to the maintenance procedure as the interruption of surrounding modules must be minimized to reduce the probability of damaging additional modules.

4. Integral Mounting: Integrally mounted panels are placed within the roof or wall structure itself. The panels are supported by the existing structural framing members and serve as the finished surface. Therefore, the roof or wall becomes a waterproof membrane. With the array acting as the roof or wall, special problems exist. In the event that a photovoltaic panel must be removed, it is imperative that a replacement be installed immediately. Without a replacement, the building is then open to the weather increasing the risk of damage to the interior.

   Installation and electrical connections, as well as maintenance procedures, may be performed from the inside of the building provided the panels are not attached above a cathedral ceiling. This mounting technique allows for venting of the back surface of the panel. However, uneven heating of the array may occur in the event that improper venting occurs in the space between the array and the interior of the building. Therefore, care must be taken during the maintenance operation to insure that proper ventilation continues in this dead space.

   Maintenance operations associated with the repair and replacement of wiring, the detection of electrical problems, and the general electrical testing of the array can take place during any weather conditions as these operations can take place under the cover of the roof of the building. It should also be noted that no additional roof structure and associated maintenance of said structure will be required in this mounting system, as this structure is not exposed to the environment.

Installation/Replacement Type Description

In panelized construction there are three categories into which installation and maintenance operations may fail. These classifications relate to the installation/replacement type and the procedures necessary to perform these operations. These three categories are:

1. Sequential
2. Partial Interruption
3. Independent

Each of these categories imposes certain design, installation and maintenance requirements on the panel and array. The installation, operation and maintenance requirements will be considerably different for each of the three categories.

The following is a brief description of each of the three panel construction types:

1. Sequential: Sequential paneling requires the successive installation and/or removal of panels. A good example of sequential paneling installation is that used for insulated tongue and groove wall panels. The rows are successively installed from one corner of the building to the next. In the event that a panel in the wall is damaged, the replacement of that panel requires the removal of all panels between the damaged panel and the nearest corner.

   This construction type is the most difficult to replace. In order to successfully utilize sequential paneling for photovoltaic systems, it is necessary to reduce the need for maintenance, requiring replacment of panels, by insuring long, uninterrupted life of the panel. This requirement may impose severe restrictions on the materials and packaging of photovoltaic arrays. Therefore, it is necessary to perform a thorough optimization relating initial costs and maintenance costs over the expected life of the system.

Due to the potential for high maintenance costs associated with sequential paneling systems, it is not likely in the near future to find photovoltaic modules requiring strict sequential paneling techniques in maintenance operations. It is possible, however, to have panels requiring sequential installation while modules utilize partial interruption or independent techniques.

2. Partial Interruption: A building panel which falls into a partial interruption category can be replaced by disturbing only the adjacent modules. This technique will be more expensive to use for the installation of panels but less expensive to maintain than the sequential paneling technique, if it is used for mounting modules into panels. It will be possible in this technique for adjacent modules to use common parts. However, due to the use of common parts it becomes necessary to disturb the surrounding modules during certain maintenance procedures, such as panel replacement. In the event that a module must be removed from this type system, it is necessary to replace it immediately with a new panel or a dummy panel to insure the integrity of the mounting system.

3. Independent: Independent paneling is a panelized construction where panels or modules can be installed, removed and replaced for maintenance with no additional interruptions or disturbances of the surrounding panels. This panelized construction technique is the least difficult to maintain but is the most widely used in commercial construction because it is generally the most efficient from an installation standpoint. However, materials cannot be shared by adjacent panels thus increasing the number of materials associated with this technique.

<u>Wiring Location</u>

Wiring should be designed of such a quality that normal operation of the photovoltaic array in any climate should not degrade the wiring in any manner. Insulation, conduit and conductors, therefore, should be designed to function for the life of the array. Occasionally, however, factors beyond the control of the designer may damage the wiring; such factors include vandals, vermin and unusual environmental conditions. It is possible for a vandal to cut insulation on wiring or even shear wiring with a knife or pair of wire cutters and risk receiving an electrical shock that could be fatal. In such a case, the owner may be held legally responsible for the vandal's death or injuries. Vermin could gnaw insulation of a wire or even sever a wire completely, in which case the animal may also receive a fatal shock. Extreme environmental conditions which could damage wiring include thermal cycling, high winds, and airborne pollutants such as ozone.

Regardless of the cause, wiring degradation occurs on three levels - universal degradation of insulation, localized shearing of conductors and insulation, and localized insulation failure. Universal degradation of insulation requires replacement of the length of the wire involved. Procedures for wire replacement require the removal of the wire from the terminal contacts at each end, removing the wire from its location, relocating a new wire, and connecting the ends of the new wire to the terminal connectors. Localized shearing can be repaired either by replacing the wire or by reconnecting the wire with a modular quick connect terminal or by splicing. Localized insulation failure can be repaired by any of the repair procedures previously mentioned but may simply require a wraparound device capable of insulating the conductor.

The ease of performing the above mentioned procedures is dependent upon the mounting type, the location of the wiring with respect to the module, and the location of the array, be it ground or roof mounted. The replacement operations for exposed wiring may be accomplished with little difficulty. Wiring located within a cable bus requires the additional operation of removing a cover or access panel before proceeding with the wiring replacement procedure. Defective wiring within a conduit must be removed from the conduit before repairs can commence. Wiring located beneath panels may require the removal of one or more panels for wiring repair unless some other means of access is provided.

Termination Type

Terminals should be designed to withstand normal operating stresses, and sealed to prevent corrosion or oxidation of metal contacts. Wiring should be secured in the terminal housing to provide reasonable resistance to dislocation of the contacts. In the event that operating stresses exceed the design limits and/or seals are broken, terminals may require repair or replacement. Damage to terminals could result from mishandling during installation, improper installation, carelessness during maintenance or replacement operations, vandalism, vermin and unusual environmental conditions. Causes for damaged terminals are dependent on terminal type, design and location. Three terminal types have been identified as candidates for the electrical interconnects of photovoltaic panels: crimp, screw, and plug/receptacle.

Two major factors, accessibility and repairability, dictate the procedures used for the repair or replacement of terminals. Terminals integral to and mounted beneath modules require the removal of the module in order to gain access to a damaged terminal unless some other means of access is provided. Terminals located within a J-Box or under a covering along the side of the panel require only the removal of a cover panel for access to the terminals. J-Boxes normally protrude from the side or the back surface of a panel. During installation and replacement operations, such a protrusion could be accidentally sheared at the connection points to the panel. However, such locations provide a measure of protection against carelessness during maintenance operations, vandalism and vermin due to the limited accessibility to the terminals. The back surface location of the J-Box also provides protection from most environmental conditions with the exception of pollutants in the atmosphere which may cause gasket deterioration and/or contact corrosion.

Procedures specific to the repairing of a J-Box vary with the nature of the problem requiring corrective actions and the location of each J-Box. Damaged cover seals require the removal of the cover plate, removal of the seal, installation of a new seal and the installation of the rebuilt or new cover plate. Additional tasks may be required in the event that internal damage has taken place as a result of a damaged cover plate. Corrosion of contacts within the J-Box requires the removal of the cover plate, spray cleaning of the contacts with a non-conductive spray cleaner, and reinstallation of the cover plate. Reattaching wires within a J-Box requires the removal of the cover plate, the removal of wire nuts connecting the wires, removal of the cable connector, clamping the cable connector to secure the cable, stripping insulation from the conductors, twisting wire nuts onto wire pairs, and the reinstallation of the cover plate. A J-Box sheared cleanly from the module without damage to the box or module may require the removal of the cover plate to gain access to the fastening devices to secure the J-Box to the panel. It is important to note that with all maintenance procedures requiring access to wiring, extreme caution should be taken to avoid the potential of shock hazards.

Modular quick connectors, e.g. the crimp or plug/receptacle, may be located at the end of a wire protruding from the front, side, or back of a photovoltaic panel. During installation and replacement operations, conductor terminations could be accidentally dislodged from the boot which shields the conductor. Locating the terminal on the back or side of the module limits accessibility to the terminal, but affords protection from careless maintenance men, vandals and vermin. Terminals located on the face of the panel or those mounted on the side, which are exposed to weathering, may experience deterioration of contacts due to corrosion, and material degradation if the proper materials are not used and proper protection is not afforded.

The procedures specific to the repair and replacement of modular quick connectors will vary with the type used.

SECTION 13
CONCLUSIONS

1. Until extensive in-field testing of photovoltaic hardware and systems has established a base on which code officials can assess the proper use of a PV device, manufacturers should design modules for electrical production only and not major building components.

2. Until such time as photovoltaics is addressed in the codes or a data base on performance and applications details is established, each installation in the commercial/industrial sector will be required to seek a code variance from the local code governing bodies.

3. Widespread PV utilization in commercial construction projects will probably occur only when building codes specifically recognize photovoltaic modules and arrays.

   - Early restrictions may be placed upon PV modules and arrays based upon correlation or interpretation with existing code references.

   - Design professionals and code officials must assume a certain amount of legal liability for materials and assemblies specified for buildings which are not addressed by the building codes.

4. Integrally mounted arrays will be subject to a much broader range of interpretations (and thus restrictions) than rack, standoff or direct mounts.

5. Wall, roof and ground mounted PV arrays will be separately addressed by code officials.

   - Code interpretations for wall mounted arrays will depend primarily upon appearance and structural requirements and constituant materials.

- Code interpretations for roof mounted arrays will depend primarily upon mounting configuration and constituant materials of the PV array.

- Code interpretations for ground mounted arrays will depend primarily upon proximity to buildings, propensity for human contact and location within or outside fire districts.

6. The photovoltiac system as producer of electricity will need to meet the electrical wiring design requirements as stipulated by the National Electric Code.

7. The design of the electrical system hardware should take the total system into consideration, including:

   - Mounting type
   - Electrical characteristics of components
   - Series/parallel arrangement
   - Physical requirements imposed through array design; e.g., environmental exposure.

8. The certifications of a photovoltaic module/panel by a recognized testing laboratory as prewired electrical equipment would facilitate acceptance by code officials.

9. The consideration of potential wiring damage in the commercial/industrial sector should be made and appropriate steps taken to alleviate that potential through system redesign or conductor covering.

   There are three general approaches in constructing a safe and effective wiring system for photovoltaics:

   - Exposed insulated cables
   - Insulated cables in open raceways
   - Insulated conductors in closed raceways

Each of these methods has a place in a building application and each may be used in a PV system.

10. PV array conductor sizing should be based upon:

   - Maximum short-circuit current
   - Physical arrangement of conductors; e.g., in a conduit
   - Temperature of the conductor's operating environment
   - Desired voltage drop

11. Commercial/industrial users of PV will need to meet more stringent electrical safeguards when voltages are in excess of 600 volts. Voltage level will depend on array level, i.e. panel, subgroup or total array; size; losses; safety; etc. Voltage levels from 30 volts to greater than 1000 volts are possible from the code viewpoint. Economics will greatly influence this decision, and each project must be evaluated to determine the appropriate level.

12. Module voltage level will be determined based on the potential safety hazards associated with the handling of modules.

13. PV electrical wiring termination needs to meet performance standards as established by such bodies as Underwriters' Laboratories and ASTM. The three most viable generic electrical terminals appear to be:

   - Crimp
   - Screw
   - Plug and receptacle

14. PV array grounding philosophy should be developed with a total system consideration. Proper PV system grounding should be characterized by the following:

   - Exposed-conductive-material, redundant array grounding
   - Inverter metallic enclosure grounding
   - Isolation transformer to separate DC/AC components

- Ungrounded metallic battery support/enclosure
- Ungrounded and inaccessible conductor metallic enclosure
- Ungrounded system leads

15. All PV arrays should incorporate the use of surge arrestors to reduce the potential loss of life and property due to lightning. Air terminals can also reduce the possibility of lightning related damage, but may not be cost effective.

16. Insurance premiums, tax deductions, depreciation, and utility rates all play an important role in determining system economies in the commercial/industrial market, but first cost is of primary concern in most cases.

17. The greatest flexibility in integration with conventional building structural systems is realized with 4' x 5' nominal modules. NOTE: This is a center-to-center dimension, not an actual module dimension, and design of the module must consider the desired panel dimensions.

18. The maximum recommended panel size is 8' x 40' which is based on maximum standard shipping sizes.

19. Architectural design flexibility of a panel will greatly influence the size and shape of the panel. The joints internal to the panel should provide this visual flexibility.

SECTION 14

RECOMMENDATIONS

1. Major emphasis should continue to be placed on the development of safety standards for photovoltaics. Only through the development of such standards will a successful market debut occur.

2. PV manufacturers should place design emphasis on the whole system, consisting of: modules, electrical conductors and terminals, and mounting hardware.

3. Submittal of the array subsystem to a recognized testing laboratory would facilitate easy code acceptance in the field for listed systems. "Prewired electrical equipment" status would remove the burden of component acceptance interpretation on the part of the code official.

4. It is strongly recommended that early PV modules, panels and arrays be designed as single function systems only in order to eliminate as many of the code official's concerns as possible, thus easing the code variance process. As more in-field data is obtained and as the issue of PV is addressed in the code, modules may then be designed to perform multi-functions.

5. PV manufacturers should put into motion the mechanisms for specific building code acceptance. Dialog should be occurring between manufacturers and the code developing bodies responsible for the building codes and the electrical code.

6. Particular attention should be placed upon educational services for design professionals, code officials, building owners, developers, and other participants in the building sequence, by PV product manufacturers if photovoltaic hardware is to be used in the building industry.

7. All PV manufacturers should open lines of communication with the Underwriters' Laboratories to achieve fire resistance rating classification in the U.L. Fire Resistance Directory and/or Building Products Directory.

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