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RESIDENTIAL PHOTOVOLTAIC MODULE AND ARRAY REQUIREMENT STUDY

JPL CONTRACT NO. 955149

LOW-COST SOLAR ARRAY PROJECT
ENGINEERING AREA

FINAL REPORT APPENDICES

June 1979

The JPL Low-Cost 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 low cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

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APPENDIX 1. CODES, STANDARDS AND MANUALS OF ACCEPTED PRACTICE

PURPOSE: To define within the context of the residential construction industry codes, standards and manuals of accepted practice, and to describe the persons involved in development, implementation and use of these documents.

CONCLUSIONS: Codes and standards are currently in wide use in the residential marketplace, and will, because of the central role they play in residential product development, determine what choices are open for residential photovoltaic module designs. Codes are more stringent in industrial applications than residential.

Manuals of accepted practice are in existence in the residential industry, especially for product or industry related procedures that are somewhat specialized. They define design, installation, and operational procedures simply, thus allowing widespread application of a technology or device without extensive technical training of installation and service personnel.

RECOMMENDATIONS: Using this document as a guide to identify the critical areas controlling design development, it should be noted that compliance to the concerns outlined in this document will not assure that product approvals will be forthcoming. Manufacturers, before proceeding with any new prototype designs, should consult all major codes and standards, and the testing labs that verify compliance.

CODES, STANDARDS, AND MANUALS OF ACCEPTED PRACTICE

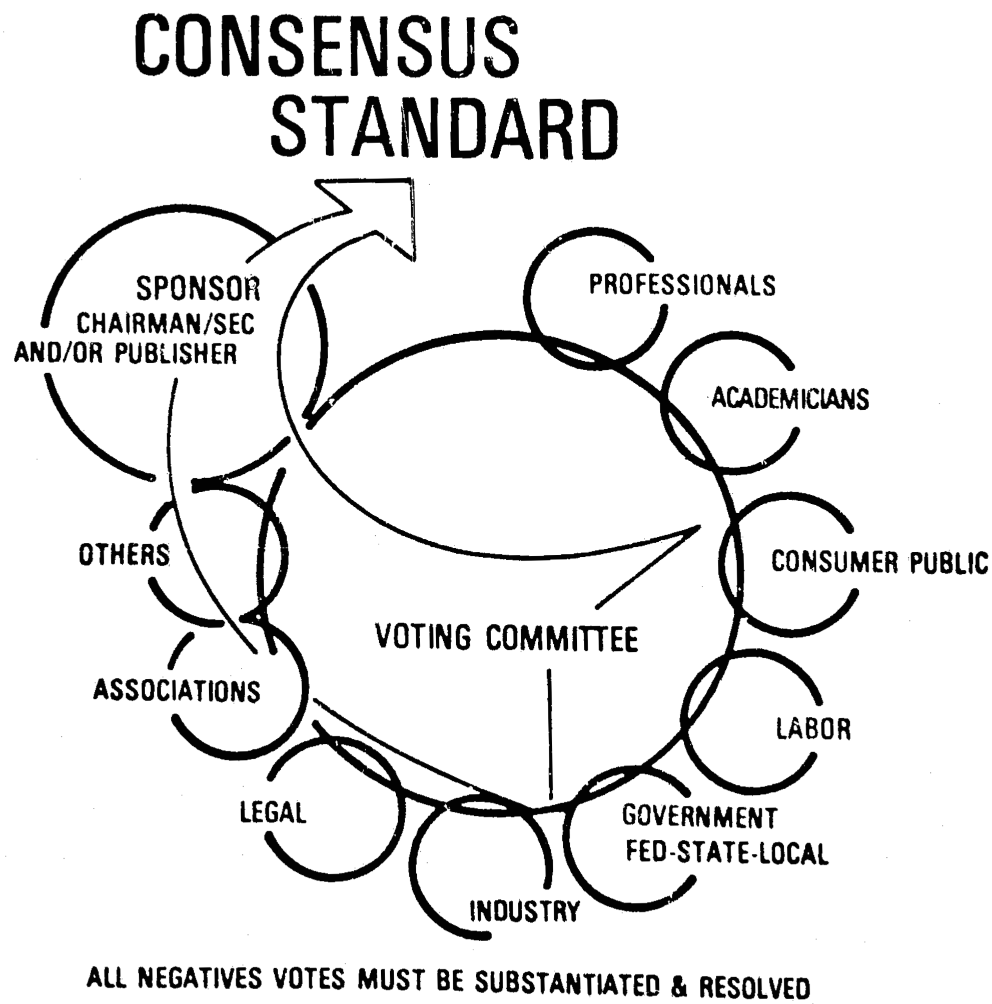
Building Codes and all of the various documents referenced by these codes make up the general body of legal concerns that the manufacturer must address if his product is to have widespread application in the residential marketplace.

Building Codes are bodies of regulations whose purpose it is to protect the concerns of public health, safety and welfare. These codes are controlled.

through government legislative bodies and their appointees and are intended to apply to all building situations. Code changes, since they occur through the legislative process, are frequently lengthy and complex. A code is, therefore, the most permanent of the regulatory documents confronting the PV module manufacturer and carries specific legal implications. Ideally, the code should provide a series of criteria which can be met with a variety of solutions. Codes written in this manner are generally referred to as performance language codes, rather than prescriptive language codes. Prescriptive language defines rather explicitly one method which is deemed to be acceptable. The primary difference is flexibility. Performance language allows for a variety of solutions all of which meet particular criteria designed to protect public health, safety and welfare.

Standards, on the other hand, outline the way code criteria can be met. Standards are methods whose concern results in meeting a predictable quality level. A standard is a model which defines a measuring stick by which code criteria can be evaluated. Standards, or more completely termed consensus standards, are promulgated by the professional community as a whole. The professional community can be made up of many diverse interests within the residential or even broader marketplace who wish to work together in regards to the application of any particular technology in the residential building industry. (See Figure 1-1) Standards respond, therefore, to the state-of-the-art, and change as technologies develop and are tested through application. They are subject to change more quickly than codes, and can exist in an evolving state as they are not being directly controlled by the legislative process.

Supporting both codes and standards are Manuals of Accepted Practice, which describe proven procedures or techniques which are most often used within the building industry. They provide a formula through which the characteristics required in a standard can be achieved. A manual in this particular case is prescriptive by nature. Produced by the building industry, a manual describes procedures normal to that industry and may carry the marketing or design prejudices of that particular group. Manuals of accepted practice change quickly as they evolve with technology, developing procedures through which a technology can be applied. They are widespread throughout the building industry,



CONSENSUS STANDARD DEVELOPMENT PROCESS

FIGURE 1-1

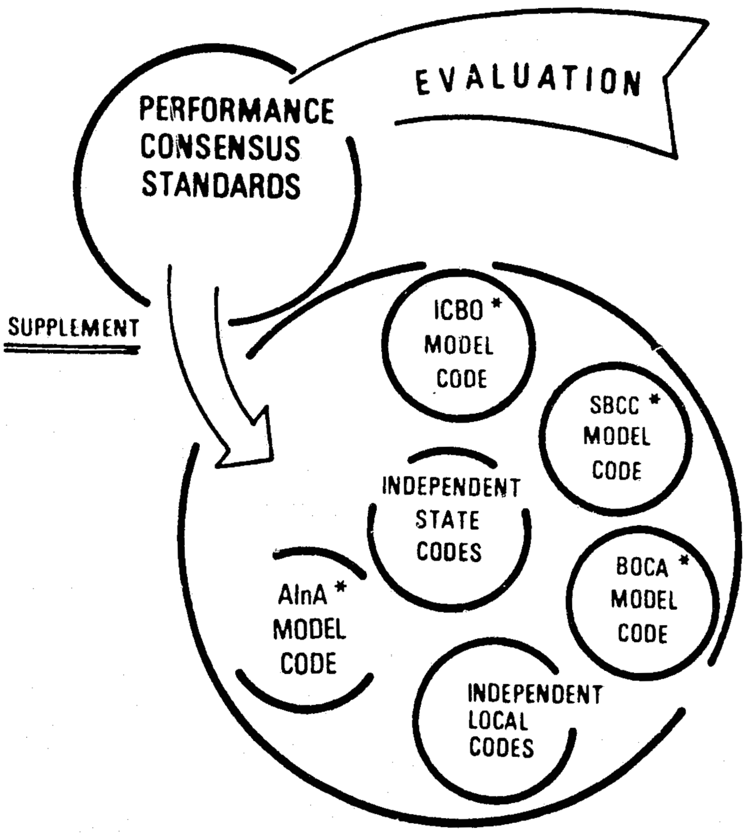
and can be regional in nature, addressing locally applicable methods and materials. There are, to date, no manuals of accepted practice which apply to the residential PV industry.

A building code official, whose responsibility it is to issue permits and approvals of proposed building solutions, should make reference to all three types of documents with discrimination.

Since in practice there is a considerable overlap between these documents, with standards frequently becoming embodied in the language of a code rather than referred to by designation (as shown by Figure 1-2), an understanding of their proper relationship is important to anyone intending to manufacture a product for use in residential construction.

In defining those code provisions which are applicable to residential photovoltaic modules, the objective is not only to identify those existing code provisions which potentially hinder the application of photovoltaic modules, but also to identify those in-place provisions which will play a role in defining that module. For example, code areas such as structural, wind and snow loading, voltage requirements, etc., may act as elements which shape a solution rather than limit it. It is important to recognize, however, that the development of PV code provisions will be following a unique path among the development of building codes. Most codes which have been developed over time, have been in response to a particular situation. The Chicago fire gave rise to fire codes. Structural failures gave rise to code provisions stipulating load requirements. In each case, the code provision was developed in response to a particular circumstance. With regard to solar energy, the public demand and concern for its speedy and proper application has become so great, that in an attempt to be responsive, the government and code groups have sought to provide regulations which will protect the public health, safety and welfare before the technology matures. If these provisions are not very carefully written, they can have the effect of limiting a developing technology. The following is a list of the code documents developed by city and model code groups which were reviewed for applicability to the subject of residential photovoltaic modules:

- BOCA Basic Building Code (BOCA)



* ICBO = INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS (UNIFORM BUILDING CODE)

* SBCC = SOUTHERN BUILDING CODE CONGRESS INTERNATIONAL, INC. (STANDARD BUILDING CODE)

* BOCA = BUILDING OFFICIALS AND CODE ADMINISTRATORS INTERNATIONAL, INC. (BASIC BUILDING CODE)

* AInA = AMERICAN INSURANCE ASSOCIATION (NATIONAL BUILDING CODE)

PERFORMANCE CONSENSUS STANDARDS SUPPLEMENT BUILDING CODES

FIGURE 1-2

- BOCA Basic Plumbing Code (BOCA)
- BOCA Basic Mechanical Code (BOCA)
- BOCA Basic Fire Prevention Code (BOCA)
- Life Safety Code (NFPA)
- Pittsburgh Building Code (City)
- Los Angeles Solar Energy Code (Los Angeles County)
- Los Angeles Building Code (Los Angeles County)
- National Building Code (American Insurance Association)
- National Electrical Code (NFPA)
- Standard Building Code (SBCC)
- Standard Plumbing Code (SBCC)
- Standard Mechanical Code (SBCC)
- Uniform Building Code (ICBO)
- Uniform Plumbing Code (ICBO)
- Uniform Mechanical Code (ICBO)
- Uniform Fire Code (ICBO)
- Uniform Solar Energy Code (IAPMO)

Each of these codes was reviewed from the standpoint of specific concerns that the module manufacturer will need to address to have an end product which will comply. A list of the concerns reviewed for each code except the National Electric Code (NEC) follows:

Codes and Roof Coverings
Codes and Roof Structures
Codes and Roof Loading Characteristics
Codes and Veneers
Codes and Insurances

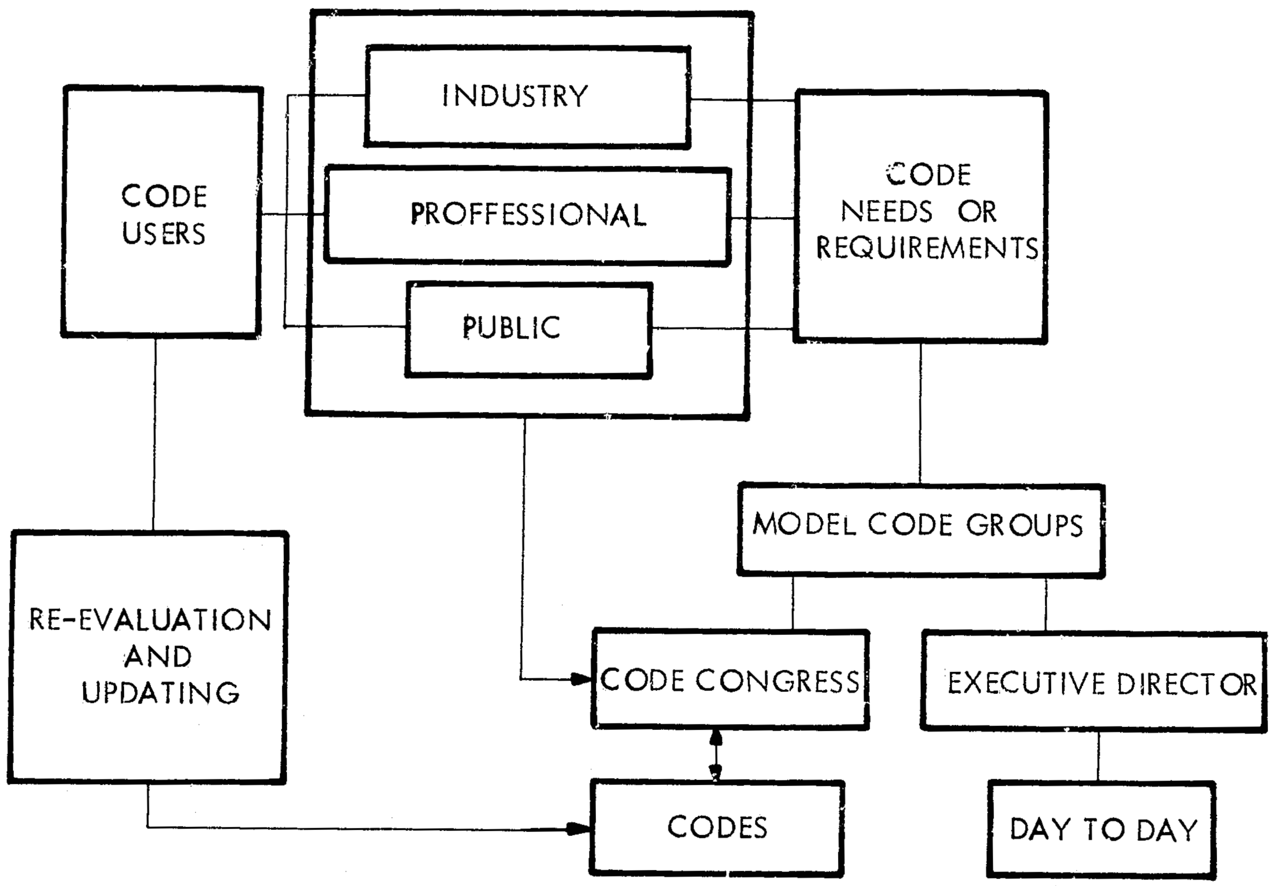
The NEC was approached and reviewed somewhat differently. Because the document has been divided into discrete categories which in themselves deal with different aspects of the PV module the code was reviewed in its entirety with comments offered on each section that could have a bearing on the residential PV module design.

See Appendix 3 for the Model and City Code Review and Appendix 4 for the NEC Review.

The three model building codes -- the Basic Building Code, BOCA; The Southern Standard Building Code,SBCC; and the Uniform Building Code, ICBO -- through their requirements for the materials and systems of construction, serve as an excellent test for preliminary assumptions that might be made regarding the design of the Residential Photovoltaic Module. A model code is a written document devised and used by a broad group of individuals involved in various aspects of the residential construction industry - See Figure 1-3. All of these groups are concerned with unifying and standardizing requirements for the industry that relate to life, safety and health of the building occupants. Materials which are under consideration for incorporation in the construction of the device can realistically be evaluated in the context of the codes' requirements for similar systems and materials. An understanding of such things as the effects of code restrictions limiting the area of flammable materials and their use in the construction of a dwelling can assist in the avoidance of serious marketability problems. This is especially true since national acceptability of the product is desired.

The location of the module -- roof, wall or independent of the dwelling -- as well as mounting technique -- integral, direct, standoff or rack (See Appendix I 2 Studies Approach) -- can result in differing interpretations on just what requirements will be enforced by each particular code. For example, materials which may be in compliance if used as part of an independent rack mounted module may be in violation of the Code if the module is integrally mounted on the roof. These interpretations can even vary between codes.

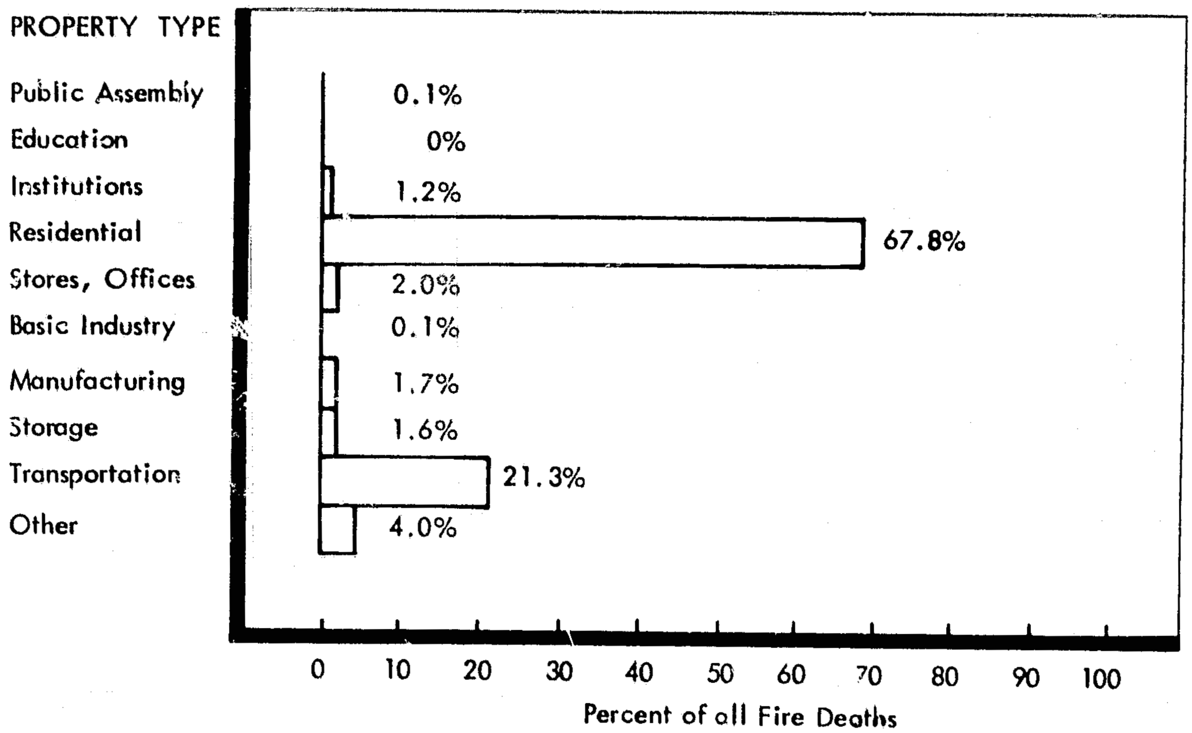
The codes as written do not appear to be a heavy influence on the construction and materials of one and two family dwellings, and so offer a good deal of latitude for this type of occupancy. Codes, however, are more specific, and therefore, more restrictive in their requirements for commercial, industrial, and institutional structures. Areas containing these types of occupancies are identified as having a greater potential risk of fire and are treated accordingly. Another reason for more stringent requirements is that a relatively large number of people use or work in these types of buildings. These occupancies also tend to contain a high ratio of building area to land covered when compared to one and two family dwellings and may often house, what are considered by the codes, hazardous functions. However, regardless of the



CODE DEVELOPMENT AND USAGE

FIGURE 1-3

restrictions, the fact remains that most fire related deaths occur in the home (Figure 1-4). So, care and concern must be taken when developing products for residential use.



Source: Int. Conf. of Building Officials-Building Standards 1979

Number of Fire Deaths Related to Property Type

FIGURE 1-4

CODE CHANGES - WHO INITIATES THEM

This chapter is a reprint of an article entitled: Decision-Aiding Communications in the Regulatory Agency: The Partisan Uses of Technical Information, by Ventre, Francis T., published by the U.S. Department of Commerce/National Bureau of Standards, special publication 473 - Research and Innovation in the Building Regulatory Process.

It was felt that the entire "flavor" of the article will allow the manufactorer of PV modules to have a unique and enlightened view of the code process presented without interruption of thought.

DECISION-AIDING COMMUNICATIONS IN THE REGULATORY AGENCY:
THE PARTISAN USES OF TECHNICAL INFORMATION

by

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This paper, based on a nationally representative survey of 1,200 municipal building departments, describes the partisan uses of information in a regulatory setting. Each of the agencies was facing a specific decision to alter its regulations to accommodate innovative building techniques. The agencies identified the various members of the building community--builders, designers, vendors, users, regulators--who came forward to initiate the change, to discuss its advantages or disadvantages, and then to assert a position either supporting or resisting the agency decision to modify the regulation. The local building industry, accused by many of being the greatest source of resistance to technical innovation, was found to be the strongest force for change, equaling sometimes surpassing the positive influence of the model code groups.

Key words: Regulation; building codes; decision making; public policy.

INTRODUCTION

Responsible regulation of building technology requires that codes be technically current and socially responsive. That is to say that regulations themselves must reflect a dynamic equilibrium between emerging social needs and new technological opportunities. Maintaining the building code in this condition is a responsibility of the regulatory agency. In discharging this duty, building officials must determine the adequacy and appropriateness of innovative building techniques with respect to public safety, health, and welfare before permitting their use in the jurisdiction for which they are responsible. This paper describes how those determinations are made and identifies those elements of the building community that participate in those decisions. This information is based on a nationally representative survey of about one thousand local building departments.[1] The survey results interpreted in this paper show that some widely held beliefs about who influences the code change process are, quite simply, wrong.

AN OUTLINE OF THE CODE CHANGE PROCESS

A sponsor seeking regulatory approval for a new technique presents to the building department data (often in the form of engineering standards and test methods) showing the candidate technique's compliance with or equivalence to applicable code requirements. The regulatory agency might require evidence of further testing to specified engineering standards by qualified laboratories. The sponsor provides this information, usually at considerable additional expense. The effort is worth the cost, though, because once a regulatory agency approves the material, method, assembly, or engineering standard under review, a new market area is opened to the innovator.

This is the bare-bones outlines of the procedure by which state and local codes undergo piecemeal or incremental modernization. The process is repeated thousands of times--recall there are over 5,000 local and a score of state building codes in force in the U.S. Moreover, the process might involve a slightly different cast of participants and there are variations in the substantive documentation required in each jurisdiction.

DECISION-AIDING COMMUNICATION IN BUILDING REGULATORY AGENCIES

When faced with potentially difficult technical decisions, the scant agency resources for independent determination of technological questions are routinely augmented by the agency's constituency and other sources of information. In other words, the agency consults with its clientele and reference groups before acting. The clientele are those individuals and organizations whose lives and livelihoods are immediately affected by the agency actions; the reference entities are the several score of professional associations and technical societies who can legitimize or otherwise authenticate the action of the public officials.

The decision-aiding communications to the local building departments take several forms. There are personal interactions with the technical representatives acting for vendors of building products, with local contractors and builders, and with architects and engineers who appear frequently at the agency's door in the course of routine business. There is association with other local building officials either in periodic formal meetings (typical for jurisdictions subscribing to one of the model codes) or on an occasional basis. There is, too, the sporadic involvement with citizens, singly or in groups, seeking relief of one sort or another. The relative frequency of those personal encounters is shown in Figure 1. Finally, there are the impersonal sources of technical information: principally, engineering reports, sales literature, test results, trade periodicals, and government publications.

These personal and impersonal information channels each have distinctive, though not always obvious, biases or predispositions: some are clearly promotional; others, scrupulously impartial. Agencies use these channels in a continuing surveillance of their political and technological environment.[2] From this environment and these sources come signals for agency action or inaction. These messages course through personal and impersonal channels to the key officials in the building department. And, in this transmission, the weight lent to the messages is affected by the qualities of both the sources and the channels. All the foregoing are commonplaces of communications theory[3] and all are manifested in the communications preceding the technical decisions of building departments.

How important are these message flows to the agency?

A 1970 International City Management Association (ICMA) survey of local building departments found that although the department staff members occasionally initiate suggestions for improving the local code, the preponderance of the more innovative practices are brought in from outside the agency, chiefly by the agency's clientele. Discussions of imminent changes are carried on widely. But support for and resistance to code changes under review call forth intensive participation by only a few members of the agency's professional reference groups and from its clientele, which is itself a mere subset of the total building community.

In brief, the staff-short agency faced with a decision on innovative technology resorts to a form of collective decision-making. Others from beyond the agency may contribute to this decision by providing information on either the technique itself or the ramifications—both social and technical—of code-approval of the technique. But since most of the sources of this information have a partisan interest in the decision, the agency interposes between itself and this information-bearing clientele a filter of skepticism. This filtration function must be incorporated into any model of information flow in regulatory policy making.

The model of the agency decision process proposed in this paper is framed in a way both to reconstruct the tacit logic of the decision and to isolate precisely those functions of the agency clientele about which the least is known and the most is speculated. Both normative and behavioral theories of decision making plus the author's own experience in local, State, and Federal regulatory policymaking recommend that the agency decision to accommodate the regulations to an innovative technique may be usefully analyzed as a multi-stage process with members of clientele and reference groups each playing a greater or lesser role at each of the stages.[4]

The agency engages the participation of its clientele and reference groups in different modes as it progresses, stage by stage, to a decision. Accordingly, the five modes of participation open to the clientele and reference groups are as: 1) originators of proposed code changes, forwarding them for the agency's consideration; 2) discussants of those changes with agency officials while the changes are under review; 3) service as trustworthy sources of information pertaining to the innovation and its implications for the building community; 4) supporters of the proposed change; and 5) resistors of the proposed change.

The members of the clientele—those whose welfare and livelihoods are directly affected by agency decisions—are: architects and engineers, building material producers or suppliers, and their national and local representatives; local or out of town builders and, a special case of the latter, manufacturers of prefabricated buildings; and representatives of international unions and their local business agents; and, the ultimate clients, representatives of the general public, usually spokesmen for civic and voter groups. The reference entities—individuals or groups with whom building officials "identify" (in the psychological sense) and to whom the officials look for legitimation and approval—include: first and foremost, building officials from near and far and particularly those organized into professional groups like the model code associations and, much less prominent, the trade and professional media that inform and, to a degree, muster the strikingly diverse building community.

The clientele and reference groups include both the industry-based agents of technological change, who typically advocate use of new materials, products, or methods, and the spokesmen for enhanced building performance, who typically advocate safer and more economical buildings. Both groups try to achieve their goals by influencing regulatory policy in their favor but the greater or lesser influence of one group in comparison to the other (and, in fact, the actual make-up of those groups) can be known only after agency decisions have been documented and analyzed. By tracing actual agency decisions through each of the five stages mentioned earlier, the differential influence of the several actors at each stage can be identified. A thousand building departments reported to the ICMA how this five-part process variously involved twenty members of the building community as the agency reached a decision on modifying the building regulations to accommodate innovative techniques. This provides the data base for the following description of the partisan uses of technical information.

Table 1 lists the 14 techniques the agencies were considering when they reported to the ICMA. The 14 techniques, collectively, may be considered an index of technological currency. That is, codes that permit more of the 14 techniques may be considered more progressive and up to date.

CLIENTELE AND REFERENCE GROUP INFLUENCES ON REGULATORY DECISIONS

The ICMA survey indicates that the building department's clientele and, to a much lesser extent, its reference groups utterly dominate the flow of communications affecting code changes under consideration. They eclipse in importance even the building department staff itself. This is true at every stage of the process: introducing the innovation, discussing it, providing trustworth information on the change, and arguing for or against the change. The survey also indicates, however, that the clientele, strong as it is, represents so many diverse interests that its collective characteristic is one of ambivalence in the face of technological change. With the possible exception of the building trade unions, there were no members of the agency clientele in persistent and pervasive opposition to the modernization of building regulations. This finding undercuts two widely held but thinly-substantiated beliefs. The first is that local building interests categorically attempt to suppress regulatory acceptance of technological innovation. The second is that the responsible officials succumb to this pressure. Contrary to these beliefs, which we may call the "obstructionist doctrine," the ICMA data reveal that local building interests were, in fact, the leading advocates of the 14 code changes.

The close-up view of the agency clientele in action reveals who specifically among them are the most active advocates of regulations that are technologically responsive: suppliers of building products and the builders who use them are the prominent sources of new ideas. Somewhat surprisingly, architects and engineers, whose professional ethoses (and popular stereotypes) would place them in a technological avant-garde are not prominent innovators—at least not on code changes considered by building officials to be the "most difficult" among the 14 on the index of technological currency. When the building officials reported to ICMA on the "least difficult" changes, the design profession figured much more prominently as initiators. Local building officials reported the same tendencies for themselves: low participation on difficult (and, likely, controversial) decisions; high participation on less difficult decisions. This suggests that the design professionals that serve the building industry are much less venturesome and innovative than are the construction professionals, the builders. In other words, in matters of changing regulations to accommodate technical change, the design professionals actually behave in much the same way as do regulatory bureaucrats they frequently malign. The building product suppliers and the builders themselves are the prominent advocates of technological currency in the building codes, as the following diagrams illustrate.

Figures 2a through 2e illustrate the ICMA survey findings on the greater or lesser participation of the clientele and reference groups at each of the five stages of the agency decision to adopt a recent code change. The figures are a composite of agency-identified participants in decisions concerning all of the fourteen techniques comprising the index of technological curreny. The agency clientele and reference groups are listed at the left margin. They are arranged in descending order of their "trustworthiness" as sources of information on the code change under review. (The responding agencies provided this ranking, as will be explained shortly.) The horizontal bars represent the relative extent of clientele and reference group participation in the various decision phases. Let us analyze each of the Figures visually at first and then search for significant intercorrelations among the actors and the roles they play in the change process.

Figure 2a illustrates the first appearance of "technology-push" on the regulatory system, and the push comes from the industrial agents of technological change: building product suppliers and the local builders. It is these suppliers and builders, and not the putative avant-garde of designers, who bring to the building department the initial suggestion to revise the code to accommodate the techniques comprising the index of technological currency. The first awareness of a technical possibility comes by way of personal, rather than documentary, sources. Sales representatives and builders are more prominent sources of new ideas than are periodicals, brochures, or government reports. This deserves a comment.

Local building officials are exceptional in their primary reliance on personal experience and interaction rather than documentary sources of novel technology. Exceptional because studies of technological communication--whether in the realms of medicine or agriculture and involving either physicians or farmers--report that impersonal media and documentary sources usually bring the first awareness of an innovative practice. Generally, according to communications researchers, this initial awareness through an impersonal source is followed by personal contact and face-to-face relations between the change-agent and the user. These personal contacts and relations legitimize the information (often by adding detail) previously transmitted through the impersonal medium. This "two-step flow of communication"[5]--from impersonal media through the opinion leader to the final receivers--so prominent in studies of both mass communications and innovation does not apply to the local building official. Rather, he relies on more basic, interpersonal means of monitoring his technological environment. In the view of some media specialists, this reliance on personal communications instead of more efficient mass communications is a defining characteristic of primitive societies in less-developed economies.[6] Since much of its innovation proceeds without benefit of modern diffusion techniques, there may be a justification for calling this aspect of the building industry "primitive."

A final observation also touches on the anomalous behavior in the building department when a technological change is initiated. In most studies of innovation—and especially those involving collective decisions (as when an agency and its clientele participate)—initiators of those decisions are likely to be cosmopolites and persons without routine and everyday contact with the social system that is the locus of the change.[7] Not so in the building regulatory agency. Here, even the "idea men"—mostly from among the clientele—tend to the <u>local</u> building material supplier, the <u>local</u> builder, the local <u>staff</u>.

An explanation for this may be that the "local" initiators of change—the building products suppliers and builders—are in many cases merely local agents for firms that produce and market construction goods nationally. The case of the builders is similar. They, typically, are members of local builders' associations whose national federation, the National Association of Homebuilders (NAHB), provides the local associations with technical assistance. Thus, even residential construction, that most local of industries, has numerous connections with national organizations.

The second of the five stages of agency decision making is the widespread discussion given to newly proposed code changes. Of the five decision-aiding activities analyzed here, "discussion" enjoys the widest participation. Just how widely discussion is spread is illustrated in Figure 2b. Discussion of prospective code changes serves several important purposes both for the agency and for the agency's clientele. It gives to both an opportunity to identify and corroborate the probable impact the prospective code change might have and it is the place where the agency and clientele both put a technological toe in the political water without an irrevocable commitment to support or resist the adoption of the proposed change. Clearly, "discussion" is an activity with high payoffs in several categories. It is virtually costless to both agency and clientele since most of the discussants are already regularly encountered during the routine office day.[8]

What, precisely, are the benefits of discussion? For the clientele, the discussion step serves as a distant early warning of potential policy changes that might induce a disruption of stable marketing arrangements among competing building product manufacturers. If the discussion period is long enough—and it may be months—the local clientele had an opportunity to consult with their national and regional affiliates for advice on tactics either to advance, retard, or be neutral to the prospective change.

The agency, for its part, "discusses" the prospective change with its reference groups, notably, the model code associations or building officials nearby or in distant cities. Another benefit the agency derives from the "discussion" stage is the momentary visibility it enjoys among the clientele, showing that the code the agency enforces is an "open code, openly arrive at." An important secondary agency use of the discussion stage is to identify possible effects of the code change that might redound harshly upon the agency itself. Such circumspection would save the agency later embarrassment at the hands of parties aggrieved by an adverse code decision and its consequences. It must be borne in mind that the avoidance of embarrassment is a prominent consideration in any organizational decision—whether with the Joint Chiefs of Staff or in the building department—and especially so when a "wrong decision" might effect the economic welfare of local industry groups or the life safety of a community's inhabitants. Either eventuality could result in the chief executive's disciplining the erring department. Since only one local building official in eight has a specified term of office, and since for half that one in eight the term is one year,[9] discipline could take catastrophic form: dismissal if punishment for error exceeds reward for non-error, this biases the decision making quite strongly—it favors status quo, for example.

A final utility of the discussion phase may be psychological. The job-insecure and poorly-paid local officials have an opportunity to associate with their certainly more affluent and often higher status clients. It is a truism of social psychology that lower status members of social hierarchies with little or no possibility of social mobility direct their communications upward "as a form of substitute upward locomotion."[10]

We suggested at the outset of this study that the development of regulatory policy, indeed, the very evolution of the regulatory function, is a dialectical process that seeks a dynamic equilibrium between the forces representing the diverse interests of specific sectors of the building community. The building regulatory system must respond to shifting societal values and to emerging technological possibilities. We may call one a "society-pull" and the other a "technology-push," both impinging on the building regulatory system. In contemporary America, "technology-push" is dominated by industrial agents of technical change while "society-pull" is largely in the hands of public agencies and "public interest" groups. This ever-present but usually subdued dialectical process rises to maximum visibility during the agency decision to accommodate innovative technology. At that time, the constituents of the building community come forward to support or resist the building department's contemplated change in the regulation. Figures 2d and 2e identify the participants in this process and the horizontal bars denote relative degrees of partisan ship among the agency's clientele and reference groups. The ardor of their partisan ship may be gauged by the relative lengths of the bars: strongest supporters of the code changes included in the index of technological currency are, in decreasing order, local builders, local building product suppliers, out of town building product suppliers, manufacturers of prefabricated buildings and the design professions (the latter two tied); strongest resistors of code changes in the index are: local union representatives, local building product suppliers, and international union representatives. These results invite interpretation.

On visual inspection alone, Figure 2d shows that, generally speaking, those who initiate the changes, usually the industrial agents of "technology-push," are those who come out and fight the hardest for them. This is to be expected and the statistics bear out the expectation: the rank orders of the rosters of "originating" actors (illustrated in Figure 2a) and "supporting" actors (illustrated in Figure 2d) are highly correlated. (Table 2 lists the extent of agreement among the rank ordering of actors at each of the decision stages.) Also to be expected: the rosters of actors "supporting" and "resisting" the code modification are in relative disarray with respect to one another. However, one is not the inverse of the other.[11] In other words, constituent groups among the clientele that may strongly support a code change also contain elements that might resist the change. For instance, a code change to allow the substitution of one building material for another (as in the case of PLADRN or MTLCHM; see Table 1 for explanation of abbreviations) might provoke a conflict among building product manufacturers. Similarly, a definitional change that might enable the substitution of one trade for another (as happened when the BOCA Basic Building Code redefined terms describing installation of underground utilities) might provoke a reaction and conflict among the building trades unions. The warning should be obvious: generalizations addressing the entire agency clientele are instantly suspect. Unfortunately, the popular but mistaken "obstructionist doctrine" relies on and propagates such erroneous generalizations.

In identifying the patterns of communication and of potential influence, Figure 2c, that indicating trust, is the most telling diagram of all. It reveals that local building departments are leery of and deliberately weigh the flood of signals, messages and blandishments that bombard them from the individuals and organizations identified in Figures 2a, b, d, and e. Some signals are severely discounted: these are represented in the diagram by the lower ranked actors; others are respected: these are the actors at the head of the roster in Figure 2c. Why should this be so?

Building officials know that they, responsible for regulations that can dispense or withhold economic privaleges, are pursued ardently by their clientele. This suit (a "technology-push" on the building regulatory system) must be weighed against considerations of the public welfare with which the agency is entrusted (when the agency acts as a "society-pull" on the building regulatory system). This push and pull must also be weighed against the well-being of other segments of the clientele (who exert society-pull and technology-push from other directions). Moreover, there is a management clientele within the agency and motivations among individual officials themselves that affect the degree of skepticism or deference given the incoming messages. In the parlance of communications science, the regulatory officials must discriminate between "signal" and "noise" as they gather information on which to base a rational decision.

Credibility, as it is selectively extended to the several participants, is measured to a relative scale in Figure 2c and can be used to calibrate the volume and nature of client-agency communication.[12] Social psychologists report that, other things being equal, the higher the trustworthiness of an information source, the higher likelihood of its credibility and influence with the decision-maker seeking information. In a structure of formal authority, of course, the hierarchial place of the information source would likely to dictate its credibility and the deference paid to it, especially by those in subordinate positions.[13] But the present study deals with an informal system outside the formal structure of governmental authority. That informal system, however, is no less influential for its informality. The system is influential because it links the building department and its personnel with the local and national building community.

THE EFFECTS OF THE MODEL CODES ON THE AGENCY DECISION PROCESS

Building regulations are based on one of three sources: they may be adapted from any of the four advisory model codes; they may be based upon the regulations of a superior government, usually a State, but occasionally a county; or they may be drafted by the enforcing agency itself. Roughly three-fourths of all codes in use at the time of the ICMA survey were based on one of the model codes. Those jurisdictions basing their codes on the model codes were, in fact, enforcing regulations that were more technically current. Specifically, localities enforcing codes based on models prohibited fewer of the techniques comprising the index of technological currency described earlier; in contrast, jurisdictions enforcing locally-drafted regulations prohibited significantly more techniques.[14]

What is it about an association with a model code group that results in a more technically current code? How does affiliation with a model code association affect the code change decision process in the building agency? The ICMA survey revealed that the code modification process in agencies enforcing model code differs only slightly from the process used in agencies enforcing agency-based codes. This finding is clearly illustrated in Figure 3a through 3e whose horizontal bars depicting the extent of clientele and reference group participation in the code change decisions are similar to those found in Figure 2a through 2e with but one change: each bar in Figure 3a through 3e distinquishes among the bases of the regulations being acted upon: model code based regulations, state/county code-based regulations, or agency drafted regulations. From this analysis, there is hardly any difference in clientele participation, role by role, in agency code modernization decisions. Why, then, do agencies basing their codes upon the national models have more technically current codes?

To a certain extent, model code cities act with greater autonomy and more freedom from the partisans in their local clientele. This is demonstrated in Figure 3a, where building departments without recourse to the technical services of the model code organizations are shown to be much more reliant on local sources for new ideas. Local building material producers or supplier representatives, both with wholly respectable and legitimate but nevertheless highly partisan interests in one or another technique, completely dominate the origin of new ideas among departments enforcing a locally-written code. But the same figure shows that model code agencies are not immune from local influences either, and although they are less reliant than local code agencies on the necessarily partisan recommendations of the local suppliers, agencies enforcing model-based codes are twice as likely to pick up new ideas from their local sources as they are from the meeting of their own model code associations. But the departments affiliated with model code organizations have an important advantage over the locally-oriented agencies: they have access to a source of technical judgement that is relatively free of partisan leanings toward one or another technique. This is the critical difference.

This difference between the code change decision processes in the three types of jurisdictions is mapped in Figure 3a through 3e. The exception that matters is in the centrally important "trust" role: it is clear that in the absence of an alternative, the model code movement has drawn itself the role of impartial legitimizer of technological innovations. This essential role of autonomous authenticator of technical options has emerged under different auspices in different countries;[15] in the United States, this role has been assumed by the model code associations. Let us consider how this situation came about.

Both in Figure 3c and in Table 3 (the later is merely the rank order of the trustworthy sources by code type),[16] we see the difficulty under which most building departments—whether or not they subscribe to a model code—are forced to operate. Too small to specialize internally, attached to governments too small to develop the necessary independent evaluation of building products, the departments enforcing agency-written codes are forced to place greatest significance on the testimony of salesmen and vendors who are perceived as partisan advocates of one or another techniques. To offset this, the agencies seek autonomous, independent expertise. For the present, the expertise is the "stock in trade" of the model code groups, one of the "correlative services offered with the code," in the words of a respected model code official.[17] The phrase "for the present" is used advisedly, however, for the newly founded National Institute of Building Sciences (NIBS) has been authorized by Congress to pursue "correlative services" of its own.[18]

CONCLUSION

The findings in this study confirm some but undercut more of the widely held views about the nature of technological change in building construction and the social controls on that process operating through the building regulatory system. Regulations are continually altered to accommodate innovative technology and this work appears to be a cooperative effort of the regulators and the regulated. Affected groups in the building community—but rarely from the building-using public—come forward to supplement the meager technical resources of the agency at every step in the updating process: to nominate a candidate technique, to discuss its virtues and shortcomings, to support or resist its adoption into the regulations governing the building enterprise. This is a form and a forum of regulatory politics, but not the only one, for other arenas beckon for study: the decision process within the model code groups, for one. For the moment, though, recall that the obstructionist doctrine alleges that a conspiracy of entrenched, usually local building interests dominate the code modification process and that this is to blame for technologically somnolent industry. But, surely, this is a page from a sophist's textbook: invidious results deriving from insidious causes. For when the dynamics of this process are analyzed, conspiracies of local actors are found not in control of these deliberations. In the first place, agency officials are in control and are usually skeptical of zealous partisan advocacy in behalf of a favored building technique. To counter this stridency, officials discount a great deal of what they hear from partisans of one or another candidate techniques. These officials consult with each other, mainly with their professional peers through the programs of the model code associations. And they invest their greatest trust in those sources of technical information whom they consider to be impartial. In the second place, even when one or two actors are extraordinarily assertive, their views frequently do not prevail. Let me cite a specific case. Of the 14 items comprising the index of technological currency, the innovation that diffused with greatest speed during the 1960's was plastic pipe for use in drain, waste and vent systems. Plastic pipe gained in less than ten years a level of regulatory acceptance that took copper pipe over 40 years to achieve. Similarly, plastic pipe, while commercially available only a little over 10 years, had by 1970 achieved 80 percent of the regulatory acceptance won by non-metallic sheathed electrical cable, a material on the market since World War II. These data from the ICMA survey are illustrated in Figure 4. Plastic pipe achieved this rapid acceptance by regulatory agencies in the face of the most intense mobilization of resistance by industry and labor groups in the memory of most building officials at work today. Yet to many if not most observers of the building industry of the last ten years, the battle for acceptance of plastic pipe is usually cited as an example of the failure of regulations to remain current because of local industry pressure.[19]

The building regulatory system--through its networks of codes, standards and associated administrative apparatus--casts a pervasive and prevailing influence over the form and content of the built environment. Through this system, governments assert a form of social control over the rate and direction of change in building technology. Social choices among technical possibilities are made whenever regulations are amended to permit the use of innovative building techniques. These regulatory choices have economic and social ramifications for the building industry and for building owners and users. Consequently, these code decisions are contentious, closely attended, and likely influenced in some way by the parties benefitted or deprived thereby. One form this influence takes is the timely provision of technical information for the decision-makers' use. This paper has tried to shed some light on that process.

FOOTNOTES

1. The International City Management Association administered this survey in 1970 to the building departments of all U.S. municipalities over 10,000 population and a small sample of smaller cities and towns. About half of all departments questioned responded (in two related analyses, n = 930 and 1,241) and returns from each city size class above 10,000 were large enough to be representative. In sum, the generalizations in this paper are valid for cities over 10,000 but should be extended to places under 10,000 with caution.

2. A thorough discussion of clientism among agencies is found in Grant McConnel, Private Power and American Democracy (New York: Vintage, 1966) and in Ira Sharkansky, Public Administration: Policy Making in Government Agencies (Chicago, Markham, 1970). The importance of environmental monitoring and its particular relation innovation is analyzed in Paul R. Lawrence and Jay W. Lorsch, Organization and Environment: Managing Differentiation and Integration (Boston, Division of Research, Harvard Graduate School of Business Administration, 1967).

3. See, for instance, Colin Cherry, On Human Communication (Cambridge: MIT Press, 1957) and Ronald G. Havelock, et. al. Planning for Innovation (Ann Arbor: University of Michigan, Institute for Social Research, July 1969), especially Chapters 5 and 6.

4. This model is based on the literatures on the diffusion of technological innovation and on administrative decision making. Since documentation on the administration of the building regulatory function is confined to manuals of recommended practice, it was necessary to interview directly many building officials on these matters.

5. Elihu Katz, "The Two-Step Flow of Communication: An Up to Date Report on an "hypothesis, "Public Opinion Quarterly," Vol. 21, (Summer 1957), pp. 61-78. This landmark article established the importance of the "impersonal medium - personal contact" chain. This concept displaced the then-extant notion of media influencing mass behavior directly.

6. E. Rogers and F. Shoemaker, Communication of Innovation, (New York, Free Press, 1971), p. 256. Richard L. Meier and Karl Deutsch have also written on communication as an indicator of development.

7. Ibid., p. 277.

8. See Figure 1.

9. Charles G. Field and Francis T. Ventre, "Local Regulation of Building: Agencies, Codes, Politics," 1971 Municipal Year Book (Washington, ICMA, 1971), pp. 139-165.

10. Thomas J. Allen and Stephen I. Cohen, "Information Flow in Research and Development Laboratories," Administrative Science Quarterly, Vol., 14, No. 1, (March, 1969), p. 16. Allen and Cohen cite several authorities for this, notably, H. H. Kelley.

11. If they were, their Spearman Rank Order Correlation coefficients would approach R = -1.0. As it is, the coefficient of rank-order correlation between the "support" and "resist" rosters in R = -0.26 and is statistically unsignificant.

12. An adjustment for each actor on any innovation might be stated symbolically as:

$$PI_{ij} = fT_{ij}(O_{ij} + D_{ij})(S_{ij} - R_{ij}), \text{ where}$$

PI = potential influence;

T = poust index;

O = index of original sponsorhip of innovation;

D = index of discussion activity;

S = index of supporting activity;

R = index of resisting activity;

i = actor;

j = specific innovation.

O and D are cumulative properties but S and R are complementary; the cumulation of the latter yeilds are an algebraic sign that is associative and is distributed across all terms in the expression making a vector of a scalar.

13. A book-length treatment of this subject is: Harold L. Wilensky, Organizational Intelligence: Knowledge and Policy in Government and Industry (New York, Basic Books, 1967).

14. Field and Ventre, op. cit.

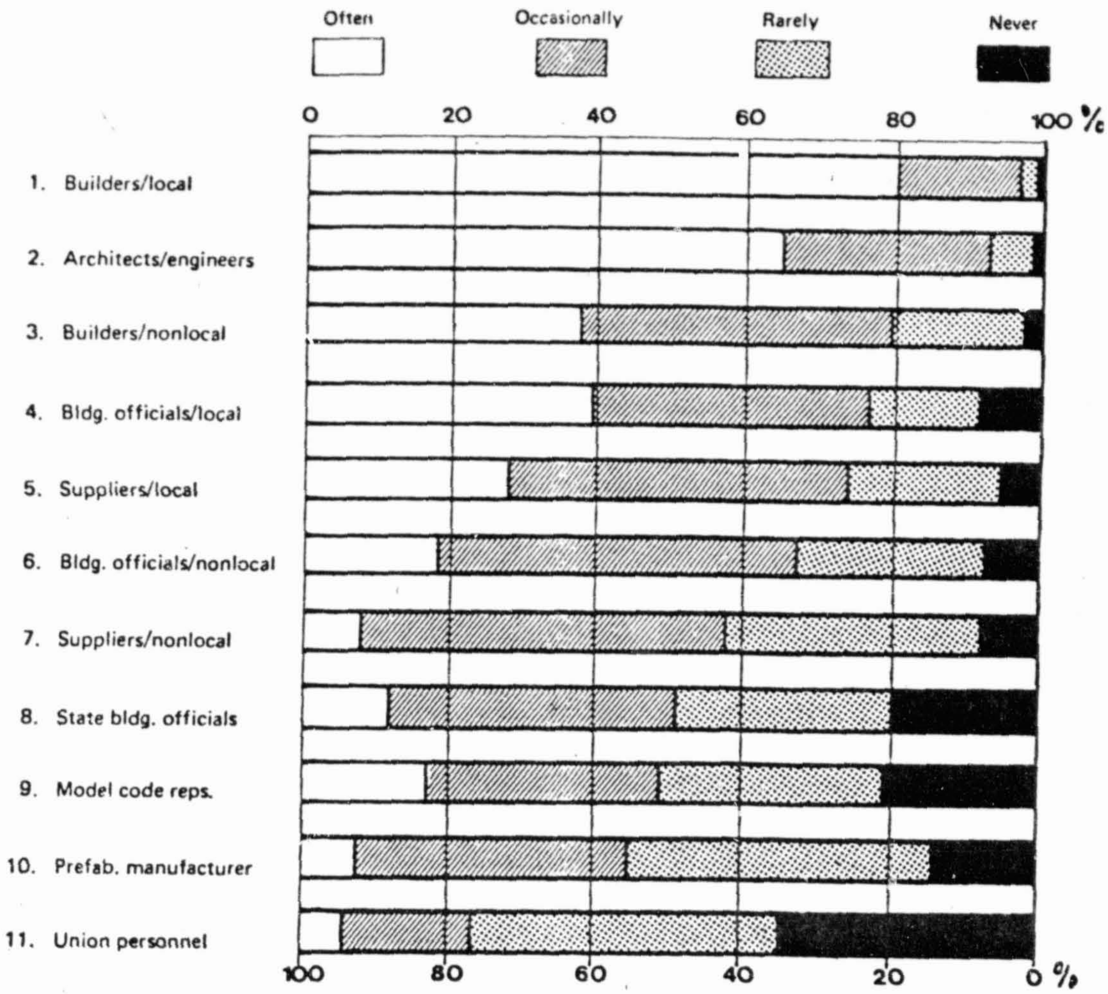
15. Methods and ins'.tutions for the evaluation of building techniques by national organizations in South Africa, the United Kingdom, France, the Netherlands, Austria, Belgium, Spain, Italy, Portugal, Japan, and Denmark are described in a set of papers in Performance Concept in Buildings, proceedings of a joint RILEM-ASTM-CIB Symposium, Vol. 1, invited papers. Issued as National Bureau of Standards Special Publication 361, Volume 1. The papers are found at pp. 491-534.

16. The rosters of actors participating in code modification decisions in model and in non-model code agencies are highly rank-order correlated, role by role. The largest discrepancy occurs on the "trust" question. The Spearman R's: Originate, 0.93; Discuss, 0.92; Trust, 0.85; Support, 0.91; Resist, 0.88.

17. Paul E. Baseler, "Revision and Administration of the Building Code," Management Information Service, Report No. 208 (May, 1061), ICMA, p. 44. Italics in the Original.

18. The Institute was established by Title VIII of the Housing and Community Development Act of 1974, Public Law 93-383.

19. The "Battle of Plastic Pipe" is documented in Francis T. Ventre Social Control of Technological Innovation: The Regulation of Building Construction, unpublished doctoral dissertation, Massachusetts Institute of Technology, June, 1973, Chapter 6.



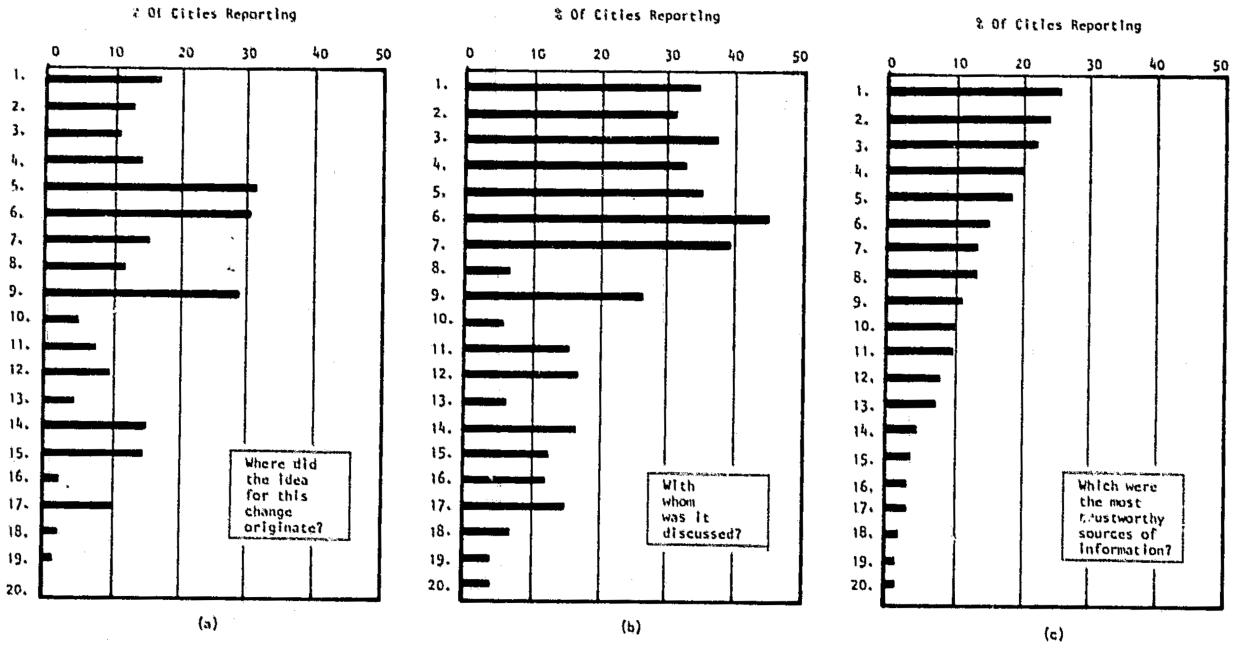
1. Builder personnel: local. 2. Architects or engineers. 3. Builder personnel: out-of-town. 4. Building officials from cities: within your county. 5. Building material producers and suppliers personnel: local. 6. Building officials from cities: outside your county. 7. Building material producers and suppliers personnel: out-of-town. 8. Building official from state building agency. 9. Representative of a model code group. 10. Prefabricated home manufacturer or his representative. 11. Building trade union personnel.

FIGURE 1

CLASSIFICATION OF ELEMENTS OF THE INDEX OF TECHNOLOGICAL CURRENCY

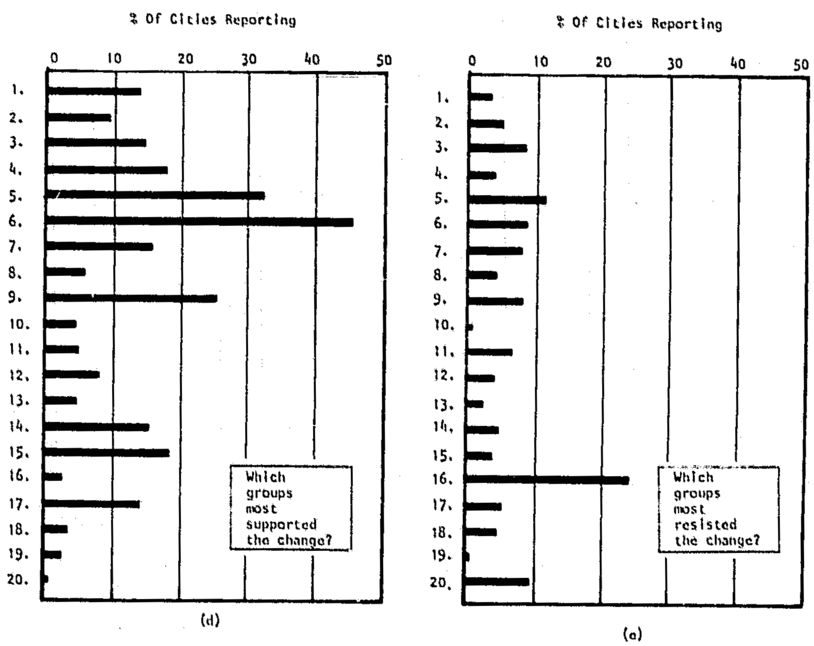
Identification Number	CODE CHANGES	SYMBOL	TYPE OF CHANGE: MATERIAL SUBSTITUTION	MATERIAL ELIMINATION	METHOD	DESIGN
1.	Nonmetallic Sheathed electrical cable	NMTCBL	X			
2.	Prefabricated metal chimneys	MTLCHM	X		X	
3.	Off-site preassembled combination drain, waste, and vent plumbing system for bathroom installation	PLMTRE			X	
4.	Off-site preassembled electrical wiring harness for installation at electrical entrance to dwelling	WRHRNS			X	
5.	Wood roof trusses, placed 24" on center	WDTRUS			X	X
6.	Cooper pipe in drain, waste. and vent plumbing systems	COPDRN	X			
7.	ABS (acrylonitrile-butadiene-styrene) or PVC (polyvinyl-chloride) plastic pipe in drain, waste, and vent plumbing systems	PLADRN	X			
8.	Bathrooms or toilet facilities equipped with ducts for natural or mechanical ventilation, in lieu of operable windows (or skylights)	BTHDCT	X			X
9.	Party walls without continuous air space	PRTYWL				X
10.	Use of single top and bottom plates in non-loading vearing interior partitions	SNGLPL		X		X
11.	Use of 2" x 3" studs in non-loading bearing interior partitions	2X3STD		X		X
12.	Placement of 2" x 4" studs 24" on center in non-load-bearing interior partitions	2X4STD		X		X
13.	In wood frame construction, sheathing at least ½ inch thick, in lieu of corner bracing	WDSHTH		X		X
14.	Wood frame exterior walls in multi-family structures of three stories or less	WDFRMF	X			X

TABLE 1



1. Meetings of professional associations. 2. Building officials from cities outside county. 3. Building officials from cities within county. 4. Architects or engineers 5. Building material producers or supplier representatives: local. 6. Builder representatives: local. 7. Building department staff. 8. Trade or professional magazines. 9. Building material producers or supplier representatives: out-of-town. 10. Government publications. 11. Other sources. 12. Meetings or conventions of materials producers. 13. Building product catalogs. 14. Yourself. 15. Prefabricated home manufacturer representatives. 16. Union representatives: local. 17. Building representatives: out-of-town 18. Civic or voter groups. 19. Mass media (TV, magazines, newspapers). 20. Union representatives: out-of-town.

For the most difficult code item adoption with responses disaggregated by code type: (a) where did the idea for this change originate? (b) with whom was it discussed? (c) which were the most trustworthy sources of information? (d) which groups most supported the change? (e) which groups most resisted the change?



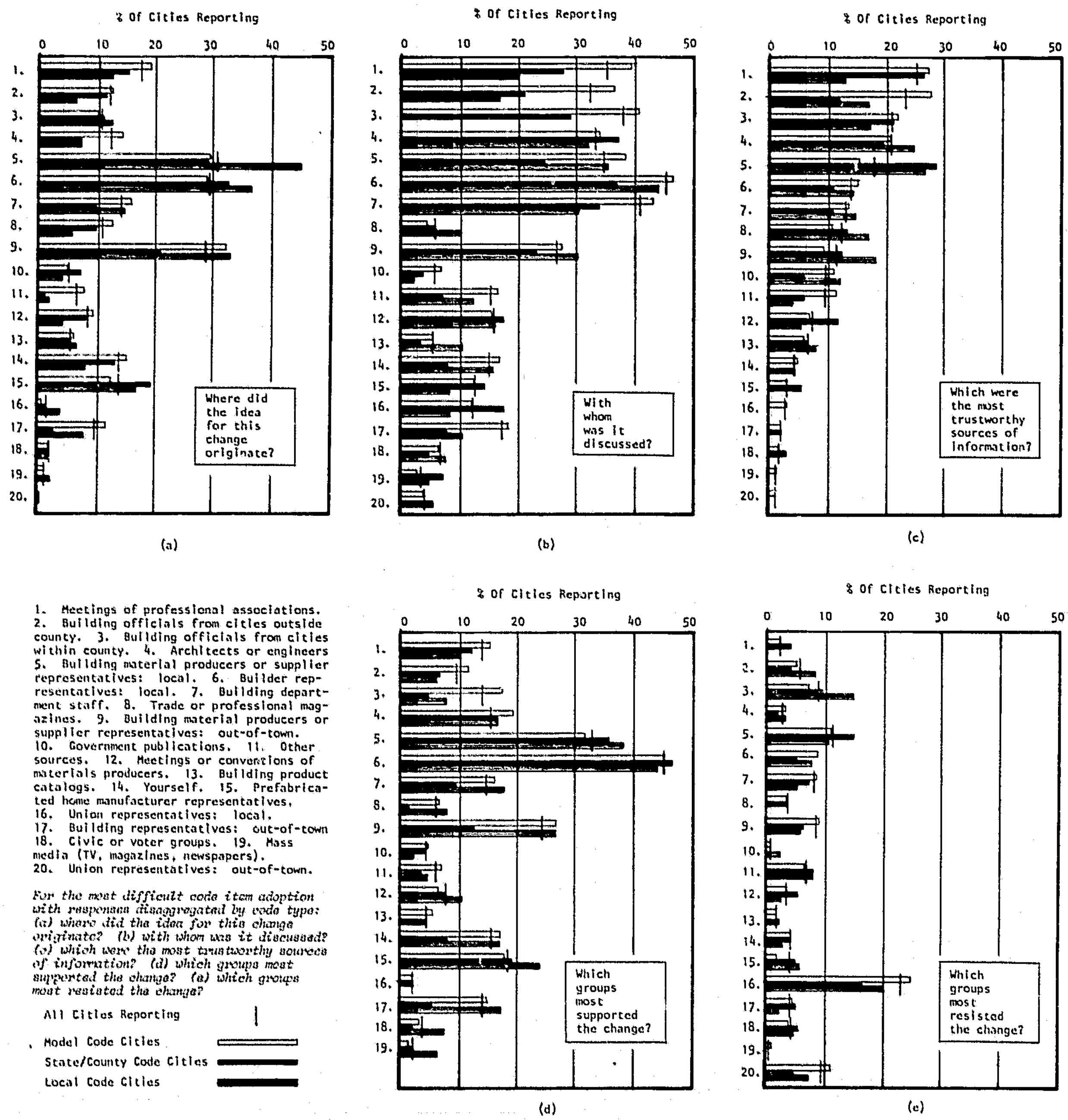
PARTICIPATION IN COLLECTIVE DECISION MAKING IN THE LOCAL BUILDING DEPARTMENT BY ACTOR AND ROLE

FIGURE 2

Concordance Between Rank-Ordered Rosters of
Actors Prominent in Local Building Department
Decisions on Innovative Technology

Rosters Compared	Spearman's R	Student's t	Statistical Significance p
1) Trust vs. Originate	0.68	3.93	0.005%
2) Trust vs. Discuss	0.79	5.46	0.005%
3) Trust vs. Support	0.53	2.65	0.01 p 0.005%
4) Trust vs. Resist	0.12	0.51	25 p 40%
5) Support vs. Resist	0.26	1.15	10 p 25%
6) Originate vs. Support	0.93	4.19	0.0005%
7) Originate vs. Resist	0.28	1.17	10 p 25%
8) Support (with union representatives suppressed) vs. Resist (with union representatives suppressed)	0.74	3.64	0.005 p 0.0005%

TABLE 2



PARTICIPATION IN COLLECTIVE DECISION MAKING IN THE LOCAL BUILDING DEPARTMENT, BY ACTOR AND BY ROLE, CONTROLLING FOR TYPE OF LOCAL CODE IN FORCE

FIGURE 3

LOCAL BUILDING OFFICIALS' RANKING OF MOST TRUSTED SORUCE OF INFORMATION ON MOST DIFFICULT CODE ITEM ADOPTION DECISION, BY TYPE OF CODE

Model code	State/county	Local code
1 Meetings of professional associations	1 Local building material producer or supplier representative	1 Local building material producer or supplier representative
2 Building officials from distant cities	2 Meetings of professional associations	2 Architects or engineers
3 Building officials from nearby cities	3 Building officials from nearby cities	3 Out-of-town building material producer or supplier representative
4 Architects or engineers	4 Architects or engineers	4 Trade or professional magazines or journals
5 Local building material producer or supplier representative	5 Trade of professional magazines or journals	4 Building officials from nearby cities
6 Local builder representative	6 Building department staff	4 Building officials from distant cities
7 Building department staff	6 Meetings or conventions of building materials producers	7 Building department staff
8 Other unspecified sources	6 Building officials from distant cities	7 Local builder representative
9 Government publications	6 Local builder representatives	9 Meetings of professional associations
9 Trade or professional magazines or journals	6 Out-of-town building material producer or supplier representative	9 Government publications
11 Out-of-town building material producer or supplier representative	11 Government publications	11 Building product catalogs or brochures
12 Meetings or conventions of building materials producers	11 Building product catalogs or brochures	12 Meetings or conventions of building materials producers
13 Building product catalogs or brochures	11 Other unspecified sources	13 Yourself
14 Yourself	14 Prefabricated home manufacturer representatives	13 Unspecified other sources
15 Local building trades union representative	15 Out-of-town builder representatives	15 Local building trades union representative
16 Prefabricated home manufacturer representative	15 Civic or voter groups	15 Out-of-town building trades union representative
16 Out-of-town builder representative	17 Yourself	15 Prefabricated home manufacturer representative
18 Mass media	17 Local building trades union representative	15 Out-of-town builder representative
18 Civic or voter groups	17 Out-of-town building trades union representative	20 Mass media
18 Out-of-town building trades union representative	20 Mass media	

TABLE 3

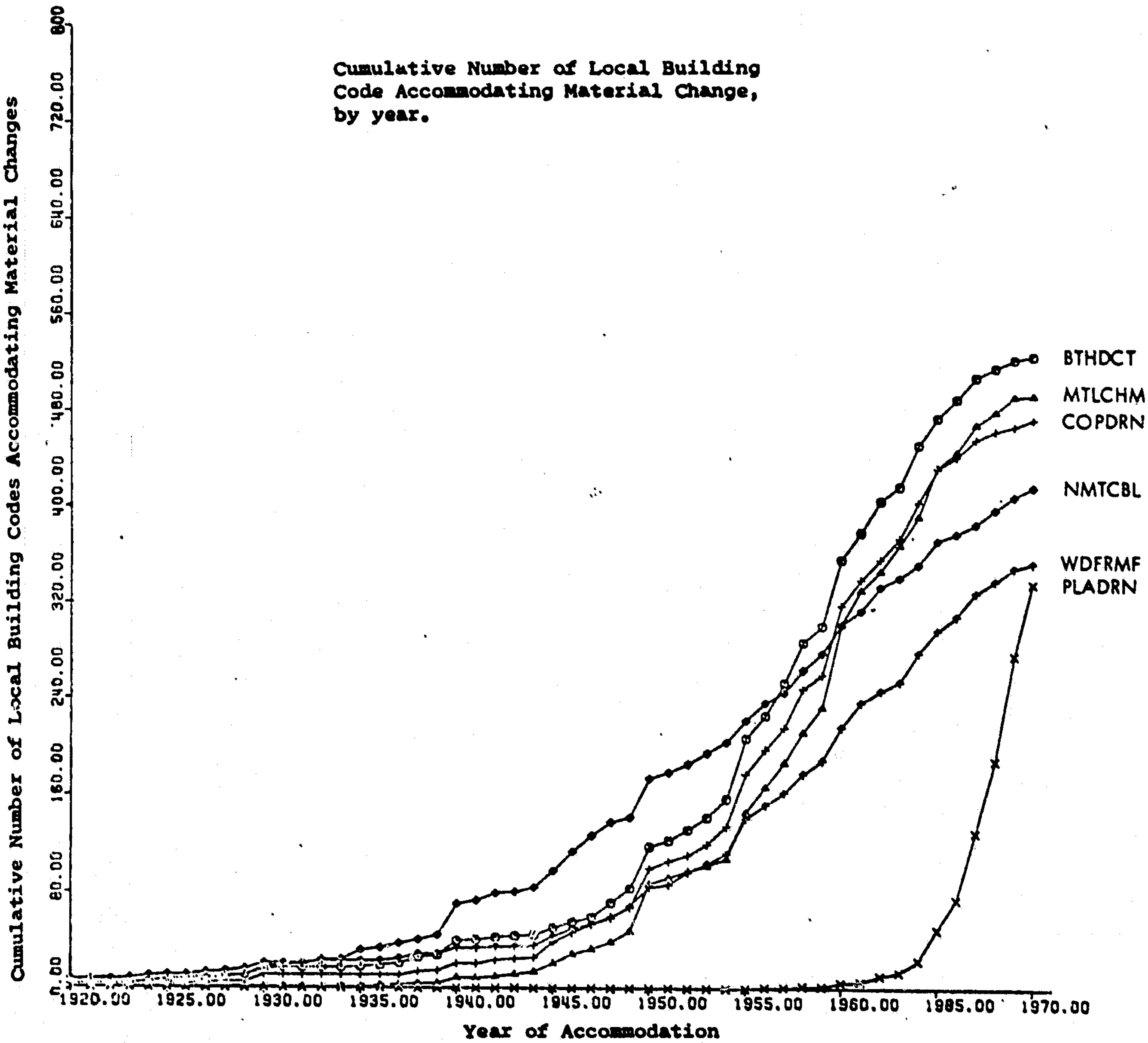

Cumulative Number of Local Building Code Accommodating Material Change, by year.
Cumulative Number of Local Building Codes Accommodating Material Changes
Year of Accommodation
BTHDCT
MTLCHM
COPDRN
NMTCBL
WDFRMF
PLADRN

FIGURE 4

APPENDIX 2. REGIONAL CODE VARIATION IMPACTS

PURPOSE: Review existing model codes, their regional influence and the impact they may have on the development of Residential PV modules.

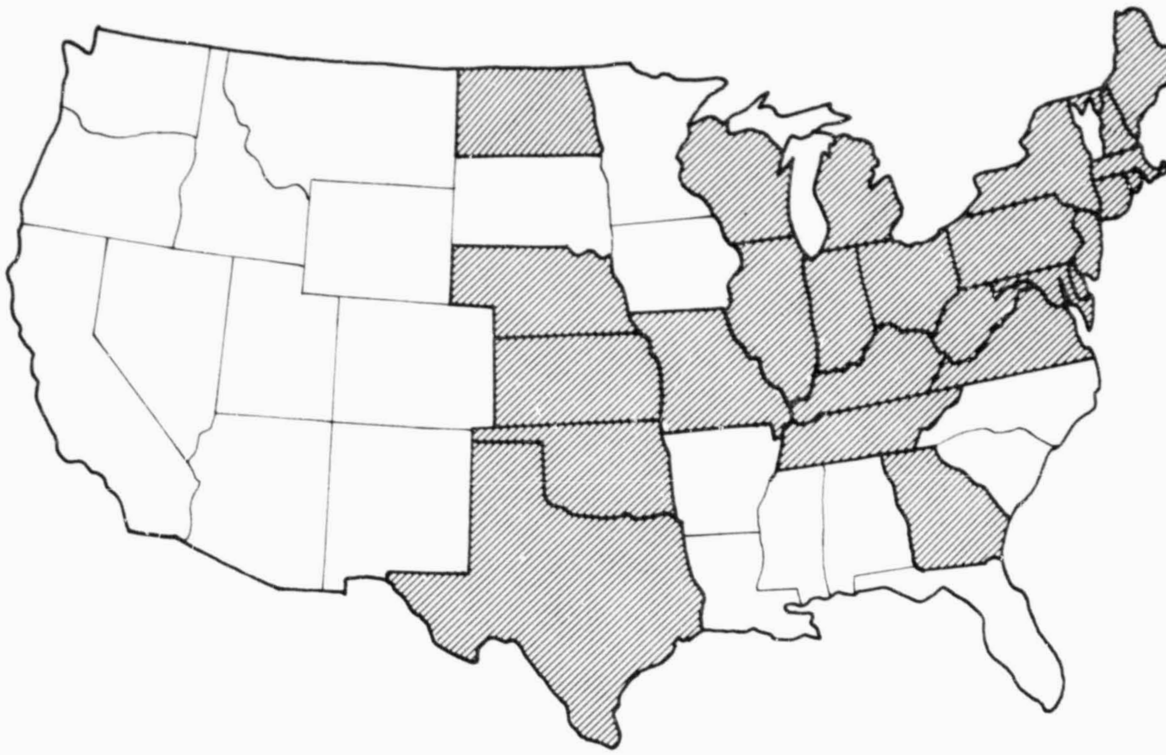
CONCLUSIONS: Model codes for buildings and solar thermal systems have a strong regional impact and can have a major impact on the design and technology advancements of the PV industry. The use of model codes, other than those developed around consensus standards, to secure necessary public safety and welfare requirements for evolving technologies is not recommended. The use of a flexible performance criteria document which advances with the technology is recommended.

RECOMMENDATIONS: In order for manufacturers to receive the widest acceptance by model code agencies, they must comply with the existing standards referenced by the codes. If compliance to these standards proves technically or economically unfeasible, changes in either the code or standard will be required. Both of these procedures could be extensive and time consuming. It is recommended that an industry wide attempt be made to further develop the Residential Photovoltaic Module Performance Criteria listed in Appendix 19. This will give the manufacturer a guide to use throughout the design development phase of his product that should insure that the end product will meet code requirements.

REGIONAL CODE VARIATION IMPACTS

There is a very wide variation from state to state, and from locality to locality in the adoption and enforcement of the codes listed in Appendix 1. On the state level, there are several states which enforce no general building code; by contrast such states as New York have developed their own State Building Construction Code, and some major cities, such as New York City, have developed specific code documents on a local basis. Falling between these two extremes, the majority of states subscribe to one of the three major model codes, the Basic Building Code (BOCA), The Uniform Building Code (ICBO) or The Standard Building Code (SBCC) In general, the Basic Building Code, promulgated by the Building Officials and Code Administrators International, Inc. is subscribed to by midwestern and northeastern regions, as shown in Figure 2-1. The Uniform Building Code, promulgated by the International Conference of Building Officials, is primarily recognized in midwestern and western regions, as shown in Figure 2-2. And the regions which have adopted the Standard Building Code, developed by the Southern Building Code Congress International are illustrated by Figure 2-3. The aggregate map, as shown in Figure 2-4, illustrates the states currently using one of these three major model codes and, therefore, the areas covered by this study. Only Montana, Minnesota and a small area in Vermont appear to use no model code. It should be pointed out that maps shown are not intended to indicate that these codes have been adopted officially by a state code enforcing agency, but rather that there is wide usage at town, county, city and perhaps state levels of the particular code. It should also be noted that this allows some utilization overlap of different code documents. In some cases, the states will adopt one of the model codes without significant variation; in other cases, the model code may be used as a base from which a state code is developed by revision. In any case, any product destined for use in the residential building industry should ideally comply with all these model code documents.

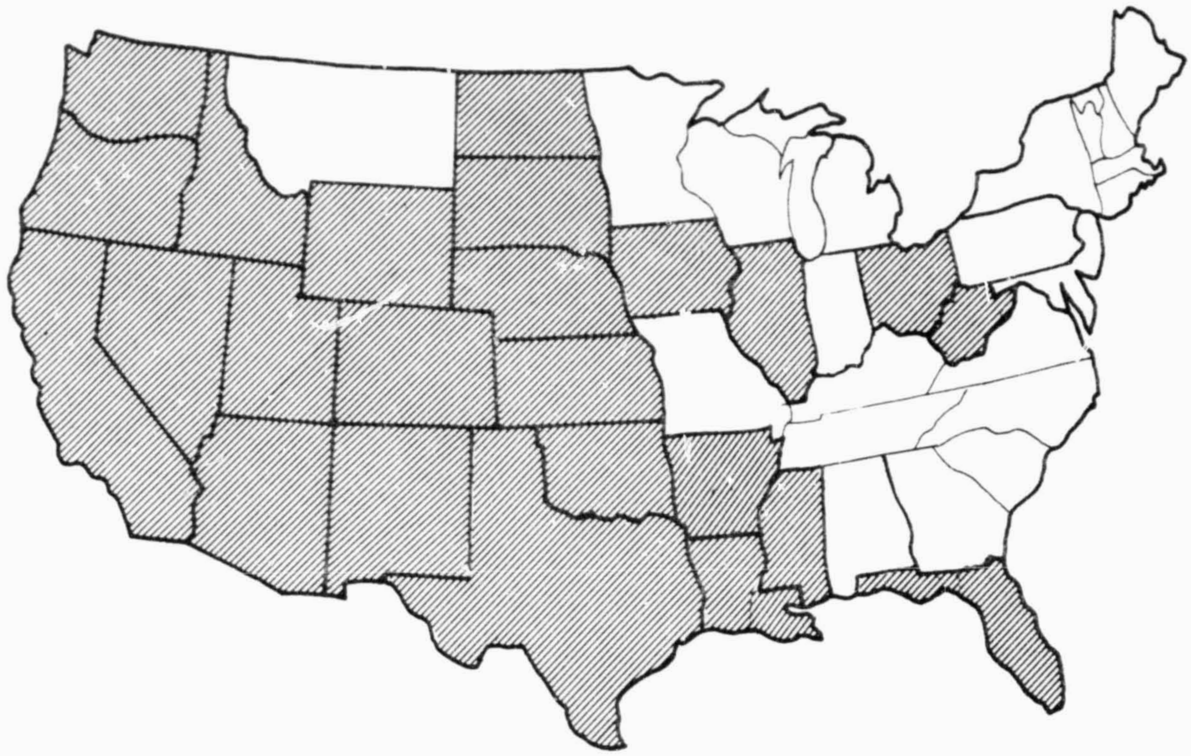
Enforcement of the building codes is an entirely different area, with as much variation as exists in the codes themselves. Most states having adopted a code, enforce that code at a local level, with the local building official having a substantial amount of authority, and hence, control over the construction in that particular locality. This situation becomes particularly important in the case of new building materials or methods which may, at the discretion of the code official, require substantial testing. However, in Oregon, no modification of the state adopted code by individual localities is permitted. Furthermore, approvals of new materials and construction methods are done by the State Building Codes Department; the acceptance of a new material or method is done on a statewide basis so it no longer falls within the discretionary powers of individual local code officials. This is important, since particularly in smaller cities or towns, the staff of code officials is frequently small, their jurisdiction quite wide, and they may not



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

BUILDING OFFICIALS AND CODE ADMINISTRATORS INTERNATIONAL INC. (BOCA)

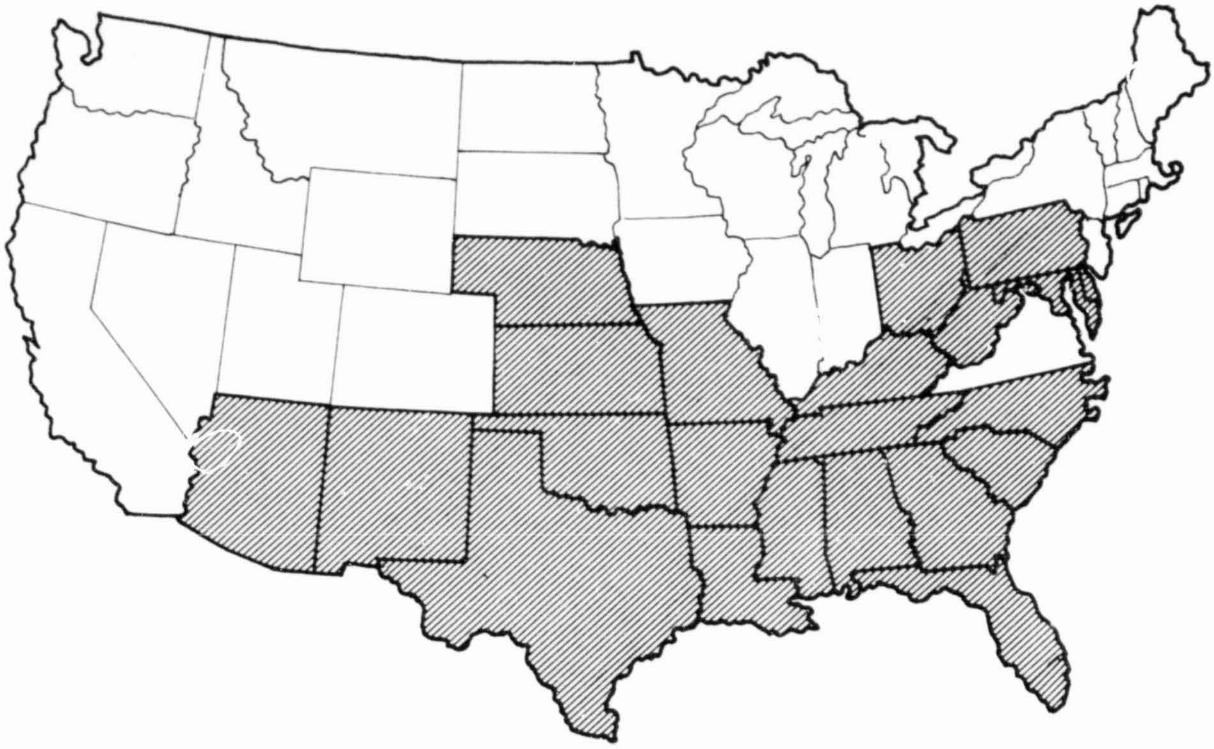
FIGURE 2-1



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

INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS

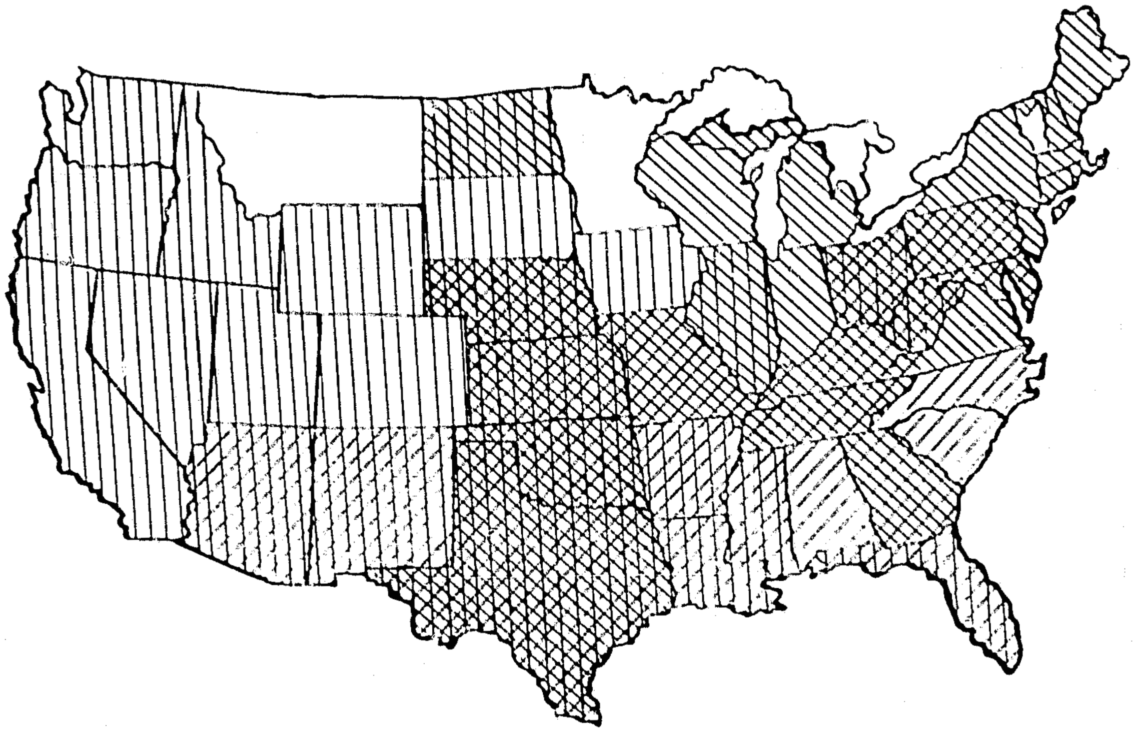
FIGURE 2-2



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

SOUTHERN BUILDING CODE CONGRESS INTERNATIONAL (SBCC)

FIGURE 2-3



- BUILDING OFFICIALS AND CODE ADMINISTRATORS (BOCA) BASIC BUILDING CODE
- SOUTHERN BUILDING CODE CONGRESS (SBCC) STANDARD BUILDING CODE
- INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS (ICBO) UNIFORM BUILDING CODE

AGGREGATE CODE MAP
FIGURE 2-4

be particularly well informed about certain areas of new construction. In cases where there exists a doubt in the mind of an uninformed code official, his reaction is frequently to either reject the application or to require substantial expensive testing before approval is granted. Most model codes have procedures to test new products and building techniques for compliance. This is very important to the product designer because stated compliance to a building code, for example -- "approved by BOCA"-- smooths the road to general acceptance of the product by the building industry.

At present, there are very few states which have adopted model solar energy codes, and in fact, very few solar codes have been developed. The major developments to date, have been the Uniform Solar Energy Code, developed by the International Association of Plumbing and Mechanical Officials, and the Los Angeles Solar Code,which was adapted from the Uniform Solar Energy Code. There is work being done by the three model code groups -- BOCA, ICBO and SBCC -- in conjunction with the Council of American Building Officials (CABO), and the National Bureau of Standards (NBS) towards the development of a Model Solar Energy Code. None of the actual solar code work done to date is applicable to residential photovoltaic modules, either to restrict or frame their development. If, however, interest arises from the development of combined PV/Thermal solar collectors these documents should be reviewed. One point that should be made is both the Uniform Solar Energy Code and the Los Angeles Solar Energy Code should not really be classified as codes. In their present configuration, they should be classified as either a standard or manual of accepted practice since they define the state-of-the-art procedures as currently accepted by the industry. By classifying these documents as codes, individuals have legally frozen technology development in various material and construction areas concerning the solar heating and cooling industry. This should be avoided in the PV industry as it is still in its infancy. Any document written in a prescriptive manner and implemented as a code describing the PV module and system would be extremely premature and serve only to restrict rather than assist technology development and implementation. Certain early technological devices or solutions would become the only "code-approvable" way a residential PV module could be made.

Resolution of these potential difficulties may be achieved by soliciting the cooperation of the Council of American Building Officials, whose responsibility it is to coordinate the activities of the three major model code groups (BOCA, ICBO, SBCC). In addition, the National Conference of States on Building Codes and Standards (NCSBCS) is playing an important role in the development of model solar codes, particularly in the area of planning for the implementation of the model solar codes which are already developed, and the training of code officials to make proper judgements with regard to solar energy systems. It should be the responsibility of a manufacturer's organization (perhaps the newly formed Photovoltaic Division of the Solar Energy Industries Association (SEIA)), to work with these groups to resolve any potential code restrictions affecting residential photovoltaic modules. Another approach would be for the federal government to initiate the development of codes and standards which would allow a measuring stick for the code officials to judge photovoltaic applications. This would be similar to previous efforts, such as the procedure for testing solar thermal collection systems, which was developed by The American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) as Standard 93-77.

It is of interest to note that the considerable work done by the Department of Energy (DOE) and the Department of Housing and Urban Development (HUD) in the solar demonstration projects has yielded rather few code enforcement difficulties. There have been some cases, however, in which a substantial penalty was imposed upon the implementation of the solar system by a code official who lacked a full understanding of the proposed system. It can be speculated that the reason for the relatively few difficulties encountered in the demonstration program is the implied support of the federal government, which tends to reassure building officials that the systems proposed are well designed and do not pose any hazard to public health, safety or welfare. There has been a greater incidence of problems with code officials in solar applications which have not been under the demonstration program. Individuals proposing solar systems have frequently encountered code officials who are less than sympathetic, and who react by imposing rather severe testing requirements for the solar system.

It is felt that the best resolution to these kinds of problems can be accomplished by the coordinated development of consensus codes and standards which provide the individual building official with a basis for judgement.

So, as a result, and with a desire to establish an aggressive attitude toward codes, a preliminary Residential Photovoltaic Module Performance Criteria (RPMPC) was developed. It is hoped that this document could fulfill the need for a code document while still accommodating the emerging PV technology. The basis for this Performance Criteria document was a document prepared by the National Bureau of Standards (NBS) for the Division of Solar Energy, Energy Research and Development Administration (ERDA) entitled, "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings." The RPMPC provides a format to reference general performance requirements and specific existing tests which will give manufacturers guidelines for the development of residential photovoltaic modules (RPM). This document will also give code officials a measuring stick for code compliance. The RPMPC format is useful to a developing industry because it allows for easy incorporation of changes to technical requirements, keeping pace with the photovoltaic industry. For a detailed explanation of this document and its use, see Appendix 19 - Residential Photovoltaic Module Performance Criteria.

APPENDIX 3. MODEL AND CITY CODES REVIEW

PURPOSE: Review five representative building codes, BOCA, ICBO, SBCC, Los Angeles and Pittsburgh, to determine if they (1) contain any category or group of categories into which it might be appropriate to include a photovoltaic module, panel, and array and (2) what requirements are imposed or might be imposed on the photovoltaic module, panel and array by these codes.

CONCLUSIONS: In the five codes reviewed, there were no applicable code categories into which photovoltaic modules, panels and arrays could be placed. Code officials will almost certainly rely upon existing categories which can be interpreted as applying to PV installation. Likely choices are roof coverings, roof structures, skylights, veneers, and loading criteria. Incombustibility or resistance to fire is by and large, not required. The use of any plastic material in the module will be limited to "approved plastics". Approved plastics are then strictly limited to area of usage. It will be necessary to perform ASTM-D-635 Flammability of Rigid Plastics Test to determine code classifications of plastic materials. This plastic restriction applied to the use of any plastic material, regardless of its location in the construction of the building, i.e., exposed or in a sandwich construction. Typical building materials for roofs, weigh in the range of 5 to 20 lb./sq. ft. Since typical modules will typically weigh less than 10 lb./sq. ft., problems should not arise in the addition of materials to roof loads. In retrofit applications, since arrays will be added to roofs consisting of building materials whose weights are at the low end of the building material weight range loading problems should not exist. Here, typical roof construction such as asphalt shingles will probably be the norm; retrofit addition of modules to a slate or tile roof would be unusual.

RECOMMENDATIONS: The national building codes will, no doubt, begin preparing new sections addressing the use of photovoltaic modules in residential construction. This cannot be expected, however, until RPM's have achieved some reasonable amount of success in the residential market. Because of the existing plastic restrictions, testing of common and potential module plastic materials should be initiated, if plastics cannot be excluded altogether. Additional tests of module/array flame spread characteristics should also be initiated to determine if the array size can be increased beyond the existing plastic area limitations in the codes.

INTRODUCTION

Model codes, as mentioned before, are designed to suit the requirements of a wide variety of cities, which vary in both size and locale. They tend, therefore, to be written in more general terms than what might be called city codes. City codes are those which are written exclusively by and for a specific city. The model code covers a wide range of possibilities, and each city subscribing to the code selects those parts which are appropriate for its needs. Modifications based on local peculiarities are also not uncommon. However, the analysis of the three model codes encompasses the most prevalent requirements for construction materials and systems. Also, local modifications of the code tend to be more lenient rather than more stringent in their requirements.

To serve as the basis of comparison with the model codes, the building codes of the cities of Pittsburgh, Pennsylvania and Los Angeles, California were reviewed. These were selected because they represent two of the extremes which may be encountered. The Pittsburgh Code was enacted in 1947 and, without significant amendment or modernization, is still in effect today. It does not reflect some of the common contemporary trends in building codes. A good example is the omission of any evaluation or ruling on the various types of thermal insulation or, for that matter, even the inclusion of insulation in the index. On the other hand, the Pittsburgh Code is an appropriate choice because of its longevity and the absence of any glimmer of future change. It well represents cities and municipalities whose codes do not, in the body of their texts, reflect the contemporary thinking of code writing agencies. The effects of this type of code on the design of the RPM should, nevertheless, be addressed as it is not a rarity.

The other selected city code, the Los Angeles Code, is updated regularly. The edition used for this review, 1976, has already been updated to August, 1978.

and contains all amendments effective through that date. It is a good example, then, of a contemporary code in force in a large city. The research into the effects of existing code requirements under and/or restrictions that might be pertinent to the design of the Residential Photovoltaic Module (RPM) falls into four general categories. These categories are roof coverings, roof structures, veneers and load characteristics. Each of these areas is commonly treated in the model codes and city codes. They were selected because they are the ones that, in BHKRA's opinion, are most likely to be selected by code agencies in their efforts to determine the RPM's compliance with and acceptability to the codes.

ROOF COVERINGS

In order to study the relationship of the roof-mounted residential photovoltaic module (RPM) to the fire resistance rating of roof coverings in residential construction, a review of three model codes -- BOCA, SBCC and ICBO -- along with two city codes __ Pittsburgh and Los Angeles -- was undertaken to determine how roof and roof coverings are evaluated for fire resistance. It was assumed that the RPM was installed on the residence by either the direct or integral mounting technique, as the other two types of mounting - rack and standoff - could not practically result in the array being judged as a roof covering. (See Appendix 13 - Mounting Type Configuration).

Both the BOCA Code and ICBO establish standards which must be met or tests which must be performed to provide a product's compliance with code requirements. BOCA lists these requirements in Appendix G, and ICBO in Chapter 32, Section 3202(b). Both codes rely on such agencies as UL and ASTM -- nationally recognized testing agencies -- as bases for product approval. (See Appendix 1- Codes and Standards, et.al.)

The BOCA classifies roof covering materials "in accordance with the severity of exposure to exterior fire and ability to resist the spread of fire from surrounding buildings and structures." Materials which have not been tested and classified by a nationally recognized authority like Underwriters Laboratories are categorized as "Non-classified roofings", the lowest of four possible ratings noted. Section 926.3.4 states, however, that non-classified roof coverings may be used on "Buildings and structures of unprotected frame construction (that is, Type 4B Unprotected, when the distance from any other building is not less than 12 feet)." As one or two family dwellings commonly fall within the definition of this exception, RPM components would most probably be acceptable by code even though they were not tested for compliance to code standards.

The determination of the fire resistant rating required by ICBO is less clear. Section 1704, which deals with roof coverings, requires fire retardant coverings "...except in Type V Buildings (allows wood frame construction) housing Group R (Residential) Occupancies, where it may be as specified in Section 3203(f)." This statement roughly approximates the exception mentioned in the BOCA Code. Section 3203(f) lists a wide variety, though by no means all, of the materials which are acceptable roof coverings. Included are wood shingles, and shakes. This suggests that RPM components could be combustible to some extent. A similar approach is taken by the SBCC. This code also fails to be specific about its requirements for roof coverings to be used in one or two family dwellings. Paragraph 1707.9 "Roof Coverings" states that "Any roof covering permitted in this code may be applied to dwellings..." Again, all conceivable roof coverings cannot possibly be addressed. However, paragraph 103.6 Alternate Materials and Alternate Methods of Construction, states that the code is "...not intended to prevent the use of any material, or method of construction not specifically prescribed by this code, provided any such alternate has been approved and its use authorized by the Building Official." This statement clearly encourages the use of new materials and techniques. As with the ICBO, the SBCC accepts wood shingles and shakes for use on dwellings, again suggested that RPM components could be combustible to some extent.

Plastic as roof coverings bear special attention. Each of the three codes addresses plastics, and accepts for use as roofing so-called "approved plastics." Approval varies between codes, but BOCA is a good example. Samples of plastic must be subjected to a test for burning rate. ASTM D 635, and the rate of burning in turn, determines the classification of the plastics; that is, Class B for example has an average extent of burning of less than eight-tenths (0.8) inches per minute according to ASTM D 635.

BOCA and SBCC permit the use of approved plastics in roofs which are not required to have a fire rating. As one or two family dwellings are not required by either code to have roofs which have a fire rating, approved plastics may be used. This limit varies depending on the Code Classification, as previously described.

BOCA Classification	Max. Panel Area (Individual Unit)	Total Area of Plasic on Roof (% of floor area)
Class A	300 ft^2	30%
Class B	200 ft^2	25%
Class C	100 ft^2	20%
SBCC Class CC1	300 ft^2	30%
Class CC2	100 ft^2	25%

ICBO states in Paragraph 5205(d) that "Combinations of approved plastics used in roofs and skylights shall not exceed 25% of the floor area of the room or occupancy sheltered." Paragraph 5206 states that the maximum panel area of plastic used in roof monitors or sawtooth roofs shall not exceed 200 square feet and that the total aggregate area of plastics used in skylights, monitors and sawtooth glazing shall not exceed 30% of the floor area of the room or occupancy sheltered.

All three codes require a separation of four feet horizontally between plastics as a cover material for the RPM. A 2,000 square foot residence would be limited to between 400 square feet and 600 square feet of array area.

* * *

The Building Code of the City of Pittsburgh has been selected as representative of those for medium to large size cities. Additionally, it has changed little since its approval in 1947. In the City of Pittsburgh Code, one and two family dwellings, categorized as Group "E" Occupancy, (Dwelling), may be constructed up to three stories in height if of Type VI (Wood Frame) Construction. Type VI may be further defined as that "...Type of construction in which the structural parts and materials are of wood or are dependent upon wood frame for support, including construction having combustible exterior veneer..." In other words, Type VI is conventional residential construction, acceptable in virtually all Fire Zones throughout the city where one and two family dwellings are permitted.

Table 14-A "Minimum Fire-Resistive Requirements for the Various Types of Construction" states that roof panels of Type VI buildings need carry no fire resistive rating. The component materials of the RPM are, therefore, not limited by code to those which are fire resistive.

Plastics are addressed in Part VI, Miscellaneous, of the Rules and Regulations Section under the heading "Glass Fiber Reinforced Plastic Panels." This section states that "Glass fiber reinforced plastic panels having a flame spread not over 75, as tested by an approved laboratory and labeled accordingly, may be used in roofs and skylights of buildings in any Fire Zone (Part IV, Chapter 13 - Restrictions in Fire Zones), if the total area of such panels does not exceed 35 percent of the entire roof area. This material may be used for side walls where permitted by code." Plastics, then, are permitted as an element of an RPM when installed as a direct or integral mounting.

The City of Los Angeles Building Code in Chapter 32 - Roof Coverings, requires that the "roof covering of every building shall be a fire retardant roof covering." However, outside of Fire Zones and Fire Buffer Zones -- that is, commercial and industrial zones delineated in Chapter 16 - Restrictions in Fire Zones -- wood shingles and shakes are permitted on wood frame buildings. This concession is similar to those made in other codes already discussed, and suggested that for standard residential construction -- Type V, wood Frame -- fire resistive materials are not required by code. This assumption is further supported in Section 91.1708, Type V Buildings- Special Provisions, whichin turn refers to Division 48 - Dwellings and Accessory Buildings. Division 48 concludes its discussion on roofing with this statement: "The Department may approve any other type of roof covering if it finds that such roof covering is equal in durability, strength and weather resistance to any of the types specified in this Section." Fire resistance is not mentioned.

Another exception listed in Section 91.3202 is plastic materials. "Corrugated sheets" of code-approved plastics are permitted for use as roof coverings where roofs are not required to be fire-retardant. The approval process is detailed in Division 16 - Plastics. Unlike other codes, no area limitations are specified for this type of installation. The single area and aggregate area limitations as in the other codes, apply only to certain approved plastics which are used in roofs which are required to be fire retardant.

The National Fire Code differs from the other codes already discussed. The "Suggested Fire-Resistive Roofing Ordinance", Vol. 4, p. 203-4, specifically prohibits roofing materials of less than Class C rating, as determined by

Underwriters Laboratories, Inc., for use in dwellings. Listings of individual roofing materials will be found in the U.L. Building Materials List. Wood shingles are also prohibited.

The selection of the materials which compose the RPM will be subject to these restrictions. For materials not rated by UL a series of tests is noted: "Methods of Fire Tests of Roof Coverings, NFPA No. 256." These tests will determine a materials' acceptability.

Plastics are addressed in Appendix A, "Recommendations on plastics in Building Codes and Standards NFPA No. 220M". This appendix lists additional standard fire tests which should be applied to plastics. Plastic as a roofing material is not discussed. It must, therefore, be assumed that the tests for roof coverings would apply in determining whether this would be an acceptable material for this type of installation.

For the great majoirty of applications, the physical composition of shingle photovoltaic modules will make little difference in that a fire rating is not ordinarily required for detached residences at least 12 feet apart. Despite this, application of the same module may be desired for a different occupancy or for use in a fire zone, and may therefore require a fire rating (determined by acceptable testing procedures). Conventional roof coverings are usually composed of layers of similar materials, forming a fiarly uniform product. The shingle module currently under development is comprised of laminations of various materials both combustible and non-combustible. Making a judgment about the flame-spread of a shingle module based on its most or least combustible component has no meaning because of the test procedures involved in the rating system. Candidates for an A, B, or C rating must withstand an intermediate flame test, a burning brand test, and a flame spread test, all of which require test samples composed of a number of shingle elements attached to wood decking representing a typical roofing installation. ASTM E-108, UL 790 and NFPA 256 tests are nearly identical and require test samples for the first two tests to be 3'-4" x 4'-4". The flame spread test requires a 4'-4" x 13'-0" sample. No single component of the roofing elements are tested separately but the entire in-place construction must withstand the test. Although PV shingle modules contain cellulosic and synthetic rubber materials which can burn, the hexagonal glass cover is the only material which is exposed on the roof surface other than the edge thickness of the flexible substrate which is ordinarily overlapped. Because of the incombustibility of the glass covers, the fire resistivity of the shingle elements could be largely enhanced. It must be recognized that the starter courses of the shingles has half hexagons of exposed hypalon. These small areas would be more vulnerable to fire and could more readily spread flame to the underlying wood deck.

* * *

Summary: The Residential Photovoltaic Module, installed on the roof of a one or two family dwelling, in either the direct or integral mounting, may be required to conform to existing building code restrictions for roof coverings. This being the case, those provisions of the selected codes bearing on this subject have been reviewed. The evaluations by the model codes and city codes of materials used as roof coverings are generally consistent, at least as they relate to one and two family residential construction. Incombustibility or resistance to fire is by and large, not required. The probability of conflagration and associated dangers, common with multi-family or high density residential construction, which dictate severe code requirements and restrictions are not present in low density neighborhoods of one and two family detached dweelings. As a result, all codes considered, with the exception of the National Fire Code, are reasonably lenient in their demands. The NFPA being concerned almost exclusively with fire prevention and protection, its requirements for roof coverings are understandably more severe. The NFPA, also, is more oriented toward commercial, industrial and institutional construction than toward one and two family dwellings.

The restrictions on plastics used in roofing are of two general types. First, each code requires that any plastics planned for use in roofing must meet minimum properties - usually flame spread or flammability - in order to be considered, in code language, "approved plastics". The plastic must be tested by a nationally-recognized service - Underwriters Laboratories for example - in conformance with tests stipulated by the code - ASTM D635, Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position, for example.

Even after approval, the area of the plastic material is limited by the code.

The limits vary slightly among the different codes, but are usually a maximum area stated as a percentage of the roof area or a percentage of the floor area of the dwelling. A residence of 2,000 square feet would be limited, for example, to between 400 and 600 square feet of approved plastic mounted integrally with the roof.

ROOF STRUCTURES

For this study, it was assumed that the RPM is to be installed on one or two family residences by either a rack or standoff device (See Appendix 13 - Mounting Type Configurations). All three codes--BOCA, SBCC and ICBO--along with the codes for the City of Pittsburgh and Los Angeles were studied to determine the relationship of a roof-mounted RPM to code requirements for roof mounted structures on residential construction.

To begin this section, it is important to establish a few definitions to avoid confusion. According to both BOCA and SBCC the definitions of roof structure, penthouse and additional story are as follows: A roof structure is "an enclosed structure on or above the roof of any part of a building". A penthouse is "an enclosed structure above the roof of a building other than a roof structure or bulkhead, occupying not more than 33-1/3% of the roof area." An additional story can be defined as "any enclosed structure covering an area greater than 33-1/3% of the roof area". The ICBO does not specifically define any of the above items, but for the purpose of this report the three codes will be considered synonomous.

In the discussion of the requirements for the standoff or rack mounted RPM, the first item to be determined is whether the RPM is more likely to be considered a "roof structure" or "penthouse". Due to the probable area requirements of the RPM for a dwelling (1,000 ft^2) it appears likely that the 33-1/3% limit of coverage for a penthouse will be exceeded by the roof mounted RPM. The RPM will most likely then be considered a "roof structure."

The BOCA Code states in Paragraph 925.5 and 925.10 that the roof structure shall conform to the requirements for building type of the building to which they are accessory. The SBCC in Paragraph 717.2(a) states essentially the same requirements as does the ICBO in Section 3601(d). Assumptions can be made in this light. Roof structures constructed to the standards of the buildings to which they are a part should satisfy the code requirements. Additionally, they should conform to requirements for wind, snow, seismic loads, as well as live and dead loads.

If roof structures are categorized as an additional story -- as they are in BOCA Paragraph 925.5 -- the minimum allowable construction type for the dwelling may be revised. For example, if a two-story residence is defined as three story due to the installation of a standoff or rack mounted RPM, BOCA in Table 305, Height and Area Limitations of Buildings, requires a change from Type 4B Unprotected Frame Construction to Type 4A Protected Frame Construction. The effects of this revision can be determined by reviewing Table 214, Fire Resistance Ratings of Structural Elements, in the BOCA Code.

Some of the areas affected by the Construction Type revision follow. Type 4A Construction is required to have a Class C rated roof covering; therefore, any material used as a roof covering must have been classified Class "C" by a recognized testing laboratory -- Underwriters Laboratories, for example -- or tested in accordance with roof covering standards listed in Appendix G of the Code. Since the RPM must be considered the roof covering of the "third story" as a result of the re-definition caused by paragraph 925.5, it must carry a Class C rating. This requirement will have a severly limiting effect on the selection of materials for the RPM, especially the cover material. Fortunately, this chain of reasoning applies only to standoff or rack mounted RPM's and then only if they are installed on a two-story residence and judged to be a third story.

Type 4A - Protected Frame Construction - also requires that certain other fire resistance ratings be complied with. The roof structure and floor structure are required to carry a one-hour fire resistive rating. As a result, additional expense is introduced to the fabric of the dwelling beyond what can normally be expected for the installation of the RPM. Type 4B Construction - Unprotected Frame - does not carry these restrictions on floor and roof assemblies or the requirement of Class C roof coverings. The roof covering restructions are in effect for all structures whether within the "Fire Limits" or not. Fire limits are defined in Paragraph 301.2 as comprising "...the areas containing congested business, commercial, manufacturing and industrial uses or in which such uses are developing." Residential construction, it can be seen, would not normally be contained within the fire limits.

In the ICBO, the aggregate area of penthouses and roof structures is limited in Section 3601(b), to no more than 33-1/3% of the area of the supporting roof. This suggests that greater coverage qualifies the structure as an additional story. In any event, as Section 3601(d) requires that roof structures "... shall be constructed with walls, floors and roof as required for the main portion of the Building," either interpretation will have the same result.

The ICBO in Table 5D, Maximum Height of Buildings, permits R-3 occupancy buildings (one and two family dwellings) to be constructed to the height of three stories using Type VN Construction ('N' meaning no general requirements for fire resistance). The addition of a third story to a two-family dwelling does not result, as it did in the BOCA Code, in a change to a more rigorous "Type of Construction". Therefore, the conclusions arrived at in investigating the code's effect on integral or direct-mounted RPM's would be appropriate here. In the standoff or rack-mounted RPM which is judged by the code to be another story, the array would be interpreted as a roof covering.

The rack or standoff mounted RPM might also conceivably be interpreted as similar enough to an outdoor display structure or sign to subject it to the provisions of the codes which deal with these elements. BOCA and SBCC deal with the subject nearly identically while the ICBO does not address signs at all. Neither code provides a strict definition of what constitutes a sign though the SBCC includes in Paragraph 2301.1 "sign" as part of its definition for Outdoor Advertising Displays. BOCA defines roof sign as "A display sign which is erected, constructed and maintained above the roof of a building."

Both codes prohibit the use of combustible materials in roof signs. BOCA, Section 1410, Roof Signs; SBCC Section 2303. There are exceptions, however, in both codes. BOCA permits the use of combustibles (Paragraph 1408.6.1) as ornamental features, and approved plastics (Paragraph 1408.6.2) sign facings to the limit of 100 square feet. The SBCC requires that roof signs shall be constructed entirely of steel except that "...ornamental moulding and battens behind the steel facing and the decorative lattice work may be of wood construction" (Paragraph 2303.2(b). Paragraph 2304 permits the use of approved plastics defined in the Paragraph for "...display surface material and for the letters, decorations and facings on signs...". The area of plastic allowable on "display surface(s)" may not exceed 1100 square feet.

Another requirement of both codes pertinent to roof sign construction is that the sign be mounted no less than six feet above the ro[illegible] If the RPM is judged then by the code requirements for signs, the restrictions on materials, size and positioning will have a significant effect on the possible choices available to the designer.

The integral mount RPM could conceivably be interpreted as similar enough to skylights to make compliance with the code requirements for skylights necessary. If the cover material is plastic the following requirements for skylight assemblies glazed with plastic would be appropriate. In all three codes, the framing material need not be non-combustible. The area of plastic within each unit is limited to 100 square feet and the maximum aggregate amount in all skylights no greater than 25% of the floor area of the room or space sheltered by the roof. The SBCC requirements are different in that it allows 300 square feet per unit when the plastic is Class CC1 - as defined in Paragraph 2601.2, Definitions - and 33-1/3% maximum aggregate amount when skylights are Class CC-1 plastic. All three codes require that there be a separation between units of not less than four feet, and that unit be mounted at least four inches above the plane of the roof. Further, the SBCC and ICBO require that plastic glazing used in skylight construction have edges protected with metal or a non-combustible material.

In the event that glass is used as a component of the RPM and compliance with the regulations for skylights is required, different considerations are in effect. All three codes require that glass used in skylights be wireglass, the ICBO allowing the use, also, of tempered glass, minimum 7/32" thick. The only allowance of plain glass is for skylights "...placed over shafts and stair enclosures..." or "...used for emergency heat and smoke ventings...". There is, however, the additional requirement that the plain glass be protected above and below by mesh screen of non-combustible construction. Clearly, then, a code interpretation that categorizes an RPM as a skylight will have a seriously limiting effect on the construction and installation of the units.

The City of Pittsburgh Building Code does not strictly define roof structures but does state that they must occupy less than 50% of the gross area of the building or they are considered another story (Section 3001). Like the model codes, the construction materials of any roof structures must be consistent with the requirements of the code for the occupancy on which the structure is placed.

This code's requirements for skylights (Section 2902) are consistent with those of BOCA and SBCC. Generally, glazing must be wire glass, though plain glass is permitted if protected above and below with wire mesh. There are no restrictions on framing materials. Glazing materials other than glass, plastic for example, are not addressed.

Signs are treated in the Pittsburgh Code similarly to the model codes. Section 3608(b) states that signs, including uprights, supports and braces shall be an incombustible material except that approved plastics -- as defined in Section 3607(b) -- may be used as facing material, letters and decorations on signs to the limits of 575 square feet. In display areas over 100 square feet, plastic must not exceed 100 square feet plus 25% of the difference between 100 square feet plus 25% of the difference between 100 square feet and the area of the display surface. Decorative lattice and moldings may be of wood.

Roof signs erected on roofs of wood construction must have the supporting members attached to and supported entirely by masonry, concrete or steel construction. This is a significant departure from the requirements of model codes for roof signs. Additionally, signs must be constructed to have not less than five feet between roof and lowest part of the sign.

The Los Angeles City Code is similar to the model codes in its treatment of the subject of roof structures. Section 91.3601(b) of Division 36 - Roof Structures stipulates that the aggregate area of all penthouses and roof structures shall not exceed 33-1/3% of the floor area sheltered by the roof. If they do, they are to "...be included in the height of and shall conform to the construction requirements of the building upon which it is erected." Therefore, roof structures are treated as another story. This requirement is the same as all model codes.

Table 17-A establishes a height limitation of three stories or 50 feet for Type V (wood frame) construction. Therefore, unless the RPM is installed on the roof of a three story dwelling, its components will not be required to be fire resistive.

This code's requirements for skylights differ somewhat from those of the other codes discussed. The maximum aggregate area for wireglass glazed skylights (Section 91.3606(b)) is 40% of the floor area sheltered by the roof upon which they are erected, unless the glazing material is a code approved plastic (see Division 61, Plastics). If the plastic is approved, the limit drops to 25% and the maximum area for individual skylights is 100 square feet. Plain glass is not included as an acceptable glazing material.

As in the ICBO and SBCC, plastic glazing for skylights must have its edges protected by metal or non-conbustible material. The code also requires that skylights be constructed to comply with roof loading requirements of the code. Group R Occupancies (residential) are the subject of Section 91.3603(h). This section expressly permits the use of wood as sash material for skylights in Group R buildings.

Roof signs are treated much the same as by the Pittsburgh Code. They must be constructed of incombustible material or approved plastic, though wood is permitted for use in mouldings and blocking. Unlike the other codes, however, the Los Angeles Code stipulates - Table No. 52A - the size, thickness, and type of glass panels which may be used in signs.

Summary: The Residential Photovoltaic Module may be judged for code compliance on the basis of existing requirements for similar elements in residential construction. Some categories for consideration are penthouses, roof structures, skylights, and signs. These are especially appropriate for standoff and rack mounted modules.

All four categories have been investigated to determine how code requirements for these elements might affect the design of the RPM if it were judged for compliance on this basis. Of these, one is more likely than the others to form the basis for a code official's judgement of the acceptability of the RPM.

It is improbable that an RPM could be expected to comply with the requirements for the roof mounted signs. The module is neither a display nor a vehicle for advertising. Additionally, since penthouses are usually defined as occupying 33-1/3% or less of the roof area and the RPM undoubtedly occupies more, code requirements for penthouses should not be applicable. Although an integrally mounted RPM might resemble a skylight from the exterior of a dwelling, it is not transparent or translucent and fulfills an entirely different function. Roof structure, defined as an enclosed structure on or above the roof of any part of a building, is the most appropriate existing element in residential construction by which to judge code compliance of the standoff or rack mounted RPM.

The codes reviewed all address the requirements for roof structures. Generally, they must be constructed of materials which are consistent with the requirements for the building on which they are erected. Other than the restrictions in the use of plastic materials as previously discussed under "Roof Coverings" and later discussed under "Veneers", a good deal of latitude is permitted. The only exception to this can be found in the BOCA Code and is discussed in the Body portion of this Section.

Code compliance of the RPM evaluated in the context of the requirements for roof structures should be readily attainable. Roof structures on one and two family dwellings need not be constructed of incombustible materials. They should conform, however, to the code requirements for wind, snow, seismic loads and live and dead loads.

VENEERS

This section deals with the relationship of a wall-mounted residential photovoltaic module (RPM) to code requirements for exterior veneers. This module installation technique, although not specifically outlined in this report, was considered to be similar enough to the integral or direct type that these could be used without any difficulties. Again the three model codes and two city codes were reviewed for pertinent items. For the purpose of this review, the definition of veneer, as defined by all of the code documents, is a facing attached to a wall for the purpose of ornamentation, protection or insulation, and not to be calculated as contributing to the strength of the wall. It is also assumed that the RPM is either a direct or integral mount. In this case, the RPM attached to the wall structure of a dwelling might be required to comply with code directives for exterior wall veneers. The definitions in the SBCC and ICBO make it clear that exterior veneers are required to carry only their weight. The RPM would not then be required, for example, to fulfill the structural purpose of sheathing or bracing if installed in wood frame construction. The ICBO states in Section 3004 that "Veneer shall support no load other than its own weight and the vertical dead load of veneer above." The SBCC concurs in this and further stipulates in paragraph 1414.1 (b) "...neither shall it be assumed to add to the strength of the wall." The BOCA Code, Pittsburgh Code, and Los Angeles Code deal with veneers in much the same way. Therefore, since the RPM is not subject to the code requirements based on structural loading, a greater number of options in its design may be possible.

Exterior wall veneers, like roof coverings, need not be of noncombustible materials on structures whose walls are not required to carry a fire resistance rating. This can be determined by reviewing Table 214 in the BOCA Code or Table 5A in the ICBO. Therefore, since the wall of one and two family dwellings are not required to be fire-resistive (all codes agree on this) an RPM installed on that wall needn't be fire resistive.

There are, however, special requirements which apply to the wall-mounted RPM if plastics are used in its construction. Just as was the case with plastic roof panels and plastic skylights, only "approved plastics" may be used in wall panels. The BOCA Code states in Section 2003.0, Exterior Wall Panels, that "...approved plastic materials may be used as wall panels, in exterior walls not required to have a fire resistance rating..." This statement is consistent with the intentions of the other codes. Nevertheless, the maximum single area as well as aggregate area are limited by all the codes. The SBCC, for example in Table 2603.1, allows for a maximum of 10% of the area of the exterior walls to be approved plastic material if it is classified CC-1 and the Fire Separation -- that is distance -- between dwellings is more than six feet but less than eleven feet. The maximum allowable square footage of a single area of plastic is 50 square feet. The allowable areas increase as the fire separation increases to "over 30 feet". The areas, then, permitted by the

SBCC are 30% and 300 square feet. The vertical separation between the panels is three or four feet depending on the classification of the plastic. Clearly, then, the Fire Separation will have a significant effect on the use of plastic materials in the wall mounted RPM since it dictates so directly the allowable area of plastic. The code classification of the plastic can also have an effect on allowable areas. Again referring to Table 2603.1 in the SBC, under the Fire Separation "11 feet or more but less than 30 feet" the maximum allowable percentage of wall area for Class CC-1 plastic is 25%, for Class CC-2, 15%. The maximum square foot single area for Class CC-1 is 90 square feet, and 70 square feet for Class CC-2.

The Los Angeles Code requirements differ from those of the other codes and in some respects are more restrictive. For example, Section 91.2903 stipulates that approved plastic units less than 3/16" thick are not to exceed one square foot in area. Those neither more than 1/2" nor less than 3/16" thick shall not exceed four square feet nor be greater than four feet in any dimension. The aggregate area shall not exceed 30% of the area of the wall face of the story on which it is installed and be separated vertically by noncombustible wall surface to a height of four feet.

A wall mounted RPM which incorporates plastics in its construction will, in all liklihood, be subjected to existing code requirements that will significantly effect its design and accpetability. No other material selection will have this effect on the RPM. If plastics are, therefore, rejected as a material's option in the design of the wall mounted RPM, its acceptability, under existing code provisions, becomes more likely.

There are a different set of criteria which bear on the RPM in the event that glass is a component of the module. The BOCA Code, Pittsburgh Code, and SBCC treat the subject of glass veneers in much the same way -- BOCA in Section 862.0 Structural Glass Veneers, SBCC in paragraph 1414.10 Glass Veneer. Both require that glass have a minimum thickness of 11/32", that the maximum allowable area of a single piece is ten square feet and maximum length four feet. As with other veneer materials, structural requirements beyond self-support are not addressed. The Los Angeles Code, on the other hand, applies the same restrictions of thickness and area to glass as it does to plastic.

Glass used as a part of the exterior wall of a dwelling may, however, be more likely required by the codes to comply with the restrictions and guidelines for glazing rather than glass veneers. Again, both BOCA and SBCC deal with glazing in the same fashion. The SBCC states in paragraph 2703.2: "For safety, glass or glass areas in exterior walls, in screens, in partitions, and in other openings subject to wind loading shall be capable of withstanding the wind loads as shown in Section 1205.1 acting either inward or outward. In the case of regular plate, float or sheet glass supported on four sides, the design factor shall be not less than 2.5". This is a significant difference from the code requirements for plastics and glass veneers. The ICBO exempts from its requirements for glazing Group R (Residential) Occupancies of three stories or less.

The Los Angeles code also exempts two and three story residential buildings from the area limitations and minimum glazing requirements of Section 91.1711, Glazing of Openings. That is, provided that the "...walls which contain glass are not closer to a public way than one-half the vertical distance from the ground to the top of the glazed opening." Glazing with approved plastics is permitted but not without restrictions. Plastic glazing may not exceed 30% of the area of the wall face of the story in which it is installed, for example, and must be installed in accordance with Table No. 17E Minimum Glazing Requirements. Assemblies must be separated vertically by four feet of incombustible wall surfacing and above the first story a single pane of plastic shall not exceed twelve square feet nor three feet in vertical dimension. These requirements are more consistent with those for veneers, and create similar problems.

Summary: If the wall mounted Residential Photovoltaic Module is to be judged on the basis of code requirements for veneers, some conclusions can be drawn. As a veneer, the RPM need not conform to code required structural loading criteria for building walls. There are also no fire resistance requirements for veneers.

If glass or plastic are among the components of the module, stringent code regulations will be applied. These take the form of restrictions on the total area of glass or plastic, the maximum area of individual glass or plastic units and requirements that individual units be separated by a certain specified minimum distance. The presence of glass or plastic may also result in the application of the normal code requirements for glazing. The significance of this is that, unlike veneers, glazing is required to withstand code mandated wind loading criteria.

LOAD CHARACTERITICS

This section deals with the relationship of the roof mounted RPM to building code loading criteria for residential construction. Again the three model codes -- BOCA, SBCC and ICBO -- were reviewed along with the city codes of Pittsburgh and Los Angeles. The installation of the RPM was considered to be either an integral, direct, standoff, or rack mount (See Appendix 13 - Mounting Types Configurations). It should be noted that no specific information was derived here, due to the vast references to loading characteristics throughout the code documents. Rather, a general discussion is presented.

All model codes investigated address the subject of the loading criteria which are to be used in designing the structure of a building. These criteria are the result of three factors: geography, use, construction.

The geographical location of a building determines the code mandated values for wind loading, snow loading, earthquake loading. The Standard Building Code, for example, charts the basic wind speeds in miles per hour - Figure 1205.1, which are applicable in various parts of the United States. These are then used, following the directions in the code, to determine the design of structural members and systems providing the stability for the building or structure.

The Live Load is defined in Section 1203 of the SBCC as "...the greatest loads that probably will be produced by the intended uses and occupancies..." of a building. The Live Loads which are considered minimums by the code are listed in Section 1203. Roof live loads are set forth in Table 1203.7.

The Dead Load of a building as defined in Section 1202 of the SBCC is "...the weight of all permanent construction, such as floors, roofs, permanent partitions, stairways and walls." Table 3-1 contains a list of the weights of construction materials.

The application of code-mandated design loads to the RPM will vary with the mounting type. The integrally mounted RPM should be designed as part of the roof panel. Wind, snow and earthquake loads would apply as well as the requirements that the RPM support roof live loads. The exceptions would be the area which ascribe to the BOCA Code or the SBCC. The BOCA, in Section 718, excludes one and two family dwellings from its earthquake requirements. The SBCC in Section 1206, requires seismic design only when "local authorities" call for it. A direct mount RPM, on the other hand, will be supported by the roof structure and need not be designed under the same constraints as the integral mount. It will contribute to the dead load on the roof structure as will the standoff and rack mounted units.

If the standoff and rack mounted RPM's were to be interpreted as falling within the requirements for roof mounted signs the code would directly influence the structural requirements for the sign. BOCA addressed this subject in Section 1408.2, Design Loads; SBCC in Section 3202, Structural Requirements. The same is true if the RPM is interpreted as a roof structure. Generally, as in the Uniform Building Code Chapter 36, roof structures are to be constructed in a manner consistent with the requirements of the main portion of the building, that is, in compliance with all dead and live load requirements and the information provided on wind, snow and earthquake loading.

The successful integration of a roof-mounted RPM will depend, not only on its ability to resist environmental conditions and loads, but also the characteristics of its own weight and configuration. These two areas can at times be cumulative, and, also, at times result in reduction factors to adjust live load conditions.

By definition, dead load is "...the weight of all permanent construction such as floors, roofs, permanent partitions, stairways and walls." Table 3-1 contains a list of the weights of some of the more frequently used construction materials. The average residential building roof envelope would be made up of a combination of three or more of these materials.

TABLE 3-1

WEIGHTS OF BUILDING MATERIALS

MATERIALS	Weight Lb. Per Sq.Ft.
CEILINGS	
Gypsum Ceiling block, 2" thick, unplastered	10
Plaster board, unplastered	3
Plaster, 3/4", and wood lath	8
Plaster, 3/4" and metal lath	8
Plaster, on tile or concrete	5
Suspended, metal lath and plaster	10
FLOORS	
Hardwood flooring, 3/8" thick	4
Sheathing, yellow pine 1", Oregon pine, spruce or hemlock, 7/8" thick	2½
Sheathing, yellow pine, 1" thick	4
Wood block, creosoted, 3" thick	15
Cement finish, per inch thick	12
Cinder concrete, per inch thick	9
Cinder concrete fill, per inch thick	5
Terazzo, Tile, Mastic, Linoleum, per inch thick, including base	12
Gypsum slab per inch thick	5
ROOFS	
Corrugated metal, galvanized:	
20 Manufacturer's Standard Gauge	1.66
24 Manufacturer's Standard Gauge	1.16
28 Manufacturer's Standard Gauge	.78

MATERIALS	Weight Lb. Per Sq.Ft.
Roofing felt, 3 ply and gravel	5½
Roofing felt, 5 ply and gravel	5½
Roofing felt, 3 ply & slag	4½
Roofing felt, 5 ply & slag	5½
3-ply ready roofing	1
Tile or slate	5-20
PARTITIONS	
Channel studs, metal lath, cement plaster, solid 2" thick	17.5
Studs, 2"x4", wood or metal lath, 3/4" plaster both sides	18
Studs, 2"x4", plaster board ½" plaster both sides	18
Plaster, ½", on gypsum block or clay tile (one side)	4
Hollow clay tile, 2"	13
Hollow clay tile, 3"	16
Hollow clay tile, 4"	18
Hollow clay tile, 5"	20
Hollow clay tile, 6"	25
Hollow clay tile, 8"	30
Hollow clay tile, 10"	35
Hollow gypsum block, 3"	10
Hollow gypsum block, 4"	13
Hollow gypsum block, 5"	15½
Hollow gypsum block, 6"	16½
Solid Gypsum block, 2"	9½
Solid Gypsum block, 3"	13
Steel partitions	2

TABLE 3-1 (Cont.)

MATERIALS	Weight Lb.Per Sq.Ft.
WALLS	
Brick, 8" thick	84
Brick, 12" thick	121
Brick, 16" thick	168
Brick, 20" thick	205
Brick, 24" thick	243
Wall tile, 6" thick	243
Wall tile, 8" thick	33
Wall tile, 10" thick	40
Wall tile, 12" thick	45
Brick 4", tile backing 4"	60
Brick 4", tile backing 8"	75
Brick 9", tile backing 4"	100
Brick 9", tile backing 8"	115
Limestone 4", brick 9"	140
Limestone 4", brick 13"	175
Limestone 4", tile 12"	100
Corrugated metal siding same as roofs	
Windows, glass, frame and sash	8
ASHLAR MASONRY, Per Cu.Ft.	
Granite, syenite, gneiss	165
Limestone, marble	160
Sandstone, bluestone	140
MORTAR RUBBLE MASONRY	
Granite, syenite, gneiss	155
Limestone, marble	150
Sandstone, bluestone	130
DRY RUBBLE MASONRY	
Granite, syenite, gneiss	130
Limestone, marble	125
Sandstone, bluestone	110
BRICK MASONRY	
Pressed brick	140
Common brick	120
Soft brick	100

MATERIALS	Weight Lb.Per Sq.Ft.
CONCRETE MASONRY	
Cement, stone, sand	144
Cement, slag, etc.	130
Cement, cinder, etc.	100
VARIOUS BUILDING MATERIALS	
Ashes, cinders	40-45
Cement, portland, loose	94
Cement, portland, set	183
Mortar, set	103
Lime, gypsum, loose	53-64
Slags, bank slag	67-72
Slags, bank screenings	98-117
Slags, machine slag	96
Slags, slag sand	49-55
EARTH, ETC., EXCAVATED	
Clay, dry	63
Clay, damp, plastic	110
Clay and gravel, dry	100
Earth, dry, loose	76
Earth, moist, loose	78
Earth, moist, packed	96
Earth, mud, flowing	108
Riprap, limestone	80-115
Riprap, sandstone	90
Riprap, shale	105
Sand, gravel, dry loose	90-105
Sand, gravel, dry, wet	118-120
MINERALS	
Asbestos	153
Barytes	281
Basalt	184
Bauxite	159
Borax	109

TABLE 3-1 (Cont.)

MATERIALS	Weight Lb.Per Cu.Ft.
Chalk	137
Clay, marl	137
Dolomite	181
Feldspar, orthoclase	159
Gneiss, serpentine	159
Granite, syenite	175
Greenstone, trap	187
Gypsum, alabaster	159
Hornblende	187
Limestone, marble	165
Magnesite	187
Phosphate rock, apatite	200
Pumice, natural	40
Porphyry	172
Quartz, flint	165
Sandstone, bluestone	147
Shale, slate	175
Soapstone, talc	169
STONE, QUARRIED, PILED	
Basalt, granite, gneiss	96
Limestone, marble, quartz	95
Sandstone	82
Shale	92
Greenstone, hornblende	107
BITUMINOUS SUBSTANCES	
Asphaltum	81
Coal, anthracite	97

MATERIALS	Weight Lb.Per Cu.Ft.
Coal, bituminous	84
Coal, lignite	78
Coal, peat, turf, dry	47
Coal, charcoal, pine	23
Coal, charcoal, oak	33
Coal, coke	75
Graphite	131
Paraffine	56
Petroleum	54
Petroleum, refined	50
Petroleum, benzine	46
Petroleum, gasoline	42
Pitch	69
Tar, bituminous	75
EXCAVATIONS IN WATER	
Sand or gravel	60
Sand or gravel or clay	65
Clay	80
River Mud	90
Soil	70
Stone riprap	65
COAL AND COKE, PILED	
Coal, anthracite	47-58
Coal, bituminous lignite	40-54
Coal, peat, turf	20-26
Coal, charcoal	10-14
Coal, coke	23-32

It is reasonable to assume that the majority of all single family residential roofs begin with module wood frame rafters or trusses at 24 inches on center with 1/2 to 3/4 inch exterior plywood sheathing and 15 to 30 pound building felts. The usual differences come in the final finish material the choice of which usually comes from an aesthetic consideration. The majority of roof finish materials are either asphalt shingles, concrete or clay tile, or slate.

Total dead load normally encountered in typical roof envelope would be:

Modular wood framing @24 inches on center	-	1.5 psf
1/2 to 3/4 inch plywood sheathing	-	2 psf
15 to 30 pound building felts	-	1 psf
	Subtotal	4.5 psf

Adding dead load weights of asphalt shingles, cement or clay tile, and slate to this figure, total dead load weights are 7 psf, 19 psf, and 13.5 psf respectively. Considering an average roof rafter span of 14'-0", an allowable total load of 87 lb/ft is noted for a 2 x 10 inch (1100 psi) wood beam. Considering 30 psf average snow live load, a total imposed load of 2 ft x 43.5 psf = 87 lb/ft is realized. The concurrence of the imposed load with the allowable load would indicate that for most new or retrofit installations, the manufactured weight of the RPM must not exceed the weight of the material in the above composite envelope that it is replacing, if no further strengthening of the conventional framing is desired. This would be true mostly for the integral-type mounting. A direct mounting could make use of the inherent reserve capacity built into a working stress versus ultimate stress design analysis. However, RPM imposed loads from standoff or rack mounted arrays would dictate a closer look at the need for additional framing beyond the conventional.

Live loading imposed on roof structures, as well as RPM arrays, would be snow, wind, and earthquake, all of which have regional limits on intensity. Figures 1203.7, 1205.1 and 1206.1 of the BOCA Code (See Figures 3-1, 3-2 and 3-3) show these regional limits for the loadings indicated.

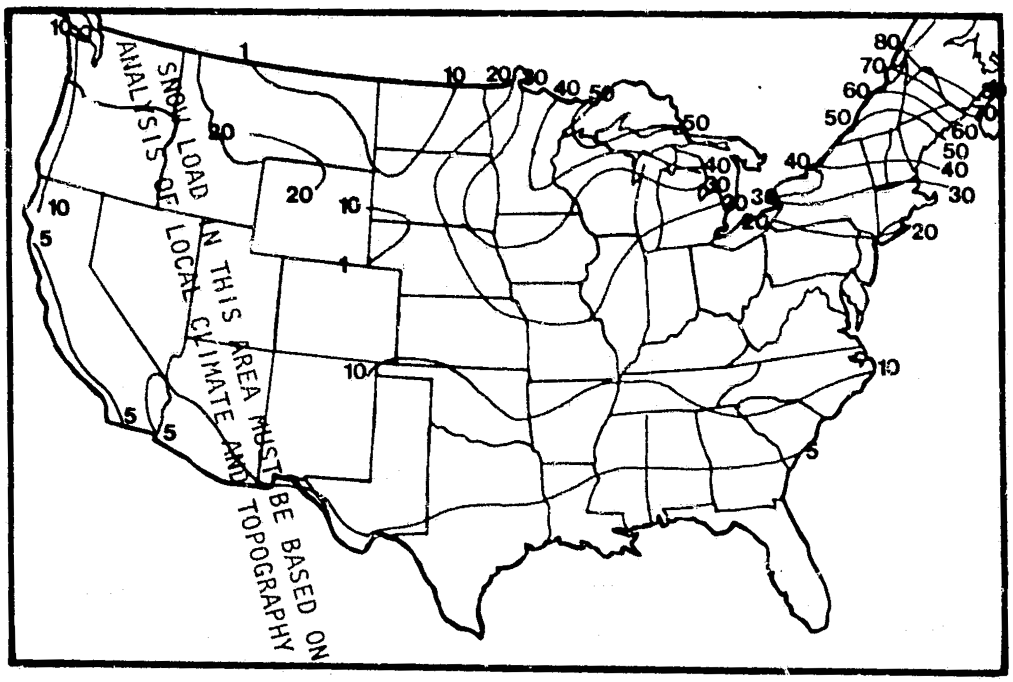


FIGURE 3-1

Estimated Ground Snow Load in Lbs./Sq. Ft.
50-Year Mean Recurrence Interval

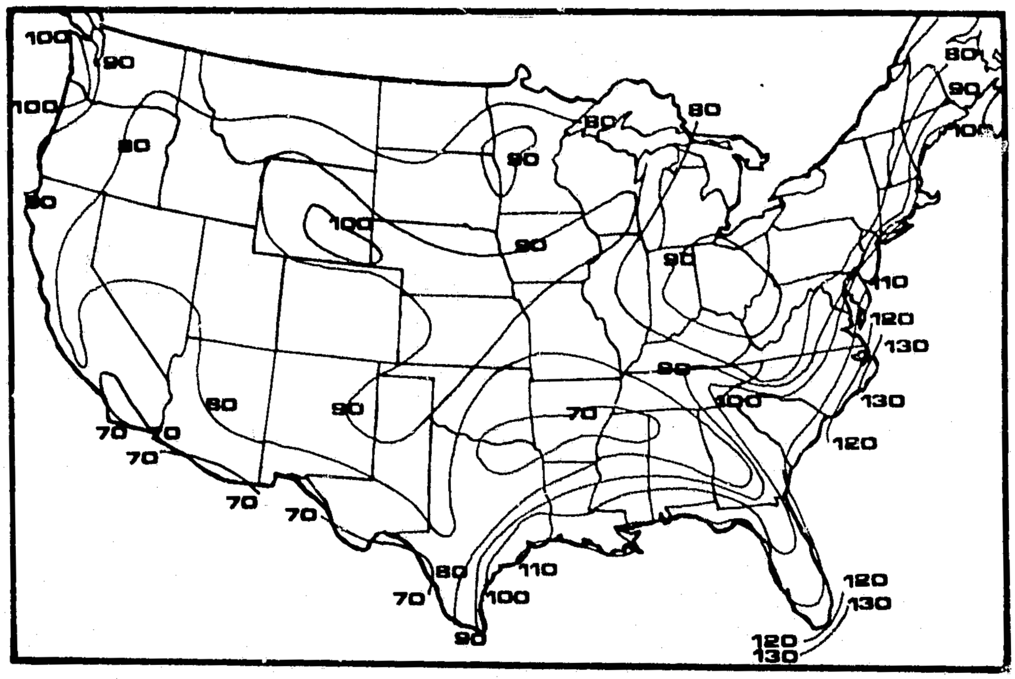


FIGURE 3-2

BASIC WIND SPEEDS IN MILES PER HOUR

Annual Extreme Fastest-Mile Speed 30 Feet Above Ground,
100-Year Mean Recurrence Interval

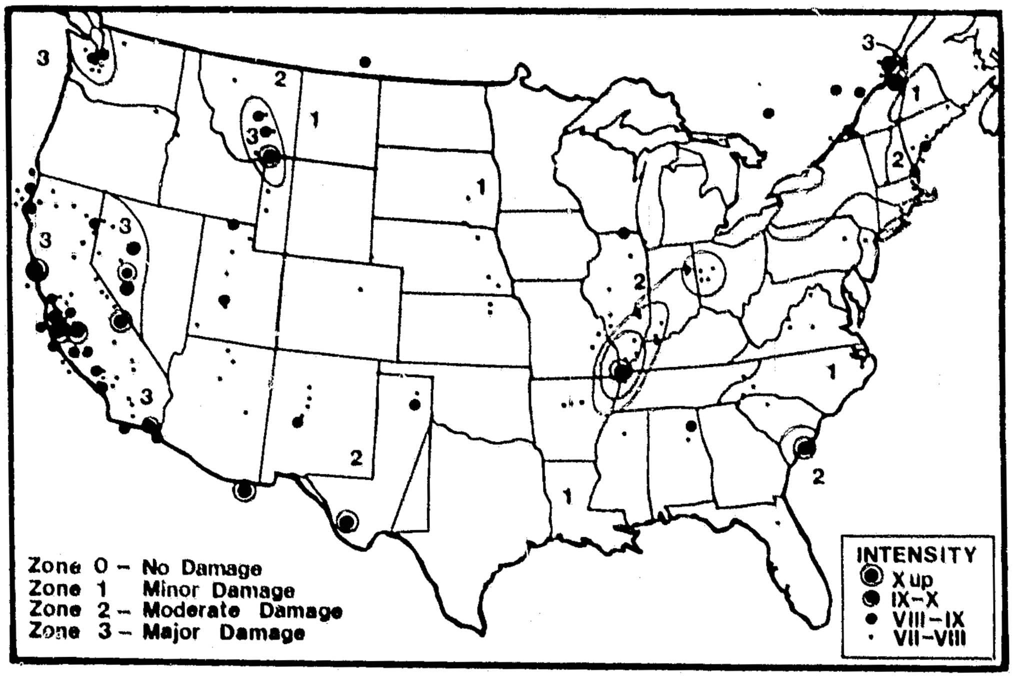


FIGURE 3-3

Risk Zones and Damaging Earthquakes of the United States Through 1968

It must be understood, however, that very rarely are the previously mentioned dead and live loads cumulative. For instance, it would be rare to have full dead load, maximum snow and wind at the same time. Paragraph 1203.7.F1 of the BOCA code addresses this situation when it permits reduction in roof snow loads depending on the shape and slope of the roof causing a wind scouring action to prevent or reduce the buildup of snow. This approach to loading requirement would be most applicable to standoff or rack mounted arrays. Height of roof or PV array above the ground will also have varying effect on the winds, increasing as the height increases, as shown in Table 1205.1 (See Table 3-2). Venturi effects, possible wind gusts and drifting of snow around or behind obstructions would also be significant factors to consider when mounting a PV array on a roof. All of these can cause additional loads above those normally encountered. In very rare cases, however, would more than one live load source be used at one time and even then a chance for a reduction factor could be possible.

TABLE 3-2

BASIC WIND LOAD PRESSURES IN POUNDS PER SQUARE FOOT

(See Figure 3-1)

Height Above Ground, Feet	100 Yr. Recurrence of Fastest Mile of Wind, MPH							
	70	80	90	100	105	110	120	130
0 - 30	10	13	16	20	23	24	29	34
31 - 50	14	18	22	28	31	34	40	47
51 - 100	16	21	27	33	37	40	48	56
101 - 200	20	26	33	40	45	49	58	68
201 - 300	23	30	38	47	52	57	67	79
301 - 400	25	33	42	52	57	62	74	87
401 - 500	27	36	45	55	61	67	80	94
501 - 800	30	39	50	62	68	74	89	104
801 -1,000	33	43	55	68	75	82	97	114
Over 1,000	34	45	56	70	77	84	100	117

-- Measured above the average level of the ground adjacent to the structure.

-- To be modified by shape factors

-- Velocity Pressures are based on the formula

$P = 0.00256 \times V^2 \times \frac{H}{30}$ where:

V = Wind Speed in MPH; and

H = the height above grade (in feet) of the pressure being computed.

This formula is only applicable to heights 30 feet or greater.

The significance of these loading conditions to the RPM designer is that it indicates that material weights used in the roofing envelope are constant, and as such the contribution of the weight of the RPM must be taken into account as an integral part of that envelope and still stay below the allowable limits of the conventional structural support system used. Also, of significance to the designer is that even though live loads are not necessarily cumulative, significant increases or decreases in loadings on the RPM can occur depending on the location and configuration the designer chooses for the PV array. For example, standoff mounted array on a 30° angle in Florida would receive a much higher wind load than a similarly mounted array in Pennsylvania. However, a dead load contribution of a PV array would not be affected by its height above ground or geographic location, but must nonetheless be integrated carefully in the composite roof envelope weights.

It would, therefore, be wise for the manufacturer of a RPM to adhere to the most critical, yet practical, criteria as found in the various major national codes; wind loads as set forth in the South Florida Coastal Code, snow as found in northernmost areas of the United States, and earthquake as found in California. While this may appear as overcompensation, it does allow a wider market area without the manufacturing cost of regional design restrictions.

CONCLUSIONS

Until separate sections dealing specifically with photovoltaic arrays begin to appear in building codes, roof-top arrays will almost certainly be judged, at least in part, by existing code provisions for roof coverings, roof structures, skylights, veneers, and loading criteria.

After investigating three model codes, two city codes and the National Fire Code, the following conclusions can be drawn. Residential Photovoltaic Modules may be built of virtually any material, including wood, and be judged acceptable within the requirements of code provisions currently in effect. The lone exception, and it is an important one, is plastics.

The demands made by the codes upon the use of plastics are so severe as to suggest that a great deal of delay and complication can be avoided by eliminating plastics from the list of possible component materials for the module. The delays would be the result of two factors. First, to gain acceptability for a material or assembly which is either unknown to the code agency or appears to violate existing provisions of the code, it is necessary to follow the time consuming and expensive procedures dictated by the code. This involves such things as the submission of data gained by subjecting the material or assembly to prescribed tests which must be conducted by an independent testing laboratory. Second, this process must be repeated for each area or region under the jurisdiction of a different code. It is also conceivable that it may be necessary to re-submit the module for approval every time the design is modified, area or quantity of plastic changed or re-shaped.

It is true that plastics have already been incorporated into the design of some solar thermal collectors and certain passive solar installations. These have been constructed, apparently, in areas not subject to the jurisdiction of any of the model codes. As solar systems of all kinds gain in popularity, and their use in residential construction increases to a significant percentage of the total, all code agencies will begin preparing regulations for their design and installation. If, at that time, significant changes do not occur in the manner that codes currently regulate plastics, the solar collector industry will suffer a serious setback.

All of these difficulties argue against the use of plastics in the construction of the Residential Photovoltaic Module. This is especially true when considered with other code requirements which limit the area of plastic used on a roof as a function of floor area or roof area. Taken alone, this limitation is sufficient cause for avoiding the use of plastics. The area of array required for a conventional dwelling far exceeds the limit. Changes in these provisions of the code may be possible, but considering the flammability of plastics and the conventional code wisdom as it relates to the spread of fire, this seems unlikely. In any event, only a few well-publicized fires involving plastics in collectors will be sufficient to create serious doubts -- real or imagined-- in the minds of the public.

REVIEWED SECTIONS OF BUILDING CODES

ROOF COVERINGS

The BOCA Basic Building Code/1975

- Article 2 Definitions and Classifications
  - Section 209.0 Use Group R, Residential Buildings
  - Table 214 - Fire Resistance Ratings of Structural Elements
- Article 9 Fire Resistive Construction Requirements
  - Section 903.0 Fireresistance tests
  - Section 926.0 Roof Coverings
- Article 20 Light-Transmitting Plastic Construction
  - Section 2000.0 General
  - Section 2004-0 Roof Panels
- Appendix G Fire Test and Flame Spread Test Standards

The Uniform Building Code/UBC/1976

- Chapter 5 Classification of all Buildings by Use or Occupancy and General Requirements for Occupancies
  - Table 5D Maximum Height of Buildings
- Chapter 14 Requirements for Group R, Division 3 Occupancies
  - Section 1401 Group R, Division 3 Occupancies Defined
- Chapter 17 Classification of all Buildings by Types of Construction and General Requirements
  - Section 1704 Roofs
- Chapter 22 Type V Buildings
  - Section 2201 Definitions
- Chapter 32 Roof Construction and Covering
  - Section 3201 General
  - Section 3202 Roof Construction and Materials
  - Section 3203 Roof Coverings
- Chapter 52 Plastics
  - Section 5201 General
  - Section 5202 Approved Plastics
  - Section 5206 Monitors and Sawtooth Roofs

The Standard Building Code/SBC/1976

- Chapter I Administration
  - Section 103 Powers and Duties of Building Officials
- Chapter IV Classification of Building by Occupancy
  - Section 411 Residential Occpuancy - R

- Chapter VI Classification of Buildings by Construction
  - Section 607 Type VI Construction
- Chapter VII Fire Protection Requirements
  - Section 706 Roof Coverings
- Chapter XVII Wood Construction
  - Section 1707 Roof and Ceiling Framing
- Chapter XXVI Light Transmitting Plastics
  - Section 2601 General
  - Section 2604 Roof Panels
  - Table 2604 Area Limitations for Plastic Roof Panels and Skylights

<u>Building Code of the City of Pittsburgh</u>

- Chapter 5 Classification of All Buildings by Use or Occupancy, and Heights and Types of Construction for All Occupancies
  - Table 5B Height and Structural Limitations for the Various Types of Occupancy
- Chapter 10 Group E Occupancies (Dwelling)
- Chapter 14 Classifications of All Buildings by Types of Construction
- Chapter 20 Type VI Buildings (Wood Frames)
- Chapter 27 Roof Construction and Covering
- Rules and Regulations
  - Part VI Miscellaneous
  - <u>Glass Fiber Reinforced Plastic Panels</u>

<u>National Fire Codes - Volume 4/1967-68</u>

- Classification of Roof Coverings NFPA No. 203
- Appendix B - Recommendations on Plastics in Building Codes and Standards NFPA No. 220M
- Methods of Fire Tests of Roof Coverings NFPA No. 256

<u>City of Los Angeles Building Code/1976 Edition</u>

- Division 5 Occupancy
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- Chapter 34 Skylights

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- Chapter 29 Fire Doors and Windows and Skylights

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The BOCA Basic Building Code/1975

- Article 8, Part C Building Enclosures, Walls and Wall Thickness
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- Chapter 11 Definitions
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  - Table 2707 Relative Resistance to Wind Load

The Uniform Building Code/UBC/1976

- Chapter 4 Definitions and Abbreviations
  - Section 415 Noncombustible
- Chapter 30 Veneer
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  - Section 5204 Glazing of Unprotected Openings
  - Section 5209 Exterior Veneer
- Chapter 54 Glass and Glazing
  - Section 5401 General

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- Chapter 4 Definitions of Certain Terms

- Chapter 23 Walls
  Section 2309 Thin Veneers

- Rules and Regulations
  Part VI Miscellaneous
  Glass Veneer Regulations
  Glass Fiber Reinforced Plastic Panels

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- Division 17 Types of Construction
  Section 91.1711 Glazing of Openings

- Division 29 Veneered Walls

ASTM D374-74 Thickness of Solid Electrical Insulation - Method of Test for

ASTM D635-72 Standard Method of Test for Flammability of Self-Supporting Plastics

ASTM D1929-68 Standard Method of Test for Ignition Properties of Plastics

ASTM D2843-70 Chamber Method of Test for Measuring the Density of Smoke from The Burning or Decomposition of Plastic Materials

ASTM E84-80 Method of Test for Surface Burning Characteristics of Building Materials

ASTM E108-70 Roof Coverings - Methods of Fire Test of

ASTM E136-65 Noncombustible Material Tests, Standard Specifications

UL Test Method for Fire Hazard Classification of Building Materials.
Standard Test Method, Subject 723 (Aug. 1960)

LOAD CHARACTERISTICS

The BOCA Basic Building Code

- Article 7 Structural and Foundation Loads and Stresses
  Section 710.0 Roof Loads
  Section 711.0 Snow Loads
  Section 712.0 Wind Loads
  Section 713.0 Wind on Vertical Surfaces
  Section 714.0 Wind Load on Roofs
  Section 715.0 Wind Loads on Signs, Tank and Radio Towers and Chimneys
  Section 716.0 Unusual Wind Exposures
  Section 717.0 Overturning and Sliding
  Section 718.0 Earthquake Load
  Section 719.0 Combination of Loads

- Article 14 Signs and Outdoor Display Structures
  - Section 1408.2 Design Loads

The Standard Building Code/SBC/1976

- Chapter XII Minimum Design Loads
  - Section 1203 Live Loads
  - Section 1205 Wind Loads
  - Section 1206 Earthquake Loads

  Appendix A Weights of Building Materials

The Uniform Building Code/UBC/1976

- Chapter 23 General Design Requirements
  - Section 2302 Definitions
  - Section 2303 Design Methods
  - Section 2305 Roof Design
  - Section 2306 Reduction of Live Loads
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  - Table 23 C Minimum Roof Live Loads
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  - Table 23 F Wind Pressure for Various Height Zones Above Ground
  - Figures No. 1, No. 2, No. 3, No. 4

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- Chapter 21 - Design Loads and Materials of Construction

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- Division 23 Loads and General Design
  - Section 91.2301 General
  - Section 91.2302 Live Loads
  - Section 91.2303 Reduction of Live Loads
  - Section 91.2304 Arrangement of Live Loads
  - Section 91.2305 Horizontal Forces
  - Section 91.2306 Design for Horizontal Force

APPENDIX 4. NATIONAL ELECTRICAL CODE REVIEW

PURPOSE: The NEC, as the most widely-accepted electrical code, was reviewed to identify the electrical requirements for residential PV modules. Because the NEC does not specifically address photovoltaic systems or modules, it was necessary to: 1) review general electrical requirements for terminals, grounding, guarding of live parts, operating voltage, conductor sizes, and wet location applications: and 2) review requirements for specific equipment such as generators, appliances, lighting fixtures and modular building components for manufactured buildings to determine any applicable requirements or possible classification for PV modules and arrays.

CONCLUSIONS: If the practical safeguarding of persons and property is used as the overriding design guideline for photovoltaic modules, compliance with the NEC can be expected. Live parts operating at 50 volts or more shall be guarded against accidental contact during installation. Quick connect terminals are a recognized method for making electrical connections. Metal framed panels will require grounding unless special provisions for isolating live wires are made. Metal frames used as conductor raceways require grounding. Factory installed internal wiring of equipment does not come under the jurisdiction of the Code, if the equipment has been listed by an electrical testing laboratory. All conductors used for general wiring shall not be smaller than #14 AWG copper. However, the NEC allows wiring in lighting fixtures and similiar equipment to be as small as #18 AWG copper. This implies the possible use of #18 AWG copper wire if NEC officials feel PV modules resemble lighting fixtures. Future development of module and array wiring should not be limited to currently approved wiring methods although the process is lengthy new methods will be recognized if they are engineered with safety in mind. Conductor operating temperatures for specific mounting types must be determined so that conductors can be properly sized in accordance with the NEC. Modular wiring systems intended to minimize field labor are recognized by the Code.

RECOMMENDATIONS: Until specific requirements for photovoltaic modules and systems are identified in the NEC, the module manufactorer must design modules based on the principle of safety first. In addition, the manufacturer should become familiar with general and equipment specific electrical requirements as presently enforced by the NEC.

At present, the residential PV systems and modules could be defined as a modular building component and are generally covered by Article 545 - Manufactured Building. In order to eliminate possible confusion by field electrical inspectors and local building review boards, it may be in the best interest of the photovoltaic industry to work with the NEC Committee in developing specific requirements for photovoltaic systems and modules.

* * * * *

Introduction

The National Electrical Code is the most widely adopted set of electrical requirements in the world and will be reviewed to identify all existing regulations that may have bearing on residential photovoltaic applications. The NEC is recognized by all major building codes including BOCA, UBC, SBC, and most municipal codes. The only known exceptions to national acceptance are several municipal electrical codes such as those established by the City of Los Angeles and the City of Chicago.

The NEC is sponsored by the National Fire Protection Association under the auspices of the American National Standards Institute.

Realizing that the Code was written without consideration for photovoltaic systems, some informal interpretation as to intent was necessary.

Throughout this review, the module and panel are referenced. A module is defined as an integral unit with factory wired cells that are electrically isolated except for the terminals which may or may not be guarded from direct contact. The module may have an integral metallic or nonmetallic frame, or the module may not have any frame (as with the shingle concept). The panel is generally assumed to be comprised of modules. All electrical connections are factory wired. The panel may or may not have a metallic or nonmetallic frame.

It is conceivable that the panel may integrate the frame as a raceway and/or junction box similar to that done with fluorescent lighting fixtures. The frame could also utilize "knockouts" where continuous raceways are required. This lighting fixture analogy is conceivable but has not been assumed. The wiring methods conceived are limited to array branch circuits and connections. (Array branch circuit shall be defined, here as the set of conductors between the panel or module terminal and the final conductor serving the residence or serving the storage system.)

Voltage levels considered do not exceed 600 Volts. Those voltages of particular concern are 30, 100, and 200 Volts dc.

The review technique for the NEC will be different than that used for the building codes. Rather than generating topics of concern, around which each code was reviewe , each Code Article that appeared to have any relevance was reviewed. Those articles containing relevant information have been extracted, and reproduced with commentary added.

In the process of reviewing the NEC, we started with assumptions as to what a PV module could be classified. Then, as review proceeded, additional interpretations and other relevant requirements became apparent. These additional interpretations and requirements, along with conclusions are reflected in the commentary.

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ARTICLE 90: INTRODUCTION

90-1. Purpose

(a) The purpose of this Code is the practical safeguarding of persons and property from hazards from the use of electricity.

The National Electrical Code (NEC) is the most widely adopted set of electrical safety requirements in the world and is offered for use in law and for regulatory purposes in the interest of life and property protection.

(b) This Code contains provisions considered necessary for safety. Compliance therewith and proper maintenance will result in an installation essentially free from hazard, but not necessarily efficient, convenient, or adequate for good service or future expansion of electrical use.

Hazards often occur because of overloading of wiring systems by methods or usage not in conformity with the Code. This occurs because initial wiring did not provide for increases in the use of electricity. An initial adequate installation and reasonable provisions for system changes will provide for future increases in the use of electricity.

(c) This Code is not intended as a design specification nor an instruction manual for untrained persons.

The National Electrical Code is intended for use by capable engineers and electrical contractors for the basic design and/or installation of electrical equipment, by inspection authorities exercising legal jurisdiction over electrical installations, and by instructors teaching electrical apprentices or students.

Commentary:
The important sentence: "The purpose of this code is the practical safe guarding of persons and property from hazards arising from the use of electricity." Safety during operation and installation should be an overriding design criteria during development of the module.

90-2. Scope

(a) COVERED. This Code covers:

(1) Electric conductors and equipment installed within or on public and private buildings or other structures, including mobile homes and recreational vehicles; and other premises such as yards, carnival, parking and other lots, and industrial substations.

(2) Conductors that connect the installations to a supply of electricity.

(3) Other outside conductors on the premises.

(b) NOT COVERED. This Code does not cover:

(1) Installations in ships, watercraft, railway rolling stock, aircraft, or automotive vehicles other than mobile homes and recreational vehicles.

(2) Installations underground in mines.

(3) Installations of railways for generation, transformation, or distribution of power used exclusively for operation of rolling stock or installations used exclusively for signaling and communication purposes.

(4) Installations of communication equipment under the exclusive control of communication utilities, located outdoors or in building spaces used exclusively for such installations.

(5) Installations under the exclusive control of utilities for the purpose of communication, or metering; or for the generation, control, transformation, transmission, and distribution of electric energy located in buildings used exclusively by utilities for such purposes or located outdoors on property owned or leased by the utility or on public highways, streets, roads, etc., or outdoors by established rights on private property.

(c) SPECIAL PERMISSION.

The authority having jurisdiction for enforcing this Code may grant exception for the installation of conductors and equipment, not under the exclusive control of the electric utilities and used to connect the electric utility supply system to the service-entrance conductors of the premises served, provided such installations are outside a building or terminate immediately inside a building wall.

90-3. CODE ARRANGEMENT.

This Code is divided into nine chapters. Chapters 1, 2, 3, and 4 apply generally; Chapters 5, 6, and 7 apply to special occupancies, special equipment, or other special conditions. These latter chapters supplement or modify the general rules. Chapters 1 through 4 apply except as amended by Chapters 5, 6, and 7 for the particular conditions.

Chapter 8 covers communications systems and is independent of the other chapters except where they are specifically referenced therein.

Chapter 9 consists of tables and examples.

90-4. ENFORCEMENT.

This Code is intended to be suitable for mandatory application by governmental bodies exercising legal jurisdiction over electrical installations and for use by insurance inspectors. The authority having jurisdiction of enforcement of the Code will have the responsibility for making interpretations of the rules, for deciding upon the approval of equipment and materials, and for granting the special permission contemplated in a number of the rules.

The authority having jurisdiction may waive specific requirements in this Code or permit alternate methods, where it is assured that equivalent objectives can be achieved by establishing and maintaining effective safety.

90-5. FORMAL INTERPRETATIONS.

To promote uniformity of interpretation and application of the provisions of this Code, the National Electrical Code Committee has established interpretation procedures.

The procedures for formal interpretations of the provisions of the National Electrical Code are outlined in the regulations governing committee projects that may be obtained from the Asst. V.P.-Standards of the National Fire Protection Association. The formal interpretations procedure can be found in Section 16 and has been reprinted in its entirety in the appendix to this Handbook.

The Interpretations committee is made up of five or more members or alternates of the Technical Committee(s) having primary jurisdiction of the Code covering the subject under consideration. The members are to be selected by the Chairman of the Correlating Committee or the Asst. V.P.-Standards if the Chairman is not available. No member or alternate is to be eligible for appointment to an Interpretation Subcommittee if he or she is directly involved in the particular case prompting the request for the Interpretation. The Interpretation Subcommittee should include Committee members or alternates representing the same interest categories as the requester and the other parties involved as well as representatives of other parties. The personnel of Interpretation Subcommittees may be varied for each request.

The Committee cannot be responsible for subsequent actions by authorities enforcing the NEC as to whether they accept or reject the findings. The authority having jurisdiction has the responsibility of interpretating the Code rules and should attempt to resolve all disagreements at the local level.

Two general forms of Formal Interpretations are recognized: (a) those making an interpretation of the literal text and (b) those making an interpretation of the intent of the Technical Committee when the particular text was adopted.

Interpretations not subject to processing are those that (1) do not involve a determination of compliance of a design, installation, or product or equivalency of protection, (2) do not involve a review of plans or specifications or require judgment or knowledge that can only be required as a result of on-site inspection, and (3) do not involve texts that clearly and decisively provide the requested information.

Formal Interpretations of Code rules are published in the NFPA Fire News and sent to interested trade publications.

Commentary:

Formal, or informal interpretations should be sought as questions arise regarding Code intent for any early design work. The formal interpretation procedure from the Handbook Appendix is reprinted here.

NEC APPENDIX SECTION 16: FORMAL INTERPRETATIONS PROCEDURE

16.1 GENERAL

The following formal interpretation procedure is for the purpose of providing formal explanations of the meaning or intent of any specific provision or provisions of any Document.

NOTE: This formal interpretation procedure does not prevent any Committee Chairman, member of any Committee or the Staff Liaison from expressing an opinion on the meaning or intent of any provision of any such Document, provided that the opinion is clearly identified as not being a formal interpretation of the Committee or of the Association.

16.2 NATURE OF FORMAL INTERPRETATIONS.

Two general forms of formal interpretations are recognized:

(a) those making an interpretation of the literal text, and

(b) those making an interpretation of the intent of the Technical Committee when the particular text was adopted.

16-3. EDITIONS TO BE INTERPRETED.

Interpretations shall be rendered on the text of the latest adopted Document and any text of earlier editions which is identical to the text in the latest Document. Interpretations may be rendered to the requester on text of an outdated Document where such has been revised in or deleted from later editions. If possible, the requester should be informed why the text was revised or deleted.

16-4. METHOD OF REQUESTING FORMAL INTERPRETATIONS

A request for a formal interpretation shall be directed to the Assistant Vice President - Standards, at the National Fire Protection Association Headquarters. The request shall include a statement in which shall appear specific references to a single problem and identifying the portion of the Document (article, section, paragraph, etc.) and edition of the Document on which an interpretation is requested. Such a request shall be in writing and shall indicate the business interest of the requester. A request involving an actual field situation shall so state and all parties involved shall be named and notified.

16-5. QUALIFICATIONS FOR PROCESSING.

A request for an interpretation may be processed if it:

(a) complies with 16-2 and 16-4

(b) does not involve a determination of compliance of a design, installation or product or equivalency of protection

(c) does not involve a review of plans or specifications, or require judgement or knowledge that can only be acquired as a result of on-site inspection

(d) does not involve text that clearly and decisively provides the requested information

16-6. DETERMINATION OF QUALIFICATION

The Assistant Vice President-Standards, after consultation with the appropriate Committee Chairmen, shall determine the qualification in accordance with 16-5.

16-7 EDITING OF INTERPRETATION REQUEST

A request for an interpretation may be re-phrased. The re-phrased version and any pertinent background information shall be sent to the requester and all parties named in the request for agreement. A deadline for receipt of agreement shall be established.

16-8. ESTABLISHMENT OF INTERPRETATIONS SUBCOMMITTEE

If accepted for consideration, each request shall then be submitted to letter ballot of an Interpretations Subcommittee made up of five or more members or alternates of the Technical Committee(s) having primary jurisdiction of the Document covering the subject under consideration. The members shall be selected by the Committee Chairmen or the Assistant Vice President-Standards, if the Chairmen are not available. No member or alternate shall be eligible for appointment to an Interpretations Subcommittee if he or she is directly involved in the particular case prompting the request for the interpretation. The Interpretations Subcommittee should include Committee members or alternates representing the same interest categories as the requester and the other parties involved, as well as representatives of other parties. The personnel of Interpretations Subcommittees may be varied for each request.

16-9. VOTING ON INTERPRETATIONS

In any case where more than twenty percent of the Subcommittee members disagree on the interpretation, the request for interpretation shall be referred to the Technical Committee(s). Under these conditions, a formal interpretation requires a two-thirds majority agreement of the Technical Committee(s) as tallied in accordance with 12-4. Where the necessary agreement is not received, the item shall be placed on the docket for regular processing by the Technical Committee(s) for subsequent possible action.

16-10 PUBLICATION OF INTERPRETATION

If the required agreement is secured from the Interpretations Subcommittee(s) or from the Technical Committee, the requester and all named parties shall be informed by the Staff Liaison and the interpretation shall be published by the Association in one of its publications sent to all members and announced in an Association news release to other media.

Interpretations of text of an outdated Document which has been revised in or deleted from later editions shall not be published by the Association but shall be sent to the requester and all parties named in the request.

16-11 ACTION FOLLOWING ISSUANCE OF FORMAL INTERPRETATIONS

Any Technical Committee(s) whose Document has been the subject of a formal interpretation shall review the item on which the interpretation has been issued to determine whether any change may be desired to the text of the Document on which the interpretation has been rendered. If such a change is indicated, the Technical Committee(s) shall process such change in conformance with procedures set forth in Sections 10, 11, and 12.

16-2 APPLICABILITY OF FORMAL INTERPRETATIONS

Any formal interpretation issued shall apply to the edition of the Document for which the interpretation is made and to any other edition of the Document if the text is identical to the text of the edition of which the formal interpretation was rendered.

Commentary:

Should any Code changes or additions be made to cover PV systems, they would probably initially take the form of a Tentative Interim Amendment (TIA). A TIA is a Code addition or revision pending formal acceptance. The following rules on TIA's are excerpted from the appendix to the 1978 NEC Handbook. They were originally published as NFPA Regulations Governing Committee Projects.

NEC APPENDIX SECTION 15: TENTATIVE INTERIM AMENDMENTS

15-1 AUTHORIZATION

A Tentative Interim Amendment to any existing Standard, Code, Recommended Practice, Manual or Guide may be processed if the Tentative Interim Amendment is of an emergency nature requiring prompt action and has the endorsement of a member of the involved Technical Committee.

15-2 DETERMINATION OF COMPLIANCE

A proposed Tentative Interim Amendment shall be submitted to the Assistant Vice President-Standards who, after consultation with the appropriate Committee Chairmen, shall determine compliance with 15-1.

15-3 PROCESSING

If such compliance is determined, the Assistant Vice President-Standards shall submit the proposed Tentative Interim Amendment to the responsible Committee and it shall be processed in the following manner:

(a) the text of a proposed Tentative Interim Amendment, as submitted shall not be changed by the Committee except to correct obviously incorrect references.

(b) a proposed Tentative Interim Amendment which meets the provisons of 15-1 shall be published by the Association in Fire News and other appropriate media with a notice that the proposed Tentative Interim Amendment has been forwarded to the responsible Technical Committee for processing and that anyone interested may respond to the proposed Tentative Interim Amendment within the time period established and published.

(c) Committees shall process a proposed Tentative Interim Amendment within sixty days; such time to be measured from the closing date for responses (see 15-3(b)) to submittal to the Council for approval for release.

(d) The proposed Tentative Interim Amendment shall be submitted to letter ballot of the Technical committee and at least three-quarters of the members shall have voted in favor of the Tentative Interim Amendment.

NOTE: In calculating the three-fourths majority, those who have expressed in writing valid reasons for not having voted, and those who after a second request fail to return their ballots within the specified time limit, are omitted from the calculations. In no event will an affirmative vote by less than a simple majority of the total members of the Technical Committee eligible to vote satisfy the requirement that there be a three-fourths majority.

(e) the proposed Tentative Interim Amendment shall be reviewed by the Correlating Committee, if any, which shall make a recommendation to the Council with respect to the disposition of the Tentative Interim Amendment.

(f) all Committee actions on the proposed Tentative Interim Amendment shall be reported to the Council for action in accordance with 15-4.

15-4 ACTION OF THE COUNCIL

The Council shall:

(a) review the committee action,

(b) accept or reject the Committee action,

(c) direct a different action,

(d) authorize release of the proposed Tentative Interim Amendment, if approved.

15-5. PUBLICATION OF TENTATIVE INTERIM AMENDMENT.

The Association shall publish in one of its publications sent to all members notice of the issuance of each Tentative Interim Amendment, shall issue a news release to applicable and interested technical journals, and shall also include in any subsequent distribution of the Document to which the Tentative Interim Amendment applies the text of the Tentative Interim Amendment in a manner judged most feasible to accomplish the desired objectives. The tentative character of the Tentative Interim Amendment shall be clearly indicated in the publication and release.

15-6 SUBSEQUENT PROCESSING OF TENTATIVE INTERIM AMENDMENTS

The Technical Committee concerned shall process the subject matter of any Tentative Interim Amendment through normal Technical Committee procedures (see Section 11 and 12) at the next meeting of the Association to which the Technical Committee reports.

15-7 EXCEPTION

When the Board of Directors authorizes other procedures for the processing and/or issuance of Tentative Interim Amendments, the provisions of this Section shall not apply.

90-6 EXAMINATION OF EQUIPMENT FOR SAFETY

For specific items of equipment and materials covered by this Code, examinations for safety made under standard conditions will provide a basis for approval where the record is made generally available through promulgation by organizations properly equipped and qualified for experimental testing, inspections of the run of goods at factories, and service-value determination through field inspections. This avoids the necessity for repetition of examinations by different examiners, frequently with inadequate facilities for such work, and the confusion that would result from conflicting reports as to the suitability of devices and materials examined for a given purpose.

It is the intent of this Code that factory-installed internal 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 as having the facilities described above and which requires suitability for installation in accordance with this Code.

Nationally recognized testing laboratories, inspection agencies, or other organizations concerned with product evaluation publish lists of equipment or materials that have been tested and meet nationally recognized standards or that have been found suitable for use in a specified manner. The Code does not contain detailed information on equipment or materials, but refers to the products as "Listed", "Labeled", or "Approved for the Purpose". See Article 100, "Definitions", for explanation of these terms.

It is not the intent of the Code to apply to the internal factory-installed wiring, or to the construction of listed equipment at the time of installation, unless damage or alterations are detected.

Commentary:

Viewing the panel as a piece of equipment and the module as a component, the manufacturer is most concerned with meeting the testing laboratories standards for approval. Compliance to testing laboratory standards is dependent on the handling of module details by each manufacturer. PV module/panel approval can be expedited by using standard electrical components where possible. Attempted use of non-approved components should be preceded by review of UL Standards for Safety for all similar devices previously tested. The approval periods range from 6 - 8 weeks for assemblies comprised of approved components to 2 - 3 months for assemblies of unapproved components. These periods represent approvals with no revisions. One year approval periods are not uncommon when revisions are required.

In the second paragraph of Section 90-6, it states that testing laboratory recognition is partly based on approval processes "which require suitability for installation in accordance with the Code". That is, the NEC will only recognize testing laboratories that consider safety during installation as part of their testing procedure. Therefore, the module manufacturer must be aware of NEC safety requirements for installation (for example, see Commentary following NEC 110-17 Guarding of Live Parts). Safety during installation is not only a systems concern - it must be considered during design of the module/panel.

ARTICLE 100 - DEFINITIONS

Commentary:

Definitions of the terms used in the NEC are essential. Misinterpretation of the Code usually occurs due to incorrect assumptions as to definition. Only the definitions for general application (i.e., Part A) are reprinted here. Part B is not included. Some editing of Part A has been done to eliminate those definitions that have no relevance to this study.

SCOPE

Only definitions of terms peculiar to and essential to the proper use of this Code are included. In general, only those terms used in two or more articles are defined in Article 100. Other definitions are included in the article in which they are used but may be referenced in Article 100.

Part A of this article contains definitions intended to apply wherever the terms are used throughout this Code. Part B contains definitions applicable only to the parts of articles covering specifically installations and equipment operating at over 600 volts, nominal.

ACCESSIBLE

(As applied to wiring methods.) Capable of being removed or exposed without damaging the building structure or finish, or not permanently closed in by the structure or finish of the building. (See "Concealed" and "Exposed".)

Wiring methods located behind removable panels designed to allow access are not considered permanently enclosed.

ACCESSIBLE

(As applied to Equipment.) Admitting close approach because not guarded by locked doors, elevation, or other effective means. (See "Readily Accessible".)

AMPACITY

Current-carrying capacity of electric conductors expressed in amperes.

APPLIANCE

Utilization equipment, generally other than industrial, normally built in standardized sizes or types, which is installed or connected as a unit to perform one or more functions such as clothes washing, air conditioning, food mixing, deep frying, etc.

APPROVED

Acceptable to the authority having jurisdiction.

The phrase "authority having jurisdiction" is used in NFPA standards in a broad manner since jurisdiction and "approval" agencies vary as do their responsibilities. Where public safety is primary, the "authority having jurisdiction" may be a federal, state, local, or other regional department or individual such as a fire chief, fire marshal, chief of a fire prevention bureau, labor department, health department, building official, electrical inspector, or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the "authority having jurisdiction". In many circumstances the property owner or his delegated agent assumes the role of the "authority having jurisdiction"; at government installations, the commanding officer or departmental official may be the "authority having jurisdiction."

APPROVED FOR THE PURPOSE

Approved for a specific purpose, environment, or application described in a particular Code requirement.

Suitability of equipment or materials for a specific purpose, environment or application may be determined by a nationally recognized testing laboratory, inspection agency or other organization concerned with product evaluation as part of its listing and labeling program. (See "Labeled" or "Listed".)

The above paragraph note to this definition has been included for information because it had been interpreted by some to mean that only the authority having jurisdiction can determine the acceptability of equipment or materials for a specific purpose, environment or application. This fine print note provides a basis whereby authorities having jurisdiction can accept listed or labeled materials or devices that have been evaluated by nationally recognized testing laboratories.

ASKAREL

A generic term for a group of nonflammable synthetic chlorinated hydrocarbons used as electrical insulating media. Askarels of various compositional types are used. Under arcing conditions the gases produced, while consisting predominantly of noncombustible hydrogen chloride, can include varying amounts of combustible gases depending upon the askarel type.

ATTACHEMENT PLUG (PLUG CAP) (CAP)

A device which, by insertion in a receptacle, establishes connection between the conductors of the attached flexible cord and the conductors connected permanently to the receptacle.

BONDING

The permanent joining of metallic parts to form an electrically conductive path which will assure electrical continuity and the capacity to conduct safely any current likely to be imposed.

BONDING JUMPER

A reliable conductor to assure the required electrical conductivity between metal parts required to be electrically connected.

BONDING JUMPER, CIRCUIT

The connection between portions of a conductor in a circuit to maintain required ampacity of the circuit.

BONDING JUMPER, EQUIPMENT

The connection between two or more portions of the equipment grounding conductor.

BONDING JUMPER, MAIN

The connection between the grounded circuit conductor and the equipment grounding conductor at the service.

BRANCH CIRCUIT

The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s).

BRANCH CIRCUIT, APPLIANCE

A branch circuit supplying energy to one or more outlets to which appliances are to be connected; such circuits to have no permanently connected lighting fixtures not a part of an appliance.

BRANCH CIRCUIT, GENERAL PURPOSE

A branch circuit that supplies a number of outlets for lighting and appliances.

BRANCH CIRCUIT, INDIVIDUAL

A branch circuit that supplies only one utilization equipment.

An individual circuit is a circuit that supplies "only" one utilization equipment, that is, one range, or one space heater, or one motor. See Section 210-23.

It may supply "only" one single receptacle for the connection of a single attachment plug. See Section 210-21(b).

A branch circuit may be installed to supply one duplex receptacle which can accommodate two cord-and plug-connected appliances or similar equipment and therefore this circuit would not be considered an individual branch circuit.

BRANCH CIRCUIT, MULTIWIRE

A branch circuit consisting of two or more ungrounded conductors having a potential difference between them, and an identified grounded conductor having equal potential difference between it and each ungrounded conductor of the circuit and which is connected to the neutral conductor of the system.

BUILDING

A structure which stands alone or which is cut off from adjoining structures by fire walls with all openings therein protected by approved fire doors.

A building is a structure used or intended for supporting or sheltering any use or occupancy. Definitions of the terms "fire walls" and "fire doors" are the responsibility of the municipal and/or state building codes and interpretations of "building terms" have been avoided by NEC committees. Fire-resistance rating is defined as the time, in minutes or hours, that materials or assemblies have withstood a fire exposure.

CABINET

An enclosure designed either for surface or flush mounting and provided with a frame, mat, or trim in which a swinging door or doors are or may be hung.

Both cabinets and cutout boxes are covered in Article 373. Cabinets are designed for surface or flush mounting with a trim to which a swinging door(s) is hung. Cutout boxes are designed for surface mounting with a swinging door(s) secured directly to the box.

CIRCUIT BREAKER

A device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without injury to itself when properly applied within its rating.

See definition in Part B of this article for definition applying to circuits and equipment over 600 volts, nominal.

ADJUSTABLE (As Applied To Circuit Breakers)

A qualifying term indicating that the ciruit breaker can be set to trip at various values of current and/or time within a pre-determined range.

INSTANTANEOUS TRIP (As Applied To Circuit Breakers)

A qualifying term indicating that no delay is purposely introduced in the tripping action of the circuit breaker.

INVERSE TIME (As Applied To Circuit Breakers)

A qualifying term indicating there is purposely introduced a delay in the tripping action of the circuit breaker, which delay decreases as the magnitude of the current increases.

NONADJUSTABLE (As Applied To Circuit Breakers)

A qualifying term indicating that the circuit breaker does not have any adjustment to alter the value of current at which it will trip or the time required for its operation.

SETTING (Of Circuit Breaker)

The value of current and/or time at which an adjustable circuit breaker is set to trip.

CONCEALED

Rendered inaccessible by the structure or finish of the building. Wires in concealed raceways are considered concealed, even though they may become accessible by withdrawing them. [See "Accessible - (As applied to wiring methods)."]

Raceways and cables supported within the hollow frames or permanently closed in by the finish of buildings are considered "concealed". Open-type work, such as raceways and cables in open areas, for example, in unfinished basements, in accessible underfloor areas or attics, or attached to the surface of finished areas, which may be removed without damage to the building structure or finish is not considered "concealed". See definition of "Exposed (as applied to wiring methods)."

CONDUCTOR

BARE: A conductor having no covering or electrical insulation whatsoever. (See "Conductor, Covered,")

COVERED: A conductor encased within material of composition or thickness that is not recognized by this Code as electrical insulation. (See "Conductor, Bare".)

INSULATED: A conductor encased within material of composition and thickness that is recognized by this Code as electrical insulation.

CONDUIT BODY

A separate portion of a conduit or tubing system that provides access through a removable cover(s) to the interior of the system at a junction of two or more sections of the system or at a terminal point of the system.

Boxes such as FS and FD or larger cast or sheet metal boxes are not classified as conduit bodies. See Table 370-6(a).

This definition is intended to clarify that conduit bodies are a portion of a raceway system with removable covers to allow access to the interior of the system.

In the past, conduit bodies have been commonly referred to in the trade as condulets of the LB, LL, LR, C, and T conduit fittings. Section 300-15, 345-14, 346-15, 347-16, 348-14, 348-15, 370-1, 370-6(c), and 370-18(a). Exception may be referred to for the rules on the usage of conduit bodies.

CONNECTOR, PRESSURE (SOLDERLESS)

A device that establishes a connection between two or more conductors or between one or more conductors and a terminal by means of mechanical pressure and without the use of solder.

CONTINUOUS LOAD

A load where the maximum current is expected to continue for three hours or more.

CONTROLLER

A device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected. See also Section 430-81(a).

A "controller" is any switch, circuit breaker, or device normally used to start and stop motors and other apparatus and, in the case of motors, is to be capable of interrupting the stalled-rotor current of the motor.

COPPER-CLAD ALUMINUM CONDUCTORS

Conductors drawn from a copper-clad aluminum rod with the copper metallurgically bonded to an aluminum core. The copper forms a minimum of 10 percent of the cross-sectional area of a solid conductor or each strand of a stranded conductor.

CUTOUT BOX

An enclosure designed for surface mounting and having swinging doors or covers secured directly to and telescoping with the walls of the box proper. (See "Cabinet".)

DEAD FRONT

Without live parts exposed to a person on the operating side of the equipment.

DEVICE

A unit of an electrical system which is intended to carry but not utilize electric energy.

Units, such as switches, circuit breakers, receptacles, and lampholders, that distribute or control, but do not consume, electricity are termed devices.

DISCONNECTING MEANS

A device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply.

See definition in Part B of this article for definition applying to circuits and equipment over 600 volts, nominal.

For disconnecting means for service equipment see Part H of Article 230; for fuses and thermal cutouts, see Part D of Article 240; for circuit breakers, see Part G of Article 240; for appliances, see Part D of Article 422; for space heating equipment, see Part C of Article 424; for motors and controllers, see Part H of Article 430, and for air-conditioning and refrigerating equipment, see Part B of Article 440. See also references for "Disconnecting Means" in Index.

DWELLING

DWELLING UNIT: One or more rooms for the use of one or more persons as a housekeeping unit with space for eating, living, and sleeping, and permanent provisions for cooking and sanitation.

MULTIFAMILY DWELLING: A building containing three or more dwelling units.

ONE-FAMILY DWELLING: A building consisting solely of one dwelling unit.

TWO-FAMILY DWELLING: A building consisting solely of two dwelling units.

ENCLOSED

Surrounded by a case, housing, fence or walls which will prevent persons from accidently contacting energized parts.

ENCLOSURE

The case or housing of apparatus, or the fence or walls surrounding an installation to prevent personnel from accidentally contacting energized parts, or to protect the equipment from physical damage.

EQUIPMENT

A general term including material, fittings, devices, appliances, fixtures, apparatus, and the like used as a part of, or in connection with, an electrical installation.

EQUIPMENT GROUNDING CONDUCTOR

See "Grounding Conductor, Equipment".

EXPLOSION-PROOF APPARATUS

Apparatus enclosed in a case that is capable of withstanding an explosion of a specified gas or vapor surrounding the enclosure by sparks, flashes, or explosion of the gas or vapor within, and which operates at such an external temperature that a surrounding flammable atmosphere will not be ignited thereby.

EXPOSED (As Applied To Live Parts)

Capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to parts not suitably guarded, isolated, or insulated. (See "Accessible" and "Concealed".)

EXPOSED (As Applied To Wiring Methods)

On or attached to the surface or behind panels designed to allow access. [See "Accessible - (As applied to wiring methods)".]

EXTERNALLY OPERABLE

Capable of being operated without exposing the operator to contact with live parts.

FEEDER

All circuit conductors between the service equipment, or the generator switchboard of an isolated plant, and the final branch-circuit overcurrent device.

FITTING

An accessory such as a locknut, bushing, or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function.

GARAGE

A building or portion of a building in which one or more self-propelled vehicles carrying volatile flammable liquid for fuel or power are kept for use, sale, storage, rental, repair, exhibition, or demonstrating purposes, and all that portion of a building which is on or below the floor or floors in which such vehicles are kept and which is not separated therefrom by suitable cutoffs.

GROUND

A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth.

GROUNDED

Connected to earth or to some conducting body that serves in place of the earth.

GROUNDED CONDUCTOR

A system or conduit conductor that is intentionally grounded.

GROUNDING CONDUCTOR

A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes.

GROUNDING CONDUCTOR, EQUIPMENT

The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor and/or the grounding electrode conductor at the service equipment or at the source of a separately derived system.

GROUNDING ELECTRODE CONDUCTOR

The conductor used to connect the grounding electrode to the equipment grounding conductor and/or to the grounded conductor of the circuit at the service equipment or at the source of a separately derived system.

The grounding electrode conductor is to be of copper, aluminum, or copper-clad aluminum and is used to connect the equipment grounding conductor and/or the grounded conductor (at the service equipment or at the separately derived system) to the grounding electrode for either grounded or ungrounded systems. It is sized by using Table 250-94. See also Article 250 Parts H and J.

GROUND-FAULT CIRCUIT-INTERRUPTER

A device whose function is to interrupt the electric circuit to the load when a fault current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit.

GUARDED

Covered, shielded, fenced, enclosed, or otherwise protected by means of suitable covers, casings, barriers, rails, screens, mats, or platforms to remove the likelihood of approach or contact by persons or objects to a point of danger.

See Section 110-17, 110-34, 430-133, 450-7, and Article 710.

ISOLATED

Not readily accessible to persons unless special means for access are used.

See Sections 110-31, 110-34, and 710-22. See definition of "Switch, Isolating" in Article 100.

LABELED

Equipment or materials having a label, symbol, or other identifying mark of a nationally recognized testing laboratory, inspection agency, or other organization concerned with product evaluation that maintains periodic inspection of production of labeled equipment or materials and by whose labeling is indicated compliance with nationally recognized standards or tests to determine suitable usage in a specified manner.

Equipment and conductors required or permitted by this Code are acceptable only when approved for a specific environment or application by the authority having jurisdiction.

"Listing" or "labeling" by a nationally recognized testing laboratory will provide a basis for approval. See Section 90-6.

LIGHTING OUTLET

An outlet intended for the direct connection of a lampholder, a lighting fixture, or a pendant cord terminating in a lampholder.

LISTED

Equipment or materials included in a list published by a nationally recognized testing laboratory, inspection agency, or other organization concerned with product evaluation that maintains periodic inspection of production of listed equipment or materials, and whose listing states either that the equipment or material meets nationally recognized standards or has been tested and found suitable for use in a specified manner.

The means for identifying listed equipment may vary for each testing laboratory, inspection agency, or other organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

See comments that follow the definition of "Labeled".

LOCATION

DAMP LOCATION: Partially protected locations under canopies, marquees, roofed open porches, and like locations, and interior locations subject to moderate degrees of moisture, such as some basements, some bars, and some cold-storage warehouses.

DRY LOCATION: A location not normally subject to dampness or wetness. A location classified as dry may be temporarily subject to dampness or wetness, as in the case of a building under construction.

WET LOCATION: Installations underground or in concrete slabs or masonry in direct contact with the earth, and locations subject to saturation with water or other liquids, such as vehicle washing areas, and locations exposed to weather and unprotected.

LOW-ENERGY POWER CIRCUIT

A circuit that is not a remote-control or signaling circuit but has its power supply limited in accordance with the requirements of Class 2 and Class 3 circuits. (See Article 725.)

MULTIOUTLET ASSEMBLY

A type of surface or flush raceway designed to hold conductors and receptacles, assembled in the field or at the factory.

In dry locations, metallic and nonmetallic multioutlet assemblies are permitted; however, they are not to be installed where concealed. See Article 353 for details of recessing these assemblies.

OUTLET

A point on the wiring system at which current is taken to supply utilization equipment.

OVERCURRENT

Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload (see definition) short circuit, or ground fault.

A current in excess of rating may be accommodated by certain equipment and conductors for a given set of conditions. Hence the rules for overcurrent protection are specific for particular situations.

OVERLOAD

Operation of equipment in excess of normal, full load rating, or of a conductor in excess of rated ampacity which, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload. (See "Overcurrent".)

For motor apparatus application, see Section 430-31.

PANELBOARD

A single panel or group of panel units designed for assembly in the form of a single panel; including buses, automatic overcurrent devices, and with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall or partition and accessible only from the front. (See "Switchboard".)

POWER OUTLET

An enclosed assembly which may include receptacles, circuit breakers, fuseholders, fused switches, buses and watt-hour meter mounting means; intended to supply and control power to mobile homes, recreational vehicles or boats, or to serve as a means for distributing power required to operate mobile or temporarily installed equipment.

PREMISES WIRING (SYSTEM)

That interior and exterior wiring, including power, lighting, control, and signal circuit wiring together with all of its associated hardware, fittings, and wiring devices, both permanently and temporarily installed, which extends from the load end of the service drop, or load end of the service lateral conductors to the outlet(s). Such wiring does not include wiring internal to appliances, fixtures, motors, controllers, motor control centers, and similar equipment.

QUALIFIED PERSON

One familiar with the construction and operation of the equipment and the hazards involved.

RACEWAY

A channel designed expressly for holding wires, cables, or busbars, with additional functions as permitted in this Code.

Raceways may be of metal or insulating material, and the term includes rigid metal conduit, rigid nonmetallic conduit, intermediate metal conduit, liquidtight flexible metal conduit, flexible metallic tubing, flexible metal conduit, electrical metallic tubing, underfloor raceways, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways.

RAINPROOF

So constructed, protected, or treated as to prevent rain from interfering with successful operation of the apparatus.

RAINTIGHT

So constructed or protected that exposure to a beating rain will not result in the entrance of water.

Raceways on exterior surfaces of buildings are to be made raintight. See Sections 225-22 and 230-53.

For boxes and cabinets, see Section 300-6.

READILY ACCESSIBLE

Capable of being reached quickly for operation, renewal, or inspections, without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, chairs, etc. (See "Accessible".)

Overcurrent devices are to be readily accessible. See Section 240-24(a). There is considered to be a high degree of safety when switches or circuit breakers can be disconnected quickly without being hindered by obstacles. See Section 230-72(c) for services. See also the Exceptions to this rule for services, Section 230-91; for busways, Section 364-12; and for supplementary overcurrent protection, Section 240-10.

RECEPTACLE

A receptacle is a contact device installed at the outlet for the connection of a single attachment plug.

A single receptacle is a single contact device with no other contact device on the same yoke. A multiple receptacle is a single device containing two or more receptacles.

The basic receptacle is a single contact device for the connection of a single attachment plug. A multiple receptacle is a contact device containing two or more receptacles for the connection of two or more attachment plugs.

RECEPTACLE OUTLET

An outlet where one or more receptacles are installed.

REMOTE-CONTROL CIRCUIT

Any electric circuit that controls any other circuit through a relay or an equivalent device.

SEALABLE EQUIPMENT

Equipment enclosed in a case or cabinet that is provided with a means of sealing or locking so that live parts cannot be made accessible without opening the enclosure. The equipment may or may not be operable without opening the enclosure.

SERVICE

The conductors and equipment for delivering energy from the electricity supply system to the wiring system of the premises served.

SERVICE CABLE

Service conductors made up in the form of a cable.

SERVICE CONDUCTORS

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

Service conductors from an overhead distribution system originate at the utility pole, or wires attached to it, and terminate at the service equipment.

Service conductors from an underground distribution system originate at the utility manhole and terminate at the service equipment. When primary conductors are extended to outdoor pad-mounted or underground transformers on private property, the service conductors originate at the secondary connections of the transformers.

See Article 230, Part K for service conductors exceeding 600 V.

SERVICE DROP

The overhead service conductors from the last pole or other aerial support to and including the splices, if any, connecting to the service-entrance conductors at the building or other structure.

SERVICE-ENTRANCE CONDUCTORS, OVERHEAD SYSTEM

The service conductors between the terminals of the service equipment and a point usually outside the building, clear of building walls, where joined by tap or splice to the service drop.

SERVICE-ENTRANCE CONDUCTORS, UNDERGROUND SYSTEM

The service conductors between the terminals of the service equipment and the point of connection to the service lateral.

Where service equipment is located outside the building walls, there may be no service-entrance conductors, or they may be entirely outside the building.

SERVICE EQUIPMENT

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.

Service equipment consists of a circuit breaker or a fused switch provided to disconnect all conductors in a building or other structure from the service-entrance conductors.

The disconnecting means is to consist of not more than six circuit breakers or six switches and be readily accessible, either inside or outside the building or structure nearest the point of entrance of the service-entrance conductors.

See Article 230, Part H.

SERVICE LATERAL

The underground service conductors between the street main, including any risers at a pole or other structure or from transformers, and the first point of connection to the service-entrance conductors in a terminal box or meter or other enclosure with adequate space, inside or outside the building wall. Where there is no terminal box, meter, or other enclosure with adequate space, the point of connection shall be considered to be the point of entrance of the service conductors into the building.

SERVICE RACEWAY

The raceway that encloses the service-entrance conductors.

SETTING (Of Circuit Breaker)

The value of the current at which it is set to trip.

SIGNALING CIRCUIT

Any electric circuit that energizes signaling equipment.

SPECIAL PERMISSION

The written consent of the authority having jurisdiction.

The authority having jurisdiction for enforcement of the Code has responsibility for making interpretations and granting special permission contemplated in a number of the rules. Examples, see Section 110-16(a), Exception No. 2, or Section 230-2, Exception No. 4.

SWITCHBOARD

A large single panel, frame, or assembly of panels on which are mounted, on the face or back or both, switches, overcurrent and other protective devices, buses, and usually instruments. Switchboards are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets. (See "Panelboard".)

Busbars are to be arranged to avoid inductive overheating.

Service busbars are to be isolated by barriers from the remainder of the switchboard.

Most modern switchboards are totally enclosed to reduce to a minimum the probability of communicating fire to adjacent combustible materials and to guard live parts.

VOLTAGE (Of A Circuit)

The greatest root-mean-square (effective) difference of potential between any two conductors of the circuit concerned.

Some systems, such as 3-phase 4-wire, single-phase 3-wire, and 3-wire direct-current may have various circuits of various voltages.

A 3-phase, 4-wire wye system has two voltages (277/480, 120/208). The "voltage of the circuit" is the highest voltage between any two conductors, that is, 480 V and 208 V. The "voltage of the circuit" of a 2-wire feeder or branch circuit (one phase and the grounded conductor) derived from the above systems would be the voltage between the two wires of the lower voltage, that is, 277 V and 120 V.

The same applies to DC or single-phase, 3-wire systems where there are two voltages.

VOLTAGE, NOMINAL

A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (as 120/240, 480Y/277, 600, etc.).

The actual voltage at which a circuit operates can vary from the nominal within a range that permits satisfactory operation of equipment.

See "Voltage Ratings for Electric Power Systems and Equipment (60Hz)," **ANSI C84.1-1970 and supplement C84.1a-1973.**

VOLTAGE TO GROUND

For grounded circuits, the voltage between the given conductor and that point or conductor of the circuit that is grounded; for ungrounded circuits, the greatest voltage between the given conductor and any other conductor of the circuit.

The "voltage to ground" of a 277/480 V wye system would be 277 V; of a 120/280 V wye system would be 120 V; and a 3-phase, 3-wire ungrounded 480V system, 480 V.

WATERTIGHT

So constructed that moisture will not enter the enclosure.

WEATHERPROOF

So constructed or protected that exposure to the weather will not interfere with successful operation.

Rainproof, raintight, or watertight equipment can fulfill the requirements for weatherproof where varying weather conditions other than wetness, such as snow, ice, dust, or temperature extremes, are not a factor.

ARTICLE 110 - INSTALLATIONS

110-2 APPROVAL

The conductors and equipment required or permitted by this Code shall be acceptable only when approved.

See Examination of Equipment for Safety, Section 110-3. See definitions of "Approved", "Approved for the purpose", "Labeled", and "Listed".

Approval of equipment is the responsibility of the electrical inspection authority and many such "approvals" are based on tests and listings of nationally recognized testing laboratories such as Underwriters Laboratories Inc. (UL). Plublished lists indicating electrical equipment that has been examined can be secured from UL representatives in principal cities of the United States.

110-8 WIRING METHODS

Only wiring methods recognized as suitable are included in this Code. The recognized methods of wiring shall be permitted to be installed in any type of building or occupancy, except as otherwise provided in this Code.

The scope of Article 300 applies generally to all wiring methods, except as amended, modified, or supplemented by Chapter 5 (Special Occupancies), Chapter 6 (Special Equipment), and Chapter 7 (Special Conditions).

Chapter 8 (Communications Systems) is independent of the other chapters except where it is specifically referenced by the Code.

Commentary:

The "recognized methods of wiring" are discussed in detail in Article 300.

Article 545 - Manufactured Building which "covers requirements for a manufactured building and/or building components" includes modifications of Article 300 wiring methods which could pertain to the photovoltaic module. These modifications along with their importance are discussed in Chapter Three and Article 545 commentaries.

110-14 ELECTRICAL CONNECTIONS

Commentary:

This section establishes general requirements for electrical connections both terminals and splices. The entire section including NEC Handbook Commentary is reprinted here. Following the reprinted material is a brief comment concerning quick connect terminals.

110-14 ELECTRICAL CONNECTIONS

Because of different characteristics of copper and aluminum, devices such as pressure terminal or pressure splicing connectors and soldering lugs shall be suitable for the material of the conductor and shall be properly installed and used. Conductors of dissimilar metals shall not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductors (such as copper and aluminum, copper and copper-clad aluminum, or aluminum and copper-clad aluminum), unless the device is suitable for the purpose and conditions of use. Materials such as solder, fluxes, inhibitors, and compounds, where employed, shall be suitable for the use and shall be of a type which will not adversely affect the conductors, installation, or equipment.

(a) TERMINALS

Connection of conductors to terminal parts shall ensure a thoroughly good connection without damaging the conductors and shall be made by means of pressure connectors (including set-screw type), solder lugs, or splices to flexible leads.

Exception: Connection by means of wire binding screws or studs and nuts having upturned lugs or equivalent shall be permitted for No. 10 or smaller conductors.

Terminals for more than one conductor and terminals used to connect aluminum shall be of a type approved for the purpose.

(b) SPLICES

Conductors shall be spliced or joined with splicing devices suitable for the use or by brazing, welding, or soldering with a fusible metal or alloy. Soldered splices shall first be so spliced or joined as to be mechanically and electrically secure without solder and then soldered. All splices and joints and the free ends of conductors shall be covered with an insulation equivalent to that of the conductors or with an insulating device suitable for the purpose.

Field observations and trade magazine articles indicate that failures of electrical connections are the cause of many equipment burn-outs and fires. Many of these failures are attributable to improper terminations, poor workmanship, different characteristics of dissimilar metals, and improper binding screws or splicing devices.

Recent revisions in Underwriters Laboratories Inc. requirements for listing solid aluminum conductor in sizes No. 12 and 10 AWG and for listing snap switches and receptacles for use on 15- and 20-A branch circuits incorporate stringent tests which take the factors listed in the previous paragraph into account.

SCREWLESS PRESSURE TERMINAL CONNECTORS OF THE CONDUCTOR PUSH-IN TYPE ARE FOR USE WITH COPPER AND COPPER-CLAD ALUMINUM CONDUCTORS ONLY.

Instructions describing proper installation techniques and emphasizing the need to follow these techniques and practice good workmanship are required to be included with each coil of No. 12 and No. 10 AWG insulated aluminum wire or cable.

New product and material designs which provide for increased levels of safety of aluminum wire terminations have recently been developed by the electrical industry.

To assist all concerned parties in the proper and safe use of solid aluminum wire in making connections to wiring devices used on 15- and 20-A branch circuits, the following information is presented. Understanding and utilizing this information is essential to proper application of materials and devices now available.

For New Installations

The following was prepared by the Ad Hoc Committee on Aluminum Terminations: Comply with Section 110-14(a) of the 1978 NEC when aluminum wire is used in new installations.

New Materials and Devices

a. For direct connection use only 15- and 20-A receptacles and switches marked "CO/ALR" and connected as described under "Installation Method."

The "CO/ALR" marking is on the device mounting strap. The "CO/ALR" marking means the devices have been tested to stringent heat cycling requirements to determine their suitability for use with UL labeled aluminum, copper, or copper-clad aluminum wire.

1. Strip wires 3/8"
2. Pretwisting unnecessary. Hold stripped wires together with ends even. (Lead stranded wires slightly.)
3. Screw on connector - push wires firmly into connector when starting.

COPPER TO COPPER
ALUMINUM TO ALUMINUM
COPPER TO ALUMINUM (dry locations only)

Temperature rating: 150° C. (302°F). Max
Listed as a PRESSURE TYPE wire connector on the following solid and/or stranded wire combinations.

2 or 3 #8	3 # 10 with 1 or 2 # 14
2 # 8 with 1 or 2 # 10	2 # 10 with 1, 2, 3, or 4 # 12
2 # 8 with 1, 2, or 3 # 12	2 # 10 with 1, 2, or 3 # 14
1 # 8 with 1, 2, 3, or 4 #10	1 # 10 with 1, 2, 3, 4, or 5# 12
1 # 8 with 1, 2, 3, 4, or 5# 12	1 # 10 with 1, 2, 3, or 4 # 14
3 # 8 with 1 # 12	2, 3, 4, 5, or 6 # 12
2, 3, 4, or 5 # 10	4 # 12 with 1 or 2 # 14
5 # 10 with 1 # 12	3 # 12 with 1, 2, or 3 # 14
4 # 10 with 1 or 2 # 12	2 # 12 with 1, 2, or 3 # 14
4 # 10 with 1 # 14	1 # 12 with 2, 3, or 4 # 14
3 # 10 with 1, 2, or 3 # 12	

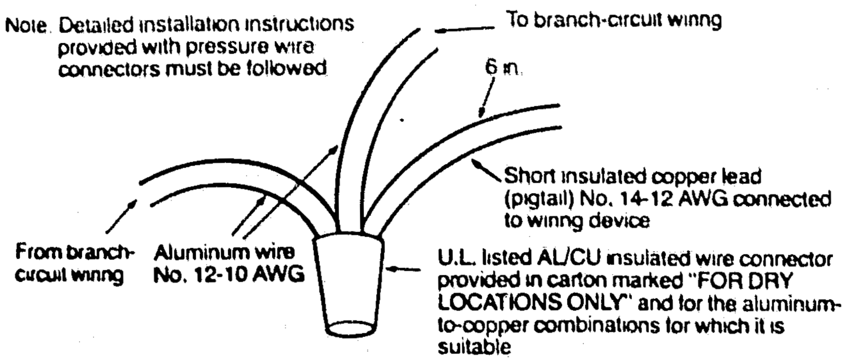


Figure 110-2. Pigtailing copper to aluminum conductor. (*Underwriters Laboratories Inc.*)

Note. **Pigtailing, either field- or factory-wired, as illustrated in Figure 110-2, is recognized by the *NEC*.**

NOTE: Pigtailing, either field- or factory-wired, as illustrated in Figure 110-2, is recognized by the NEC.

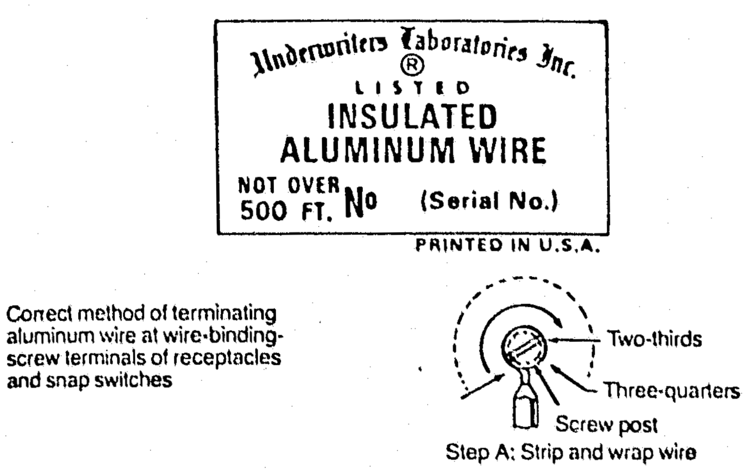
b. Use solid aluminum wire, No. 12 or 10 AWG, marked with the Underwriters Laboratories' new aluminum insulated wire label, as shown in Figure 110-3. Follow the installation instructions packaged with the wire. Conductor bearing this UL label is judged under the requirements for the chemistry, physical properties, and processing of the conductor which became effective September 20, 1972.

Installation Method

1. Wrap the freshly stripped end of the wire two-thirds to three-quarters of the distance around the wire-binding screw post, as shown in Step A of Figure 110-3.

   The loop is made so that rotation of the screw in tightening will tend to wrap the wire around the post rather than unwrap it.

2. Tighten the screw until the wire is snugly in contact with the underside of the screw head and with the contact plate on the wiring device, as shown in Step B of Figure 110-3.



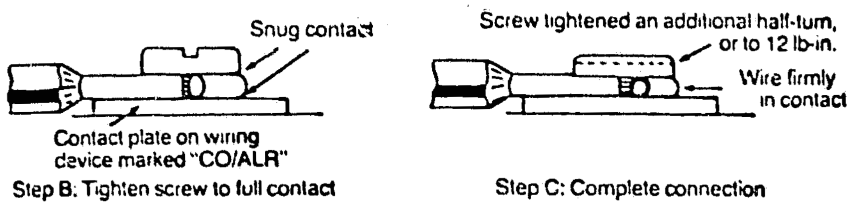


Figure 110-3. Correct method of terminating aluminum wire at wire-binding screw terminals of receptacles and snap switches. (Underwriters Laboratories Inc.)

3. Tighten the screw an additional one-half turn, thereby providing a firm connection. Where torque screwdrives are used, tighten to 12 pound inches. See Step C of Figure 110-3.

4. Position the wires behind the wiring device so as to decrease the likelihood of the terminal screws loosening when the device is positioned into the outlet box.

Figure 110-4 illustrates incorrect methods for connection and should not be used.

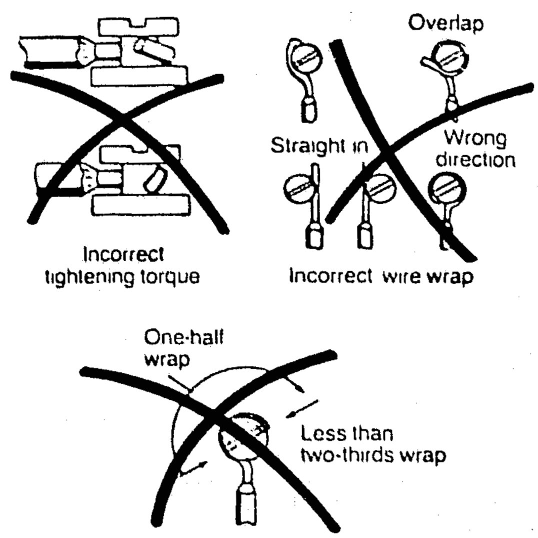


Figure 110-4. Incorrect methods of terminating aluminum wire at wire-binding screw terminals of receptacles and snap switches. (Underwriters Laboratories Inc.)

Existing Inventory

When UL-labeled solid aluminum wire No. 12 and 10 AWG not bearing the new aluminum wire label is used, it should be used with wiring devices marked "CO/ALR" and connected as described in "Installation Method". This is the preferred and recommended method for using such wire.

Note. Pigtailing, either field- or factory-wired, as illustrated in Figure 110-2, is recognized by the NEC.

In the following types of devices the terminals shall not be directly connected to aluminum conductors but may be used with UL-labeled copper or copper-clad conductors:
Receptacles and snap switches marked "AL-CU"
Receptacles and snap switches having no conductor marking
Receptacles and snap switches having backwired terminals or screwless terminals of the push-in type.

For Existing Installations

If examination discloses overheating or loose connections the recommendations described under "For New Installations - Existing Inventory" should be followed.

Commentary:

Based on the terminal costing study done as part of the Electrical Interface Studies (see Appendix 15 - Studies) and a study prepared by Bechtel Corporation (Ref: "Engineering Study of the Module/Array Interface for Large Terrestrial Photovoltaic Arrays", Bechtel Corporation, June 1977, Final Report pp. 71-82),ERDA/JPL/954698-77/1, quick connect terminals appear to be the most economical inter module or module-to-array branch circuit connectors.

Although quick connect terminals are not specifically mentioned in the NEC test, there is reference (see the third paragraph following 110-14(b) of the NEC Commentary) to a "screwless pressure terminal connector of the conductor push-in type" These are quick connect terminals. Quick connect do meet the requirements of the NEC for electrical connections, as long as they are testing laboratory approved. (UL Standard 310 for Quick Connect Terminals requires the use of copper and copper-clad aluminum conductors only.)

One modular lighting and communications system presently used in the building industry uses a quick connect terminal; actually a nonstandard NEMA (National

Electrical Manufacturer's Association) receptacle and plug, that is UL approved and accepted by the NEC. This system, manufactured by Wiremold of West Hartford, Connecticut is described in the Wiring and Terminal studies of Appendix 15 of this document.

Some similar modular lighting systems are running into NEC opposition. The reasons for this opposition and a more complete description of the Moldwire System are presented in the Terminal Study, Appendix 15.

Another quick connect design currently pending UL recognition as an acceptable component of a manufactured building component, is now being manufactured by Amp Inc. (See Commentary following Section 110-8 and Article 545 for explanation of manufactured building and manufactured building components.) This connector is intended for use with three conductor nonmetallic sheathed cable (commonly called Romex) and is designed such that connection to the conductor can be made without stripping the insulation from the cable.

Although quick connect terminals are recognized by the NEC, acceptance by all municipality codes does not automatically follow. Through a conversation with Mr. W. P. Hogan of the Chicago Bureau of Electrical Inspection and Chairman of NEC Panel No. 9 (Panel No. 9 has jurisdiction over Articles 370, 373, 380, 384. Article 370 covers requirements for Boxes and Fittings), it has been learned that the City of Chicago does not recognize quick connect terminals as an approved permanent connection technique and does not permit the use of the Moldwire ODS for lighting or communication systems. Chicago has one of the strictest electrical codes in the country. Careful review of Chicago's electrical code should be performed if PV penetration into that market area is expected. Due to time restriction and anticipated small market in the Chicago jurisdiction a review of this code was not undertaken.

110-17 GUARDING OF LIVE PARTS (600 Volts or less, nominal)

(a) Except as elsewhere required or permitted by this Code, live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by approved cabinets or other forms of approved enclosures or by any of the following means:

(1) By location in a room, vault, or similar enclosure that is accessible only to qualified persons.

(2) By suitable permanent, substantial parititons or screens so arranged that only qualified persons will have access to the space within reach of the live parts. Any openings in such partitions or screens shall be so sized and located that persons are not likely to come into accidental contact with the live parts or to bring conducting objects into contact with them.

(3) By location on a suitable balcony, gallery, or platform so elevated and arranged as to exclude unqualified persons.

(4) By elevation of 8 feet or more above the floor or other working surface.

(b) In locations where electric equipment would be exposed to physical damage, enclosures or guards shall be so arranged and of such strength as to prevent such damage.

(c) Entrances to rooms and other guarded locations containing exposed live parts shall be marked with conspicuous warning signs forbidding unqualified persons to enter.

For motors, see Section 430-132 and 430-133. For over 600 volts, see Section 110-34.

Live parts of electric equipment should be covered, shielded, enclosed, or otherwise protected by covers, barriers, mats, or platforms to remove the likelihood of contact by persons or objects. See definitions for "Dead Front", "Guarded", and "Isolated" in Article 100.

Commentary:

Section 110-17 references Sections 430-132 and 430-133. These two sections follow.

430-132 WHERE REQUIRED

Exposed live parts of motors and controllers operating at 50 volts or more between terminals shall be guarded against accidental contact by enclosure or by location as follows:

(a) By installation in a room or enclosure that is accessible only to qualified persons.

(b) By installation on a suitable balcony, gallery, or platform, so elevated and arranged as to exclude unqualified persons.

(c) By elevation 8 feet or more above the floor.

430-133 GUARDS FOR ATTENDANTS

Where live parts of motors or controllers operating at over 150 volts to ground are guarded against accidental contact only by location as specified in Section 430-132, and where adjustment or other attendance may be necessary during the operation of the apparatus, suitable insulating mats or platforms shall be provided so that the attendant cannot readily touch live parts unless standing on the mats or platforms.

For working space, see Sections 110-16 and 110-34.

Commentary:

The guarding live parts in PV modules is an important design requirement. During installation, assuming exposure to sunlight, the panel will be generating electricity and live parts must be guarded.

In regard to voltage level, some research into "safe" voltage levels verified the 50 volt minimum for live part protection. Quoting from a paper written in 1956 by C. F. Dalziel (Member AIEE) on "Let-Go Currents and Voltages": "From the foregoing [experiment] it is apparent that, wet contact conditions, the reasonably safe 60 cycle let-go voltage for man, for the major current pathways through the body, are between about 10 and 21 volts rms, and the corresponding voltage for direct current are 51 to 104 volts." (The testing proceedure simulated the hand to foot pathway by having the subjects grasp with wet hands a pair of 6-inch long-nose pliers in the right hand when standing barefoot in a bucket of salt water to a depth of about 4 inches. The hand to hand pathway was simulated by a copper wire connected from the right hand to an armband on the upper arm.) As further confirmation, quoting from the same article, the author notes: "At a conference sponsored by the Comite Medical of the Electricite de France during the CIGRE meetings of June 1952, French authorities consider the maximum voltages safe for man were approximately 24 volts for 50 cycle ac and 50 volts for direct current." He goes on to say because of biological variability, no absolutely safe voltage level can be determined. It appears then as though the 50 volt level specified in the code has a strong experimental base and that all PV modules operating at voltages over 50 must be protected from accidental contact.

However, the over 50 volt protection requirement does not address specific hazards involved with photovoltaic installation. Voltages less than 50 V dc may be "safe" if your feet are on the ground but these voltages may become hazardous when put in the context of a typical roof top installation. That is, voltages less than 50 V dc may not be lethal but the fall off the roof may.

Guarding may be as simple as a recessed terminal or a required nighttime installation. Final determination of design and/or installation requirements for approval will be made by an electrical testing laboratory.

110-21 MARKING

The manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product may be identified shall be placed on all electric equipment. Other markings shall be provided giving voltage, current, wattage, or other ratings as are specified elsewhere in this Code. The marking shall be of sufficient durability to withstand the environment involved.

Manufacturer's markings are to be located so as to be visible or easily accessible, during or after installation.

Commentary:
This is somewhat of a mundane electrical code requirement that must not be overlooked. In addition to voltage and peak wattage, the manufacturer should also include markings showing module polarity and possibly weight.

ARTICLE 200 - USE AND IDENTIFICATION OF GROUNDED CONDUCTORS

Commentary:
Article 200 deals with identification of terminals, connection to grounded systems, and identification of grounded conductors. Should the modules or panels require grounding, this section then becomes important. Assuming the panel design will require some internal wiring similar to that found in typical residential use, Article 200 will apply to wiring of the panel, if Code approved wiring is required. The applicable sections are included here.

200-1 SCOPE

This article provides requirements for (1) identification of terminals; (2) grounded conductors in premises wiring systems; and (3) identification of grounded conductors.

See Article 100 for definitions of "Grounded Conductor" and "Grounding Conductors".

200-2 GENERAL

All premises wiring systems shall have a grounded conductor that is identified in accordance with Section 200-6.

Exception: Circuits and systems exempted or prohibited by Sections 210-10, 215-7, 250-3, 250-5, 250-7, 503-13, and 517-104.

Isolated circuits are required in hazardous areas of hospital anesthetizing locations. The ungrounded conductors of these circuits are colored orange and brown and are provided with a continually operatings "Line Isolation Monitor." See Section 517-104(d) and (e). See also NFPA 56A, Standard for the Use of Inhalation Anesthetics.

The grounded conductor, when insulated, shall have insulation which is suitable, other than color, for any ungrounded conductor of the same circuit.

200-3 CONNECTION TO GROUNDED SYSTEM

Premises wiring shall not be electrically connected to a supply system unless the latter contains, for any grounded conductor of the interior system, a corresponding conductor which is grounded.

For the purpose of this section, "electrically connected" shall mean connection capable of carrying current as distinguished from connection through electromagnetic induction.

Grounded conductors of premises wiring are to be connected to the premises system grounded conductor to assure a common continuous grounded system.

200-6 MEANS OF IDENTIFYING GROUNDED CONDUCTORS

(a) Sizes No. 6 or Smaller. An insulated grounded conductor of No. 6 or smaller shall be identified by a continuous white or natural gray outer finish along its entire length.

Exception No. 1: The grounded conductor of a mineral-insulated metal-sheathed cable shall be identified at the time of installation by distinctive marking at its terminations.

Exception No. 2: Where the conditions of maintenance and supervision assure that only qualified persons will service the installation, grounded conductors in multiconductor cables shall be permitted to be permanently identified at their terminations at the time of installation by a distinctive white marking or other equally effective means.

(b) Sizes Larger Than No. 6. An insulated grounded conductor larger than No. 6 shall be identified either by a continuous white or natural gray outer finish along its entire length or at the time of installation by a distinctive white marking at its terminations.

Exception: Where the conditions of maintenance and supervision assure that only qualified persons will service the installation, grounded conductors in multiconductor cables shall be permitted to be permanently identified as their terminations at the time of installation by a distinctive white marking or other equally effective means.

(c) Flexible Cords. An insulated conductor intended for use as a grounded conductor, where contained within a flexible cord, shall be identified by a white or natural gray outer finish or by methods permitted by Section 400-22.

Article 200 contains the grounded circuit indentification requirements. The grounded circuit conductor is referred to throughout the Code as the identified conductor or the grounded conductor. The NEC formerly made recommendations for identification of ungrounded circuit conductors for branch circuits. Section 210-5, however, no longer requires or recommends an identification scheme for ungrounded branch-circuit conductors.

Section 215-8, covering 3-phase, 4-wire delta connected systems with the midpoint of one phase grounded, requires that the higher phase-to-ground conductor is to be identified by the color orange, by tagging, or by some other effective means at every point of connection where the neutral is also present. The high leg of 120/240 4-wire, 3-phase delta systems is 208 V to ground (120 V x 1.73).

Both Sections 200-6(a) and (b) contain Exceptions introducing a new concept for identifying grounded conductors of multiconductor cables. These Exceptions allow the identification of conductors at the time of installation by a distinctive white marking or other equally effective means. A variety of other schemes, equally effective, include numbering, lettering, or tagging. These Exceptions are intended to apply in locations where a regulated system of maintenance and supervision assures that only qualified persons will service the installation.

For the identification of branch-circuit conductors, see Section 210-5. For the identification of the high leg (delta system) conductor, see Section 215-8. See Section 384-3(f) for the phase arrangement of 3-phase buses on switchboards and panelboards.

200-7 USE OF WHITE OR NATURAL GRAY COLOR

A continuous white or natural gray covering on a conductor or a termination marking of white or natural gray color shall be used only for the grounded conductor.

Exception No. 1: An insulated conductor with a white or natural gray finish shall be permitted as an ungrounded conductor where permanently reidentified to indicate its use, by painting or other effective means at its termination and at each outlet where the conductor is visible and accessible.

Exception No. 2: A cable containing an insulated conductor with a white or natural gray outer finish shall be permitted for single-pole, 3-way, or 4-way switch loops where the white or natural gray conductor is used for the supply to the switch, but not as a return conductor from the switch to the switched outlet. In these applications, reidentification of the white or natural gray conductor shall not be required.

Exception No. 3: A flexible cord for connecting an appliance having one conductor identified with a white or natural gray outer finish, or by any other means permitted by Section 400-22, shall be permitted whether or not the outlet to which it is connected is supplied by a circuit having a grounded conductor.

Exception No. 4: A white or natural gray conductor of circuits of less than 50 volts shall be required to be grounded only as required by Section 250-5(a).

200-9 MEANS OF IDENTIFICATION OF TERMINALS

The identification of terminals to which a grounded conductor is to be connected shall be substantially white in color. The identification of other terminals shall be of a readily distinguishable different color.

Exception: Where the conditions of maintenance and supervision assure that only qualified persons will service the installations, terminals for grounded conductors shall be permitted to be permanently identified at the time of installation by a distinctive white marking or other equally effective means.

See the comments following Section 200-6.

200-10 IDENTIFICATION OF TERMINALS

(a) Device Terminals. All devices provided with terminals for the attachment of conductors and intended for connection to more than one side of the circuit shall have terminals properly marked for identification.

Exception No. 1: Where the electrical connection of a terminal intended to be connected to the grounded conductor is clearly evident.

Exception No. 2: Single-pole devices to which only one side of the line is connected.

Exception No. 3: The terminals of lighting and appliance branch-circuit panelboards.

Exception No. 4: Devices having a normal current rating of over 30 amperes other than polarized attachment plugs and polarized receptacles for attachment plugs as required in (b) below.

(b) Plugs, Receptacles, and Connectors. Receptacles, polarized attachment plugs and cord connectors for plugs and polarized plugs shall have the terminal intended for connection to the grouned (white) conductor identified by a metal or metal coating substantially white in color.

If the terminal for the grounded conductor is not visible, the conductor entrance hole for the connection shall be marked with the word "white".

The terminal for the connection of the equipment grounding conductor shall be identified by: (1) A green-colored, not readily removable terminal screw with a hexagonal head; (2) A green-colored, hexagonal, not readily removable terminal nut; or (3) A green-colored pressure wire connector. If the terminal for the grounding conductor is not visible, the conductor entrance hole shall be marked with the word "green" or otherwise identified by a distinctive green color.

Exception: Two-wire attachment plugs shall not be required to have their terminals marked for identification.

ARTICLE 225 - OUTSIDE BRANCH CIRCUITS AND FEEDERS

Commentary:

Rack and Stand Off mounting type will require wiring located outside of the building. Those sections that relate to the residential PV systems are reprinted here.

225-1 SCOPE

This article covers electric equipment and wiring for the supply of utilization equipment located on or attached to the outside of public and private buildings, or run between buildings, other structures or poles on other premises served.

225-4 CONDUCTOR COVERING

Where within 10 feet of any building or other structure, open wiring on insulators shall be insulated or covered. Conductors in cables or raceways, except Type MI cable, shall be of the rubber-covered type or thermoplastic type and in wet locations shall comply with Section 310-7. Conductors for festoon lighting shall be of the rubber-covered or thermoplastic type.

225-10 WIRING ON BUILDINGS

The installation of outside wiring on surfaces of buildings shall be permitted for circuits of not over 600 volts as open wiring on insulators, as multi-conductor cable approved for the purpose, as Type MC cable, as Type MI cable, in rigid metal conduit, in intermediate metal conduit, in busways as provided in Article 364, or in electrical metallic tubing.

225-11 CIRCUIT EXITS AND ENTRANCES

Where outside branch and feeder circuits leave or enter a building, the requirements of Section 230-43, 230-52 and 230-54 shall apply.

ARTICLE 230 - SERVICE

Commentary:

Those sections referenced in 225-11 are reprinted here with commentary as appropriate.

230-1 SCOPE

This article covers service conductors and equipment for control and protection of services; the number, types, and sizes of services and service equipment; and the installation requirements.

Commentary:

The PV panel may be generally defined as the service. See NEC definition of service.

230-43 WIRING METHODS FOR 600 VOLTS OR LESS

Service-entrance conductors shall be installed in accordance with the applicable requirements of this Code covering the type of wiring method used and limited to the following methods: (1) open wiring on insulators; (2) rigid metal conduit; (3) intermediate metal conduit; (4) electrical metallic tubing; (5) service-entrance cables; (6) wireways; (7) busways; (8) auxiliary gutters; (9) rigid nonmetallic conduit; (10) cablebus; (11) Type MC cable; or (12) mineral-insulated metal-sheathed cable.

Commentary:

By NEC definition:

Service conductors are "the supply conductors that extend from the street main or from transformers to the service equipment of the premises supplied". Assuming the modules/panels are considered the service, any wiring extending from the module/panel to the service equipment could be considered a service entrance conductor. If the wiring from the modules/panels is bussed to a central box or conductor, the final conductor(s) entering the residence could be considered the service entrance conductor. If the PV system wiring is internal to the residence, as with an integral mount, is the conductor leading to the service equipment considered a service entrance conductor? A formal interpretation or code addition will be required to clarify the situation.

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.

230-54 CONNECTIONS AT SERVICE HEAD

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

(b) 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 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 from the point of attachment.

(d) Service cables shall be held securely in place by connection to service-drop conductors below the gooseneck or by a fitting approved for the purpose.

(e) Service heads shall have conductors of opposite polarity brought out through separately bushed holes.

(f) 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) Service-drop conductors and service-entrance conductors shall be arranged so that water will not enter service raceway or equipment.

Most areas require service raceways and service cables to be equipped with a raintight service weather head. Service (SE) cables, however, may be continuous from utility pole to metering or service equipment or, where shaped in a downward direction or "gooseneck" and sealed by taping and painting, may be used without a service head. See Figure 230-4.

Wherever practical, service heads and goosenecks are to be located above the service-drop attachment. Individual conductors should extend in a downward direction, as shown in Figure 230-4, or drip loops are to be formed.

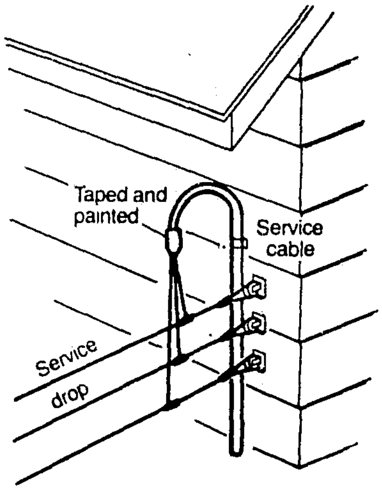


Figure 230-4. A service-entrance cable that terminates in a "gooseneck" without a raintight service weather head.

Figure 230-4. A service-entrance cable that terminates in a "gooseneck" without a raintight service weather head.

ARTICLE 240 - OVERCURRENT PROTECTION

Commentary:

The assumption is that any overcurrent device used will not be a necessary part of the array. Maximum output can be predicted, therefore overcurrent should not be a problem.

ARTICLE 250 - GROUNDING

A. General

250-1 SCOPE

This article covers general requirements for grounding and bonding of electrical installations, and specific requirements in (a) through (g) below.

(a) Systems, circuits, and equipment required, permitted, or not permitted to be grounded.

(b) Circuit conductor to be grounded on grounded systems.

(c) Location of grounding connections.

(d) Types and sizes of grounding and bonding conductors and electrodes.

(e) Methods of grounding and bonding.

(f) Conditions under which guards, isolation, or insulation may be substituted for grounding.

(g) Connections for lightning arresters.

Systems and circuit conductors are grounded to limit voltages due to lightning, line surges, or unintentional contact with higher voltage lines, and to stabilize the voltage to ground during normal operation. Systems and circuit conductors are solidly grounded to facilitate overcurrent device operation in case of ground faults.

Conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, are grounded to limit the voltage to ground on these materials and to facilitate overcurrent device operation in case of ground faults. See Section 110-10.

Commentary:

This article is very important as most of it applies to the RPM. Of particular importance are items (a), through (f). Item (g), "Connection of Lightning Arrestors" was not reviewed as it is considered a system problem.

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 form 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.

(b) Three-Wire Direct-Current Systems. The neutral conductor of all 3-wire DC systems supplying premises wiring shall be grounded.

Commentary:

Grounding and grounded conductors are defined in Article 100.

Exceptions #2 and #3 of 250-3 require explanation. The 50 volt exception is easily understood. Low voltage means lower safety hazard. The 300 volt exception is not so easily understood, and has been the subject of minor *controversy within the NEC Code committees. It is a hold over from the late 40's and early 50's when DC was available in some cities. At that time, equipment that operated on 300 volts was limited to permanent equipment such as overhead cranes. The equipment was grounded but the system was not. The 300 volt exception should not be expected to stay in effect.*

250-22 POINT OF CONNECTION FOR DIRECT-CURRENT SYSTEMS

DC systems to be grounded shall have the grounding connection made at one or more supply stations. A grounding connection shall not be made at individual services nor at any point on premises wiring.

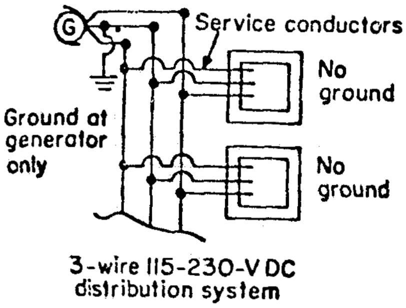


Figure 250-3. The neutral is shown grounded at the generator site in this 3-wire DC distribution system. Grounding of a 2-wire DC system would be accomplished in the same manner.

Commentary:

One reason suggested by NEC Committee member C. L. Pittman for the "point-of-connection" requirement of not grounding at individual services is because of underground water line corrosion problems that are believed to be caused by earth currents. Pipe corrosion was frequently a problem with electrically driven trolleys which used the rail as the grounded conductor.

The severity of this corrosion problem has not been verified; it would obviously be dependent on the magnitude of the earth current involved. Relative to PV residential application, which would typically use the water supply line for the grounding conductor, the point of connection may or may not be important. Relative to the design of the PV module/panel the systems grounding requirements have no effect.

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, 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.

Commentary:
RPM frames are likely to be used for protection of conductors and/or cable. Assuming the frames are defined as enclosures, grounding is required.

E. Equipment Grounding

Commentary:
Sections E, F & G (Equipment Grounding, Methods of Grounding, and Bonding) are the basis for bonding and grounding requirements used throughout the Code. These three sections are also referenced in Article 545 (See Commentary following Section 110-8).

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) Where within 8 feet vertically or 5 feet horizontally of ground or grounded metal objects and subject to contact by persons.

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

(c) Where in electrical contact with metal.

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

(e) 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) 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 devices, 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 above ground or grade level.

Commentary:

In reference to item (d), Articles 500 through 503 cover the requirements for locations where fire or explosion hazards may exist. Other articles cover special occupancies which do not apply to the RPM.

250-43 EQUIPMENT FASTENED IN PLACE BY PERMANENT WIRING METHODS (FIXED) SPECIFIC

Exposed, noncurrent-carrying metal parts of the kinds of equipment described in (a) through (j) below, regardless of voltage, shall be grounded.

(a) Switchboard frames and structures supporting switching equipment.

Exception: Frames of DC, single-polarity switchboards where effectively insulated.

(b) Generator and motor frames in an electrically operated organ.

Exception: Where the generator is effectively insulated from ground and from the motor driving it.

(c) Motor frames, as provided by Section 430-142.

(d) Enclosures for motor controllers.

Exception: Lined covers of snap switches.

(e) Electric equipment for elevators and cranes.

(f) Electric equipment in garages, theaters, and motion picture studios.

Exception: Pendant lampholders supplied by circuits not over 150 volts to ground.

(g) Electric signs and associated equipment.

Exception: Where insulated from ground and from other conductive objects and accessible only to authorized persons.

(h) Motion picture projection equipment.

(i) Lighting fixtures as provided in Part E of Article 410.

Commentary:

Based on Section 250-42 (a) the module panel shall be grounded as it is "subject to contact by persons", but exception #2 suggests that an installation detail permitting an exception for the RPM is probable. Similarly in Section 250-43 (b) with generators, exceptions are given if live parts are effectively insulated from ground.

250-44 NON-ELECTRIC EQUIPMENT

The metal parts of nonelectric equipment described in (a) through (e) below shall be grounded.

(a) Frames and tracks of electrically operated cranes.

(b) Frames of nonelectrically driven elevator cars to which electric conductors are attached.

(c) Hand-operated metal shifting ropes or cables of electric elevators.

(d) Metal partitions, grill work, and similar metal enclosures around equipment of over 750 volts between conductors except substations or vaults under the sole control of the supply company.

(e) Mobile homes and recreational vehicles as required in Articles 550 and 551.

Where extensive metal in or on buildings may become energized and is subject to personal contact, adequate bonding and grounding will provide additional safety.

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 away from lightning rod conductors, or they shall be bonded to the lightning rod conductors.

Commentary:

The first point to be addressed is whether a lightning rod will be necessary. Assuming it is, typical residential applications may not allow a six foot distance from module/panel to lightning rod, therefore if the frame is *metal and if the frame is grounded, some means of connecting the rod to the array must be available. This connection may be as simple as a ground lead fastened to the module/panel by way of a sheet metal screw. Also, the manufacturer may want to investigate a non-metallic module/panel to eliminate the grounding requirement.*

F. Methods of Grounding

Commentary:

Those sections that may apply, should grounding of the module, panel, or array become necessary, are reprinted here.

250-50 EQUIPMENT GROUNDING CONDUCTOR CONNECTIONS

Equipment grounding conductor connections at the source of separately derived systems shall be made in accordance with Section 250-26(a). Equipment grounding conductor connections at service equipment shall be made on the supply side of the service disconnecting means and shall be made as indicated in (a) or (b) below.

(a) For Grounded System. The connection shall be made by bonding the equipment grounding conductor to the grounded circuit conductor and the grounding electrode conductor.

(b) For Ungrounded System. The connection shall be made by bonding the equipment grounding conductor to the grounding electrode conductor.

Exception for (a) and (b) above: For branch-circuit extensions only in existing installations that do not have an equipment grounding conductor in the branch circuit, the grounding conductor of a grounding-type receptacle outlet shall be permitted to be grounded to a grounded cold water pipe near the equipment.

250-51 EFFECTIVE GROUNDING PATH

The path to ground from circuits, equipment, and conductor enclosures shall:

(a) Be permanent and continuous

(b) Have capacity to conduct safely any fault current likely to be imposed on it.

(c) Have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit.

Exception: A self-restoring grounding contact shall be permitted on grounding-type attachment plugs used on the power supply and of portable hand-held, hand-guided, or hand-supported tools or appliances.

(b) By means of a grounding conductor run with the power supply conductors in a cable assembly or flexible cord properly terminated in grounding-type attachment plug with one fixed grounding contact. An uninsulated grounding conductor shall be permitted but, if individually covered, the covering shall have a continuous outer finish that is either green or green with one or more yellow stripes.

Exception: A self-restoring grounding contact shall be permitted on grounding-type attachment plugs used on the power supply cord of portable hand-held, hand-guided, or hand-supported tools or appliances.

(c) By means of a separate flexible wire or strap, insulated or bare, protected as well as practicable against physical damage, where part of equipment, or by special permission.

250-57 EQUIPMENT FASTENED IN PLACE OR CONNECTED BY PERMANENT WIRING METHODS (FIXED) - GROUNDING

Noncurrent-carrying metal parts of equipment, where required to be grounded, shall be grounded by one of the methods indicated in (a), (b), or (c) below.

(a) By any of the equipment grounding conductors permitted by Section 250-91(b).

(b) By an equipment grounding conductor contained within the same raceway, cable, or cord or otherwise run with the circuit conductors. Bare, covered or insulated equipment grounding conductors shall be permitted. Individually covered or insulated grounding conductors shall have a continuous outer finish that is either green, or green with one or more yellow stripes.

Exception No. 1: An insulated conductor larger than No. 6 shall, at the time of installation, be permitted to be permanently identified as a grounding conductor at each end and at every point where the conductor is accessible. Identification shall be accomplished by one of the following:

(1) Stripping the insulation from the entire exposed length.

(2) Coloring the exposed insulation green or

(3) Marking the exposed insulation with green colored tape or green colored adhesive labels.

Excpetion No. 2: For direct-current circuits only, the equipment grounding conductor shall be permitted to be run separately from the circuit conductors.

Exception No. 3: Where the conditions of maintenance and supervision assure that only qualified persons will service the installation, an insulated conductor in a multiconductor cable shall, at the time of installation, be permitted to be permanently identified as a grounding conductor at each end and at every point where the conductor is accessible by one of the following mean:

(1) Stripping the insulation from the entire exposed length.

(2) Coloring the exposed insulation green, or

(3) Marking the exposed insulation with green tape or green colored adhesive labels.

See Section 250-79 for equipment bonding jumper requirements.

(c) By special permission, other means for grounding fixed equipment may be used.

See Section 400-7 for use of cords for fixed equipment.

250-58 EQUIPMENT CONSIDERED EFFECTIVELY GROUNDED

Under the conditions specified in (a) and (b) below, the noncurrent-carrying metal parts of the equipment shall be considered effectively grounded.

(a) Equipment Secured to Grounded Metal Supports. Electric equipment secured to and in electrical contact with a metal rack or structure provided for its support and grounded by one of the means indicated in Section 250-57. The structural metal frame of a building shall not be used as the required equipment grounding conductor for AC equipment.

250-61 USE OF GROUNDED CIRCUIT CONDUCTOR FOR GROUNDING EQUIPMENT

(a) Supply-Side Equipment. A grounded circuit conductor shall be permitted to ground noncurrent-carrying metal parts of equipment on the supply side of the service disconnecting means, such as meter enclosures, service raceways, etc., and on the supply side of the main disconnecting means of separate buildings and of separately derived systems as provided in Sections 250-24 and 250-26 respectively.

G. Bonding

Commentary:

There are two techniques for grounding: (1) using ground conductors, (2) using bonded metal frames (assumes frames are part of the module or panel). This section outlines requirements for the second technique.

250-70 GENERAL

Bonding shall be provided where necessary to assure electrical continuity and the capacity to conduct safely any fault current likely to be imposed.

250-71 BONDING SERVICE EQUIPMENT

The noncurrent-carrying metal parts of equipment indicated in (a), (b), and (c) below shall be effectively bonded together.

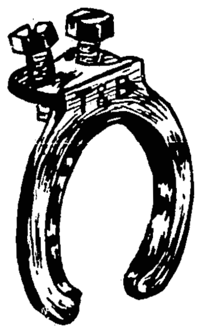
(a) Except as permitted in Section 250-55, the service raceways, cable trays, or service cable armor or sheath.

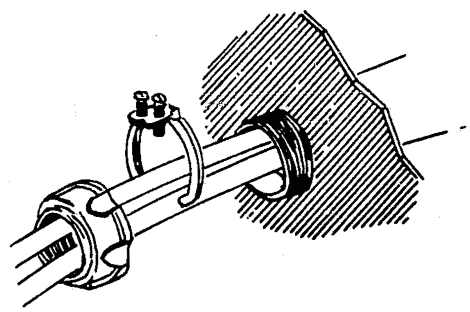
(b) All service equipment enclosures containing service-entrance conductors, including meter fittings, boxes, or the like, interposed in the service raceway or armor.

(c) Any conduit or armor enclosing a grounding electrode conductor.

250-72 METHOD OF BONDING SERVICE EQUIPMENT

Electrical continuity at service equipment shall be assured by one of the methods specified in (a) through (e) below.





Figures 250-15 and 250-16. Figure 250-15 (left) shows a grounding wedge lug for providing an electrical connection between a conduit and a box. Figure 250-16 (right) shows the manner in which the lug is installed. (The Thomas & Betts Co., Inc.)

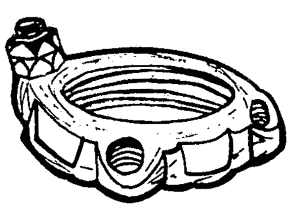


Figure 250-17. A threaded grounding bushing showing openings for set screws to assure electrical and mechanical connection. (General Electric Co.)

(a) Bonding equipment to the grounded service conductor in a manner provided in Section 250-113.

(b) Threaded couplings and threaded bosses on enclosures with joints shall be made up wrenchtight where rigid metal conduit and intermediate metal conduit are involved.

(c) Threadless couplings made up tight for rigid metal conduit, intermediate metal conduit and electrical metallic tubing.

(d) Bonding jumpers meeting the other requirements of this article. Bonding jumpers shall be used around concentric or eccentric knockouts that are punched or otherwise formed so as to impair the electrical connection to ground.

(e) Other devices, such as bonding-type locknuts and bushings, approved for the purpose.

250-75 BONDING OTHER ENCLOSURES

Metal raceways, cable armor, cable sheath, enclosures, frames, fittings, and other metal noncurrent-carrying parts that are to serve as grounding conductors shall be effectively bonded where necessary to assure electrical continuity and the capacity to conduct safely any fault current likely to be imposed on them. Any nonconductive paint, emanel, or similar coating shall be removed at threads, contact points, and contact surfaces or be connected by means of fittings so designed as to make such removal unnecessary.

Commentary:

A panel design using the metal frame as the raceway will use this technique for grounding. Wireways are further discussed in Commentary following Article 352.

250-77 BONDING LOOSELY JOINTED METAL RACEWAYS

Expansion joints and telescoping sections of raceways shall be made electrically continuous by equipment bonding jumpers or other means approved for the purpose.

250-78 BONDING IN HAZARDOUS LOCATIONS

Regardless of the voltage of the electrical system, the electrical continuity of metal noncurrent-carrying equipment in any hazardous location as defined in Article 500 of this Code shall be assured by any of the methods specified for services in Section 250-72(b) through (e) that are approved for the wiring method used.

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 Table 250-94, but the tap conductors shall be permitted to be sized in accordance with the grounding electrode conductors specified in Table 250-94 for the largest conductor serving the respective enclosures.

(b) Types of Equipment Grounding Conductors. The equipment grounding conductor run with or enclosing the circuit conductors shall be one or more or a combination of the following: (1) a copper or other corrosion-resistant conductor. This conductor shall be solid or stranded; insulated, covered, or bare; and in form of a wire or a busbar of any shape; (2) rigid metal conduit; (3) intermediate metal conduit; (4) electrical metallic tubing; (5) flexible metal conduit approved for the purpose and installed with fittings approved for the purpose; (6) armor of Type AC cable; (7) the sheath of mineral-insulated metal-sheathed cable; (8) the metallic sheath or the combined metallic sheath and grounding conductors of Type MC cable; (9) cable trays as permitted in Sections 318-2(c) and 318-6; (10) other raceways specifically approved for grounding purposes.

Exception No. 1: Flexible metal conduit and flexible metallic tubing shall be permitted for grounding if all the following conditions are met:

a. The total length in any ground return path does not exceed 6 feet.
b. The circuit conductors contained therein are protected by overcurrent devices rated at 20 amperes or less.
c. The conduit or tubing is terminated in fittings approved for the purpose.

Exception No. 2: Liquidtight flexible metal conduit shall be permitted for grounding in the 1 1/4-inch and smaller trade sizes if the total length in any ground return path does not exceed 6 feet and the conduit is terminated in fittings approved for the purpose.

Exception No. 3: For direct-current circuits only, the equipment grounding conductor shall be permitted to be run separately from the circuit conductors.

(c) Supplementary Grounding. Supplementary grounding electrodes shall be permitted to augment the equipment grounding conductors specified in Section 250-91 (b), but the earth shall not be used as the sole equipment grounding conductor.

250-92 INSTALLATION

Grounding conductors shall be as specified in (a) and (b) below.

(a) Grounding Electrode Conductor. A grounding electrode conductor or its enclosure shall be securely fastened to the surface on which it is carried. A No. 4 or larger conductor shall be protected if exposed to severe physical damage. A No. 6 grounding conductor that is free from exposure to physical damage shall be permitted to be run along the surface of the building construction without metal covering or protection where it is rigidly stapled to the construction; otherwise, it shall be in rigid metal conduit, intermediate metal conduit, electrical metallic tubing, or cable armor. Grounding conductors smaller than No. 6 shall be in rigid metal conduit, intermediate metal conduit, electrical metallic tubing, or cable armor.

Metal enclosures for grounding conductors shall be electrically continuous from the point of attachment to cabinets or equipment to the grounding electrode, and shall be securely fastened to the ground clamp or fitting. Metal enclosures that are not physically continuous from cabinet or equipment to the grounding electrode shall be made electrically continuous by bonding each end to the grounding conductor. Where intermediate metal conduit is used for protection for a grounding conductor, the installation shall comply with the requirements of Article 345. Where rigid metal conduit is used as protection for a grounding conductor, the installation shall comply with the requirements of Article 346. Where electrical metallic tubing is used, the installation shall comply with the requirements of Article 348.

Aluminum or copper-clad aluminum grounding conductors shall not be used where in direct contact with masonry or the earth or where subject to corrosive conditions. Where used outside, aluminum or copper-clad aluminum grounding conductors shall not be installed within 18 inches of the earth.

(b) Equipment Grounding Conductor. An equipment grounding conductor shall be installed as follows:

(1) Where it consists of a raceway, cable tray, cable armor, or cable sheath or where it is a wire within a raceway or cable, it shall be installed in accordance with the applicable provisions in this Code using fittings for joints and teminations approved for use with the type raceway or cable used. All connections, joints, and fittings shall be made tight using suitable tools.

(2) Where it is a separate grounding conductor as provided in Section 210-7 or by special permission as provided in Section 250-57(c), it shall be installed in accordance with (a) above in regard to restrictions for aluminum and also in regard to protection from physical damage.

Exception: Sizes smaller than No. 6 shall not be required to be enclosed in a raceway or armor where run in the hollow spaces of a wall or partition or where otherwise installed so as not to be subject to physical damage.

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) 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) 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) In no case shall the grounding conductor be smaller than No. 8.

250-94 SIZE OF ALTERNATING-CURRENT GROUNDING ELECTRODE CONDUCTOR

The size of the grounding electrode conductor of a grounded or ungrounded AC system shall not be less than given in Table 250-94.

Exception No. 1: Grounded Systems. Where connected to made electrodes (as in Sdction 250-83), that portion of the grounding electrode conductor which is the sole connection between the grounding electrode and the grounded system conductor shall not be required to be larger than No. 6 copper wire or its equivalent in ampacity.

Exception No. 2: Ungrounded Systems. Where connected to made electrodes (as in Section 250-83), that portion of the grounding conductor which is the sole connection between the grounding electrode and the service equipment shall not be required to be larger than No. 6 copper wire or its equivalent in ampacity.

250-95 SIZE OF EQUIPMENT GROUNDING CONDUCTORS

The size of copper, aluminum, or copper-clad aluminum equipment grounding conductors shall not be less than given in Table 250-95.

Where conductors are run in parallel in multiple raceways, as permitted in Section 310-4, the equipment grounding conductor, where used, shall be run in parallel. Each parallel equipment grounding conductor shall be sized on the basis of the ampere rating of the overcurrent device protecting the circuit conductors in the raceway in accordance with Table 250-95.

When conductors are adjusted in size to compensate for voltage drop, grounding conductors, where required, shall be adjusted proportionately in size.

Exception No. 1: An equipment grounding conductor not smaller than No. 18 copper and not smaller than the circuit conductors if an integral part of a listed flexible cord assembly shall be permitted for grounding cord-connected equipment where the equipment is protected by overcurrent devices not exceeding 20-ampere rating.

Exception No. 2: The equipment grounding conductor shall not be required to be larger than the circuit conductors supplying the equipment.

Exception No. 3: Where a raceway or a cable armor or sheath is used as the equipment grounding conductor, as provided in Sections 250-57(a) and 250-91(b).

250-97 OUTLINE LIGHTING

Isolated noncurrent-carrying metal parts of outline lighting systems shall be permitted to be bonded together by a No. 14 conductor protected from physical damage, where a conductor complying with Section 250-95 is used to ground the group.

250-98 GROUNDING CONDUCTOR IN COMMON RACEWAY

A grounding conductor shall be permitted in the same raceway or enclosure with other conductors of the system to which it is connected.

250-99 GROUNDING CONDUCTOR CONTINUITY

(a) Separable Connections. Separable connections such as those provided in draw-out equipment or attachment plugs and mating connectors and receptacles shall provide for first-make, last-break of the equipment grounding conductor.

Exception: Interlocked equipment, plugs, receptacles and connectors which preclude energization without grounding continuity.

(b) Switches. No automatic cutout or switch shall be placed in the grounding conductor of a premises wiring system.

Exception: Where the opening of the cutout or switch disconnects all sources of energy.

K. Grounding Conductor Connections

Commentary:

This section will give the manufacturer some idea of typical grounding connections approved by the NEC. Portions pertaining to the RPM are reprinted.

250-111 TO RACEWAY OR CABLE ARMOR

The point of connection of the grounding conductor to interior metal raceways, cable armor, and the like shall be as near as practicable to the source of supply and shall be so chosen that no raceway or cable armor is grounded through a run of smaller size than is called for in Section 250-95.

TABLE 250-95
MINIMUM SIZE GROUNDING CONDUCTORS FOR GROUNDING RACEWAY AND EQUIPMENT

Rating or Setting of Automatic Overcurrent Device In Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size	
	Copper Wire No.	Aluminum or Copper-Clad Aluminum Wire No.
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6
200	6	4
400	3	1
600	1	2/0
800	0	3/0
1000	2/0	4/0
1200	3/0	250 MCM
1600	4/0	350 MCM
2000	250 MCM	400 MCM
2500	350 MCM	600 MCM
3000	400 MCM	600 MCM
4000	500 MCM	800 MCM
5000	700 MCM	1200 MCM
6000	800 MCM	1200 MCM

250-112 TO GROUNDING ELECTRODE

The connection of a grounding electrode conductor to a grounding electrode shall be accessible and made in a manner that will assure a permanent and effective ground. Where necessary to assure this for a metal piping system used as a grounding electrode, effective bonding shall be provided around insulated joints and sections and around any equipment that is likely to be disconnected for repairs or replacement.

Exception: A connection to a concrete encased, driven, or buried grounding electrode shall not be required to be accessible.

250-113 TO CONDUCTORS AND EQUIPMENT

Required grounding conductors and bonding jumpers shall be connected by pressure connectors, clamps, or other approved means. Connection devices or fittings that depend on solder shall not be used.

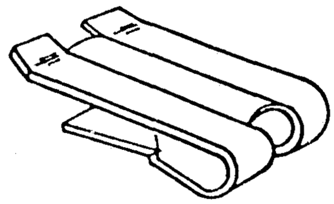


Figure 250-23. A clip used to connect a copper grounding conductor to a box.

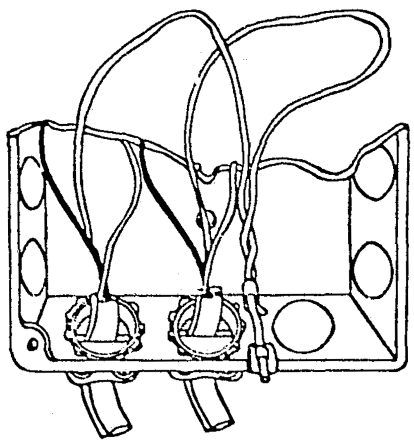


Figure 250-24. An application of a grounding clip.

250-114 CONTINUITY AND ATTACHMENT OF BRANCH-CIRCUIT EQUIPMENT GROUNDING CONDUCTORS TO BOXES

Where more than one equipment grounding conductor of a branch circuit enters a box, all such conductors shall be in good electrical contact with each other and the arrangement shall be such that the disconnection or removal of a receptacle, fixture, or other device fed from the box will not interfere with or interrupt the grounding continuity.

(a) Metal Boxes. A connection shall be made between the one or more equipment grounding conductors and a metal box by means of a grounding screw which shall be used for no other purpose, or an approved grounding device.

(b) Nonmetallic Boxes. One or more equipment grounding conductors brought into a nonmetallic outlet box shall be so arranged that a connection can be made to any fitting or device in that box requiring grounding.

250-115 CONNECTION TO ELECTRODES

The grounding conductor shall be connected to the grounding fittings by suitable lugs, pressure connectors, clamps, or other approved means. Connections depending on solder shall not be used. Ground clamps shall be suitable for the materials of the grounding electrode and the grounding electrode conductor. Not more than one conductor shall be connected to the grounding electrode by a single clamp or fitting unless the clamp or fitting is approved for the use. One of the methods indicated in (a), (b), (c), or (d) below shall be used.

(a) An approved bolted clamp of cast bronze or brass or plain or malleable iron.

(b) A pipe fitting, pipe plug, or other approved device screwed into a pipe or pipe fitting.

(c) A sheet-metal-strap type ground clamp having a rigid metal base that seats on the electrode and having a strap of such material and dimensions that it is not likely to stretch during or after installation.

(d) An equally substantial approved means.

250-117 PROTECTION OF ATTACHMENT

Ground clamps or other fittings shall be approved for general use without protection or shall be protected from ordinary physical damage as indicated in (a) or (b) below.

(a) Installations where they are not likely to be damaged.

(b) Enclosing in metal, wood, or equivalent protective covering.

250-118 CLEAN SURFACES

Nonconductive coatings (such as paint, lacquer, and enamel) on equipment to be grounded shall be removed from threads and other contact surfaces to assure good electrical continuity.

CHAPTER THREE - WIRING METHODS AND MATERIALS

Commentary:

Chapter Three includes: 1) generally applicable wiring requirements such as voltage limitations and protection requirements; 2) conductor requirements such as description, insulation, and ampacity rating; and 3) approved wiring systems such as Open Wire on Insulators and Nonmetallic Sheathed Cable.

Wiring systems can be generally classified as either insulated conductors or cable. Insulated conductors can be: 1) wired in an exposed system if placed on insulators -- this is called Open Wire on Insulators and is described in Article 320; 2) wired in a concealed system using segments of flexible tubing and insulators for protection -- this is called Concealed

Knob and Tube and is described in Article 324; and 3) used with conduit, wireways, or some other protective means. Approved conduit systems are described in Articles 346 through 352. Cable incorporates a protective sheathing that usually eliminates the need for conduit or wireways. Approved cable systems are given in Articles 326, through 340. Article 328 Flat Conductor Cable (FCC) has recently been added as an approved wiring system under a Tentative Interim Amendment. (TIA is explained in commentary following 90-5.) FCC however, is not approved for residential applications. See Article 328 for further discussion.

If the photovoltaic system is intended for immediate residential application, the wiring systems of Chapter Three or an approved adaptation of a modular building system should be used.

Assuming the manufacturer chooses to develop the modular concept (for example,a plug-in quick connect terminal and pre-wired cable with receptacles), the electrical system must be designed to meet the requirements of Article 545 -Manufactured Building. All the wiring methods of Chapter Three and "wiring systems specifically intended and approved for use in manufactured building," are approved for use in manufactured or modular building.

The repercussions of Article 545 relative to the emerging residential photovoltaic industry are great. It allows the development of a pre-engineered factory fabricated system requiring only plug-in type electrical connections at the site, minimizing labor and material costs. See Article 545 for further discussion.

It must be understood that future development of the module, panel, or array should not be limited to the wiring methods currently approved for use in residences. Based on unofficial conversations with NEC committee members, it can be assumed that new wiring methods will be recognized as long as they are engineered with safety in mind. Should new technologies develop which might reduce costs or simplify installations, testing laboratories and/or Code officials should be contacted for guidance toward expediant acceptance into electrical codes and standards.

However, testing laboratory approval and NEC approval do require time even with guidance. For example, a consortium of flat conductor cable manufacturers initiated a UL Fact Finding Investigation in 1975 into the feasibility of using their products as a wiring system in buildings. The Fact Finding Investigation, which lasted approximately one year, was the first step toward NEC approval. The cable has been approved for limited applications and is included in the 1978 NEC as a Tentative Interim Amendment. A proposal for code revision is to be published in August 1979 after which it is to be released for public review through November 9, 1979. Following Code-Making Panels review, Correlating Committee Review, and Technical Committee Documentation, the Amendment <u>*may*</u> *become an Article in the 1981 Code.*

ARTICLE 300 - WIRING METHODS

300-1 SCOPE

(a) The provisions of this article shall apply to all wiring installations.

Exception No. 1: Only those sections referenced in Article 725 shall apply to Class 1, Class 2, and Class 3 circuits.

Exception No. 2: Only those sections referenced in Article 760 shall apply to fire protective signaling circuits.

Exception No. 3: Only those sections referenced in Article 800 shall apply to communication systems.

(b) The provisions of this article are not intended to apply to the conductors which form an integral part of equipment, such as motors, controllers, motor control centers, or factory-assembled control equipment.

Commentary:

Of those exceptions listed above, only Exception No. 1 could apply to the PV module; it references Article 725. Article 725 covers Class 1, Class 2, and Class 3 Remote-control, Signaling, and Power-Limited Circuits. Class 1 circuits are defined as circuits supplied from sources having a rated output of not more than 30 volts and 1000 volt-amperes. Class 2 and 3 DC circuits are limited to 150 volts and 0.75 volt-amperes.

Only a module/panel or group of modules/panels operating at not more than 30 volts with a rated output of not more than 1000 watts could fit the NEC definition for power limited circuits. The only advantage to this is that wire sizes as small as #18 AWG can be used rather than the #14 AWG limit of Article 310 for general use conductors.

300-2 VOLTAGE LIMITATIONS

Wiring methods specified in Chapter 3 shall be used for voltages not exceeding 600 where not specifically limited in some section of Chapter 3. The shall be permitted for voltages over 600 where specifically permitted elsewhere in this Code.

300-4 PROTECTION AGAINST PHYSICAL DAMAGE

Where subject to physical damage, conductors shall be adequately protected.

(a) Cables Through Wood Framing Members

(1) Bored Holes. In both exposed and concealed locations, where a cable or raceway-type wiring method is installed through bored holes in joists, rafters, or similar structural wood members, holes shall be bored at the approximate center of the face of the member. Holes in studs for cable-type wiring methods shall be bored so that the edge of the hole is not less than 1 1/4 inches from the nearest edge of the stud or shall be protected from nails and screws by either a steel plate or bushing at least 1/16 inch thick and of appropriate length and width installed to cover the area through which nails or screws might penetrate the installed cable.

The intent of this section is to prevent wallboard nails from being driven into cables. By keeping the edge of the drilled hole 1 1/4 inch from the nearest edge of the stud, most wallboard nails would not penetrate the stud far enough to injure the cables. The model building codes provide maximum requirements for bored or notched holes in studs and Paragraph (a)(2) indicates that consideration should be given to the size of notches in studs so as not to affect the strength of the structure.

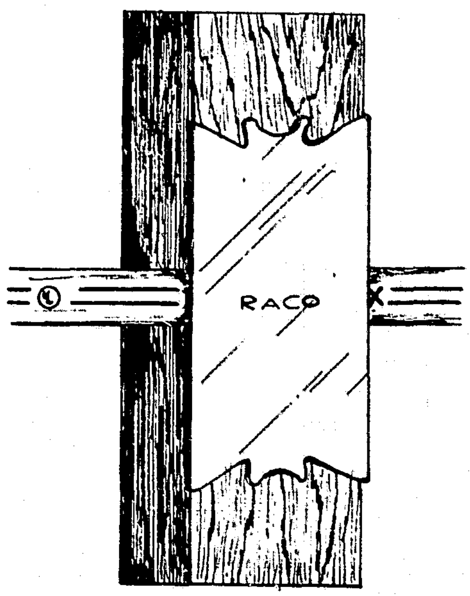


Figure 300-1. Steel plate to protect nonmetallic-sheathed cables within 1 1/4-inch of the edge of a stud. (RACO)

(2) Notches in Wood. Where there is no objection because of weakening the building structure, in both exposed and concealed locations, cables shall be permitted to be laid in notches in wood studs, joists, rafters or other wood members where the cable at those points is protected against nails or screws by a steel plate at least 1/16 inch thick installed before the building finish is applied.

(b) Cables Through Metal Framing Members. In both exposed and concealed locations where nonmetallic-sheathed cables pass through either factory or field punched, cut or drilled slots or holes in metal members, the cable shall be protected by bushings or grommets approved for the purpose securely fastened in the opening. Where nails or screws are likely to penetrate the cable, a steel sleeve, steel plate or steel clip not less than 1/16 inch in wall thickness shall be used to protect the nonmetallic cable.

Exception: When the slots or holes are so formed that no metal edge can cut or tear cable insulation, bushings or grommets shall not be required.

Commentary:

Adequate protection is generally dependent on the wiring system; for example, sheathed cable or insulated conductors in conduit. Insulated conductors for general wiring require conduit for protection unless an open wire on insulators or a knob and tube wiring system is used.

Metallic and nonmetallic conduit in addition to providing protection to conductors, also, protect surroundings against fire hazard that may result from over heating or arcing at the enclosed conductors, and serve to support the conductors. Metal conduit can provide a grounded enclosure to prevent shock hazard and can provide a system ground path eliminating the need for a grounding conductor.

Cable wiring systems, in general, have a metallic or PVC sheathing that protects against damage to conductors.

In very hazardous areas, other protective means such as enclosures or guard strips must be used.

300-15 BOXES OR FITTINGS - WHERE REQUIRED

(a) Box or Fitting. A box or fitting shall be installed at each conductor splice connection point, outlet, switch point, junction point, or pull point for the connection of conduit, electrical metallic tubing, surface raceway, or other raceways

Exception No. 1: A box or fitting shall not be required for a conductor splice connection in surface raceways, wireways, header-ducts, multi-outlet assemblies, and auxiliary gutters, cable trays and conduit bodies having removable covers which are accessible after installation.

Conduit bodies (Types "T", "L", etc.) are a part of the conduit or tubing system and should not contain more conductors than permitted for the raceway. Conduit bodies having providions for less than three conduit entries are not to contain splices, taps, or devices unless they are durably and legibly marked with their cubic inch capacity and the maximum number of conductors that is permitted to be enclosed is to be computed as per Table 370-6(b). See Sections 370-6(b) and 370-6(c).

For the use of conductors No. 4 or larger, see Section 370-18(a).

Exception No. 2: As permitted in Section 410-31 where a fixture approved for the purpose is used as a raceway.

Commentary:

This is a very critical electrical requirement. It states that all connections and splices must be protected and must be accessible after installation. It also implys that no wire shall be spliced or connected and then drawn into conduit or racewqy so that the connection is inaccessible.

As mentioned in the commentary following Section 110-14, it was determined from the Terminal Study that a quick connect terminal would be the most economical for the panel/array branch circuit connection. Based on the NEC definition for fittings, "an accessory such as a lock nut, bushing, or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function", the quick connect design appears to meet 110-14 requirements and can replace the junction box.

(b) Box Only. A box shall be installed at each conductor splice connection point, outlet, switch point, junction point, or pull point for the connection of Type AC cable, Type MC cable, mineral-insulated metal-sheathed cable, nonmetallic-sheathed cable, or other cables, at the connection point between any such cable system and a raceway system and at each outlet and switch point for concealed knob-and-tube wiring.

Exception No. 1: As permitted by Section 336-11 for insulated outlet devices supplied by nonmetallic-sheathed cable.

Exception No. 2: As permitted by Section 410-62 for rosettes.

Exception No. 3: Where accessible fittings approved for the purpose are used for straight-through splices in mineral-insulated metal-sheathed cable.

Exception No. 4: Where cables enter or exit from conduit or tubing which is used to provide cable support or protection against physical damage.

Exception No. 4 was inserted in the Code to permit conduit or tubing to be used as support and protection against physical damage without terminating in a box at such places as boilers or furnaces where nonmetallic-sheathed cables would dangle in free air for 5 or 6 ft. This Exception also permits conduit or tubing to be used as physical protection for underground cables exiting from buildings or outdoors on poles, without a box being required on the end of the conduit.

Exception No. 5: Wiring devices with integral enclosures approved for the purpose, having brackets that securely fasten the device in walls or ceilings of frame construction for use with nonmetallic-sheathed cable, shall be permitted without a separate box.

See Sections 336-5, Exception No. 2, 336-11, 545-10, and 551-15(a) Exception.

Commentary:

The wiring devices described in Exception No. 5 are similar in concept to the quick connect.

ARTICLE 310 - CONDUCTORS FOR GENERAL WIRING

Commentary:

Article 310 is divided into three parts - general requirements, conductors 600 volts or less, and conductors 600 volts or more.

All of this article except that dealing with 600 volts or more relates directly to residential PV array. Only those sections requiring comment are reprinted here.

This article covers general use conductors. Conductors and cable systems developed to meet specific needs are covered in separate Articles that explain their particular installation requirements.

510-1 SCOPE

This article covers general requirements for conductors and their type designations, insulations, markings, mechanical strengths, ampacity ratings, and uses. These requirements do not apply to conductors that form an integral part of equipment, such as motors, motor controllers, and similar equipment, or to conductors specifically provided for elsewhere in this Code.

For flexible cords and cables, see Article 400. For fixture wires, see Article 402.

510-5 MINIMUM SIZE OF CONDUCTORS

Whether solid or stranded, conductors shall not be smaller than No. 14 copper or No. 12 aluminum or copper-clad aluminum.

Exception No. 1: For flexible cords as permitted by Section 400-12.

Exception No. 2: For fixture wire as permitted by Section 410-23.

Exception No. 3: For fractional hp motors as permitted by Section 430-22.

Exception No. 4: For cranes and hoists as permitted by Section 610-14.

Exception No. 5: For elevator control and signaling circuits as permitted by Section 620-12.

Exception No. 6: For Class 1, Class 2 and Class 3 circuits as permitted by Sections 725-16, 725-37, and 725-40.

Exception No. 7: For fire protective signaling circuits as permitted by Sections 760-16, 760-27, and 760-30.

Commentary:

Note first that these requirements do not apply to conductors that form an integral part of the module.

Of the exceptions listed following the minimum size requirements, only Exception No. 2 can apply to the module or array. See Article 410 for further explanation.

510-7 WET LOCATIONS

(a) Insulated Conductors. Insulated conductors used in wet locations shall be (1) lead-covered; (2) Types RHW, RUW, TW, THW, THWN, XHHW; or (3) of a type approved for the purpose.

(b) Cables. Cables of one or more conductors used in wet locations shall be of a type approved for the purpose and use.

Such conductors shall not be used for direct burial in the earth unless of a type approved for the purpose.

310-8 CORROSIVE CONDITIONS

Conductors exposed to oils, greases, vapors, gases, fumes, liquids, or other substances having a deleterious effect upon the conductor or insulation shall be of a type approved for the purpose.

Commentary:

All conductors used in rack and stand off mounting types must be approved for wet locations unless they are protected by waterproof enclosures.

Conduit is available that is approved for both dry or wet locations. Those approved for wet locations are either galvanized steel, aluminum, or PVC. Those approved for indoors are either enamel coated metal, steel, or non-metallic (PVC). Approved conduit types are described in Articles 345 through 352.

Cables approved for wet locations are covered in Articles 330 and 339. Corrosive protection is not required for a typical residential installation, however, an integral mount array over a battery storage area is a conceivable design which would require insulated conductors in conduit or cable approved for that purpose.

310-9 TEMPERATURE LIMITATION OF CONDUCTORS

No conductor shall be used in such a manner that its operating temperature will exceed that designated for the type of insulated conductor involved. In no case shall conductors be associated together in such a way with respect to type of circuit, the wiring method employed, or the number of conductors that the limiting temperature of any conductor is exceeded.

Most terminations are designed only for 60°C or 75°C maximum temperatures; therefore, the higher rated ampacities for conductors of 90°C, 110°C, etc., cannot be utilized unless the terminations have comparable ratings.

Tables 310-16 through 310-19 have correction factor tables for ambient temperatures that exceed 30°C (86°F). To assign the proper allowable load current to a conductor in an ambient above 30°C, the appropriate correction factors must be used to determine the maximum allowable load permitted on any given conductor.

Example: A No. 2 TW copper conductor is to be installed in a raceway in an ambient temperature of 50°C. According to Table 310-16, the ampacity of the conductor is 95 A which is multiplied by 0.58 (taken from the correction factors at the bottom of the table); thus the maximum allowable load current of the No. 2 conductor is reduced to 55.1 A (95 A x 0.58 = 55.1 A).

If six of these conductors were run in a raceway, Note 8 to the Tables would require the maximum allowable load current to be reduced to 80 percent, which, in this case, would be 55.1 A x 0.8 = 44.08 A. Under these conditions the No. 2 conductor would be suitable for a 40 A circuit.

The basis for determining the ampacities of conductors for Tables 310-16 through 310-19 was the "NEMA Report of Determination of Maximum Permissible Current-Carrying Capacity of Code Insulated Wires and Cables for Building Purposes" dated June 27, 1938.

The temperature rating of a conductor (see Table 310-13) is the maximum temperature, at any location along its length, that the conductor can withstand over a prolonged time period without serious degradation. The principal determinants of operating temperatue are (1) the ambient temperature (which may vary along the length as well as from time to time), (2) the heat generated internally by load current flow, and (3) the rate at which the internally generated heat dissipates into the ambient medium (air, earth, etc.). Cognizance must also be taken of adjacent load-carrying conductors which will both raise the temperature of the conductors and partially impede dissipation of heat.

Conductors that have a rating above the anticipated maximum ambient termperature should be chosen. The operating temperature of conductors should be controlled at or below its rating by coordinating conductor size, number of associated conductors, and allowable load current for the particular conductor rating and ambient temperature. Tables 310-17 and 310-19 give ampacities, or allowable load currents, for isolated conductors (not in contact with other conductors). Tables 310-16 and 310-18 give ampacities where up to three conductors are closely associated (in contact). All tabulations are based on a 30°C ambient temperature condition and should be corrected for the anticipated ambient using the correction factors at the bottom of the tables. Where more than three conductors are associated together, the additional correction given in Note 8 to the Tables is to be applied.

Commentary:

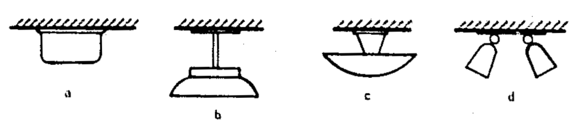
Operating temperature of the module, panel, and array wiring must be known to safely size the conductors. Those parameters most important in determining operating temperature are module design characteristics (e.g., NOCT or some other measure), panel wiring details (e.g., prewired raceways in metal conduit or exposed wiring), array wiring method (e.g., wiring exposed to vented attic space or concealed between the panel and roof), and mounting detail (e.g., integral over a vented attic space or stand off with allowance for free air movement).

UL TABLE 1

MINIMUM TEMPERATURE RATING OF WIRING

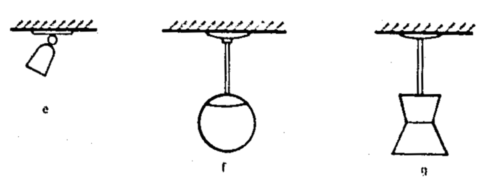
Type of Fixture	Position of Lamp Base	°C	°F
Ceiling-mounted, enclosed (a) glass fitter (b), dropped-glass (c), single-or multiple-bullet shade types (d or e)	Any	150	302
Suspended, enclosed lamp	Up, or horizontal	150	302
Suspended, enclosed lamp (f)	Down	90	194
Suspended, open lamp (g)	Up, or horizontal	90	194
Suspended, open lamp (g)	Down	60	140
Wall Bracket, open or enclosed lamp (h)	Up, or horizontal	90	194
Wall Bracket, enclosed lamp (i)	Down	90	194
Wall Bracket, open lamp (k)	Down	60	140

UL FIGURE 1



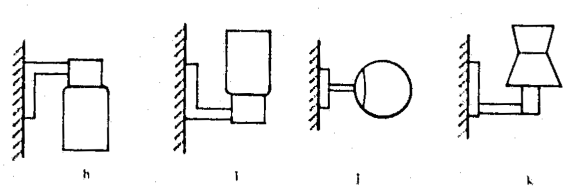
CEILING-MOUNTED FIXTURES

(a) Enclosed lamp. (b) Glass fitter. (c) Dropped-glass (semi-flush).
(d) Multiple bullet shade (e) Single bullet shade



STEM-SUSPENDED FIXTURES

(f) Enclosed lamp (g) Open lamp



WALL-BRACKET FIXTURES

(h) Enclosed lamp (base up) (i) Enclosed lamp (base down) (j) Enclosed lamp (base horizontal) (k) Open lamp (base down)

Standards for module designs and mounting details will probably be established by an independent testing laboratory, such as UL. As an example of what these standards might look like, minimum temperature ratings for wiring used in lighting fixtures, reprinted from UL Standard 57, are given in UL Table 1 and UL Figure 1. A similar table using different parameters is likely for residential photovoltaics.

310-10 CONDUCTOR INDENTIFICATION & MARKING

Commentary:
Conductor Identification and Marking requirements should not be a consideration of the module manufacturer - this should all be handled by the wiring manufacturer.

310-12 CONDUCTOR APPLICATION

Insulated conductors listed in Table 310-13 shall be permitted for use with any of the wiring methods recognized by Chapter 3 as specific in the table.

Thermoplastic insulation may stiffen at temperatures colder than minus 10°C (plus 14°F), requiring care be exercised during installation at such temperatures. Thermoplastic insulation may also be deformed at normal temperatures where subjected to pressure, requiring care be exercised during installation and at points of support.

310-13 CONDUCTOR CONSTRUCTION

Insulated conductors for use at 600 volts or less shall comply with Table 310-13.

Table 310-13 lists the various types of insulated conductors as covered by the requirements of this Code. More detailed wire classification information from sizes Nos. 14 through 2,000 MCM may be obtained from standards or directories, such as those published by the Underwriters Laboratories Inc.

Table 310-13 also includes conductor applications and maximum operating temperature. Some conductors have dual ratings, such as Type XHHW, rated 90°C for dry locations and 75°C for wet locations; or, Type THW, 75°C for dry and wet locations and 90°C for special applications within electric-discharge lighting equipment. In no case are conductors to be associated together in such a way, with respect to type of circuit, the wiring method employed, or the number of conductors, that the limiting temperature of any conductor is exceeded (see Section 310-9). Most terminals of wiring devices, switches, and panelboards have not been tested for use with conductors whose maximum insulation temperature exceeds 75°C.

The maximum continuous ampacities for copper, copper-clad aluminum, and aluminum are listed in Tables 310-16 through 310-19 and accompanying Notes 1 through 12.

310-15 AMPACITY

The maximum continuous ampacities for copper, aluminum, and copper-clad aluminum conductors shall be as specified in Tables 310-16 through 310-19 and accompanying Notes 1 through 12.

Commentary:

Table 310-13 is not reprinted in this report. A complete listing of wires and wire classification information is available from UL and wire manufacturers. NEC Allowable Ampacity Tables and Notes are reprinted on the following pages.

ARTICLE 320 - OPEN WIRING ON INSULATORS

320-1 DEFINITION

Open wiring on insulators is an exposed wiring method using cleats, knobs, tubes, and flexible tubing for the protection and support of single insulated conductors run in or on buildings, and not concealed by the building structure.

Open wiring on insulators is an exposed wiring method and is not to be concealed by the structure or finish of the building. It is permitted indoors or outdoors, in dry or wet locations, and where subject to corrosive vapors. Open wiring may be any of the general-use conductors listed in Table 310-13, such as Types TH, T, TW, XHHW; the selection, of course, is dependent upon whether the location is wet or dry, temperature considerations, ampacities, etc.

This method of wiring may be used for transformer hook-ups in vaults or at substations, temporary lighting and power circuits on construction sites, lighting and power circuits in agricultural buildings, and services, and is commonly used for feeders in industrial locations. See Section 305-2, 547-3, 230-43, and Article 710.

320-3 USES PERMITTED

Open wiring on insulators shall be permitted on systems of 600 volts, nominal or less for industrial or agricultural establishments, indoors or outdoors, in wet or dry locations, where subject to corrosive vapors, and for services.

Commentary:

Open wire on insulators is not allowed for residential applications. Although the NEC Article does not specifically state this, conversations with Code Committee member A. P. Haggerty, and several Pittsburgh area electrical inspectors verifys that approval of open wire on insulators is for agricultural and industrial establishments only.

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310-15. Ampacity. The maximum continuous ampacities for copper, aluminum and copper-clad aluminum conductors shall be as specified in Tables 310-16 through 310-19 and accompanying Notes 1 through 14.

Table 310-16.
Allowable Ampacities of Insulated Copper Conductors

Not More than Three Conductors in Raceway or Cable or Direct Burial (Based on Ambient Temperature of 30°C, 86°F.)

Size AWG MCM	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	250°C (482°F)
18	......	......	......	21	......	......	......	......
16	......	......	22	22	......	......	......	......
14	15	15	25	25†	30	30	30	40
12	20	20	30	30†	35	40	40	55
10	30	30	40	40†	45	50	55	75
8	40	45	50	50	60	65	70	95
6	55	65	70	70	80	85	95	120
4	70	85	90	90	105	115	120	145
3	80	100	105	105	120	130	145	170
2	95	115	120	120	135	145	165	195
1	110	130	140	140	160	170	190	220
1/0	125	150	155	155	190	200	225	250
2/0	145	175	185	185	215	230	250	280
3/0	165	200	210	210	245	265	285	315
4/0	195	230	235	235	275	310	340	370
250	215	255	270	270	315	335	......	......
300	240	285	300	300	345	380	......	......
350	260	310	325	325	390	420	......	......
400	280	335	360	360	420	450	......	......
500	320	380	405	405	470	500	......	......
600	355	420	455	455	525	545	......	......
700	385	460	490	490	560	600	......	......
750	400	475	500	500	580	620	......	......
800	410	490	515	515	600	640	......	......
900	435	520	555	555	......	......	......	......
1000	455	545	585	585	680	730	......	......
1250	495	590	645	645	......	......	......	......
1500	520	625	700	700	785	......	......	......
1750	545	650	735	735	......	......	......	......
2000	560	665	775	775	840	......	......	......

* Special use only. See Table 310-13 - Page 31.
** For dry locations only. See Table 310-13 - Page 31.
These ampacities relate only to conductors described in Table 310-13.
† The ampacities for Types FEP, FEPB, RHH, THHN, and XHHW conductors for sizes 14, 12, and 10 shall be the same as designated for 75°C conductors in this Table.
For ambient temperatures over 30°C, see Correction Factors, Note 13.

Table 310-17.
Allowable Ampacities of Insulated Copper Conductors

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

Size AWG MCM	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	250°C (482°F)
18	......	......	......	25	......	......	......	......
16	......	......	27	27	......	......	......	......
14	20	20	30	30†	40	40	45	60
12	25	25	40	40†	50	50	55	80
10	40	40	55	55†	65	70	75	110
8	55	65	70	70	85	90	100	145
6	80	95	100	100	120	125	135	210
4	105	125	135	135	160	170	180	285
3	120	145	155	155	180	195	210	335
2	140	170	180	180	210	225	240	390
1	165	195	210	210	245	265	280	450
1/0	195	230	245	245	285	305	325	545
2/0	225	265	285	285	330	355	370	605
3/0	260	310	330	330	385	410	430	725
4/0	300	360	385	385	445	475	510	850
250	340	405	425	425	495	530	......	......
300	375	445	480	480	555	590	......	......
350	420	505	530	530	610	655	......	......
400	455	545	575	575	665	710	......	......
500	515	620	660	660	765	815	......	......
600	575	690	740	740	855	910	......	......
700	630	755	815	815	940	1005	......	......
750	655	785	845	845	980	1045	......	......
800	680	815	880	880	1020	1085	......	......
900	730	870	940	940	......	......	......	......
1000	780	935	1000	1000	1165	1240	......	......
1250	890	1065	1130	1130	......	......	......	......
1500	980	1175	1260	1260	1450	......	......	......
1750	1070	1280	1370	1370	......	......	......	......
2000	1155	1385	1470	1470	1715	......	......	......

* Special use only. See Table 310-13 - Page 31.
** For dry locations only. See Table 310-13 - Page 31.
These ampacities relate only to conductors described in Table 310-13.
† The ampacities for Types FEP, FEPB, RHH, THHN, and XHHW conductors for sizes 14, 12, and 10 shall be the same as designated for 75°C conductors in this Table.
For ambient temperatures over 30°C, see Correction Factors, Note 13.

Table 310-18.
Allowable Ampacities of Insulated Aluminum and Copper-Clad Aluminum Conductors

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

Size AWG MCM	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)
12	15	15	25	25†	25	30	30
10	25	25	30	30†	35	40	45
8	30	40	40	40	45	50	55
6	40	50	55	55	60	65	75
4	55	65	70	70	80	90	95
3	65	75	80	80	95	100	115
2	75	90	95	95	105	115	130
1	85	100	110	110	125	135	150
1/0	100	120	125	125	150	160	180
2/0	115	135	145	145	170	180	200
3/0	130	155	165	165	195	210	225
4/0	155	180	185	185	215	245	270
250	170	205	215	215	250	270	......
300	190	230	240	240	275	305	......
350	210	250	260	260	310	335	......
400	225	270	290	290	335	360	......
500	260	310	330	330	380	405	......
600	285	340	370	370	425	440	......
700	310	375	395	395	455	485	......
750	320	385	405	405	470	500	......
800	330	395	415	415	485	520	......
900	355	425	455	455	......	......	......
1000	375	445	480	480	560	600	......
1250	405	485	530	530	......	......	......
1500	435	520	580	580	650	......	......
1750	455	545	615	615	......	......	......
2000	470	560	650	650	705	......	......

These ampacities relate only to conductors described in Table 310-13.
* For dry locations only. See Table 310-13 - Page 31.
† The ampacities for Types RHH, THHN, and XHHW conductors for sizes 12 and 10 shall be the same as designated for 75°C conductors in this Table.
For ambient temperatures over 30°C, see Correction Factors, Note 13.

Table 310-19.
Allowable Ampacities of Insulated Aluminum and Copper-Clad Aluminum Conductors

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

Size AWG MCM	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)
12	20	20	30	30†	40	40	45
10	30	30	45	45†	50	55	60
8	45	55	55	55	65	70	80
6	60	75	80	80	95	100	105
4	80	100	105	105	125	135	140
3	95	115	120	120	140	150	165
2	110	135	140	140	165	175	185
1	130	155	165	165	190	205	220
1/0	150	180	190	190	220	240	255
2/0	175	210	220	220	255	275	290
3/0	200	240	255	255	300	320	335
4/0	230	280	300	300	345	370	400
250	265	315	330	330	385	415	......
300	290	350	375	375	435	460	......
350	330	395	415	415	475	510	......
400	355	425	450	450	520	555	......
500	405	485	515	515	595	635	......
600	455	545	585	585	675	720	......
700	500	595	645	645	745	795	......
750	515	620	670	670	775	825	......
800	535	645	695	695	805	855	......
900	580	700	750	750	......	......	......
1000	625	750	800	800	930	990	......
1250	710	855	905	905	......	......	......
1500	795	950	1020	1020	1175	......	......
1750	875	1050	1125	1125	......	......	......
2000	960	1150	1220	1220	1425	......	......

These ampacities relate only to conductors described in Table 310-13.
* For dry locations only. See Table 310-13 - Page 31.
† The ampacities for Types RHH, THHN, and XHHW conductors for sizes 12 and 10 shall be the same as designated for 75°C conductors in this Table.
For ambient temperatures over 30°C, see Correction Factors, Note 13.

TABLES 310-16 through 310-19

NOTES TO N.E.C. TABLES 310-16 THROUGH 310-19

Ampacity. The maximum, continuous, ampacities of copper conductors are given in Tables 310-16 and 310-17. The ampacities of aluminum and copper-clad aluminum conductors are given in Tables 310-18 and 310-19.

1. Explanation of Tables. For explanation of Type Letters, and for recognized size of conductors for the various conductor insulations, see Sections 310-12 and 310-13. For installation requirements, see Sections 310-1 through 310-9, 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 of Tables 310-16 and 310-18 shall be used, unless otherwise provided in this Code.

3. Three-Wire Single-Phase Residential Services. For 3-wire, single-phase residential services, the allowable ampacity of Types RH, RHH, RHW, THW and XHHW copper service-entrance conductors shall be for sizes No. 4-100 Amp., No. 3-110 Amp., No. 2-125 Amp., No. 1-150 Amp., No. 1/0-175 Amp., and No. 2/0-200 Amp., and the allowable ampacity of Types RH, RHH, RHW, THW, and XHHW aluminum and copper-clad aluminum service-entrance conductors shall be for sizes No. 2-100 Amp., No. 1-110 Amp., No. 1/0-125 Amp., No. 2/0-150 Amp., No. 3/0-175 Amp. and No. 4/0-200 Amp.

4. Aluminum and Copper-Clad Aluminum Conductors. For aluminum and copper-clad aluminum conductors the allowable ampacities shall be in accordance with Tables 310-18 and 310-19.

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. Ultimate Insulation Temperature. In no case shall conductors be associated together in such a way with respect to the kind of circuit, the wiring method employed, or the number of conductors, that the limiting temperature of the conductors will be exceeded.

8. More Than 3 Conductors in a Raceway or Cable. Where the number of conductors in a raceway or cable exceed 3, the maximum allowable load current of each conductor shall be reduced as shown in the following table:

Number of Conductors	Per Cent of Values in Tables 310-12 and 310-14
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 3 or more conductors, shall not be counted in determining ampacities as provided for in Note 8.

(b) In a 3-wire circuit consisting of two 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 in determining ampacities as provided in Note 8.

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

11. 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.

12. Aluminum-Sheathed Cable or Copper-Sheathed Cable. The ampacities of Type ALS and Type CS cables are determined by the temperature limitation of the insulated conductors incorporated within the cable. Hence the ampacities of aluminum-sheathed cable or copper-sheathed 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.

13. Use of Conductors With Higher Operating Temperatures. Where the room temperature is within 10 degrees C of the maximum allowable operating temperature of the insulation, it is desirable to use an insulation with a higher maximum allowable operating temperature; although insulation can be used in a room temperature approaching its maximum allowable operating temperature limit if the current is reduced in accordance with the correction factors for different room temperatures as shown in the correction factor table, Table 13.

Table 13

Correction Factors

Ambient Temps. Over 30°C. 86°F.

C.	F.	60°C (140°F)	75°C (167°F)	85°C (185°F)	90°C (194°F)	110°C (230°F)	125°C (257°F)	200°C (392°F)	250°C (482°F)
40	104	.82	.88	.90	.91	.94	.95	......	......
45	113	.71	.82	.85	.87	.90	.92	......	......
50	122	.58	.75	.80	.82	.87	.89	......	......
55	131	.41	.67	.74	.76	.83	.86	......	......
60	140	......	.58	.67	.71	.79	.83	.91	.95
70	158	......	.35	.52	.58	.71	.76	.87	.91
75	167	......	......	.43	.50	.66	.72	.86	.89
80	176	......	......	.30	.41	.61	.69	.84	.87
90	194	......	......	......	......	.50	.61	.80	.83
100	212	......	......	......	......	......	.51	.77	.80
120	248	......	......	......	......	......	......	.69	.72
140	284	......	......	......	......	......	......	.59	.59
160	320	......	......	......	......	......	......	......	.54
180	356	......	......	......	......	......	......	......	.50
200	392	......	......	......	......	......	......	......	.43
225	437	......	......	......	......	......	......	......	.30

ARTICLE 324 - CONCEALED KNOB-AND-TUBE WIRING

324-1 DEFINITION

Concealed knob-and-tube wiring is a wiring method using knobs, tubes, and flexible nonmetallic tubing for the protection and support of single insulated conductors concealed in hollow spaces of walls and ceiling of buildings.

Open wiring on insulators (Article 320) is an "exposed" wiring method, whereas knob-and-tube wiring is a "concealed" method. Conductors used for knob-and-tube work may be of any general-use type specified by Article 310.

324-3 USES PERMITTED

Concealed knob-and-tube wiring shall be permitted to be used only for extensions of existing installations and elsewhere only by special permission under the following conditions:

(1) In the hollow spaces of walls and ceilings.

(2) In unfinished attic and roof spaces as provided in Section 324-11.

324-4 USES NOT PERMITTED

Concealed knob-and-tube wiring shall not be used in commercial garages, theaters, and similar locations, motion picture studios, or hazardous locations.

Commentary:

Because of its limited application as extensions of existing installations and elsewhere by special permission, concealed knob and tube should not be considered as a suitable method of wiring the array.

ARTICLE 328 - FLAT CONDUCTOR CABLE (FCC)

328-4 USES PERMITTED

(a) Branch Circuits. Use of FCC systems shall be permitted both for general-purpose and appliance branch circuits, and for individual branch circuits.

(b) Floors. Use of FCC systems shall be permitted on hard, sound, smooth, continuous floor surfaces made of concrete, ceramic or composition flooring, wood, and similar materials.

(c) Walls. Use of FCC systems shall be permitted on wall surfaces in surface metal raceways.

(d) Damp Locations. Use of FCC systems in damp locations shall be permitted.

(e) Heated Floors. Materials used for floors heated in excess of 30°C (85°F) shall be approved for the purpose.

328-5 USES NOT PERMITTED

FCC systems shall not be used: (1) outdoors or in wet locations; (2) where subject to corrosive vapors; (3) in any hazardous locations; or (4) in residential, school, and hospital buildings.

Commentary:

Flat cable is not allowed in residences and therefore, cannot be used in a residential photovoltaic system. However, the NEC has not considered Flat Cable Conductor (FCC) as part of a photovoltaic system, and if a safe wiring system using flat cable is designed, residential PV systems could use it, provided it passes all the appropriate testing procedures and meets all NEC requirements.

ARTICLE 330 - MINERAL-INSULATED METAL-SHEATHED CABLE (MI)

330-1 DEFINITION

Type MI mineral-insulated, metal-sheathed cable is a factory assembly of one or more conductors insulated with a highly compressed refractory mineral insulation and enclosed in a liquidtight and gastight continuous copper sheath.

Mineral-insulated, metal-sheathed cable consists of one or more solid copper conductors insulated with highly compressed magnesium oxide and enclosed in a continuous copper sheath. It is labeled in sizes 16 AWG to 250 MCM one conductor, 16 to 4 AWG two and three conductor, 16 to 6 AWG four conductor and 16 to 10 AWG seven conductor. The cable is rated 600 V.

330-3 USES PERMITTED

Type MI cable shall be permitted as follows: (1) for services, feeders, and branch circuits; (2) in dry, wet, or continuously moist locations; (3) indoors or outdoors; (4) where exposed or concealed; (5) embedded in plaster, concrete, fill or other masonry, whether above or below grade; (6) in any hazardous location; (7) where exposed to oil and gasoline; (8) where exposed to corrosive conditions not deteriorating to its sheath; (9) in underground runs where suitably protected against physical damage and corrosive conditions.

Commentary:

Mineral insulated metal sheathed cable is probably the most versatile cable available - it can be used in almost any application. However, that level of protection is not required for a typical residential application.

ARTICLE 333 - ARMORED CABLE (AC)

333-1 DEFINITION

Type AC cable is a fabricated assembly of insulated conductors in a flexible metallic enclosure. See Section 333-4.

333-4 CONSTRUCTION

Type AC cable shall be an approved cable with acceptable metal covering. The insulated conductors shall conform with Section 333-5.

Type AC cables are branch-circuit feeder cables with armor of flexible metal tape. Cables of the AC type, except ACL, shall have an internal bonding strip of copper or aluminum, in intimate contact with the armor for its entire length.

333-5 CONDUCTORS

Insulated conductors shall be of a type listed in Table 310-13. In addition, the conductors shall have an overall moisture-resistant and fire-retardant fibrous covering. For Type ACT, a moisture-resistant fibrous covering shall be required only on the individual conductors.

333-6 USE

Except where otherwise specified elsewhere in this Code, and where not subject to physical damage, Type AC cable shall be permitted for branch circuits and feeders in both exposed and concealed work.

Type AC cable shall be permitted in dry locations; for underplaster extensions as provided in Article 344; and embedded in plaster finish on brick or other masonry, except in damp or wet locations. It shall be permissible to run or fish this cable in the air voids of masonry block or tile walls; where such walls are exposed or subject to excessive moisture or dampness or are below grade line, Type ACL cable shall be used. This cable shall contain lead-covered conductors (Type ACL) if used where exposed to the weather or to continuous moisture; for 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.

Type AC cable shall not be used where prohibited elsewhere in this Code, including (1) in theaters and similar locations, except as provided in Article 528, Places of Assembly; (2) in motion-picture studios; (3) in any hazardous locations; (4) where exposed to corrosive fumes or vapors; (5) on cranes or hoists, except as provided in Section 610-11, Exception No. 3; (6) in storage battery rooms; (7) in hoistways or on elevators, except as provided in Section 620-21; or (8) in commercial garages where prohibited in Article 511.

Exception: See Section 501-4(b) Exception.

Type ACL cable shall not be used for direct burial in the earth.

333-9 BOXES AND FITTINGS

At all points where the armor of AC cable terminates, a fitting shall be provided to protect wires from abrasion, unless the design of the outlet boxes or fittings is such as to afford equivalent protection, and in addition, an approved insulating bushing or its equivalent approved protection shall be provided between the conductors and the armor. The connector or clamp by which tye Type AC cable is fastened to boxes or cabinets shall be of such design that the insulating bushing or its equivalent will be visible for inspection. This bushing shall not be required with lead-covered cables where so installed that the lead sheath will be visible for inspection. Where change is made from Type AC cable to other cable or raceway wiring methods, a box shall be installed at junction points as required in Section 300-15.

Commentary:

Armored cable, commonly called BX, is used widely in commercial buildings. It is a flexible equivalent of insulated conductors in conduit and is frequently used to wire lighting and receptacle branch circuits in buildings. It offers more protection than Nonmetallic-Sheathed Cable, NM. (See Article 336).

BX requires boxes and fittings as per Section 333-9. However, BX is used with a plug-type terminal (generically a quick connect design) in the UL- and NEC-approved Wiremold ODS Overhead Distribution System.

Although the wording is somewhat confusing, Section 333-12(a) says cables running near either edge of rafters or studs must be protected by steel plates similar to that mentioned in 300-4(a). The intention is to prevent cable puncture by wallboard nails.

ARTICLE 336 - NONMETALLIC-SHEATHED CABLE (NM)

336-1 DEFINITION

Nonmetallic-sheathed cable is a factory assembly of two or more insulated conductors having an outer sheath of moisture-resistant, flame-retardant, nonmetallic material.

Nonmetallic-sheathed cable may be used for either exposed or concealed wiring and is a common substitute for concealed knob-and-tube wiring (Article 324) and open wiring on insulators (Article 320). The basic advantages of nonmetallic-sheathed cable (Type NM and Type NMC) are that the outer sheath provides continuous protection in addition to the rubber-covered or thermoplastic insulation applied to the conductors; the cable is easily fished in partitions of finished buildings; no insulating supports are required; and only one hole need be bored where the cable passes through a wooden cross member.

Where the cable passes through factory or field-punched holes in metal studs or similar members, it is to be protected by bushings or grommets securely fastened in the opening. See Section 300-4(b).

336-2 CONSTRUCTION

Nonmetallic-sheathed cable shall be an approved Type NM or NMC in sizes No. 14 through 2 with copper conductors and in sizes No. 12 through 2 with aluminum or copper-clad aluminum conductors. In addition to the insulated conductors, the cable may have an approved size of insulated or bare conductor for equipment grounding purposes only.

Conductors of Types NM and NMC shall be one of the types listed in Table 310-13 which is suitable for branch-circuit wiring or one which is approved for the purpose. The ampacity of Types NM and NMC cable shall be that of 60°C (140°F) conductors in Table 310-16.

(a) Type NM. The overall covering shall have a flame-retardant and moisture-resistant finish.

(b) Type NMC. The overall covering shall be flame-retardant, moisture-resistant, fungus-resistant, and corrosion-resistant.

(c) Marking. In addition to the provision of Section 310-11, the cable shall have a distinctive marking on the exterior for its entire length specifying the cable type.

336-3 USES PERMITTED OR NOT PERMITTED

Type NM and Type NMC cables shall be permitted to be used in one- and two-family dwellings, or multifamily dwellings and other structures not exceeding three floors above grade. For the purpose of this article, the first floor of a building shall be that floor designed for human habitation which is level with or above finished grade of the exterior wall line of 50 percent or more of its perimeter.

(a) Type NM. This type of nonmetallic-sheathed cable shall be permitted to be installed for both exposed and concealed work in normally dry locations. It shall be permissible to install or fish type NM cable in air voids in masonry block or tile walls where such walls are not exposed or subject to excessive moisture or dampness.

Type NM cable shall not be installed where exposed to corrosive fumes or vapors; nor shall it be imbedded in masonry, concrete, adobe, fill, or plaster; nor run in a shallow chase in masonry, concrete or adobe and covered with plaster, adobe or similar finish.

(b) Type NMC. Type NMC cable shall b permitted for both exposed and concealed work in dry, moist, damp, or corrosive locations, and in outside and inside walls of masonry block or tile.

(c) Uses Not Permitted For Either Type NM or NMC. Types NM and NMC cables shall not be used as: (1) service-entrance cable, (2) in commerical garages, (3) in theaters and similar locations, except as provided in Article 518, Places of Assembly, (4) in motion-picture studios, (5) in storage battery rooms, (6) in hoistways, (7) in any hazardous location, (8) embedded in poured cement, concrete, or aggregate.

Exception: See Section 501-4(b) Exception.

Type NMC (corrosion resistant) cable has proven very beneficial for installations in dairy barns and similar farm buildings (See Article 547) where extremely cold temperatures are experienced and ordinary types of nonmetallic cables have in some cases deteriorated rapidly due to the growth of fungus or mold.

In addition to the insulated conductors, nonmetallic-sheathed cable may have an approved size of insulated or bare conductor for equipment grounding purposes only. See Section 250-57 and Table 250-95.

336-5 SUPPORTS

Nonmetallic-sheathed cable shall be secured by staples, straps, or similar fittings so designed and installed as not to injure the cable. Cable shall be secured in place at intervals not exceeding 4 1/2 feet and within 12 inches from every cabinet, box, or fitting.

Exception No. 1: For concealed work in finished buildings or finished panels for prefabricated buildings where such supporting is impracticable, it shall be permissible to fish the cable between access points.

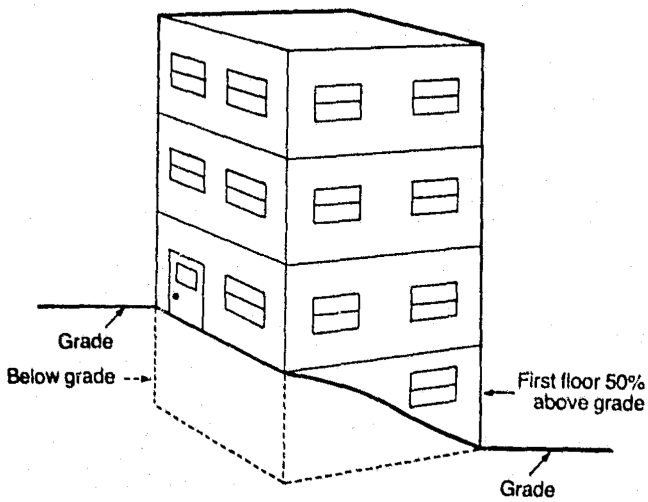


Figure 336-1. A representation of a first floor of a building which is level with or above finished grade of the exterior wall line of 50 percent or more of its perimeter.

Exception No. 2: A wiring device approved for the purpose, without a separate outlet box, incorporating an integral cable clamp shall be permitted when the cable is secured in place at intervals not exceeding 4 1/2 feet and within 12 inches from the wiring device wall opening, and there shall be at least a 12-inch loop of unbroken cable or 6 inches of a cable and available on the interior side of the finished wall to permit replacement.

For concealed work, nonmetallic cable should be installed in such a way as to be adequately protected from the physical damage that could be caused by nails or screws. Where practical, care should be taken to avoid areas where trim, door and window casings, baseboards, picture moldings, etc., may be nailed. See Section 300-4.

336-6 EXPOSED WORK - GENERAL

In exposed work, except as provided in Section 336-8 and 336-9, the cable shall be installed as specified in (a) and (b) below.

(a) To Follow Surface. The cable shall closely follow the surface of the building finish or of running boards.

(b) Protection From Physical Damage. The cable shall be protected from physical damage where necessary by conduit, pipe, guard strips, or other means. Where passing through a floor the cable shall be enclosed in rigid metal conduit, intermediate metal conduit or metal pipe extending at least 6 inches above the floor.

336-7 THROUGH STUDS, JOISTS, AND RAFTERS

The cable shall comply with Section 300-4 where installed through studs, joists, rafters, and similar members.

336-8 IN UNFINISHED BASEMENTS

Where the cable is run at angles with joists in unfinished basements, it shall be permissible to secure cables not smaller than two No. 6 or three No. 8 conductors directly to the lower edges of the hoists. Smaller cables shall either be run through board holes in joists or on running boards. Where run parallel to the joists, cable of any size shall be secured to the sides or faces of the joists.

336-9 IN ACCESSIBLE ATTICS

The installation of cable in accessible attics or roof spaces shall also comply with Section 333-12.

336-11 DEVICES OF INSULATING MATERIAL

Switch, outlet, and tap devices of insulating material shall be permitted to be used without boxes in exposed cable wiring, and for rewiring in existing buildings where the cable is concealed and fished. Openings in such devices shall form a close fit around the outer covering of the cable, and the device shall fully enclose that part of the cable from which any part of the covering has been removed.

Where connections to conductors are by binding-screw terminals, there shall be available as many terminals as conductors.

Exception: Where cables are clamped within the structure, and terminals are of a type approved for multiconductors.

336-12 BOXES OF INSULATING MATERIAL

Nonmetallic outlet boxes shall be permitted as provided in Section 370-3.

Nonmetallic boxes and nonmetallic wiring systems are desired in corrosive atmospheres; however, nonmetallic boxes sized over 100 cu. in. (for instance 5 in. x 5 in. x 5 in. = 125 cu. in.) with bonding means between all metal raceways and metal enclosed cables are permitted. See Sections 370-3, 370-7 (c), and Article 547.

Commentary:

First of all, NMC is no longer available and has been replaced by Underground Feeder (UF) cable (see Article 339). UF and NMC was phased out in favor of a sunlight resistant UF cable.

Nonmetallic Sheathed Cable (NM), or Romex as it is commonly refered to, is a common substitute for the older wiring technique of Knob-and-Tube. NM is now used almost exclusively in residential wiring and may be the most appropriate wiring method for a residential photovoltaic system. Its advantages are that it is already a very common element to the residential building industry, it incorporates three conductors into one cable for easier handling and it already has a connector designed and pending approval that can eliminate the need for a junction box (see 336-11 and commentary following 110-14.) However, it is limited by a 60°C rating (see commetnary following 310-15 for possible minimum temperature rating requirements for conductors). Also NM will require protection against physical damage where it is readily accessible, that is, a ground mounted array, or an easily accessible roof. Another important limitation is its restriction to residences, multi-family dwellings and other buildings which do not exceed three in height (see 336-3).

ARTICLE 339 - UNDERGROUND FEEDER AND BRANCH-CIRCUIT CABLE

339-1 DESCRIPTION AND MARKING

(a) Description. Underground feeder and branch-circuit cable shall be an approved Type UF cable in sizes No. 14 through No. 4/0. The conductors of Type UF shall be one of the moisture-resistant types listed in Table 310-13 which is suitable for branch-circuit wiring or one which is approved for the purpose. The ampacity of Type UF cable shall be that of 60°C (140°F) conductors in Table 310-16. In addition to the insulated conductors, the cable shall be permitted to have an approved size of insulated or bare conductor for equipment grounding purposes only. The overall covering shall be flame-retardant, moisture-resistant, fungus-resistant, corrosion-resistant, and suitable for direct burial in the earth.

(b) Marking. In addition to the provisions of Section 310-11, the cable shall have a distinctive marking on the exterior for its entire length specifying the cable type.

Underground feeder and branch-circuit cable is rated for use at 60°C, 600 V, and is labeled in sizes Nos. 14 to 4/0 AWG, copper, and Nos. 12 to 4/0 AWG, aluminum or copper-clad aluminum, for single and multiple conductor cables.

Submersible Water Pump Cable indicates a multiconductor cable in which 2, 3, or 4 single-conductor Type UF cables are twisted together without an outer covering. The cable is labeled in sizes from 14 AWG to 2 AWG, copper, and from 12 AWG to 2 AWG, aluminum or copper-clad aluminum. The cable is tag marked: "For use within the well casing for wiring deep-well water pumps where the cable is not subject to repetitive handling caused by frequent servicing of the pump units. The insulation may also be surface-marked "Pump Cable."

This cable may employ copper, or aluminum, or copper-clad aluminum conductors. Cables with copper-clad aluminum conductors are surface printed "AL (CU-CLAD)."

If single conductor Type UF cable is terminated with a fitting not specifically recognized for use with single conductor cable, special care should be taken to assure it is properly secured and not subject to damage.

339-3 USE

(a) USES PERMITTED

(1) Type UF cable shall be permitted for use underground, including direct burial in the earth, as feeder or branch-circuit cable where provided with overcurrent protection of the rated ampacity as required in Section 339-4.

(2) Where single-conductor cables are installed, all cables of the feeder circuit, sub-feeder circuit, or branch circuit, including the neutral conductor, if any, shall be run together in the same trench or raceway.

(3) For underground requirements, see Section 300-5.

(4) Type UF cable shall be permitted for interior wiring in wet, dry, or corrosive locations under the recognized wiring methods of this Code, and where installed as nonmetallic-sheathed cable, the installation shall comply with the provisions of Article 336 and shall be of the multiconductor type.

Exception: Single conductor cables shall be permitted as the nonheating leads for heating cables as provided in Section 424-43.

Type UF cable supported by cable trays shall be of the multiconductor type.

(b) USES NOT PERMITTED

Type UF cable shall not be used: (1) as service-entrance cables; (2) in commercial garages; (3) in theaters; (4) in motion-picture studios; (5) in storage battery rooms; (6) in hoistways; (7) in any hazardous location; (8) embedded in poured cement, concrete, or aggregate, except where embedded in plaster as nonheating leads as provided in Article 424; (9) where exposed to direct rays of the sun, unless approved for the purpose.

Exception: See Section 501-4(b) Exception.

Typ[illegible] cables suitable for exposure to the direct rays of the sun are ind[illegible]ed by tag marking and marking on the surface of the cable with the desig[illegible]tion "Sunlight Resistant."

Commentary:

UF has all the advantages of NM cable plus some. It can be used in wet locations, and where exposed to sunlight (if designated "Sunlight Resistant"), and does not have the three story height and residential only limitations. The manufacturer's suggested price, however, is 1.3 times that of NM.

Based on conversations with AMP representatives, the connector made for NM that eliminates the need for a junction box can probably be adapted to the UF cable. (See Terminal Study in Electrical Interface - Study Section.)

ARTICLE 345 - INTERMEDIATE METAL CONDUIT

345-1 DEFINITION

Intermediate metal conduit is a metal raceway of circular cross section with integral or associated couplings, connectors and fittings approved for the installation of electrical conductors.

Intermediate metal conduit (IMC) is a thinner walled rigid metal conduit and is satisfactory for use in all locations where rigid metal conduit may be used. Also, threaded and unthreaded fittings, couplings, connectors, etc., are interchangeable for either IMC or rigid metal conduit.

Galvanized IMC installed in concrete does not require supplementary corrosion protection. Wherever ferrous metal conduit runs directly from concrete encasement to soil burial, severe corrosive effects are likely to occur on the metal in contact with the soil. In the absence of specific local experience, soils producing severe corrosive effects are generally characterized by low resistivity, less than 2000 ohm-centimeters.

345-3 USES PERMITTED

(a) Use of intermediate metal conduit shall be permitted under all atmospheric conditions and occupancies. Where practicable, dissimilar metals in contact anywhere in the system shall be avoided to eliminate the possibility of galvanic action. Intermediate metal conduit shall be permitted as an equipment grounding conductor.

See Section 250-91.

Exception: Aluminum fittings and enclosures shall be permitted to be used with steel intermediate metal conduit.

(b) Intermediate metal conduit, elbows, couplings, and fittings shall be permitted to be installed in concrete, in direct contact with the earth, or in areas subject to severe corrosive influences when protected by corrosion protection and judged suitable for the condition.

See Section 300-6.

(c) Intermediate metal conduit shall be permitted to be installed in or under cinder fill where subject to permanent moisture when protected on all sides by a layer of noncinder concrete not less than two inches thick; when the conduit is not less than 18 inches under the fill; or when protected by corrosion protection and judged suitable for the condition.

See Section 300-6.

ARTICLE 346 - RIGID METAL CONDUIT

346-1 USE

The use of rigid metal conduit shall be permitted under all atmospheric conditions and occupancies subject to the following:

(a) Ferrous raceways and fittings protected from corrosion solely by enamel shall be permitted only indoors and in occupancies not subject to severe influences.

(b) Where practicable, dissimilar metals in contact anywhere in the system shall be avoided to eliminate the possibility of galvanic action.

Exception: Aluminum fittings and enclosures shall be permitted to be used with steel rigid metal conduit.

(c) Ferrous or nonferrous metal conduit, elbows, couplings and fittings shall be permitted to be installed in concrete, in direct contact with the earth, or in areas subject to severe corrosive influences where protected by corrosion protection and judged suitable for the condition.

See Section 300-6.

This section indicates the permitted uses for ferrous and nonferrous conduit, including their use in concrete, in direct contact with the earth, and in corrosive areas. The fine print note references Section 300-6 for additional information on protection against corrosion and specific types of corrosion-resistant materials.

It is advisable to consult with the authority enforcing this Code for the approval of corrosion-resistant materials and/or for requirements prior to the installation of nonferrous metal (aluminum) in concrete since chloride additives in the concrete mix have caused corrosion.

ARTICLE 347 - RIGID NONMETALLIC CONDUIT

347-1 DESCRIPTION

This article shall apply to a type of conduit and fittings of suitable nonmetallic material that is resistant to moisture and chemical atmospheres. For use aboveground, it shall also be flame-retardant, resistant to impact and crushing, resistant to distortion from heat under conditions likely to be encountered in service, and resistant to low temperature and sunlight effects. For use underground, the material shall be acceptably resistant to moisture and corrosive agents and shall be of sufficient strength to withstand abuse, such as by impact and crushing, in handling and during installation. Where intended for direct burial, without encasement in concrete, the material shall also be capable of withstanding continued loading that is likely to be encountered after installation.

Materials that have been recognized as having suitable physical characteristics when properly formed and treated include fiber, asbestos cement, soapstone, rigid polyvinyl chloride and high-density polyethylene for underground use, and rigid polyvinyl chloride for use aboveground

Unless marked for a higher temperature, nonmetallic conduit (Schedule 40 and Schedule 80) in this category is intended for use with wires rated 75°C or less (1) aboveground, (2) for direct burial underground, (3) where encased in concrete within buildings, and (4) where ambient temperature is 50°C or less. When encased in concrete in trenches outside of buildings it is suitable for use with wires rated 90°C or less.

Conduit installed aboveground is suitable for cables rated over 600 V when encased in not less than 2 in. of concrete.

Direct burial is suitable for cables rated over 600 V when it is buried to a depth in accordance with Table 710-3(b). Nonmetallic plastic conduit is listed in sizes 1/2 to 6 in. incl.

Listed PVC conduit is inherently resistant to atmosphere containing common industrial corrosive agents and will also withstand vapors or mist of caustic, pickling acids, plating baths and hydrofluoric and chromic acids.

PVC conduit is designed for connection to couplings, fittings and boxes by the use of a suitable solvent-type cement. Instructions supplied by the manufacturer describe the method of assembly and precautions to be followed.

For use of Schedule 80, see Sections 300-5(d), 551-51(b), and 710-3(b)(1).

347-2 USES PERMITTED

The use of rigid nonmetallic conduit and fittings approved for the purpose shall be permitted under the following conditions:

(a) Where the potential is 600 volts or less.

(1) In walls, floors, and ceilings.

(2) In locations subject to severe corrosive influences as covered in Section 300-6 and where subject to chemicals for which the materials are specifically approved.

(3) In cinder fill.

(4) In portions of dairies, laundries, canneries or other wet locations and in locations where walls are frequently washed, the entire conduit system including boxes and fittings used therewith shall be so installed and equipped as to prevent water from entering the conduit. All supports, bolts, straps, screws, et., shall be of corrosion-resistant materials or be protected against corrosion by approved corrosion-resistnat materials.

(5) In dry and damp locations not prohibited by Section 347-3.

(6) For exposed work where not subject to physical damage if approved for the purpose.

(b) Where the potential is over 600 volts, rigid nonmetallic conduit shall be encased in not less than 2 inches of concrete.

(c) For underground installations see Section 300-5 and 710-3(b).

347-3 USES NOT PERMITTED

Rigid nonmetallic conduit shall not be used:

(a) In hazardous locations, except as covered in Sections 514-8 and 515-5; and Class I, Division 2, locations as permitted in the Exception to 501-4(b).

(b) For the support of fixtures or other equipment.

(c) Where subject to physical damage unless approved for the purpose.

(d) Where subject to ambient temperatures exceeding those for which the conduit is approved.

(e) For conductors whose insulation temperature limitations would exceed those for which the conduit is approved.

Nonmetallic conduits are not permitted in ducts, plenums, and other air handling spaces.

In addition, nonmetallic conduits are not to be used where it would aid the possible spread of fire or products of combustion through fire-rated, fire-resistant or fire-stopped walls, partitions, ceilings, and floors, hollow spaces, vertical shafts, and ventilating or air-handling ducts. See Section 300-21 for prevention of fire spread.

ARTICLE 348 - ELECTRICAL METALLIC TUBING

348-1 USE

The use of electrical metallic tubing shall be permitted for both exposed and concealed work. Electrical metallic tubing shall not be used: (1) where, during installation or afterward, it will be subject to severe physical damage; (2) where protected from corrosion solely by enamel; (3) in cinder concrete or cinder fill where subject to permanent moisture unless protected on all sides by a layer of noncinder concrete at least 2 inches thick or unless the tubing is at least 18 inches under the fill. Where practicable, dissimilar metals in contact anywhere in the system shall be avoided to eliminate the possibility of galvanic action.

Exception: Aluminum fittings and enclosures shall be permitted to be used with steel electrical metallic tubing.

Ferrous or nonferrous electrical metallic tubing, elbows, couplings, and fittings shall be permitted to be installed in concrete, in direct contact with the earth, or in areas subject to severe corrosive influences when protected by corrosion protection and judged suitable for the condition.

348-2 OTHER ARTICLES

Installations of electrical metallic tubing shall comply with the applicable provisions of Article 300.

A. Installation

348-4 WET LOCATIONS

All supports, bolts, straps, screws, etc., shall be of corrosive-resistant materials or protected against corrosion by corrosion-resistant metals approved for the purpose.

Commentary:

EMT commonly called "thin wall" is usually used for indoor branch circuiting. It can be used in wet locations only if specially treated.

ARTICLE 350 - FLEXIBLE METAL CONDUIT

350-2 USE

Flexible metal conduit shall not be used: (1) in wet locations, unless conductors are of the lead-covered type or of other type approved for the specific conditions; (2) in hoistways, other than provided in Section 620-21; (3) in storage-battery rooms; (4) in any hazardous location other than permitted in Section 501-4(b); (5) where rubber-covered conductors are exposed to oil, gasoline, or other materials having a deteriorating effect on rubber; nor (6) underground or embedded in poured concrete or aggregate.

Commentary:

Flexible metal conduit is constructed of a spirally wound interlocking armor raceway commonly called "Greenfield". It is principally used for connections where vibration is a problem or where obstructions make flexible conduit necessary.

ARTICLE 352 - SURFACE RACEWAYS

A. Metal Surface Raceways

352-1 USE

The use of surface raceways shall be permitted in dry locations. They shall not be used: (1) where subject to severe physical damage unless approved for the purpose; (2) where 300 volts or more between conductors unless the metal has a thickness of not less than .040 inch; (3) where subject to corrosive vapors; (4) in hoistways; (5) in any hazardous location except Class I, Division 2 locations as permitted in the Exception to 501-4(b); nor (6) concealed except as follows:

Exception No. 1: Metal surface raceways approved for the purpose shall be permitted for underplaster extensions.

Exception No. 2: As permitted in Section 645-2(c)(2).

B. Nonmetallic Surface Raceways

352-21 DESCRIPTION

Part B of this article shall apply to a type of nonmetallic surface raceway and fittings of suitable nonmetallic material that is resistant to moisture and chemical atmospheres. It shall also be flame-retardant, resistant to impact and crushing, resistant to distortion from heat under conditions likely to be encountered in service, and resistant to low-temperature effects.

352-22 USE

The use of nonmetallic surface raceways shall be permitted in dry locations. They shall not be used (1) where concealed; (2) where subject to severe physical damage unless approved for the purpose; (3) where 300 volts or more between conductors; (4) in hoistways; (5) in any hazardous location except Class I, Division 2 locations as permitted in the Exception to 501-4(b); (6) where subject to ambient temperature exceeding 50°C; nor (7) for conductors whose insulation temperature exceeds 75°C.

Commentary:

Panel frames could be designed to act as surface raceways a ³ thus be suitable protection for insulated conductors. Fluorescent lighting fixtures typically use the metal frame as a wireway. As an example of the requirements for an integral raceway, excerpts from UL Standard 57 for Electric Lighting Fixtures follows.

UL STANDARD 57 EXCERPTS

16. Wireways

16.1 Material - Except as noted in paragraph 16.2, an enclosure for wiring shall be made entirely of metal, glass, porcelain, phenolic composition or similar material, shall be lined with metal, or shall be made of materials that comply with the requirements in paragraphs 5A.1 and 5A.2.

5A.1 Nonmetallic - A wireway, frame, component support or enclosure part of nonmetallic material shall have mechanical strength and durability and be so formed that operating parts will be protected against damage, and shall resist the abuses likely to be encountered during installation and normal use and service. The enclosure or enclosure part shall protect persons from shock hazard, and the material shall not create or contribute to a hazardous condition.

5A.2 Among the factors taken into consideration when judging the suitability of a nonmetallic material for the use are the (1) mechanical strength, (2) resistance to impact, (3) moisture-absorptive properties, (4) combustibility and resistance to ignition from electrical sources, (5) size with regard to flame spread and smoke generation, (6) dielectric withstand properties, insulation resistance, and resistance to arc tracking, and (7) resistance to distortion and creeping at temperatures to which the material may be subjected under conditions of normal or abnormal usage. The material is not to display a loss of these properties beyond the minimum acceptable level as a result of aging.

16.2 An enclosure that will completely enclose the wiring as described in paragraph 16.1 need not be provided if:

A. The wiring is armored or is lead-covered and is used with suitable fittings, or

B. All splices are enclosed in accordance with paragraphs 18.1 and 18.3, and the wiring will either be visible in accordance with paragraph 17.14, or concealed between the mounting surface and the canopy or mounting pan of a surface-mounted fixture that has no dimension over 15 inches (see paragraph 4.2).

Commentary:

Section 18 applies to splice enclosures.

18. Splice Enclosures

18.1 Material - All splices, taps, and exposed terminals shall be enclosed in metal, glass, marble, ceramic material, phenolic composition or similar composition or, except for recessed fixtures, shall be made of materials that comply with the requirements in paragraphs 5A.1 and 5A.2.

18.3 With reference to the requirement in paragraph 18.1, 1/8 inch thick rigid asbestos that is held in place may be employed to enclose splices, taps, and exposed terminals in a canopy-or surface-mounted fixture having a maximum dimension of 15 inches or less. See paragraph 4.2.

17. Wiring

17.14 Visible Wire or Cord - A fixture wire or flexible cord that is visible after the fixture is installed shall follow closely the main structure of the fixture and shall be securely held in place. Except as noted in paragraph 17.22, fixture wire may be of either the solid or the stranded construction, and if the wire is Type AF or CF and visible for more than two inches, it shall be provided with a braid or fabric tubing.

Commentary:

Paragraph 17.22 refers to wire and cord of movable parts and would not apply to the photovoltaic module.

Paragraph 4.2 defines the maximum dimension of a rectangular fixture as the diagonal.

16.3 Surface-Mounted Fixtures - A surface-mounted fixture having a maximum dimension of more than 26 inches shall be provided with a complete back cover (see paragraph 11.17). A surface-mounted fixture having a maximum dimension (see paragraph 4.2) of more than 15 inches, but not more than 26 inches shall be provided with a back cover or an equivalent construction that will completely isolate the wiring from the mounting surface except within an area the largest dimension of which is not more than 15 inches, immediately adjacent to and concentric with the outlet box.

11.17 In a fixture designed for surface mounting over an outlet box, it is necessary to provide a hole large enough to permit access to splices in the outlet box without removing the back pan of the fixture from the wall or ceiling, unless the fixture is designed to be easily removable (such as a stud-mounted ceiling pan, or a fixture which is not more than 26 inches longs. If the access hole is not provided at the factory because its correct location cannot be predetermined, or if only one wire-entrance hole or knockout less than 1 1/2 inches in diameter is provided in the mounting surface, the fixture is to be marked in accordance with paragraph 29.6.

16.4 The back cover required in paragraph 16.3 may be of sheet metal or of rigid noncombustible insulating material. A nonrigid, noncobustible insulating material may be used to isolate the wiring in a fixture having a maximum dimension of more than 15 inches but not more than 26 inches if the insulation is not less than one inch thick (when not compressed) and is mechanically secured in place by means which need not be disturbed during the installation and wiring of the fixture. A suitable adhesive applied to the entire surface of the insulation is considered to be a suitable means for securing the insulation in place.

16.5 With reference to the requirement in paragraph 16.3, a full back cover may have the opening mentioned in paragraphs 10.6, 10.7, 10.9, 11.9, 11.18, and 11.19.

Commentary:

Paragraphs 10.6, 10.7, 10.9, 11.9, 11.18, 11.19 make allowances for mounting holes.

16.6 Damage To Wires - A fixture shall be so designed that wires can be pulled through, or the fixture otherwise wired, without damaging the coverings or insulation on the conductors. A wireway shall be free from burrs and fins.

16.7 Screw threads, including those of sheet-metal screws, may be exposed in a wiring compartment for a distance of not more than 3/16 inch; except that no limit applied to the amount of exposure if the wires are held away from or positioned away from such screws. No limit applied to the exposure of threads on fixture mounting screws or nipples.

16.8 Couplings End-To-End - Knockouts to be used as wireways between end-to-end mounted fixtures shall be provided with couplings or a special construction to ensure smooth, unobstructed wire-ways between fixtures, unless the knockouts are of a standard trade size.

16.9 Wireway Size End-To-End - A fixture intended for end-to-end mounting shall be designed that at least four 1/4 inch diameter wires can be run through the fixture.

16.10 Openings For Conductors - If conductors pass through an opening in a sheet-metal wall that is 0.042 inch or less thick, except for the access hole referred to in paragraphs 11.17 - 11.19 and except as noted in paragraph 11.14, they shall be reliably held away from the edges of the opening, or shall be protected by a bushing, a grommet, or by rolling the edge of the metal at the opening not less than 120 degrees. A bushing, if used, shall be securely held in place, and an insulating bushing shall not be less than 3/64 inch thick. The edges of an opening in sheet metal thicker than 0.042 inch shall be treated to reduce the possibility of abrasion of the insulation by removal of burrs, fins, and sharp edges.

16.11 A rubber bushing is not acceptable.

39. Fixtures For Wet Locations

39.4 Exclusion of Water - A fixture shall be constructed that water cannot accumulate in and will not normally enter a wireway, fluorescent-lamp lampholder, or other electrical part of the fixture.

40. Corrosion Protection

40.1 All sheet steel or other mechanical parts of iron or steel shall be zinc-coated, cadmium-plated, or otherwise suitably protected against corrosion. Structural iron or steel parts shall be zinc-coated, cadmium-plated, enameled, painted, or provided with equivalent protection against corrosion on all surfaces.

40.2 Hot-dip galvanizing may serve as the sole corrosion protection of sheet steel, but other zinc coatings are, in addition, required to be painted on all exterior surfaces.

46. Wiring

46.1 Insulation - A conductor shall have rubber insulation and a saturated braid, except that a thermoplastic-insulated conductor may be used if not subject to vibration or to flexing at low temperature.

46.2 Splices - A splice shall be made in accordance with the requirements in paragraph 19.1 as modified in paragraph 19.2 and, unless a suitable insulated wire connector is used, shall be covered with rubber and friction tape or thermoplastic tape as outlined in paragraph 19.4. Other insulating materials may be accepted if investigated and found suitable for the particular application.

ARTICLE 370 - OUTLET, SWITCH AND JUNCTION BOXES, AND FITTINGS

370-1 SCOPE

This article covers the installation and use of boxes containing outlets, receptacles, switches or devices; junction or pull boxes and conduit bodies as required by Section 300-15. Fittings referred to in Section 300-15 used as outlet, junction or pull boxes shall conform with the provisions of this article depending on their use.

Installations in hazardous locations shall conform to Articles 500 through 517.

For systems over 600 volts, nominal, see Part D of this article.

370-2 ROUND BOXES

Round boxes shall not be used where conduits or connectors requiring the use of locknuts or bushings are to be connected to the side of the box.

This rule requires the use of rectangular or octagonal boxes having a flat bearing surface at each knockout for locknuts and bushings to ensure an adequate mechanical connection and effective electrical continuity.

370-3 NONMETALLIC BOXES

Nonmetallic boxes not over 100 cubic inches shall be permitted only with open wiring on insulators, concealed knob-and-tube wiring, nonmetallic-sheathed cable, and with rigid nonmetallic conduit.

Nonmetallic boxes over 100 cubic inches manufactured with bonding means between all raceway and cable entries shall be permitted to be used with metal raceways and metal-sheathed cable.

370-4 METAL BOXES

Where used with knob-and-tube wiring or nonmetallic-sheathed cable, and mounted on or in contact with metal or metal lath ceilings, walls, or metallic surfaces, metal boxes shall be grounded.

Years ago, the use of metal boxes with knob-and-tube wiring or nonmetallic sheathed cable (without a grounding wire) was quite common. Good practice was to ground the metal box by means of a separate grounding conductor, usually to a cold water pipe. This grounding connection would protect against the energization of conductive thermal insulation or metal lathe or any metal objects should a "hot" wire accidentally become grounded through the metal box.

B. Installation

370-5 DAMP OR WET LOCATIONS

In damp or wet locations, boxes and fittings shall be so placed or equipped as to prevent moisture from entering or accumulating within the box or fitting. Boxes and fittings installed in wet locations shall be approved for the purpose.

For boxes in floors, see Section 370-17(b).

For protection against corrosion, see Section 300-6.

Article 100 defines "Weatherproof" as, "so constructed or protected that exposure to the weather will not interfere with successful operation." Rainproof, raintight, or watertight equipment fulfills the requirements for weatherproof, protecting against rain, snow, ice, dust, or temperature extremes.

A "weatherhead" fitting is considered weatherproof because the openings for the conductors are placed in a downward position so that rain or snow cannot enter the fitting.

See definition of "Wet and Damp Locations" and "Weatherproof" in Article 100.

Commentary:

As determined by the terminal study, Appendix 15, the quick connect terminal or "fitting" is a more economical alternative to the junction box. Quick connect designs are currently available that meet or exceed the "weatherproof" requirement of 370-5. Of those currently produced, none has been found with capacity greater than #14 AWG, but conversation with one manufacturer indicates that larger ampacity connectors or terminals would not be a problem.

Should the junction box be used, the module manufacturer should be aware of other requirements in this article. All of those sections will not be included in this document. Junction box construction specifications are reprinted however to show the quality of the box and accessories required if the box is to be used as part of the panel. UL standards 50 and 514 set requirements for junction boxes.

C. Construction Specifications

370-20 METAL OUTLET, SWITCH AND JUNCTION BOXES, AND FITTINGS

Metal outlet, switch and junction boxes, and fittings shall comply with (a) through (c) below.

(a) Corrosion-Resistant. Metal boxes and fittings shall be corrosion-resistant or shall be well galvanized, enameled, or otherwise properly coated inside and out to prevent corrosion.

See Section 300-6 for limitation in the use of boxes and fittings protected from corrosion solely by enamel.

(b) Thickness of Metal. Sheet steel boxes and fittings not over 100 cubic inches in size shall be made from steel not less than 0.0625 inches thick. The wall of a malleable iron box and a diecast or permanent-mold cast aluminum, brass or bronze box shall not be less than 3/32 inch thick. Other cast metal boxes shall have a wall thickness not less than 1/8 inch.

(c) Metal Boxes Over 100 Cubic Inches. Metal boxes over 100 cubic inches in size shall comply with the provisions of 373-10(a) and 373-10(b).

Exception: It shall be permissible for covers to consist of single flat sheets secured to the box proper by screws or bolts instead of hinges. Boxes having covers of this form shall be used only for enclosing joints in conductors or to facilitate the drawing in of wires and cables. They shall not be used to enclose switches, cutouts, or other control devices.

370-21 COVERS

Metal covers shall be of a thickness not less than that specified for the walls of the box or fitting of the same material and with which they are designed to be used, or shall be lined with firmly attached insulating material not less than 1/32 inch in thickness. Covers of porcelain or other approved insulating material shall be permitted if of such form and thickness as to afford the required protection and strength.

370-22 BUSHINGS

Covers of outlet boxes and outlet fittings having holes through which flexible cord pendants may pass, shall be provided with approved bushings or shall have smooth, well-rounded surfaces, upon which the cord may bear. Where conductors other than flexible cord may pass through a metal cover, a separate hole equipped with a bushing of suitable insulating material shall be provided for each conductor.

370-23 NONMETALLIC BOXES

Provisions for supports or other mounting means for nonmetallic boxes shall be outside of the box, or the box shall be so constructed as to prevent contact between the conductors in the box and the supporting screws.

370-24 MARKING

All boxes and conduit bodies, covers, extension rings, plaster rings, and the like shall be durably and legibly marked with the manufacturer's name or trademark.

CHAPTER FOUR - EQUIPMENT FOR GENERAL USE

Commentary:

This chapter establishes safety standards for specific electrical equipment. Correspondence with NEC officials has indicated a need for defining code requirements for the PV module as the code does not specifically cover it. Richard Lloyd, Chairman of the NEC Committee, in a letter to Burt Hill Kosar Rittelmann Associates, wrote: "Because the Code does not attempt to cover the detailed requirements of equipment [the photovoltaic module or panel] it may be appropriate to cover these in a specific safety standard for the equipment itself." He added: "Perhaps this is the type of situation where a Technical Subcommittee could be useful in doing some of the preliminary work of preparing proposed requirements.

I will plan to have this subject matter considered at the next meeting of the Correlating Committee to be held in February 1979."

Module manufacturers should keep themselves informed of all proposed Code additions related to the residential modules, and should be represented by a member in the Technical Subcommittee reviewing Code additions or revisions.

Chapter 4 Articles that apply to the module (panel) are: Flexible Cords and Cables, Fixture Wires, Appliances, and Generators.

ARTICLE 400 - FLEXIBLE CORDS AND CABLES
ARTICLE 402 - FIXTURE WIRES

Commentary:

"Higher" voltage (100 - 220 volt) PV systems will produce lower currents. Some economy can be achieved by using smaller wires. Flexible cords and cables, and Fixture Wires are approved in smaller wire sizes than those conductors and cables given in Chapter Three - Wiring Methods and Materials. These Articles are reviewed to establish their acceptibility.

400-8 USES NOT PERMITTED (CORDS AND CABLES)

Unless specifically permitted in Section 400-7 flexible cords and cables shall not be used (1) as a substitute for the fixed wiring of a structure; (2) where run through holes in walls, ceilings, or floors; (3) where run through doorways, windows, or similar openings; (4) where attached to building surfaces; or (5) where concealed behind building walls, ceilings, or floors.

Commentary:

Conductors classified as flexible cords and cables are not acceptable for wiring PV arrays.

402-10 USES PERMITTED (FIXTURE WIRES)

Fixture wires shall be permitted: (1) for installation in lighting fixtures and in similar equipment where enclosed or protected and not subject to bending or twisting in use; or (2) for connecting lighting fixtures to the branch-circuit conductors supplying the fixtures.

Commentary:

The RPM operating temperature and voltage are similar to that of a typical lighting fixture (i.e., two, four foot lamps in a 2' x 4' troffer) and the RPM wiring is not subject to bending or twisting in use. The PV module appears to be similar in nature to lighting fixtures and should be approved for use with fixture wires; however, an official interpretation must be sought.

Tables of acceptable types of wire and cord for fixtures are available in the 1978 NEC, in UL Standard #57, and from wiring manufacturers.

ARTICLE 410 - LIGHTING FIXTURES

Commentary:

Review of the Lighting Fixture requirements indicated several similarities between PV panels and lighting fixtures. Those sections which are similar and shed some light on the photovoltaics module are reprinted here with commentary.

410-4 FIXTURES IN SPECIFIC LOCATIONS

(a) Wet and Damp Locations. Fixtures installed in wet or damp locations shall be approved for the purpose and shall be so constructed or installed that water cannot enter or accumulate in wireways, lampholders, or other electrical parts. All fixtures installed in wet locations shall be marked, "Suitable for Wet Locations". All fixtures installed in damp locations shall be marked, "Suitable for Wet Locations" or "Suitable for Damp Locations".

Installations underground or in concrete slabs or masonry in direct contact with the earth, and locations subject to saturation with water or other liquids, such as locations exposed to weather and unprotected, vehicle washing areas, and like locations, shall be considered to be wet locations with respect to the above requirement.

Interior locations protected from weather but subject to moderate degrees of moisture, such as some basements, some barns, some cold storage warehouses and the like, the partially protected locations under canopies, marquees, roofed open porches, and the like, shall be considered to be damp locations with respect to the above requirement.

See Article 680 for lighting fixtures in swimming pools, fountains, and similar installations.

Fixtures marked "Suitable for Wet Locations" are to be used where exposed to the weather or where subject to water saturation. Construction, design, and installation are to be such as to prevent the entrance of rain, snow, ice, and dust. Outdoor parks and parking lots, outdoor recreational areas (tennis, golf, baseball, etc.), car wash areas, and building exteriors are areas which would be considered "wet locations".

Areas protected from the weather and not subject to water saturation, but exposed to moisture, such as the underside of store or gasoline station canopies, or theater marquees, some cold-storage warehouses, some agricultural buildings, some basements, and roofed open porches and carports may be considered "damp locations" and fixtures are to be marked "Suitable for Damp Locations".

Fixtures suitable for wet or damp locations are to function under the effects of temperature changes, that is, operate efficiently during periods of extreme cold or high humidity. See Article 100, Definitions, "Location: Damp, Dry, and Wet".

E. Grounding

410-17 GENERAL

Fixtures and lighting equipment shall be grounded as provided in Part E of this Article.

410-18 EXPOSED FIXTURE PARTS

(a) The exposed conductive parts of lighting fixtures and equipment directly wired or attached to outlets applied by a wiring method which provides an equipment ground shall be grounded.

(b) Fixtures directly wired or attached to outlets supplied by a wiring method which does not provide a ready means for grounding shall be made of insulating material and shall have no exposed conductive parts.

410-19 EQUIPMENT OVER 150 VOLTS TO GROUND

(a) Metal fixtures, transformers, and transformer enclosures on circuits operating at over 150 volts to ground shall be grounded.

(b) Other exposed metal parts shall be grounded or insulated from ground and other conducting surfaces and inaccessible to unqualified persons.

Exception: Lamp tie wires, mounting screws, clips, and decorative bands on glass lamps spaced not less than 1 1/2 inches from lamp terminals shall not be required to be grounded.

410-21 METHODS OF GROUNDING

Equipment shall be considered grounded where mechanically connected in a permanent and effective manner to metal raceway, the armor of armored cable, mineral-insulated metal-sheathed cable, and the continuous sheath of Type MC cable, the grounding conductor in nonmetallic-sheathed cable, or to a separate grounding condutor sized in accordance with Table 250-95, provided that the raceway, armor, or grounding conductor is grounded in a manner specified in Article 250.

F. Wiring of Fixtures

410-22 FIXTURE WIRING - GENERAL

Wiring on or within fixtures shall be neatly arranged and shall not be exposed to physical damage. Excess wiring shall be avoided. Conductors shall be so arranged that they shall not be subjected to temperatures above those for which they are rated.

410-23 CONDUCTOR SIZE

Fixture conductors shall not be smaller than No. 18.

410-24 CONDUCTOR INSULATION

(a) Fixtures shall be wired with conductors having insulation suitable for the current, voltage, and temperature to which the conductors will be subjected.

(b) Where fixtures are installed in damp, wet, or corrosive locations, conductors shall be of a type approved for the purpose.

410-31 FIXTURES AS RACEWAYS

Fixtures shall not be used as a raceway for circuit conductors.

Exception No. 1: Fixtures approved for use as a raceway.

Fixtures approved for use as raceways are labeled by Underwriters Laboratories Inc. as "fixtures suitable for use as raceways".

Exception No. 2: Fixtures designed for end-to-end assembly to form a continuous raceway or fixtures connected together by recognized wiring methods shall be permitted to carry through conductors of a two-wire or multiwire branch circuit supplying the fixtures.

Exception No. 3: One additional two-wire branch circuit separately supplying one or more of the connected fixtures described in Exception No. 2 shall be permitted to be carried through the fixtures.

Exception No. 3 permits an additional 2-wire circuit to be carried through the fixtures to supply switched night lighting commonly used to conserve energy.

See Article 100 for definition of multiwire branch circuit.

Branch-circuit conductors within 3 inches of a ballast within the ballast compartment shall be recognized for use at temperatures not lower than 90°C (194°F), such as Types RHH, THW, THHN, FEP, FEPB, SA, XHHW and AVA.

410-37 NONMETALLIC FIXTURES

In all fixtures not made entirely of metal or noncombustible material, wireways shall be lined with metal.

Exception: Where armored or lead-covered conductors with suitable fittings are used.

410-57 RECEPTACLES IN DAMP OR WET LOCATIONS

(a) Damp Locations. A receptacle installed outdoors in a location protectdd from the weather or in other damp locations shall have an enclosure for the receptacle that is weatherproof when the receptacle is covered (attachment plug cap not inserted and receptacle covers closed.)

An installation suitable for wet locations shall also be considered suitable for damp locations.

A receptacle shall be considered to be in a locaton protected from the weather where located under roofed open porches, canopies, marquees, and the like, and will not be subjected to a beating rain or water run-off.

(b) Wet Locations. A receptacle installed outdoors where exposed to weather or in other wet locations shall be in a weatherproof enclosure, the integrity of which is not affected when the receptacle is in use (attachment plug cap inserted).

Exception: An enclosure that is weatherproof only when a self-closing receptacle cover is closed shall be permitted to be used for a receptacle installed outdoors where the receptacle is not likely to be used with other than portable tools or other portable equipment not usually left connected to the outlet indefinitely.

410-75 VOLTAGES - DWELLING OCCUPANCIES

(a) Equipment having an open-circuit voltage exceeding 100 volts shall not be installed in dwelling occupancies.

(b) Equipment having an open-circuit voltage exceeding 300 volts shall not be installed in dwelling occupancies unless such equipment is so designed that there will be no exposed live parts when lamps are being inserted, are in place, or are being removed.

Fixtures intended for use in other than dwelling occupancies are so marked. This usually indicates that the fixture has maintenance features that are considered to be beyond the capabilities of the ordinary householder or involve voltages in excess of those permitted by this Code for dwelling occupancies. See Sections 210-6(c)(1) and (c)(2).

Commentary:

Summarizing the important points:

1. *Lighting fixtures operating under 150 volts are not required to be grounded. The reason for the 150 volt level is not clear. Code officials have not been questioned in this regard.*
2. *UL protection requirements for conductors (not reprinted in this document) are similar to those given in the NEC.*
3. *Fixture conductors shall not be smaller than No. 18 AWG.*
4. *Fixtures may be used as raceways if approved for the purpose.*
5. *Definitions of damp and wet location for fixtures and fixture receptacles may reasonably be applied to RPM and PV terminals.*
6. *A 300 volt maximum has been established for lighting fixtures. This may not be as critical for PV since PV systems can be designed to be virtually inaccessible to the householder if a voltage level greater than 300 is desired.*

ARTICLE 422 - APPLIANCES

Commentary:

Since one correspondence with Code officials indicated that the RPM may be considered an appliance, this Article was carefully reviewed. It was found that this article does not contain any information that can be directly related to the PV module.

ARTICLE 445 - GENERATORS

Commentary:

Mr. Richard Lloyd, Chairman of the NEC Committee, feels that the "photovoltaic panel is a form of electric generator now covered by Article 445 of the Code." This section of the code was reviewed thoroughly.

445-1 GENERAL

Generators and their associated wiring and equipment shall comply with the applicable provisions of Articles 230, 250, 700 and 750.

Commentary:

Article 230 deals with Services, Article 250 with Grounding, Article 700 with Emergency Systems, and Article 750 with Stand-By Power Generation Systems. Articles 230 and 250 have already been reviewed and Articles 700 and 750 do not relate any information that has not already been addressed.

445-2 LOCATION

Generators shall be of a type suitable for the locations in which they are installed. They shall also meet the requirements for motors in Section 430-14. Generators installed in hazardous locations as described in Articles 500 through 503, or in other locations as described in Articles 510 through 517, and in Articles 520, 530, and 665 shall also comply with the applicable provisions of those aritcles.

Commentary:

If classified as a generator, PV modules shall be of a type suitable for the locations in which they are installed. Some PV applications may be in hazardous or highly corrosive environments. This would require specially approved wiring methods.

The integral mount panel will require conductors and terminals for dry locations. The other mounting types, unless specifically designed to prevent water from entering the frame or raceways must use conductors and terminals suitable for wet locations.

As an explanation of references made in 445-2: Articles 500 - 503 deal with locations "where fire or explosion hazards may exist"; Articles 510 - 517 "cover occupancies or parts of occupancies that are or may be hazardous *because of atmospheric concentrations of flammable liquids, gases, or vapors, or because of deposits or accumulations of materials that may be readily ignitable"; and Article 520 covers Theaters and Similar Locations, Article 530 covers Motion Picture and Television Studios and Similar Locations, and Article 665 covers Induction and Dielectric Heating Equipment.*

445-3 MARKING

Each generator shall be provided with a nameplate giving the maker's name, the rated frequency, power factor, number of phases if of alternating current, the rating in kilowatts or kilovolt amperes, the normal volts and amperes corresponding to the rating, rated revolutions per minute, insulation system class and rated ambient temperature or rated temperature rise, and time rating.

Commentary:

In addition to that mentioned, other information for PV may be required. That information will be determined by the Code Committee.

445-4 OVERCURRENT PROTECTION

(a) Constant-Voltage Generators. Constant-voltage generators, except alternating-current generator exciters, shall be protected from overloads by inherent design, circuit breakers, fuses, or other acceptable current-limiting means, suitable for the conditions of use.

(b) Two-Wire Generators. Two-wire, direct-current generators shall be permitted to have overcurrent protection in one conductor only if the overcurrent device is actuated by the entire current generated other than the current in the shunt field. The overcurrent device shall not open the shunt field.

(c) 65 Volts or Less. Generators operating at 65 volts or less and driven by individual motors shall be considered as protected by the overcurrent device protecting the motor if these devices will operate when the generators are delivering not more than 150 percent of their full-load rated current.

(d) Balancer Sets. Two-wire, direct-current generators used in conjuction with balancer sets to obtain neutrals for 3-wire systems shall be equipped with overcurrent devices that will disconnect the 3-wire system in case of excessive unbalancing of voltages or currents.

Commentary:

There appears to be no need for overcurrent protection. Maximum solar radiation and therefore maximum module output can be predicted.

445-5 AMPACITY OF CONDUCTORS

Commentary:

Conductors should be able to carry peak output. Peak output shall be specified.

445-6 PROTECTION OF LIVE PARTS

Live parts of generators of more than 150 volts to ground shall not be exposed to accidental contact where accessible to unqualified persons.

445-7 GUARDS FOR ATTENDANTS

Where necessary for the safety of attendants, the requirements of Section 430-133 shall apply.

Commentary:

The nature of the RPM makes it accessible to unqualified persons, including children and householders. Based on the detailed discussion following Section 110-17, wherein 50 V dc is questioned as a safe level for residential applications, revision of this section to exclude accessibility of live parts at any voltage should be considered.

445-8 BUSHINGS

Where wires pass through an opening in an enclosure, conduit box, or barrier, a bushing shall be used to protect the conductors from the edges of an opening having sharp edges. The bushing shall have smooth, well-rounded surfaces where it may be in contact with the conductors. If used where oils, grease, or other contaminants may be present, the bushing shall be made of a material not deleteriously affected.

Commentary:

This section applies directly.

ARTICLE 545 - MANUFACTURED BUILDING

Commentary:

Chapter Five deals with Special Occupancies.

Manufactured building is defined as "any building which is of closed construction and which is made or assembled in manufacturing facilities on or off the building site for installation, or assembly and installation on the *building site, other than mobile homes or recreational vehicles."*

Article 545 allows the RPM manufacturer the opportunity to develop a photovoltaic electrical power system in which all modules/panels are field connected with fittings and connectors that snap together. The system design can eliminate junction boxes and other enclosures that would be required of all conductor splices. A well developed system could minimize both labor and material costs making photovoltaics less costly and, so, more economically attractive.

A. General

545-1 SCOPE

This article covers requirements for a manufactured building and/or building components as herein defined.

545-2 OTHER ARTICLES

Wherever the requirements of other articles of this Code and Article 545 differ, the requirements of Article 545 shall apply.

545-3 DEFINITIONS

(a) Manufactured Building: "Manufactured Building" means any building which is of closed construction and which is made or assembled in manufacturing facilities on or off the building site for installation, or assembly and installation on the building site, other than mobile homes or recreational vehicles.

(b) Building Component: "Building Component" means any subsystem, subassembly, or other system designed for use in or integral with or as part of a structure, which can include structural, electrical, mechanical, plumbing and fire protection systems and other systems affecting health and safety.

(c) Building System: "Building System" means plans, specifications and documentation for a system of manufactured building or for a type or a system of building components, which can include structural, electrical, mechanical, plumbing, and fire protection systems, and other systems affecting health and safety, and including such variations thereof as are specifically permitted by regulation, and which variations are submitted as part of the building system or amendment thereto.

(d) Closed Construction; "Closed Construction" means any building, building component, assembly or system manufactured in such a manner that all concealed parts of processes of manufacture cannot be inspected before installation at the building site without disassembly, damage, or destruction.

545-4 WIRING METHODS

(a) All raceway and cable wiring methods included in this Code and such other wiring systems specifically intended and approved for use in manufactured building shall be permitted with approved fittings and with fittings approved for manufactured building. Where wiring devices with integral enclosures are used, sufficient length of conductor shall be provided to facilitate replacement.
(b) In closed construction, cables shall be permitted to be secured only at cabinets, boxes or fittings where No. 10 AWG or smaller conductors are used and protection against physical damage is provided as required by Section 300-4.

Commentary:
This article accepts all wiring methods of Chapter 3 along with any "wiring systems specifically intended and approved for use in manufactured building". Those systems specifically intended and approved for this type of application are not given in the Article, although several examples of components used in this type of system are given in the NEC Handbook, such as a "boxless switch or boxless receptacle" and a "nonmetallic-sheathed cable connector" used for interconnecting modular building components.

Modular building systems are generally proprietary and require close association between manufacturers to provide a well integrated system. It is the policy of the NEC to avoid promoting any proprietary wiring methods. This explains the lack of specific information on approved wiring methods.

545-5 SERVICE-ENTRANCE CONDUCTORS

Service-entrance conductors shall meet the requirements of Article 230. Provisions shall be made to route the service-entrance conductors from the service equipment to the point of attachment of the service.

545-6 INSTALLATION OF SERVICE-ENTRANCE CONDUCTORS.

Service-entrance conductors shall be installed after erection at the building site.

Exception: Where point of attachment is known prior to manufacture.

545-7 SERVICE EQUIPMENT LOCATION

The service equipment shall be located at a readily accessible point nearest to the entrance of the conductors either inside or outside the building.

545-8 PROTECTION OF CONDUCTORS AND EQUIPMENT

Protection shall be provided for exposed conductors and equipment during process of manufacturing, packaging, in transit, and erection at the building site.

545-9 OUTLET BOXES

(a) Outlet boxes of dimensions other than those required in Table 370-6(a) shall be permitted to be installed when tested and approved to applicable standards.

(b) Any outlet box not over 100 cubic inches in size, approved for the purpose and mounted in closed construction, shall be affixed with approved anchors or clamps so as to provide a rigid and secure installation.

545-10 RECEPTACLE OR SWITCH WITH INTEGRAL ENCLOSURE

A receptacle with integral enclosure and mounting means, when tested and approved to applicable standards, shall be permitted to be installed.

545-11 BONDING AND GROUNDING

Prewired panels and/or building components shall provide for the bonding and/or grounding of all exposed metals likely to become energized, in accordance with Article 250, Parts E, F and G.

545-12 GROUNDING ELECTRODE CONDUCTOR

The grounding electrode conductor shall meet the requirements of Article 250, Part J. Provisions shall be made to route the grounding electrode conductor from the service equipment to the point of attachment of the grounding electrode.

545-13 COMPONENT INTERCONNECTIONS.

Fittings and connectors which are intended to be concealed at the time of on-site assembly, when tested and approved to applicable standards shall be permitted for on-site interconnection of modules or other building components. Such fittings and connectors shall be equal to the wiring method employed in insulation, temperature rise, fault-current withstand and shall be capable of enduring the vibration and minor relative motions occurring in the components of manufactured building.

Structural components or modules are usually constructed in manufacturing facilities and then transported over the road to a building site for complete assembly of, for instance, a dwelling unit, a motel, an office building, etc. At the on-site location, approved wiring methods are employed to interconnect two or more modules. Figures 545-2 and 545-3 show a type of nonmetallic-sheathed cable connector permitted for such interconnections.

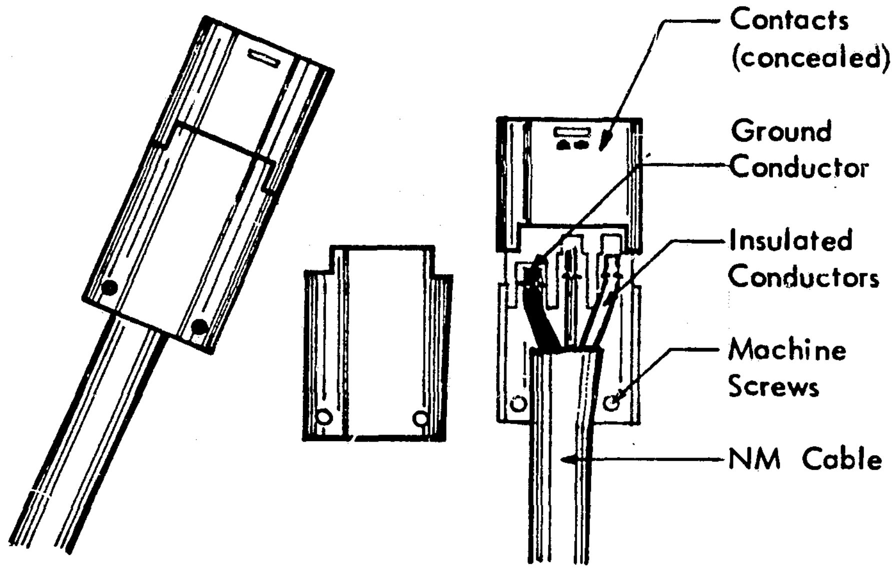


Figure 545-2. A type of nonmetallic-sheathed cable connector used for interconnecting modules in a manufactured building. The parts are shown before mating together. (Amp Inc.)

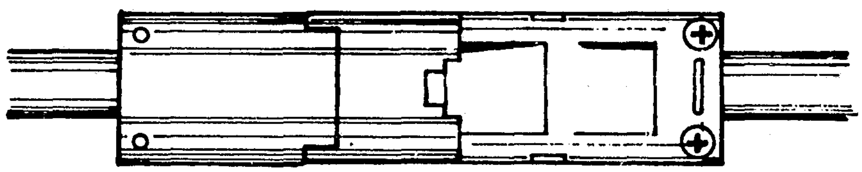


Figure 545-3. The nonmetallic-sheathed cable connector shown in Figure 545-2 after being joined together. (Amp Inc.)

ARTICLE 720 - CIRCUITS AND EQUIPMENT OPERATING AT LESS THAN 50 VOLTS

Commentary:

This article addresses the fact that lower voltage systems will operate at higher currents under typical loads. Section 720-4 states, "Conductors shall not be smaller than No. 12 copper or equivalent." PV systems should be exempted from this requirement as maximum panel current will not require No. 12 copper conductors in most cases.

ARTICLE 725 - POWER LIMITED CIRCUITS

Commentary:

See Commentary following Section 300-1.

NATIONAL ELECTRICAL CODE SUMMARY

GENERAL

The purpose of the CODE is practical safeguarding of persons and property. Photovoltaic systems are not mentioned in the present code; although because of their nature they could be classified as module building components. Future code revisions to include special PV requirements is anticipated.

SAFETY

Live parts operating at 50 volts or more shall be guarded against accidental contact during installation. This may, however, be necessary at all voltage levels.

TERMINALS

Quick connect terminals, although not specifically mentioned in the Code, are a recognized method for making electrical connections. Some municipality codes do not recognize quick connect splices where installations are considered to be permanent.

GROUNDING

Metal framed panels will require grounding unless special provisions for isolating live wires are made. Metal frames used as conductor raceways require grounding.

WIRING

Factory installed internal woring of equipment does not come under the jurisdiction of the Code, if the equipment has been listed by an electrical testing laboratory.

All conductors used for general wiring shall not be smaller than #14 copper. Wiring used in lighting fixtures and similar equipment shall not be smaller than #18 copper. PV panels may possibly be considered to be similar to lighting fixtures.

Conductor operating temperatures for specific mounting types must be determined so that conductors can be properly sized.

Modular wiring systems, i.e., factor fabricated cable/terminal assemblies intended to minimize field labor are recognized by the Code.

APPENDIX 5. STANDARDS

PURPOSE: To review and describe the generic types of standards and standards writing organizations.

CONCLUSIONS: There is a wide range of standards and organizations involved with standards that will ultimately effect any PV module manufacturer's ability to penetrate the residential marketplace with a particular module design.

RECOMMENDATIONS: With the multiplicity of standards which can effect early conceptual PV module design for the residential market, any manufacturer should be aware of at least the major documents which will guide and direct his research efforts. The outcome of this research can be either the development of a module which conforms to standards, an industry program which changes existing standards, or the writing of new standards which better describe the product's role in the residential marketplace. For a method of standards review for residential modules see Appendix 7, Standards Review Method. For a preliminary listing of relevant documents, see Appendix 19, Residential Photovoltaic Module Performance Criteria.

INTRODUCTION

Within the body of all codes, references are made to standards and tests developed by industry to evaluate new products or technologies for compliance.

A building standard, therefore, is a specific requirement or instruction for the design, manufacture, installation and use of a building component, system, or material that will provide an acceptable level of performance under in-use conditions. A standard exists when an agreement has been obtained on its content. The level of agreement ranges from a small group of interested parties to national or international standards which have been developed through the consensus process. Consensus standards supplement building codes whether they be model codes, state codes, or local codes. The most widely accepted method of this utilization is to reference standards in the appendix of the code and then to spell out the conditions of their applicability in the text of the code. As an example of the dependence of building codes on standards, the Basic Building Code references over 400 standards. There are also over 400 organizations in this country developing building standards which are used in over 1,000 different local, state and national building codes. These organizations include trade associations, engineering societies, testing laboratories, building code organizations, government agencies, and manufacturers.

TYPES OF STANDARDS

Four generic types of standards exist as defined by the American Society for Testing and Materials (ASTM). They are as follows:

- Specification - "is a precise statement of a set of requirements to be satisfied by a material, product, system, a service, indicating, whenever appropriate, the procedure by means of which it may be determined whether the requirements given are satisfied. As far as practicable, it is desirable that the requirements be expressed numerically in terms of appropriate units together with their limits"

  An example of a specification is ASTM B135, "Specification of Seamless Brass Tube."

- Test Method Standard - "covers sampling and describes the subsequent testing procedures used in determining the properties, composition, or performance that may be specified. A test method shall not include numerical limits for the properties, composition, or performance."

  An example of this type of standard is ASTM E119, "Standard Method of Fire Tests of Building Construction and Materials." This standard gives procedures for evaluating structural response during and after the test and the passage of heat, smoke and fire, but does not give acceptable limits for each. These are usually provided in the provisions of the building code.

- Classification - "as applied to materials, products, systems or services defines systematic arrangement or division into groups based on similar characteristics such as origin, composition, properties or use."

  An example of a classification standard is ASTM C27, "Classification of Fireclay and High-Alumina Refractory Brick."

- Recommended Practice - "is a procedure, guide or service that may or may not be auxiliary to a test method or specification. Examples of such include selection, preparation, application, inspection, necessary precautions for use of disposal, installation, maintenance and operation of testing apparatus."

  An example of an existing recommended practice is ASTM D750-68, "Recommended Practice for Operating Light - and Weather - Exposure Apparatus (Carbon Arc Type) for Artificial Weather Testing of Rubber Compounds."

Performance Vs. Prescriptive Standards

A prescriptive standard is quite specific in nature giving details of usage or design procedures for a building material, component or system. An example of a prescriptive requirement would be that timber wall framing shall be 2 by 4 studs on 16 inch centers. A performance standard prescribes objectives, conditions and criteria to be accomplished and allows broad leeway for the designer to achieve results. The performance statement for the above condition would be that the wall system shall be designed to specified loading and deformation criteria. This type of statement allows the innovative designer freedom to select the materials and other specific construction details.

In some cases, true performance codes (and standards) are difficult to administer, and most codes combine performance criteria and prescriptive requirements. As an example, the model building codes normally contain general statements of performance objectives for the various elements of the building followed by a description of acceptable ways to build that element, or use a given material, or a reference to a national standard which in itself is a specification. This provides broad opportunities for the designer while simplifying the design and use of conventional materials.

Voluntary Standards Developing System

Most national standards in the United States are produced through a "voluntary system" made up of government and industry, producers and consumers, institutions and individuals. It is "voluntary" because participation of interested parties is on a voluntary basis and the standards produced are intended for use within building regulations.

The consensus concept has become quite important in the voluntary standards generating process to ensure that the standards produced have widespread acceptance and use. ASTM defines a consensus standard as: "a standard produced by a body selected, organized, and conducted in accordance with the procedural standards of 'due process'. In standards development practice a consensus is achieved when substantial agreement is reached by concerned interests according to the judgement of a duly-appointed review authority." The standards of "due process" include an adequate notice of proposed standards undertaking to all persons likely to be affected, opportunity for wide participation of affected interests in meetings, adequate maintenance and distribution of meeting records, timely reports on ballots, attention to minority opinions, and other such requirements.

FEDERAL STANDARDS

The increasing federal government involvement in the problems of housing, urban development and energy are having an increasing impact on building standards and codes and their administration. The result is a series of building standards, some of which are mandatory in nature.

- FHA Minimum Property Standards (MPS) - Faced with the necessity of applying common criteria for underwriting mortgage loan insurance on a nationwide basis, the Federal Housing Administration (FHA) began development of its own set of minimum standards for new residential housing in 1934. The MPS was published in

1934. The MPS was published in 1940 for multifamily projects and in 1942 for single-family dwellings. The MPS applies to housing which is constructed under the FHA mortgage loan insurance program. (See Appendix 6 Federal Standards Review).

The MPS have played only a small role in the development of building code requirements since the FHA has never promoted them as a substitute for local building codes. However, the MPS have played a major role in shaping the design of residential housing since builders naturally shaped their designs to meet MPS requirements, even if they were not intended for inclusion under the FHA mortgage loan insurance program. The FHA "Use of Materials Bulletins" which signify FHA's approvals of new materials for housing, have become a major checkpoint for the introduction of new materials. The Veterans Administration and Farmers Home Admistration require that homes included under their mortgage insurance program comply with the FHA MPS.

- <u>Occupational Safety and Health Act</u> - The Federal Occupational Safety and Health Act of 1970 authorizes the Secretary of Labor to promulgate national health and safety standards applicable to places of employment. The national standard applies to the construction phase of all residential dwellings. However, OSHA's major impact is on commercial and industrial properties, and will not be addressed here.

In addition to the consensus developed standards which are used in building codes as previously described, there are complete building standards typified by the HUD Minimum Property Standards. Fortunately, these are almost all promulgated by the Federal Government (with some exceptions in a few states), and those dealing with residential construction are a manageable number. There are, in fact, building standards developed which specifically pertain to the solar heating and cooling of buildings such as "The Interim Performance Criteria for the Solar Heating and Cooling of Commercial Buildings" and the "HUD MPS Performance Standards for Residential Solar Heating and Cooling Systems." These two federal standard documents -- the format of one was the guideline for the Residential Photovoltaic Module Performance Criteria (RPMPC) as described in Appendix 19 -- along with all of the Standards from the American Society for Testing and Materials (ASTM), Underwriters Laboratories, Inc., (UL), and American Society of Mechanical Engineers (ASME), were reviewed for applicability to the residential photovoltaic modules.

APPENDIX 6. FEDERAL STANDARDS REVIEW

PURPOSE: Review two Federal Standards, the Housing and Urban Development (HUD) Minimum Property Standards for One and Two Family Dwellings, and the HUD Intermediate Minimum Property Standards Supplement for Solar Heating and Domestic Hot Water Systems, to determine the effect of these Standards on the design and installation of the RPM on one and two family dwellings in any of the four mounting types described in Appendix 13, Mounting Configurations.

CONCLUSIONS: Photovoltaic modules, panels, and arrays are not specifically addressed by the HUD Standards, however, the general subject of solar collectors is. The standards found here are consistent with the provisions of the model codes which were judged applicable to the RPM; roof coverings, e.g.,(Appendix 3). The one significant difference deals with structural requirements for an integral mounted array. The array must be capable of supporting a single concentrated load"...in the most critical locations" of 250 pounds distributed over a 4 in^2 area.

RECOMMENDATIONS: As the eligibility of a residence for HUD financing is determined by its adherence to HUD standards, the RPM should be designed consistent with these standards. The most critical requirement of the Standards, and one significantly different from any in the model codes, is that which deals with access to the array for servicing. In order to avoid severe point loading requirements, the RPM should be designed to provide for this access. This could result in the establishment of a maximum module and/or uninterrupted array sizes.

STANDARDS REVIEW

The "Interim Minimum Property Standards Supplement for Solar Heating and Domestic Hot Water Systems" is a supplement to and is to be used in conjunction with

MPS 4900.1 "HUD Minimum Property Standards for One and Two Family Dwellings." A dwelling complying with these standards is considered technically adequate under the programs of the Department of Housing and Urban Development. Though Residential Photovoltaic Modules are not dealt with specifically in the Solar Supplement, certain areas of commonality between the RPM and the solar thermal collectors can serve as valid guidelines for evaluating the RPM's potential compliance with existing standards.

These standards are not intended to serve as building codes (paragraph 102-1.1). However, where local code, regulation or requirement permits lower standards, the HUD Standards must be observed and are to have precedence if the property is to be considered eligible by HUD. A conflict between an applicable code and the HUD standards may also result in a property being declared ineligible "...unless the intent set forth..." in the Standards "...is fully attained by the alternate means proposed...".

Section 101 Variation to Standards specifically states, however, in paragraph S-101-1 that "These standards are intended to encourage the use of new or innovative designs, technologies, methods or materials in solar applications." The provisions are that any variations from the standards "...demonstrate, however, equivalent quality to the standards in operating effectiveness, structural soundness, durability, economy of maintenance or operation, and usability. Variations shall be made in accordance with Section 101-4 of the MPS," and Section 101-1 of the MPS.

Some sections of the standards approximate or parallel requirements of the nationally recognized model codes. For example, the Supplement in Section S-405-12, Roof Coverings, requires that the "Installation of solar collectors or system components on or as an integral part of the roof shall not reduce the fire retardant characteristics of the roof covering..." This statement is consistent with and in compliance with the requirements for roof coverings as stated in the model codes, avoiding conflicts while allowing flexibility in the choice of materials. The requirements are further enumerated in Table 4-5.1 of the supplement.

Another section of the standard which may be applied directly to the RPM is

Section S-51502.2, Cover Plates, and Appendix B-1 Properties of Typical Cover Plate Materials. The maximum areas permitted for the various types of glazing materials used in cover plates is stipulated in Figure 508.1 under a wide range of wind pressure conditions. This treatment of the cover material is similar to that of the model codes in their treatment of the requirement for veneers (Appendix 3). In view of the plastic limitations found in the model code surveys here, however, plastic materials are not dealt with.

Excluded from compliance with these requirements are glazing of two types which are defined in S-515-2.2.1.2b, and S-515-2.2.1.2c. "Glazing materials with slopes less than 45^{o} which extend below 6'-0" (from ground level) shall be safety glazed or otherwise protected against impact of falling bodies." This requirement is further explained as applying to arrays against which a passerby may fall or upon which a child may climb. The other special type of installation considered is glazing panels which are an integral part of a roof or part of a rack-mounted system on a roof. This second type appears to be more likely for the RPM. Installation of a module in a location susceptible to contact by children or passersby is not advisable.

In the case of glazing materials for modules which are rack-mounted or integrally mounted on roofs, the General Structural Requirements of Section S-601 apply. These deal with dead and live loads, wind, snow, and seismic loads as well as hail loads. The HUD standards, then, treat the integrally mounted module as a roof panel, and make similar demands on its structural integrity. These requirements, however, are enlarged to include hail loading, an aspect normally ignored in roof panel design. In fact, hail loading is ignored in Section 601, General Structural Requirements of the MPS.

The section on Design Live Loads (S-601-3) is of special interest. "Resistance to design live roof loads prescribed in Table 6-1.2 of MPS 4-900.1... shall not be required for collector panels that are mounted on roofs but do not form an integral part of the roof if adequate access is provided for service and maintenance personnel." This modification of the requirements stated in Section S-515-2.2.1.2c is both sensible and suggestive of a means for avoiding the more stringent structural requirements of the previous section. Further, Section S-601-3.2 requires that systems which must support maintenance personnel are to be capable of resisting "...a single concentrated load of 250 pounds distributed over a 4 in^2 area, acting on the installed component in the most critical locations." This should be adequate inducement for designing the RPM in a way to make it exempt from these structural requirements.

The requirements for wind, snow, hail and seismic loading of roof mounted collectors is generally unaffected by whether the collector is integrally mounted, rack, or standoff mounted. The exception is that standoff or rack mounted collectors "...shall resist any uplift load caused by the impingement of wind on the underside of the collector. This wind load is in addition to the equivalent roof area wind pressure and suction loads, and shall be determined by utilizing accepted engineering procedures which may include wind tunnel testing."

Finally, a rather general requirement, nevertheless worth considering, is stated in Section S-600-6. Safety and Health Requirements. Though the bulk of this section deals with components of solar thermal collectors, the opening statement could serve as a guideline for the RPM. This paragraph states that the incorporation of a solar system into a living unit must not create a more hazardous environment than a conventional living unit, and that it must "...not increase fire hazard or interfere with the means of safe egress in the event of a fire."

The following pages are a listing of referenced sections for all of the HUD Minimum Property Standard documents.

REVIEWED SECTIONS OF FEDERAL STANDARDS

HUD Minimum Property Standards
One and Two Family Dwellings

Introductory Statement

Chapter 4 Building Design

Table 4-5.1 Minimum Fire Resistance in Hours

Chapter 5 Materials

508-8 Glazing Panels
508-8.2 Quality
508-8.3 Maximum Glass Area
Figure 508.1 Wind Load Chart/Maximum Glass Area, Square Feet

513 Special Construction Materials

Appendix C - Maximum

Appendix F - Use of Materials Bulletins

HUD Intermediate Minimum Property Standards Supplement for
Solar Heating and Domestic Hot Water Systems
1977 Edition

Chapter 1 - General Use

S-100 Application
S-101 Variations to Standards

Chapter 4 - Building Design

S-405 Fire Protection

Chapter 5 - Materials
S-515-2.2 Cover Plates

S-515-2.2.1 General
S-515-2.2.2 Codes and Standards
S-515-2.2.3 Materials Performance

Appendix B-1 Properties of Typical Cover Plate Materials

Chapter 6 - Construction

S-601 General Construction Requirements

S-601-1 General
S-601-2 Design Dead Loads
S-601-3 Design Live Loads
S-601-4 Wind Loads
S-601-5 Snow Loads
S-601-6 Seismic Loads
S-601-7 Hail Loads
S-601-10 Collector Cover Plates

Chapter 5 Materials

508-8 Glazing Panels

508-8.2 Quality
508-8.3 Maximum Glass Area
Figure 5-8.1 Wind Load Chart/Maximum Glass Area, Sq.Ft.

513 Special Construction Materials

Appendix C - Materials Standards

Appendix F - Use of Materials Bulletins

<u>HUD Intermediate Minimum Property Standards Supplement For Solar Heating and Domestic Hot Water Systems 1977 Edition</u>

Chapter 1 - General Use

S-100 Applications
S-101 Variations to Standards

Chapter 4 - Building Design

S-405 Fire Protection

Chapter 5 - Materials

S-515-2.2 Cover Plates

S-515-2.2.1 General
S-515-2.2.2 Codes and Standards
S-515-2.2.3 Materials Performance

Appendix B-1 Properties of Typical Cover Plate Materials

Chapter 6 - Construction

S-601 General Structural Requirements

S-601-1 General
S-601-2 Design Dead Loads
S-601-3 Design Live Loads
S-601-4 Wind Loads
S-601-5 Snow Loads
S-601-6 Seismic Loads
S-601-7 Hail Loads
S-601-10 Collector Cover Plates

ANSI A58-1 Building Code Requirements for Minimum Loads in Buildings and Other Structures

ASTM E424-71 Standard Methods of Test for Solar Energy Transmittance and Reflectance (terrestrial) of sheet materials

ANSI Z97.1-1975 Safety Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings

APPENDIX 7. STANDARDS REVIEW

PURPOSE: Identify a process by which existing standards could be cataloged for review in reference to the residential photovoltaic module, panel, and array. Review the identified methods content and present the relevant ones in some format useful to the residential module designer.

CONCLUSIONS: Standards and Test Methods do exist which may be applied to the existing, yet immature, residential photovoltaic module technical characteristics outlined in this section (function, safety, mechanical, etc.) These standards are general in nature - usually developed in reference to other technical applications - and could be very restrictive to the developing PV technology, which may be parallel in character but very diverse in actual application.

RECOMMENDATIONS: Difficulty arises in the development of Standards which will direct a developing technology, such as residential photovoltaic modules, without undue restrictions. The use of in-place federal and consenses standards could place severe technical and possibly economic restrictions on the new modules. Therefore, it is imperative that the prospective photovoltaic module manufacturer work with standards development groups to generate relevant industry standards.

INTRODUCTION

The first step required to identify all the building standards affecting the residential photovoltaic module (RPM) was to develop a classification system for all potential module mounting configurations. These mounting configurations were then detailed in a preliminary fashion to allow consideration of the module to building and module to rack connection with regard to codes and standards. These four mounting types or building module integration types, are shown in Figure 7-1. Details for these mounting types have also been developed for use in cost estimating and are described further in Appendix 13, Mounting Configuration.

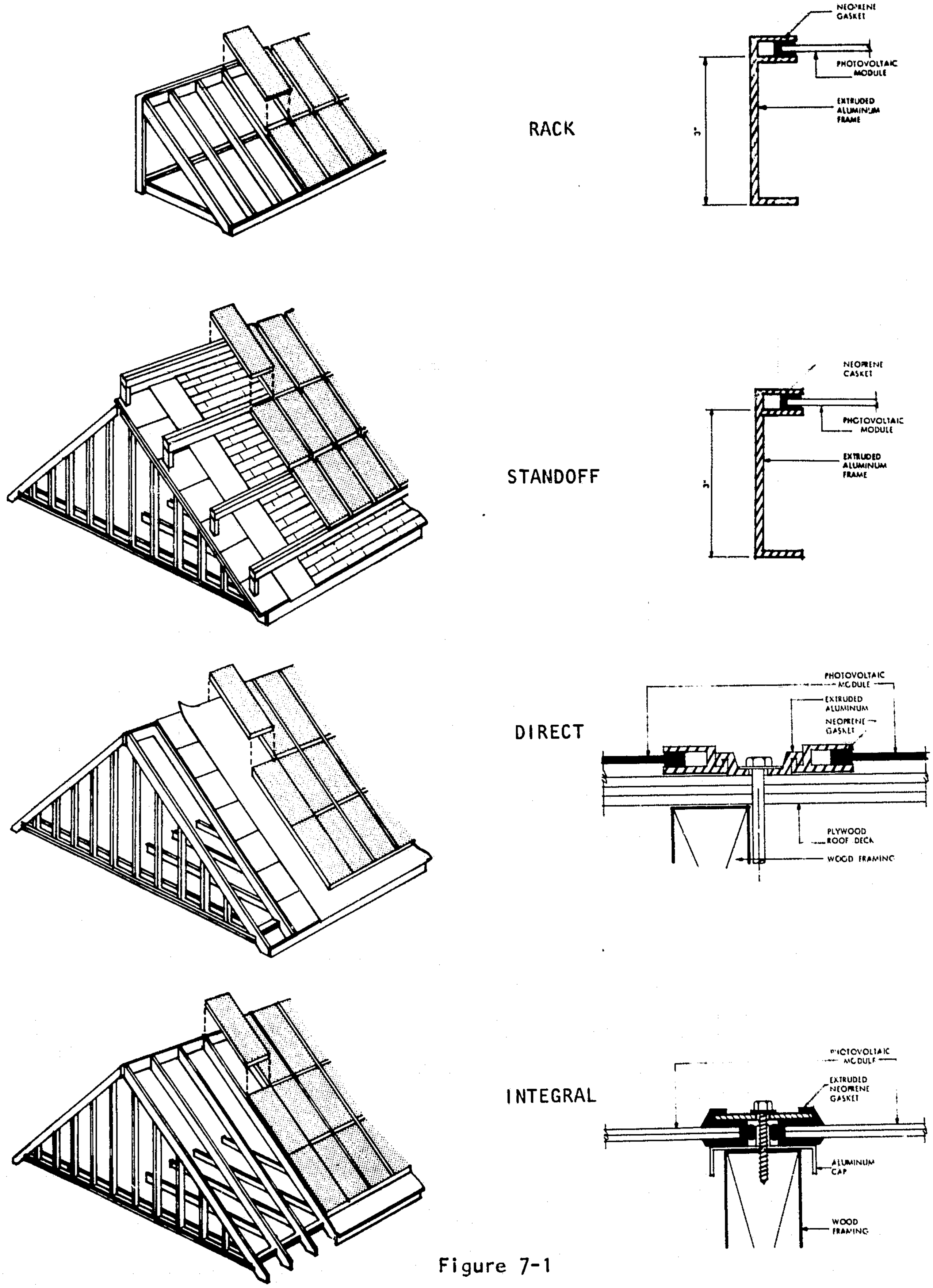

RACK
NEOPRENE GASKET
PHOTOVOLTAIC MODULE
EXTRUDED ALUMINUM FRAME
STANDOFF
NEOPRENE GASKET
PHOTOVOLTAIC MODULE
EXTRUDED ALUMINUM FRAME
DIRECT
PHOTOVOLTAIC MODULE
EXTRUDED ALUMINUM
NEOPRENE GASKET
PLYWOOD ROOF DECK
WOOD FRAMING
INTEGRAL
PHOTOVOLTAIC MODULE
EXTRUDED NEOPRENE GASKET
ALUMINUM CAP
WOOD FRAMING

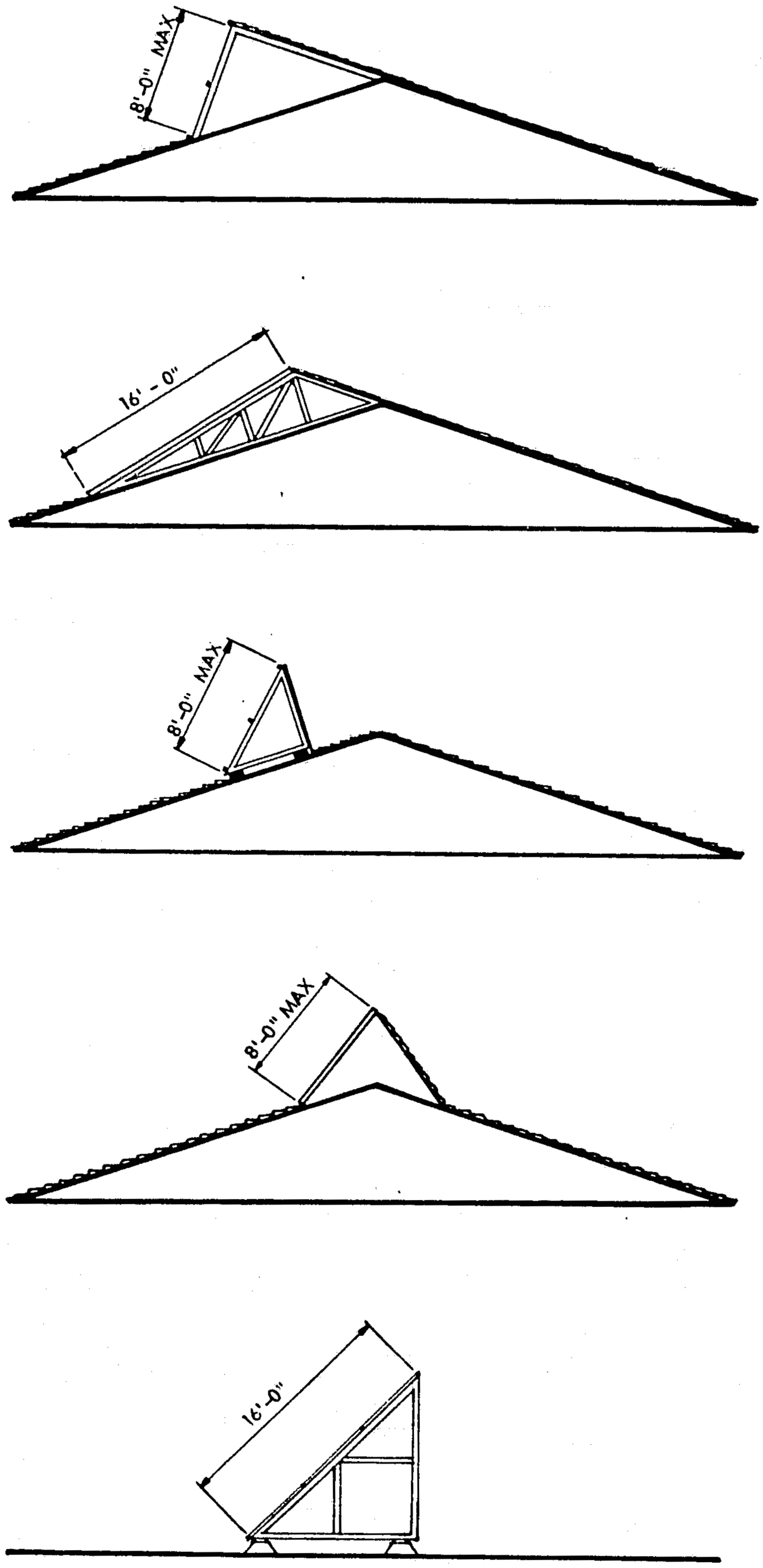
Figure 7-1

MOUNTING DESCRIPTION

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 residence or on the roof of the residence. 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 accessibility, maintenance and installation of the module and its electrical connections can be made quickly and with relative ease, thus allowing for reduction in both installation costs and maintenance costs.

   There are, however, some serious drawbacks to 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 mounted 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. Upon close inspection of the applications where roof mounted rack-type arrays can be used, five configurations can be identified as seen in Figure 7-2. Examining these five details more closely, it becomes apparent



ROOF MOUNTED RACK MOUNTING TECHNIQUES

FIGURE 7-2

that the last detail for the flat roof rack-mounted array becomes the only reasonable choice for a 1,000 $ft.^2$ rack mounted array. This choice is apparent for several reasons. First, because of the height restrictions; i.e. the rack does not exceed 16 feet, space becomes a limitation for residential rooftop applications. Secondly, added material costs associated with other details for roof rack-mounted arrays will drive the installation costs to values in excess of those costs for other type mounting systems. Thirdly, aesthetic acceptability is important in residential applications. These rack mounted rooftop arrays give a tacked-on appearance and are grossly out of proportion with respect to residential design. Further A-frame type details will impose extremely large point loads on the roof framing system. This would require sizeable increases in roofing members and a severe cost penalty.

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 (see Appendix 3 - Model and City Code Review).

3. Direct Mount. Installation of direct mounted modules is accomplished by anchoring the modules to the roof. 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. 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 materials.

Because of the direct mount system's intimate contact with the roof, 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 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. This will present problems in applications where roof 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 a 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 residential photovoltaic modules for direct mount applications.

4. Integral Mounts. Integral mounting places the module within the roof construction itself. Modules are attached to and supported by the roof structural framing members and serve as the finished roof surface. Due to the structural support given by the roof sheathing, removal of that roof sheathing will require additional structural support be given to the roof framing system. Watertightness is critical to avoid problems of water damage and mildew. Electrical connections and maintenance, if required, can be made from the attic area of the residence provided the

modules are not attached above a cathedral ceiling. A cathedral ceiling is an area of the roof where a finished ceiling is applied to the bottom of the sloping roof rafters. In either case, this mounting technique allows for venting of the back side of the module. 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.

Likewise, module area is restricted to the roof area. Modules to be used integrally must be constructed to the standard building tolerances. Because the array now becomes the roof structure, modules must be designed to withstand all live loads that are specified for residential application. Uneven heating of the array may occur in the event that improper venting occurs in the attic space. A soffit to ridge vent system is recommended (See Figure 7-3). This heating problem requires additional study in order to determine the severity and probable solutions to the problem. Further description and cost evaluations of these four basic mounting types is available in Appendix 13 - Mounting Configurations.

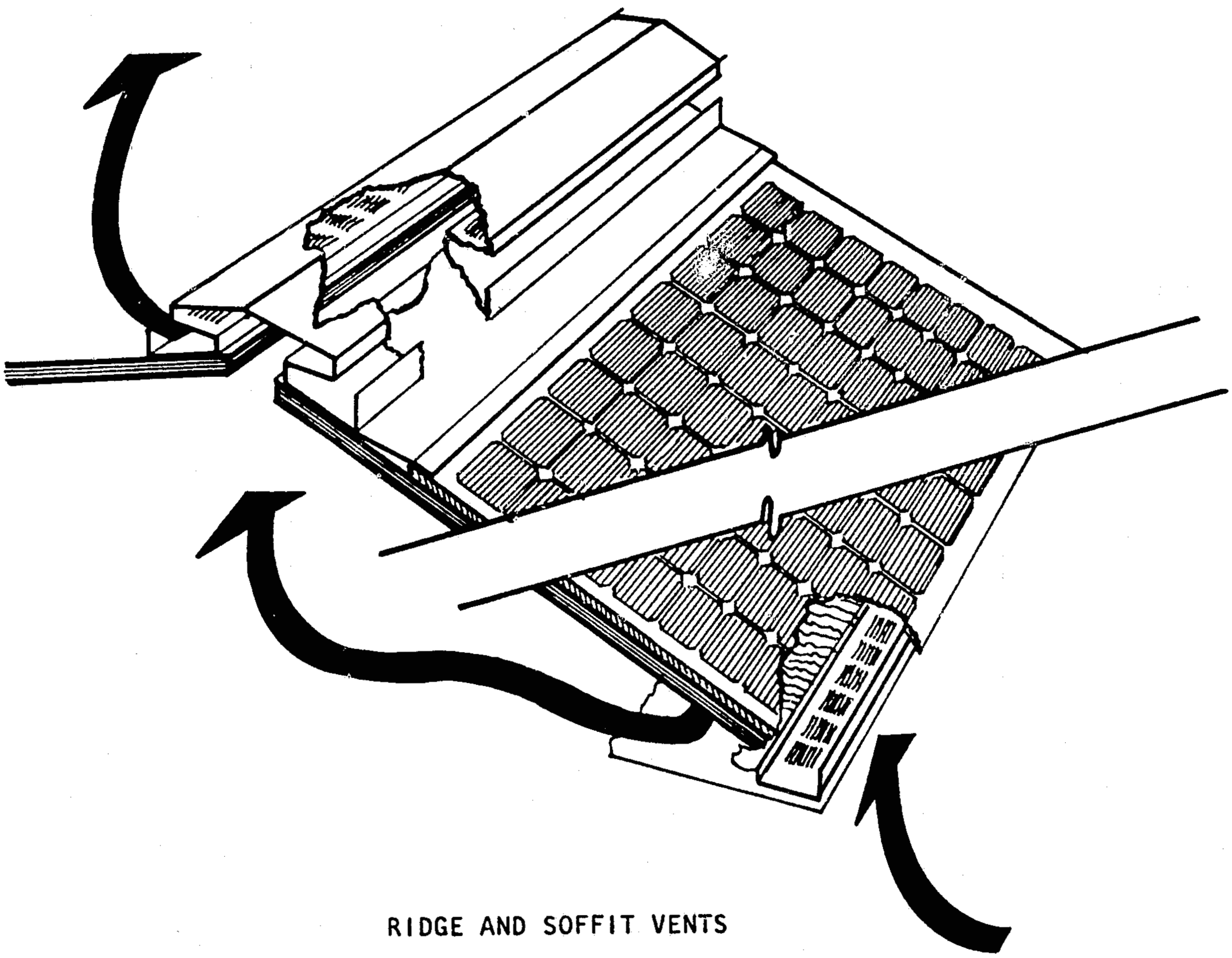
REVIEW METHOD

With the module mounting types defined, a two-dimensional matrix can be developed using basic module characteristics or criteria developed by either the Solar Energy Research Institute (SERI) for their photovoltaic standards development project or by the National Bureau of Standards/Energy Research and Development Agency (NBS/ERDA) for the Interim Performance Criteria for Solar Heating and Cooling in Commercial Buildings. The Standard Investigation Matrix shown in Figure 7-4 shows which characteristics were chosen. This matrix allowed for complete review of all the Standards listed in Appendix 9. Applicable documents were then incorporated, by reference, into the Residential Photovoltaic Module Performance Criteria (RPMPC).

In addition to the standards review activities, it was also necessary to:

A. Identify those standards-writing activities that are in progress at the present time that pertain to residential photovoltaic modules.

B. Develop design requirements in those areas where applicable building codes and standards do not exist.



RIDGE AND SOFFIT VENTS

FIGURE 7-3

	Mounting Type			
	Rack	Stand-Off	Direct	Integral
Function				
Safety				
Mechanical				
Structural				
Electrical				
Durability/Reliability				
Maintainability				

STANDARD INVESTIGATION MATRIX

FIGURE 7-4

C. Recommend methods by which the above design requirements may be implemented as a standard if the need for such a standard exists.

To accomplish these sub tasks, it was necessary to recognize and understand the existing organizations that are currently engaged in the development and implementation of solar standards.

In January 1976, based on recommendations of the National Bureau of Standards, the American National Standards Institute (ANSI) established a Steering Committee on Solar Energy Standards Development see Figure 7-5.

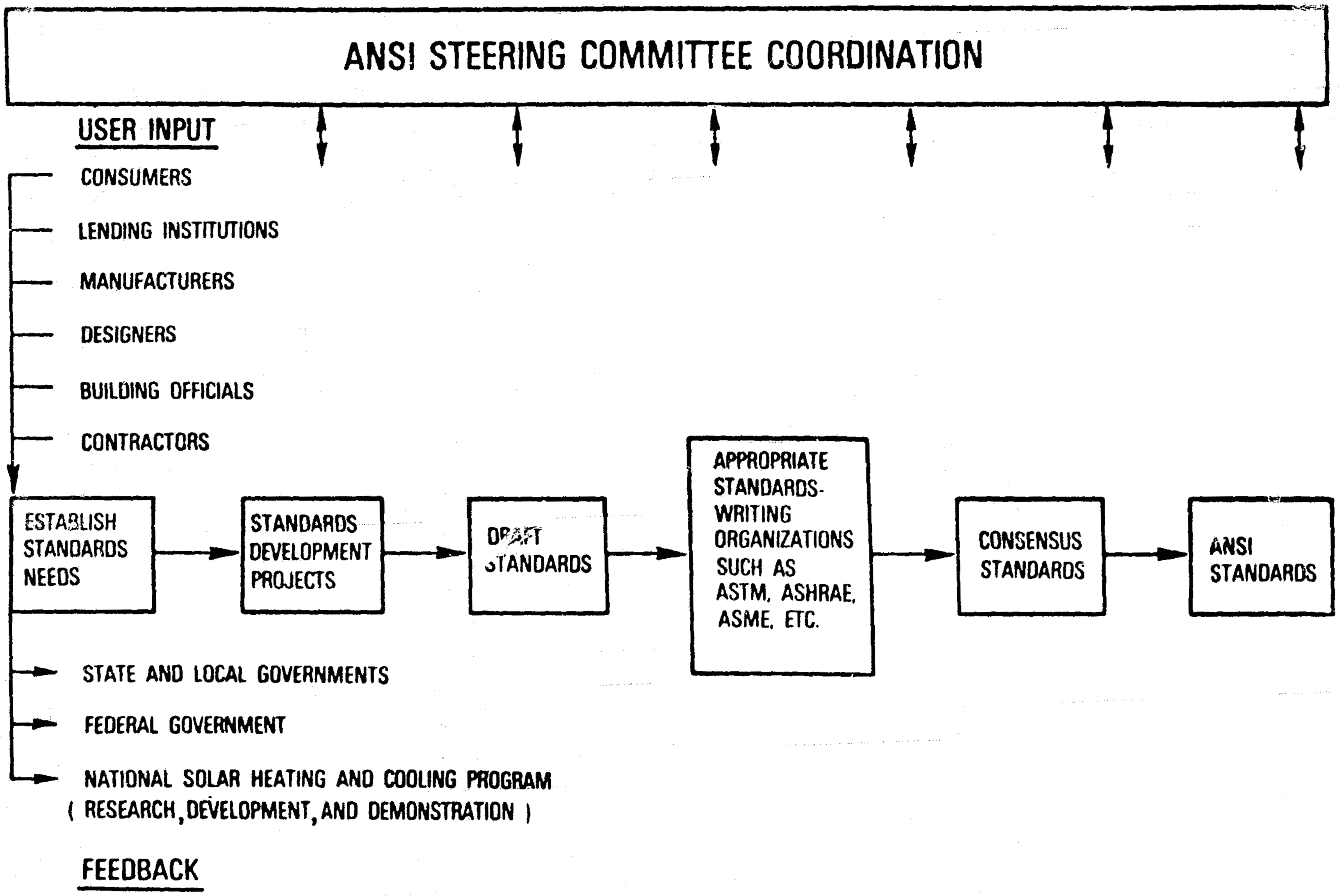
The activities of this committee, at the time of the writing of the proposal for this contract, did not include photovoltaic processes. On behalf of this contract, Burt Hill Kosar Rittelmann proposed, at an ANSI solar steering committee meeting, that photovoltaic power systems be included as an area of concern. As a result of this request an ad-hoc committee was formed to study how PV power systems could be integrated into the general committee. The result of this committee's report, represented in Figure 7-5, has been adopted by the overall steering committee.

It was agreed by the Ad Hoc Committee that this is the only kind of structure that makes sense; that is, it will accommodate needs for both Solar Heating and Air Conditioning of Buildings (SHACOB) and for PV without diluting the efforts and energies of the member organizations. Two reservations have been expressed, however:

1) Subcommittees should be established for additional technologies as the need arises and is appropriate.

2) ANSI has to act in concert with its member organizations; that is, expansion of scope should be in response to needs expressed by member organizations.

The mechanics of this coordination or adoption of effort are, however, unclear. It will be necessary to effect coordination between DOE, SERI and ANSI. This is, of course, beyond the intent of this contract. However, the role of the



SOLAR STANDARDS DEVELOPMENT
FIGURE 7-5

federal government should still be to stimulate the writing of standards by the voluntary sector.

In answer to the three tasks mentioned earlier as addition to the standards survey activity, the current standards writing activity in progress has been identified by investigating both the typical consensus process through ANSI and by determining what effort is currently underway by the federal government. SERI's work at Golden, Colorado entitled "A Plan for Development of Preliminary Performance Criteria and Test Standards for Photovoltaic Systems" was reviewed, but because of evolving nature of this project, no review was included in this report. However, it is recommended that contractors contact the contract officer at SERI to be placed on a current mailing list. The project is funded by DOE as Contract No. EG-77.C.01.4042.

Our final charge was to recommend methods by which the preceding work may be implemented. It is our belief that the effort of the federal government should assist the traditional consensus standards agencies, ANSI being the organizing body in the preparation of standards performance criteria, rather than writing standards of their own. Government standards tend to be prescriptive rather than performance oriented. Prescribing the boundaries of a technology such as PV before it has matured can be a problem. Guidelines or performance criteria along with referenced standards give designers the chance to develop creative solutions to code concerns rather than freezing the development of a technology by making perceived needs or requirements hard and fast rules. To this end, we prepared the RPMPC. This document could serve as the preliminary outline for ANSI's use in directing standards development (see Appendix 19).

APPENDIX 8. MANUALS OF ACCEPTED PRACTICE (MAP)

PURPOSE: To define, describe, give illustrations, and list appropriate contents for manuals of accepted practice for RPM's.

CONCLUSIONS: To require or desire the production of an industry accepted MAP is, premature at this time but it is not unreasonable for each manufacturer to prepare an installation and operation manual specific to their own product.

RECOMMENDATIONS: Through an agency such as Solar Energy Industry Association (SEIA) - Photovoltaic Division, manufacturers could begin to outline and write a prototype manual of accepted practice that could serve as a "seed" document for future reference and construction.

MANUALS OF ACCEPTED PRACTICE (MAP)

Manuals of accepted practice are used in industry as an interpretation of codes and standards that allows the installer to realize the intent or purpose for specific design decisions represented on the system drawings. They also allow a designer familiar with the basic concepts to design a system that will work properly and will comply with industry standards. The manual of accepted practice should never be construed as a code or as a binding legal requirement. It only represents the acceptable state-of-the-art. It may be referenced in a designer's specification, however, thus becoming a project specific requirement. The reason why MAP's should never be incorporated into the body of a code is that they are always in a state of flux, being constantly updated to incorporate changes in industrial technology. Some examples of these documents which have been developed for use in the solar heating and cooling industry are listed below:

- Solar Heating Systems Manuals; Training and Educational Department, Fluids Handling Division, International Telephone and Telegraph Corporation, 8200 North Austin Avenue, Morton Grove, Illinois 60053.
- Solar Energy Systems; Copper, Brass, Bronze Design Handbook, Copper Development Association, Inc., 405 Lexington Avenue, New York, New York 10017.

- Heating and Air Conditioning Systems Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar; Sheet Metal and Air Conditioning Contractors National Association, Inc., 8224 Old Courthouse Road, Tysons Corner, Vienna, Virginia 22180.

Each of these documents was developed by either a company - ITT in the first example - or by industry trade associations, as in the last two. The contents of each document vary from simple calculation procedures to a recommended installation procedure. There is no restriction or precedence on the contents of these documents; they can be as narrow and specific or as broad and general as desired.

To date there is no manual of accepted practice developed by or for the photovoltaic industry. It is at this time perhaps premature to be concerned over this kind of industry-wide document. There are to date many ways to build, install and operate PV arrays that would ensure compliance with all existing residential codes and standards. In fact, because of this diversity it would be best for each PV power system manufacturer, using the RPMPC (See Appendix 19) as a guide, to develop their own installation and operation manuals.

As a minimum, these manuals should include:

- Load Calculation Procedure
- Equipment Design and Sizing
- Equipment Selection and Specification
- Equipment Installation
- Controls
- Wiring
- Storage
- Start-up Procedures
- Maintenance Procedures

As the industry matures perhaps one technique for design and installation of Residential PV Modules will surface. This may be due to a variety of factors such as cost, code compliance, safety, maintainability, etc. It would, therefore, be inappropriate at this time to develop a MAP to reflect industry-wide accepted practices.

APPENDIX 9. CODES AND REFERENCED STANDARDS SUMMARY

PURPOSE: Referenced codes and standards are identified and addresses of the appropriate agencies for obtaining these documents are given.

RECOMMENDATIONS: Manufacturers involved in the design and manufacturing of photovoltaic modules should obtain these documents in order to assure compliance with existing standard test methods for the evaluation of their product.

LIST OF ADDRESSES OF CODES AND STANDARDS AGENCIES

American National Standards Institute
1430 Broadway
New York, New York 10018

American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

Building Officials and Code Administrators International, Inc.
17926 South Halsted Street
Homewood, Illinois 60430

ETL Testing Laboratories, Inc.
Industrial Park
Cortland, New York 13405

Factory Mutual Research
1151 Boston-Providence Turnpike
Norwood, Massachusetts 02062

International Conference of Building Officials
5360 South Workman Mill Road
Whittier, California 90901

National Electric Code
National Fire Protection Association
470 Atlantic Avenue
Boston, Massachusetts

National Fire Protection Association
470 Atlantic Avenue
Boston, Massachusetts 02210

Southern Building Code Congress International
3617 Eighth Avenue South
Birmingham, Alabama 35222

Underwriters Laboratories
333 Pfingsten Road
Chicago, Illinois 60062

UNDERWRITERS LABORATORY

No.	Title	Cost
UL 1	Flexible Metal Conduit	$3.00
UL 6	Rigid Metal Conduit	3.00
UL 33	Fusible Links	3.00
UL 50	Cabinets and Boxes	3.00
UL 94	Tests for Flammability of Plastic Materials	3.00
UL 96	Lightning Protection Components	3.00
UL 231	Power Outlets	3.50
UL 263	Fire Tests of Building Construction and Materials	3.00
UL 310	Quick Connect Terminals	3.00
UL 360	Liquid-Tight Flexible Steel Conduit	3.00
UL 467	Grounding and Bonding Equipment	3.00
UL 486	Wire Connector and Soldering Lugs	3.00
UL 514	Outlet Boxes and Fittings	3.50
UL 651	Rigid Nonmetallic Conduit	3.00
UL 719	Nonmetallic - Sheathed Cable	3.50
UL 723	Tests for Surface Burning Characteristics of Building Materials	3.50
UL 790	Tests for Fire Resistance of Roof Covering Materials	3.00
UL 854	Service Entrance Cables	3.50
UL 857	Busways and Associated Fittings	3.00
UL 997	Wind Resistance of Prepared Roof Covering Materials	3.00
UL 1059	Terminal Blocks	3.00

These costs are for standards only. For update services, "$3.00 standards" cost $8.00; and "$3.50 standards" cost $9.00.

NATIONAL FIRE PROTECTION ASSOCIATION

NFPA	78-1975	Lightning Protection Code	$3.75
NFPA	251-1972	Standard Methods of Fire Tests of Building Construction and Materials	$3.00
NFPA	255-1972	Method of Test of Surface Burning Characteristics of Building Materials	$3.00
NFPA	256-1976	Standard Methods of Fire Tests of Roof Coverings	$3.00
NFPA	258-1976	Standard Test Method for Measuring the Smoke Generated by Solid Materials	$3.00

AMERICAN NATIONAL STANDARDS INSTITUTE, INC.

No.	Title	Cost
ANSI A.58.1-1972/	Building Code Requirements for Minimum Loads in Buildings and Other Structures	$7.50
ANSI Z97.1-1975/	Safety Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings	4.00

AMERICAN SOCIETY OF TESTING AND MATERIALS

No.	Title	Cost
B 117-73	Standard Method of Salt Spray (Fog) Testing	$1.75*
B 287-74	Standard Method of Acetic Acid - Salt Spray (Fog) Testing	
B 368-78	Standard Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (Cass Test)	
C 297-61	Standard Method of Tension Test of Flat Sandwich Constructions in Flatwise Plane	
C 355-64	Standard Methods of Test for Water Vapor Transmission of Thick Materials	
C 393-62	Standard Method of Flexure Test of Flat Sandwich Constructions	
D 568-61	Flammability of Plastics 0.127 cm (0.050 m) and under in Thickness	
D 635-63	Flammability of Rigid Plastics over 0.127 cm (0.050 in.) in Thickness	
D 638-77a	Standard Test Method for Tensile Properties of Plastics	
D 750-68	Recommended Practice for Operating Light - and Weather - Exposure Apparatus (Carbon-Arc Type) for Artificial Weather Testing of Rubber Compounds	
D 775-73	Standard Method of Drop Test for Shipping Containers	
D 790-71	Standard Test Method for Flexural Properties of Plastics and Electrical Insulating Materials	
D 822-73	Standard Recommended Practice for Operating Light - and Water - Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer and Related Products.	
D 897-78	Standard Test Method for Tensile Properties of Adhesive Bonds	
D 1006-73	Standard Recommended Practice for Conducting Exterior Exposure Tests of Paints on Wood	
D 1014-66	Standard Method of Conducting Exterior Exposure Tests of Paint on Steel	
D 1044-76	Resistance of Transparent Plastics to Surface Abrasion Standard Test Method	
D 1149-78	Standard Test Method for Rubber Deterioration - Surface Ozone Cracking in A Chamber (Flat Specimen)	
D 1433-58	Flammability of Flexible Thin Plastic Sheeting	
D 1435-75	Standard Recommended Practice for Outdoor Weathering of Plastics	

D 1828-70	Recommended Practice for Atmospheric Exposure of Adhesive Bonded Joints and Structures	$1.75*
D 1929-68	Ignition Properties of Plastics	
D 2247-73	Standard Method for Testing coated Metal Specimens of 100% Relative Humidity	
D 2249-74	Standard Method of Predicting the Effect of Weathering on Face Glazing and Bedding Compounds on Metal Sash.	
D 2565-76	Standard Recommended Practice for Xenon Arc-Type (Water Coded Light - and Water-Exposure Apparatus for Exposure of Plastics	
D 2305-72	Methods of Testing Polymeric Film Used for Electrical Insulation	
D 2843-70	Measuring the Density of Smoke from the Burning or Decomposition of Plastics	
D 3161-76	Standard Test Method for Wind Resistance of Asphalt Shingles	
E 72-74a	Standard Methods of Conducting Strength Tests of Panels for Building Construction	
E 84-70	Standard Method of Test for Surface Burning Characteristics of Building Materials	
E 96-66	Standard Methods of Test for Water Vapor Transmission of Materials in Sheet Form	
E 108-58	Standard Methods of Fire Tests of Roof Coverings	
E 119-73	Standard Methods of Fire Tests of Building Construction and Materials	
E 136-73	Standard Method of Test for Noncombustibility of Elementary Materials	
E 424-71	Standard Methods of Test for Solar Energy Transmittance and Reflectance (terrestrial) of Sheet Materials.	
F 146-72	Standard Methods of Test for Fluid Resistance of Gasket Materials	
G 7-77a	Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials	
G 21-70	Standard Recommended Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi	
G 23-75	Standard Recommended Practice for Operating Light - and Water - Exposure Apparatus (Carbon Arc Type) for Exposure of Nonmetallic Materials	
G 24-73	Standard Recommended Practice for Conducting Natural Light Exposures Under Glass	
G 26-77	Standard Recommended Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) with and Without Water for Exposure of Nonmetallic Materials.	
G 29-75	Method of Test for Algal Resistance of Plastic Films	

*All $1.75

<u>FEDERAL SPECIFICATION</u> (General Services Administration)

DD-G-451C Flat Glass for Glazing, Mirrors and other uses

DD-G-451C - references in HUD/MPS 4900.1 p.5.8.6 $1.00

MILITARY STANDARD

MIL-STD-810C/10 March 1975/Environmental Test Methods — No Charge

- Method 501.1 High Temperature
- Method 502.1 Low Temperature
- Method 508.1 Fungus
- Method 509.1 Salt Fog
- Method 507.1 Humidity
- Method 506.1 Rain
- Method 516.2 Shock

NATIONAL BUREAU OF STANDARDS

NBS-23 Hail Resistance of Roofing Products — Out of Print

NBS-Special Publication 473 - 003-003-017-15-2
Research and Innovation in the Building Regulatory Process — $ 6.00

Session 2B, Issues in Building Regulation
"Decision-Aiding Communications in the Regulatory Agency:
The Partisan Uses of Technical Information" Francis T. Ventre

UNIFORM BUILDING CODE

Uniform Building Code
International Conferences of Building Officials — $10.00

Southern Building Code
Southern Building Code Congress International — $10.00

National Electric Code
National Fire Protection Association — $14.00

BOCA
Building Officials and Code Administrators International — $12.00

APPENDIX 10. PUBLIC SAFETY TESTING LABORATORIES

PURPOSE: To review the need for public safety testing laboratory approvals and to present one procedure (represented by Underwriter's Laboratories (UL)) for product testing.

CONCLUSIONS: Approval of a manufactured product or device, by a national testing laboratory -- UL for example -- assures every member of the residential building community -- designers, lenders, insurers, code officials, and owners -- that the product complies with all industry accepted standards. It is essential, if PV modules are used in residential application it is virtually mandatory that the product show initial and continued compliance with consensus industry standards. The display of a seal (such as a UL seal) assures this compliance and most often acceptance by code inspectors.

RECOMMENDATIONS: It is recommended that national testing laboratories be used to determine the residential PV module's compliance with applicable industry standards (See Appendix 19). A laboratory, such as UL, should be contacted for prototype module design testing.

INTRODUCTION

As manufacturers begin designing Residential Photovoltaic Modules, they may begin referencing the Residential Photovoltaic Module Performance Criteria (RPMPC) (See Appendix 19) and in turn using Standards and Tests referenced therein to direct their research toward acceptable solutions. At some point, a completed design or prototype design must be tested for compliance with existing standards and building codes. This procedure has been documented by the inclusion of sections of Underwriters Laboratory (UL) document, Testing for Public Safety, in this appendix. This gives a complete outline of a typical process for testing and approval that each product bound for the building industry must complete. Also, included is a general description of UL. This information has been reproduced with permission from Underwriters Laboratories. UL is by no means the only organization qualified to do testing and certifying for products to be used in the building industry. Other organizations such as Factory Mutual[1] and ETL Testing Laboratories[2] have similar services available and are not excluded by preference but for brevity (See addresses and phone numbers below).

UNDERWRITERS LABORATORIES, INC.

This organization, founded in 1894, is chartered as a non-for-profit organization under the laws of the State of Delaware to establish, maintain and operate laboratories for the investigation of materials, devices, products, equipment, constructions, methods and systems with respect to hazards affecting life and property. However, "UL shall not be responsible to anyone for the use of or reliance upon a UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or connection with the use, interpretation of, or reliance upon a UL Standard."

A Not-For-Profit Organization

The Certificate of Incorporation states:

"The Corporation shall have no capital stock, its activities for the furtherance of its objects and purposes shall be for service and not for profit. No distribution of any of its property, assets or income, or of any portion of them, however or wherever acquired, shall ever be made to or among any of its members, either by way of dividends or distributions, in liquidation or otherwise, but all of its property shall be considered and deemed to have been, and hereby is, dedicated to the accomplishment or furtherance of its objects and purposes. In the event of a dissolution of the corporation, its property and assets shall be transferred in trust for the furtherance of the objects of its incorporation in such a manner and under such conditions and to such persons, firms, associations or corporations as its membership, by majority designation, may appoint."

---

1 Factory Mutual Research, 1151 Boston-Providence Turnpike, Norwood, Massachusetts
Tel.(617) 762-4300

2 ETL Testing Laboratories, Inc., Industrial Park, Cortland, New York 13045
Tel. (607) 753-6711

Objectives

As stated in the Certificate of Incorporation, the objectives are:

"By scientific investigation, study, experiments, and tests to determine the relation of various materials, devices, products, equipment, constructions, methods and systems to hazards appurtenant thereto or to the use thereof, affecting life and property and to ascertain, define and and publish standards, classifications and specifications for materials, devices, products, equipment, constructions, methods and systems affecting such hazards, and other information tending to reduce or prevent bodily injury, loss of life and property from such hazards."

"To contract with manufacturers, governmental agencies, and others, for examination, classification, testing and inspection of materials, devices, products, equipment, constructions, methods and systems, and for the development of standards with reference to hazards appurtenant thereto or to the use thereof affecting life and property; and to report and circulate the results of such examinations, tests, inspections, and classifications to insurance organizations public safety authorities, government bodies, or agencies, other intested parties and the public by the publication of lists and descriptions of such examined, tested, inspected or classified materials, devices, products, equipment, constructions, methods and systems, by the provision of the attachment of markings or labels thereto or issuance of certificates thereon, or in such other manner as from time to time may be deemed advisable."

The Laboratories, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or subscriber to any other party. The opinions and findings of Underwriters Laboratories, Inc. represent its judgement given with due consideration to the necessary limitations of practical operation. The Laboratories does not warrant or guarantee the correctness of its opinions, or that its findings will be recognized or accepted.

Many products investigated by Underwriters Laboratories, Inc. may cease to meet its Standards or requirements because of misuse, exposure to adverse conditions, failure to inspect and maintain the product and its constituent components, or other factors occurring after manufacture which affect the safety of the product. Underwriters Laboratories Inc. does not and cannot attempt to anticipate all abnormal conditions. Its Standards and requirements are predicated upon proper use and maintenance within the normal useful life of the product, as well as the assumption of certain stipulated abnormal conditions wherein the product must perform in a safe manner. Its opinions, findings and evaluations are based upon and limited by these assumptions.

Procedure for Certification

The complexity of the module or assembly which you, as an Applicant, intend to submit for investigation by UL for the first time, or even on succeeding occasions, greatly influence the amount of paper work and other actions required to establish a project and to carry it to its final report phase. The thrust of UL's investigation is to ascertain and document compliance of the product with UL's safety requirements. Accordingly, whatever assistance the Applicant provides the Laboratories' engineers in expediting the process by which UL makes its determination of compliance, will shorten the time required and lower the cost of the work. It will be to your advantage to evaluate, prior to submittal, the construction and performance characteristics of your product against the requirements set forth in the Standard(s) to preclude, to the extent possible, the expenditure of time by UL engineers in examining and testing a product which you can readily determine does not meet UL's requirements.

The Standards

The Standards of Underwriters Laboratories, Inc. have been drawn up to provide specifications and requirements for the construction and the performance under test and in actual use of systems, devices, materials, and appliances of numerous classes submitted to the Laboratories. The requirements of these Standards are based upon sound engineering principles, research, records of tests and field experience. The problems of manufacture, installation and use are considered after consultation with manufacturers, users, inspeciton authorities, and others having specialized experience. Standards are subject to revision as further experience and investigation may show is necessary or desirable.

Examination and tests of submitted products are conducted by experienced engineers in one or more of the following departments: Burglary Protection and Signaling; Casualty and Chemical Hazards; Electrical; Fire Protection; Heating, Air Conditioning and Refrigeration; and Marine.

The equipment of the Laboratories allows comprehensive investigations to be conducted at convenient locations. Offices and testing stations are located at Chicago and Northbrook Illinois; Melville, New York; Tampa, Florida; and Santa Clara, California.

The corporate office and a testing station located in Chicago, Illinois contains an Electrical Department, and a section of the Fire Protection Department.

The largest facility is at Northbrook, Illinois and provides for large-scale tests conducted both indoors and outdoors. The Burglary Protection and Signaling, Casualty and Chemical Hazards, Heating, Air Conditioning and Refrigeration Departments, most of the Fire Protection Department, and headquarters of the Follow-Up Services Department are located at Northbrook. The Melville, New York office and testing station provides a laboratory facility where the examination and testing of electrical equipment and fire alarm signaling apparatus can be conducted for manufacturers on the East Coast.

The Santa Clara, California office and testing station provides conveniently located test facilities for manufacturers on the West Coast. It is equipped for the examination and testing of most electrical products, gas and oil equipment, and heating, air conditioning and refrigeration equipment. Facilities are also provided for the flame spread testing of building materials, and for tests in other classifications investigated by UL. Products of certain types, sizes and ratings must be sent to Chicago or Northbrook for tests, as some of the more elaborate testing equipment cannot be duplicated economically.

The newest addition to UL facilities is the Tampa, Florida offices and testing station. This office houses the Marine Department, an Electrical Department, and a Burglary Protection Department. Of equal importance with the examination and test work of Underwriters Laboratories, Inc. is its Follow-Up Service in the factories where listed devices are manufactured.

Should examination and tests by the Laboratories' representative disclose features not in compliance with the requirements, the manufacturer is required either to correct such items or to remove the Listing Mark from the product.

Identification of Listed Product

The Listing Mark of Underwriters Laboratories, Inc. is the only means provided for the identification of Listed Products produced under the Follow-Up Service. The appearance of a company's name in the published Lists of Underwriters Laboratories Inc. does not signify that all of the manufacturers products are Listed under the Follow-Up Service. Only those products bearing the Listed company's name and the Listing Mark should be considered as being listed by Underwriters Laboratories, Inc.

The name Underwriters Laboratories Inc. in various forms and abbreviations and the U_L symbol are registered with the U.S. Patent Office, and in numerous foreign countries, as certification marks. Listed subscribers, subject to the terms of a Listing and Follow-Up Service Agreement, are permitted to use specified forms of the Laboratories' name or symbols as a Listing Mark on products which are Listed and which comply with the Laboratories' requirements.

The Listing Mark generally appears in one of the following forms, together with the product designation.

Certain Listed products which are authorized to bear the Listing Mark may also be covered under a service designated as "Listed by Report." These are usually products or constructions for which there are no generally recognized installation requirements. The description of such product or construction, and information concerning proper field assembly and/or installation, are contained in a Report identified by the reference and date shown by the Listing. Copies of the Report may be obtained upon application to the manufacturer.

Cost of Follow-Up Services

The cost of the Service is covered by charges which vary according to the nature and extent of follow-up services required. Charges are billed to the subscriber at current rates in effect. If rates are changed, written notice is

Listing and Follow-Up Services

General

Upon successful completion of the investigation, and after agreement to the terms and conditions of the Listing and Follow-Up Service, the Laboratories publishes the names of the companies who have demonstrated the ability to provide a product conforming to the established requirements. Listing signifies that production samples of the product have been found to comply with the requirements, and that the manufacturer is authorized to use the Laboratories' Listing Mark on the Listed Products which comply with the requirements. It should be noted, however, that Listed products are not necessarily equivalent in quality or merit.

Follow-Up Service

The Listing of the product, as already described, is contingent upon the establishment of the Laboratories' Follow-Up Service. The nature of the Service to be applied to a particular class of product rests with the Laboratories. The Follow-Up Service is designed to serve as a check on the means which the manufacturer exercises to determine compliance of the product with the requirements of the Laboratories. Experience has shown that a program of this nature can be operated efficiently without calling upon the manufacturer to give undue publicity to his manufacturing processes or subjecting him to unwarranted production delays.

Under the Follow-Up Service the manufacturer attaches labels, markers or other authorized evidences of Listing (Listing Marks) to such of his products as are found by him to be in compliance with UL requirements.

Representatives of the Laboratories make periodic examinations or tests of the products at the factory and may, from time to time, select samples from the factory, the open market, or elsewhere, to be sent to a laboratories' testing station for examination or test to determine compliance with the Laboratories' requirements. Representatives charged with the responsibility for making periodic inspections are located in approximately 200 cities throughout the United States and in some foreign countries.

sent to all subscribers.

Client Advisor

At each of the laboratory facilities listed on page 5 of this discussion, UL has designated a Client Advisor to assist clients in becoming familiar with UL's operational methods, to direct a client to the proper Engineering Department, and where necessary, to bring comments, questions, and complaints to the attention of the proper parties within UL.

Initiating An Investigation

Initiation of an investigation requires that the client sign contractural agreement(s), make a preliminary deposit, furnish certain required information, and submit appropriate samples for tests and examination.

Specific information must be supplied by the Applicant to properly establish the scope of the investigation and to assist UL in providing the appropriate Application Forms to be used as a formal contract to initiate an investigation.

The following are required:

1. A description of the materials, products, or systems (hereinafter called "products") to be submitted, as well as the intended use of the product (if not obvious). The information must also include the designations of all models or types to be covered with details regarding their ratings, characteristics and information about their similarities and differences.

   Applicants are encouraged to use product designations which relate directly to the features of the product that affect its safety and performance, but are not an indication of nonsafety characteristics. Such a practice will preclude the need for UL to revise its records to include changes in designations because of design and production variations which relate only to nonsafety features. Whatever designation is used must, in almost all cases, be shown on the product.

2. An identification of the components and materials incorporated in the final assembly of the product, including manufacturer's name, catalog

numbers, sizes, ratings, etc., and an indicated whether Listed or Recognized by UL. Of particular interest is detailed data relating to any polymerics (e.g., thermoplastics) used in the product.

3. Wiring diagrams, where applicable, to facilitate an understanding of electrical circuitry which might be involved.

4. Installation and/or operating instructions as appropriate for the product.

5. Where known, any alternate materials, alternate components, or alternate arrangements of parts contemplated in future production. In order to minimize, as much as possible, repetition of test work when the alternates are subsequently in the product.

6. The name of the Applicant's representative designated to receive all communications, including the final report.

7. Name and address of company to appear in the appropriate published UL Directory.

8. Names and addresses of all factories where product is to be manufactured.

The above information will enable UL to determine which of its six Engineering Departments will conduct the investigation, to establish the Cost Limit for the work, and to provide an estimate of the time required to render a report, based on one set of tests and examinations.

Before UL's Engineering Department will release any formal report to the Applicant, it will require acceptance of UL's Follow-Up Service. This acceptance is accomplished by the signing and returning of a Follow-Up Service Agreement, which will be forwarded to the Applicant shortly after the investigation gets underway.

Although all contact between an Applicant and UL can be maintained by correspondence (possibly supplemented by telephone) a personal visit to display the product (or a model) and explain its operation, or to discuss drawings which would illustrate the purposes and function of the product, is sometimes helpful in establishing a better understanding between the Applicant and UL engineer who will be handling the investigation. Personal visits should, to the extent practical, be made by appointment in order to assure that the engineer handling your product investigation will be available, or that a qualified substitute can be provided.

Form data sheets are available from UL for certain product categories and should be utilized whenever possible to present the necessary preliminary descriptive information for use by UL in determining the extent of a contemplated investigation.

The Applicant is encouraged to relate new or modified designs to previously tested types or models so that, whenever possible, the experience of prior testing and consideration of construction features can be utilized in determining the scope of the required investigation to determine acceptability of the new or revised models or designs.

Charges for Work

Charges for engineering services are made at current billing rates for time devoted to the product by engineering, technical and support personnel. Based on information provided, a Cost Limit for anticipated engineering services will be established and specified on the Application Forms.

The cost limit covers only <u>one</u> set of tests and an examination of constructional features performed on the submitted product. It is not intended to cover (a) repetition of all or part of a test program, which might be necessary due to unacceptable results obtained during the initial program, or (b) special sets of tests, or any other work required to determine the acceptability of individual components of a kind which is separately Listed or Recognized by UL (e.g., snap switches, insulated wire, molded plastic parts, etc.)

It is sometimes desirable to expand or continue the investigation beyond that originally contemplated. Where additional tests or examinations are deemed to be desirable, UL will require proper authorization from the Applicant and an increase in the Cost Limit will normally be required. Such procedure sometimes permits contemplation of the work with minimum delay by avoiding the resubmittal processing.

The established Cost Limit does not include advances and reimbursable expenses, such as travel and living expenses (if required), communications, shipping, use of special equipment, materials, energy, fuel, photos, drawings or other reproductions, Temporary Follow-Up Service Procedures, or the printing of extra copies of a report. Such expenses are charged over and above the Cost Limit, which is set for the investigation of the product and specified in the Application Forms.

Sample Selection

While the UL engineer will determine what samples are to be tested and/or examined to represent the product(s) being submitted, there are some broad aspects of sample selection of which the Applicant should be aware.

UL's determination of compliance with its requirements is generally based upon examination and/or tests of production units as opposed to handmade or prototype units.

At the time initial contact is established, and prior to the preparation of Application Forms, the Applicant should give careful consideration as to whether the investigation will be conducted on models, prototypes, or pre-production samples of the product supplied directly by the manufacturer, or on test samples from the manufacturer's production line.

In this regard, a complete or partial investigation of a model, prototype, or preproduction product may result in a letter report or a Listing, Classification, or Recognition Report. If a letter report is provided, it will outline the test results and comment on construction features which do not meet UL's requirements. If a Listing, Classification, or Recognition Report is provided, UL will not authorize release of production bearing UL's Registered Mark until production samples of the product have been retested and re-examined to the extent considered necessary. Such production check is made by UL's personnel following instructions issued by UL, and utilizing a descriptive document furnished by UL called a Follow-Up Service Procedure.

On the other hand, if the Applicant chooses to tool up to make production samples available for the initial investigation, and the results obtained indicate a need for changes in design to meet the applicable requirements, the basic design may have to be revised, and modified samples submitted for additional examination and tests in order to achieve compliance.

As a general rule, UL encourages the submittal of prototype samples, for such a procedure affords the applicant a greater number of choices of design features, as well as less risk of major retooling, materials, or other changes.

The decisions as to which route is the most economical and efficient must be made by the Applicant. Obviously, based on prior experience, the course of action to follow will become more apparent. Initially, however, a discussion of the matter with a UL representative may serve to clarify any questionable points.

In some cases the investigation of a product can be expedited by the submittal of one set of samples to be used for test purposes, and a second set to be used for a comparison of construction features with UL's requirements. Such an arrangement could permit both testing and examination to proceed at the same time. In all cases samples forwarded to the Laboratories should be marked to the attention of the specific UL engineer to whom the project is assigned, or to the person with whom the Applicant has had prior contact, to insure that the sample's availability to the concerned engineer becomes known at the earliest possible time.

Use of Manufacturer's Data and Facilities

When products are submitted by a manufacturer whose testing facilities and procedures have been previously determined by UL to be equivalent to those utilized by UL in making its investigation, it may be possible for the Applicant to submit manufacturer-produced test data for consideration in the UL investigation. A bulletin, "Use of Manufacturer's Test Data in Product Submittals", describing the basic features of this program, may be obtained from the engineer handling the product submittal. Such a program can be helpful in reducing the time necessary to complete an investigation.

Similarly, if a manufacturer's test facilities are judged to be equivalent to those employed by UL and the facilities can be made available to perform an entire test program to be witnessed by a qualified UL technical representative, such an arrangement can sometimes result in an appreciable shortening of "waiting time" for access to the UL test equipment.

Components and Synthetic Materials

At the time of the submittal of a product, the Applicant is asked to furnish a list of components and materials (particularly those derived from synthetics) which are used in the product.

The acceptability of components and materials is usually based on conformance with applicable requirements for the particular component or material, as well as the suitability of such components or materials in the end product.

UL's "Directory of Recognized Components" contains information useful to the manufacturer of the end product in selecting components and materials which have already been evaluated and found to meet certain construction and/or performance criteria. When used within these recognized limits, the time necessary to complete the investigation of the end product can be shortened, and the costs incurred by the Applicant who submits the end products can be lessened.

Handling the Project

When properly executed Application Forms, together with any required preliminary deposit, have been recieved from the Applicant and the required test sample(s) and/or test facilities have been made available to the personnel designated to handle the product investigation, a Promise Date for completion of the engineering investigation will be established by the involved UL Engineering Department and given to the Applicant. The Promise Date established will be dependent on the anticipated work to be performed and the department work load at that time. The Promise Date is an indication of the calendar date by which the Engineering Department expects to complete the investigation of the product and report the results to the submitter. Additional time is required for the preparation of a formal Listing, Classification, or Recognition Report and Follow-Up Service Procedure.

An investigation is initiated by assignment of the project to an engineer who will supervise the testing and evaluation of the product by technically qualified personnel. The engineer, in turn, is under the direction of an Engineering Group Leader and an Associate Managing Engineer responsible for the administration of a group of technical people, referred to as Section.

Applicants are encouraged to become acquainted with the involved supervisory personnel, and feel free to discuss with them problems which may arise in the course of an investigation.

If arrangements are made in advance, it is possible for an Applicant, or his authorized representative, to witness all or a portion of the test program performed on a submitted product at the Laboratories. Such an arrangement might be useful in observing testing techniques employed, as well as affording the Applicant, or his representative, the opportunity to discontinue an investigation when, in his opinion, a continuation of the investigation would be of little value in view of the observed results. In such a case the project can be terminated and a letter report rendered covering the portion of the product investigation which had been performed.

Such a letter report, or for that matter any report not resulting in acceptance of a product at the completion of an investigation, would be utilized to facilitate the resumption of future work on modified samples of the product when it is resubmitted.

Every effort will be made by UL staff to complete the investigation on or before the Promise Date. There are occasions when Promise Dates must be extended because of the inability of the Applicant to provide necessary samples or information or because of UL's lack of available test facilities or technical personnel at a particular time. It is expected that such occurrences will be minimal and subject to adjustment as the investigation proceeds. However, if the Applicant feels that undue or unreasonable delays are taking place, he should discuss this matter with the project engineer and his supervisors to ascertain the reasons for the apparent delays and the possibility of minimizing such occurrences. If a satisfactory resolution is not reached, the Applicant is encouraged to discuss the matter with the appropriate Managing Engineer.

UL Marks on Products

If the test program indicates that the product meets UL requirements, a formal report will be prepared by the Engineering Department and utilized by the Follow-Up Services (FUS) Department of UL as the basis of the FUS Procedure, which will authorize the manufacturer to use, under specified controls, the appropriate UL Mark on the product. The FUS Department will indicate to each new Applicant the design and the way to procure the appropriate UL Mark. Any questions concerning this Mark should be directed to the FUS Department at the office handling the engineering project.

UL controls the use of its Registered Mark, and clients are encouraged to become familiar at an early date with the procedure for obtaining the appropriate Mark that is to be used by the Applicant to indicate compliance with UL's requirements.

When UL's investigation has been based on prototype samples, UL will require a factory check on production samples before authorizing the release of the product bearing UL's registered Mark. This factory check is usually made by a UL field inspector or engineer, using the UL-prepared description of the product contained in the Follow-Up Service Procedure. A period of about two weeks is normally required for preparation of the "Procedure", following official determination of the product's compliance by UL engineers. Where production schedules require that the Applicant produce and ship the product at an earlier date, UL will provide, upon request by the Applicant, a Temporary Procedure which may be used by the UL Inspector and the Applicant until the official Procedure is available. The Applicant will be billed for the extra costs of preparation and distribution of the Temporary Procedure.

Appeals Procedure

When, at the completion of an investigation, a letter report is rendered to the Applicant containing conclusions which, in his opinion, do not appear to be justified, the Applicant can, without prejudice, present and discuss his views of the matter with the involved engineer and his immediate supervisor in an effort to resolve an area of disagreement. If a satisfactory resolution of the matter cannot be obtained, the Applicant should feel free to contact the next higher supervisory level in the Engineering Department handling his product investigation and, if necessary, the entire supervisory chain up to the office of the President.

If, at this point, differences still exist relative to technical or engineering interpretations, ways and means are available for presenting the problem, particularly if of an installation nature, to one of UL's Engineering Councils, as appropriate.

If the disagreement involves a method of measurement or the interpretation of test results, the question may be referred to the National Bureau of Standards provided that, in the opinion of the Bureau, the importance of the case justifies its consideration by the Bureau, and the parties involved agree in writing to accept and abide by the findings of the Bureau. Any costs involved in such appeals procedure shall be borne by UL and its clients.

To serve as supplement, but not as a replacement, for the above described appeals mechanism, there is also available the "Technical Appeals Board (TAB) of UL".

The specific purpose of the TAB is to serve as an advisory body to consider matters of technical substance, but not matters of policy, about which any client(s) of UL, and UL, may hold an unresolved difference of opinion.

The TAB serves as a body to which the view of UL and its client may be submitted. The TAB shall be utilized only after all other administrative appeals channels in UL have been exhausted.

Further details with respect to processing an appeal may be obtained from the Chief Engineer having jurisdiction in the particular product area. Appeals procedures from the decisions of UL's field inspectors are also available. Further interpretations pertaining to such processes may be obtained from the Managing Engineer, Follow-Up Services, at the office where the engineering investigation was conducted.

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Laboratories Inc. It appeared, in a brochure entitled Testing for Public Safety, copyright 1977 (by Underwriters Laboratories Inc.) copies of which may be obtained from Underwriters Laboratories, Inc. Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.

In addition to the Listing and Follow-Up Services there are other services available from UL. These are illustrated in Figure 10-1. These have been developed to further assist the manufacturer where a non-typical product development procedure is anticipated.

Underwriters Laboratories Inc. (UL) has also developed specific test procedures for a wide variety of circumstances. For instance, in the use of solid state appliance controls, the following overall approach was utilized.

As shown by the flow chart (Figure 10-2) this procedure was divided into construction concerns and testing concerns. "The construction concerns itself with spacings, insulating materials, internal wiring, protective devices, etc. within the control itself. These spacings and insulating requirements are a function of energy levels.

The testing section is divided as follows:

A. Tests conducted to determine if any unreasonable fire or shock hazards may exist. These tests are the minimum requirements that must be successfully completed for the appliance control to be acceptable to Underwriters Laboratories.

B. If failure of the appliance control will result in a hazardous condition in the appliance then the device must operate normally after the tests conducted in A above. Alternatively a failure can be assumed whereby some protective device must operate to shut down the operation and reduce the possibility of hazard. An example of this type of control may be a semiconductor controlling a water heater coil. The semiconductor could fail in the "on state" and continuously energize the heater coil without water present. A fire hazard may exist unless some overtemperature protective device shuts down this operation.

C. If the control functions as a safety control, then A and B must be evalu-

FIGURE 10-1

TYPE OF SERVICE	APPLICABLE TO	PRODUCT IDENTIFICATION
Listing & Follow-Up Service *	Those products which have been evaluated with respect to reasonably foreseeable hazards to life and property, and where such hazards have been safeguarded to an acceptable degree.	**Listing Mark**—Employs UL's registered name or symbol generally in combination with the product name, a control number, and the word "Listed." Typical examples of the use of UL's registered name or symbol follow UNDERWRITERS LABORATORIES INC.® UND. LAB. INC.® UNDERWRITERS LABORATORIES INC. Underwriters Laboratories Inc.®
Classification & Follow-Up Service *	Those products which have been evaluated with respect to one or more of the following: 1) specific hazards only 2) performance under specified conditions 3) regulatory codes 4) other standards, including international standards. Restricted generally to industrial or commercial products.	**Classification Marking**—May appear in various forms as authorized by UL. Employs UL's name and a statement to indicate the extent of UL's evaluation of the product, such as "Classified by Underwriters Laboratories Inc. with respect to (nature of hazard) only." Similar statements relate to a product's performance under a rating system, or evaluation with respect to a statutory code or other standards. The marking also includes a reference to the appropriate UL Product Directory for additional information
Recognition & Follow-Up Service *	Those products which have been evaluated only for use as components of end-product equipment Listed or Classified by UL.	**Recognized Marking**—Consists of the manufacturer's identification and catalog number, model number, or other product designation as specified for the particular product. Except in very rare cases, the use of the UL name in any form on the product is prohibited, but the following Recognized Component Mark may be used as supplementary identification.
Certificate & Follow-Up Service *	A field-installed system at a specific location, or to specific quantities of certain products where it is impractical to apply the Listing Mark or Classification Marking to the individual product.	UL authorizes the installer or manufacturer to issue a written certificate for use by customers, inspection authorities, insurance companies, and others, based on UL's examination and/or tests.
Inspection	Products or systems involved in situations where the availability and capability of UL inspectors can assist local authorities having jurisdiction, or can provide inspection service to an industry group on a contract basis.	A report covering the inspection is issued to the contracting sponsor.
Fact-Finding and Research	Projects conducted on contract basis for manufacturers, trade associations, governmental agencies, and others in the interest of public safety. (1) **Fact-Finding Investigations**—develop product or system information and data for use by applicant in seeking recognition in or amendment of a nationally recognized installation code or standard. (2) **Research**—develops basic information, properties, and characteristics of materials, products and systems as related to safety to life or property—generally in the area of standards development	A report is issued to contracting sponsor. Reports generally cover a class rather than a specific product.
* **Follow-Up Service**	Inspections and counter checks of manufacturers' procedures for assuring production compliance with the requirements are conducted in the factories and in the field. Such inspections and checks are unannounced and at a frequency appropriate for the product or system involved.	

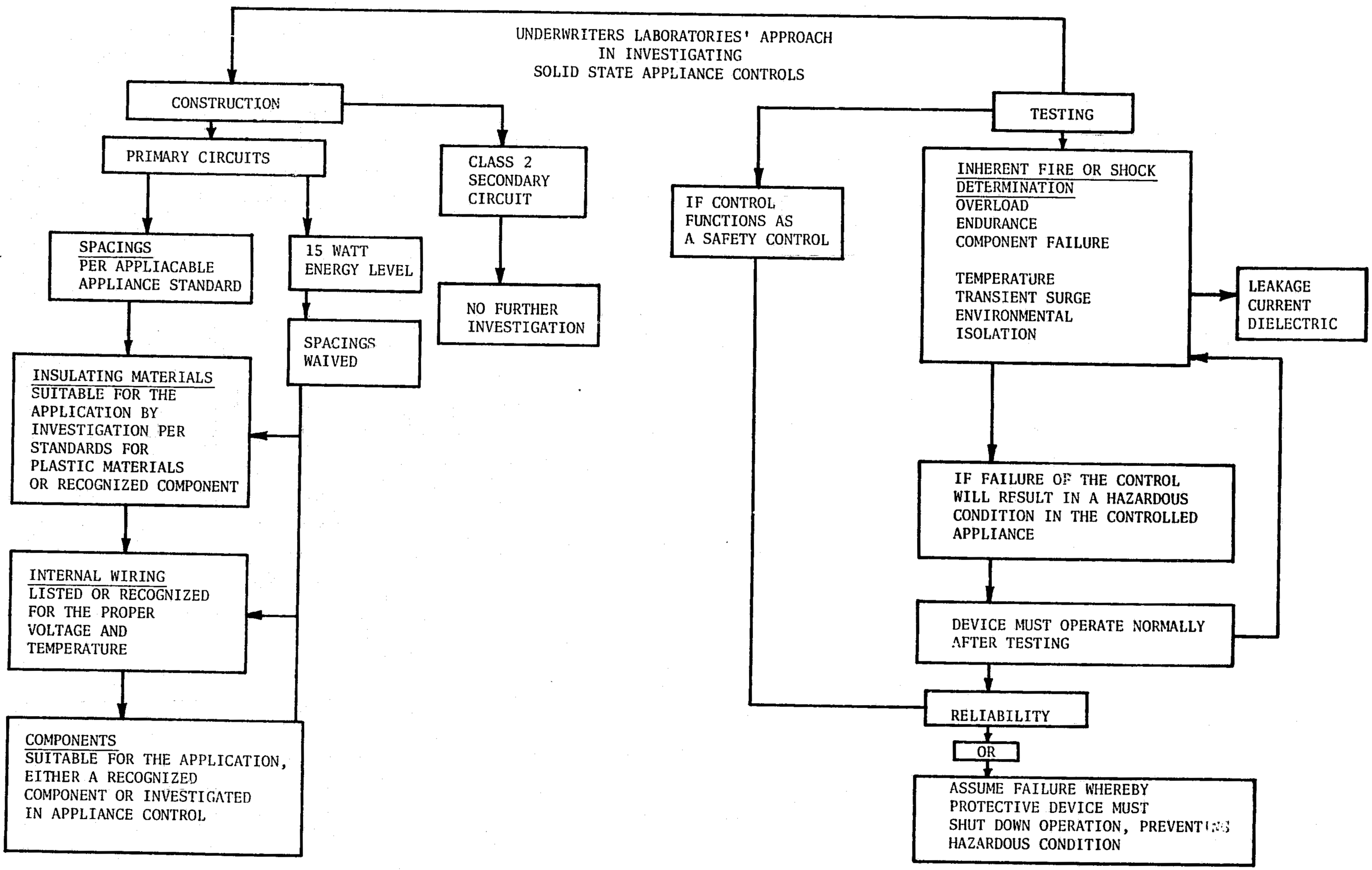
UNDERWRITERS LABORATORIES' APPROACH
IN INVESTIGATING
SOLID STATE APPLIANCE CONTROLS
CONSTRUCTION
PRIMARY CIRCUITS
CLASS 2 SECONDARY CIRCUIT
SPACINGS PER APPLIACABLE APPLIANCE STANDARD
15 WATT ENERGY LEVEL
SPACINGS WAIVED
NO FURTHER INVESTIGATION
INSULATING MATERIALS SUITABLE FOR THE APPLICATION BY INVESTIGATION PER STANDARDS FOR PLASTIC MATERIALS OR RECOGNIZED COMPONENT
INTERNAL WIRING LISTED OR RECOGNIZED FOR THE PROPER VOLTAGE AND TEMPERATURE
COMPONENTS SUITABLE FOR THE APPLICATION, EITHER A RECOGNIZED COMPONENT OR INVESTIGATED IN APPLIANCE CONTROL
TESTING
IF CONTROL FUNCTIONS AS A SAFETY CONTROL
INHERENT FIRE OR SHOCK DETERMINATION
OVERLOAD
ENDURANCE
COMPONENT FAILURE
TEMPERATURE
TRANSIENT SURGE
ENVIRONMENTAL
ISOLATION
LEAKAGE CURRENT DIELECTRIC
IF FAILURE OF THE CONTROL WILL RESULT IN A HAZARDOUS CONDITION IN THE CONTROLLED APPLIANCE
DEVICE MUST OPERATE NORMALLY AFTER TESTING
RELIABILITY
OR
ASSUME FAILURE WHEREBY PROTECTIVE DEVICE MUST SHUT DOWN OPERATION, PREVENTING HAZARDOUS CONDITION

FIGURE 10-2

ated. Follow-up production line testing at the factory by the manufacturer is counterchecked by Underwriters Laboratories' inspectors. These tests are usually an incoming component part screening to verify that certain electrical and physical properties of the component parts in the appliance control meet the component manufacturer's specifications. Also, burn-in tests consisting of a short operating period of the appliance control prior to release for field usage is required."[3]

3. Lab Data, Underwriters Laboratories Inc., Vol. 9, No. 4, Fall, 1978, PP 12, 13.

APPENDIX 11. INSURANCE REVIEW

PURPOSE: Contact various representative insurance companies with national or regional markets to determine whether any steps have already been taken, or are planned, which will establish rates for photovoltaic solar modules, and whether the materials of a module may have any bearing on insurability or rates.

CONCLUSIONS: Photovoltaic modules, panels, and arrays are not addressed by any of the insurance companies or agencies contacted. By and large, the insurance industry has assumed a wait-and-see posture. Currently, an array would be treated as part of the dwelling, and its value incorporated in the total replacement value upon which the insurance premium is based. The materials used in the construction of the module have no bearing on its insurability except as they might affect the durability of the module.

RECOMMENDATIONS: The durability of the RPM will probably be the single most important factor in the establishment of insurance rates. High premium costs can significantly affect the potential for rapid acceptance of the RPM in the residential market. The design and installation of the array should, therefore, give high priority to durability. The module should be resistant to damage from natural causes; rain, hail, snow, wind. It should also be capable of resisting some of the common forms of vandalism and accidental damage that can be expected in a residential neighborhood. The design of the module should also incorporate features which simplify repair or reaplcement as these are other factors which will affect the cost of insurance in the future.

INSURANCE REVIEW

A concern, often expressed by the homeowner considering new and innovative materials for the residential marketplace is "how will this effect my home insurance rate." Although this may not necessarily be of concern to the module designer at this time, eventually the success of the RPM will depend on its acceptance by insurance underwriters. Various representative insurance companies with national or regional markets were contacted to determine whether any steps have already been taken or are planned, which will establish rates for photovoltaic solar modules. Also, whether the materials of a module may have any bearing on insurability or rates. The RPM was considered to be installed on the roof of a one or two family dwelling.

Aetna Insurance was contacted at their Pittsburgh office which in turn suggested contacting the home office in Connecticut. We contacted the home office and were told that an organization called the Insurance Services Office sets rates for fire protection and that at this time, no rates have yet been established for any type of solar system. It was further stated that the factors which determine the rating of insurance for a residence are external fire protection, that is, location of fire hydrants, rating of the local fire department, its distance from the dwelling, and whether the dwelling is of brick or frame construction. It was the opinion of the person contacted (Mr. Woodcock, a mechanical engineer at Aetna), that guidelines for the rating of solar collectors were not likely to be issued in the near future. As of now, the cost of the solar collector would be added to the house and the insurance premium based on the replacement value of the total.

Nationwide Insurance was contacted at its Butler, PA office. The comments of a Mr. Fullerton, a salesman, were similar to those made by the Aetna representative. Specifically, Fullerton said that brick and frame construction were the only two determinants for insurance rates, that roof construction does not affect rates. The value of the RPM would be added to the value of the house rather than valued as a separate entity. We were then referred to the Insurance Services Office.

The Insurance Services Office (I.S.O.) of Pennsylvania, Pittsburgh office, was contacted. They described their services as a rating bureau that inspects all commercial properties <u>only</u> and keeps files of rate cards to which insurance companies have access.

Further information was sought at the ISO Home Office in Philadelphia. A gentleman there brought up the point that he thought solar collectors might be insured either as part of the structure or separately as a rider attached to the policy but would most likely be treated as part of the structure. This opinion is consistent with those of Aetna and Nationwide.

Philadelphia ISO pointed out that certain appurtenances on residences, such as elaborate television anntennae, are insured by means of a rider to the homeowner's policy because of their susceptibility to wind damage. This might be a clue to how a standoff or rack mounted RPM might be treated.

The next source was the American Insurance Association in New York. They could offer no information, but directed us to the National Headquarters, ISO, and a Mr. Frank Caso.

Mr. Caso stated that solar systems were discussed in committee a year ago. It was determined that additional exposure of collectors on a roof could be a factor, i.e., additional exposure to wind, hail, and the added weight on the roof structure could cause collapse. But at that time, they felt that not enough systems were in use to make any kind of a recommendation. Instead, he felt that the added cost of the system would be included in the value of the house and this would be sufficient to cover the added risk the system would involve.

Based on current information, it appears that the insurance industry has assumed a wait-and-see posture. As solar collectors of various types come into more common usage, precedence will be established to aid insurance companies in determining the risks involved in a roof mounted solar collector. Currently, insurance rates are determined by including the cost of a collector array with the cost of the house and basing the rates on the total cost. One variation which was suggested and appears possible is that solar collectors may someday be insured by means of a rider to the basic policy, if experience proves that repair and replacement costs cannot be supported by the one-cost system. No limitations now exist on materials used as components in RPM, at least no limitations based on decisions made by the insurance industry. In any event, at this time, roofing materials do not appear to have any bearing on the rates charged for insuring a home.

APPENDIX 12. STUDIES APPROACH

PURPOSE: A comprehensive approach was established in order to facilitate the undertaking of the studies in the following appendices.

CONCLUSIONS: The most appropriate approach for the studies was to isolate the module design, i.e., to establish a given module design. By taking this approach, however, changes in module design and their associated effects on other design requirements cannot be reflected or accounted for.

RECOMMENDATIONS: This appendix should be read and understood before approaching the remaining appendices, as the assumptions made here directly influence the results obtained in the following studies sections.

INTRODUCTION:

The approach taken on the studies section of this contract is not nearly as discreet as might be assumed. Rather, a more dependent or linear approach was used. A matrix was developed to identify all of the possible array options using a given 1,000 ft^2 array with a 220 volt dc output. The options, as put forth in the matrix include array dimension ratio, which will affect support, waterproofing and wiring costs; array mounting types, and the actual module construction. This matrix, shown in Figure 12-1, produces 1,536 separate module array options to study -- far too many for the scope of this study. It was decided, therefore to isolate and establish the module design. Once done, the studies were undertaken as described in the following paragraph.

Various panel sizes were identified as "first cut" or basic sizes useful to address the array area and voltage restrictions. These various panel sizes were then arranged into 1,000 ft^2 arrays. (See Figures 12-2 and 12-3) These arrangements allow careful study of the costs associated with each module, panel and array configuration. In addition to the variations on module, panel and array sizes that affect module design characteristics, there will also be numerous restrictions placed on the solar photovoltaic module due to integra-

Mount	Superstrate / Substrate	1 : 1				1 : 2				1 : 3				1 : 4				1 : 7				1 : 15			
		1. JPL 48" x 48"	2. Heating & Cooling 32" x 96"	3. Fibonnaci (3'+5'+8')x(3'+5'+8')	4. Hybrid of 2 & 3 (32")x(3'+5'+8')	1. JPL 48" x 48"	2. Heating & Cooling 32" x 96"	3. Fibonnaci (3'+5'+8')x(3'+5'+8')	4. Hybrid of 2 & 3 (32")x(3'+5'+8')	1. JPL 48" x 48"	2. Heating & Cooling 32" x 96"	3. Fibonnaci (3'+5'+8')x(3'+5'+8')	4. Hybrid of 2 & 3 (32")x(3'+5'+8')	1. JPL 48" x 48"	2. Heating & Cooling 32" x 96"	3. Fibonnaci (3'+5'+8')x(3'+5'+8')	4. Hybrid of 2 & 3 (32")x(3'+5'+8')	1. JPL 48" x 48"	2. Heating & Cooling 32" x 96"	3. Fibonnaci (3'+5'+8')x(3'+5'+8')	4. Hybrid of 2 & 3 (32")x(3'+5'+8')	1. JPL 48" x 48"	2. Heating & Cooling 32" x 96"	3. Fibonnaci (3'+5'+8')x(3'+5'+8')	4. Hybrid of 2 & 3 (32")x(3'+5'+8')
RACK MOUNT	Flat Glass / None																								
	Plastic / None																								
	Silicone Encapsulant / None																								
	Flat Glass / Plastic Substrate																								
	Plastic / Plastic																								
	Silicone Encapsulant / Plastic																								
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	Silicone Encapsulant / Metal																								
	Flat Glass / Glass Substrate																								
	Plastic / Glass Substrate																								
	Silicone Encapsulant / Glass Substrate																								
STAND-OFF MOUNT	Flat Glass / None																								
	Plastic / None																								
	Silicone Encapsulant / None																								
	Flat Glass / Plastic Substrate																								
	Plastic / Plastic																								
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	Silicone Encapsulant / Metal																								
	Flat Glass / Glass Substrate																								
	Plastic / Glass Substrate																								
	Silicone Encapsulant / Glass Substrate																								
DIRECT MOUNT	Flat Glass / None																								
	Plastic / None																								
	Silicone Encapsulant / None																								
	Flat Glass / Plastic Substrate																								
	Plastic / Plastic																								
	Silicone Encapsulant / Plastic																								
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	Plastic / Metal																								
	Silicone Encapsulant / Metal																								
	Flat Glass / Glass Substrate																								
	Plastic / Glass Substrate																								
	Silicone Encapsulant / Glass Substrate																								
INTEGRAL MOUNT	Flat Glass / None																								
	Plastic / None																								
	Silicone Encapsulant / None																								
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	Flat Glass / Glass Substrate																								
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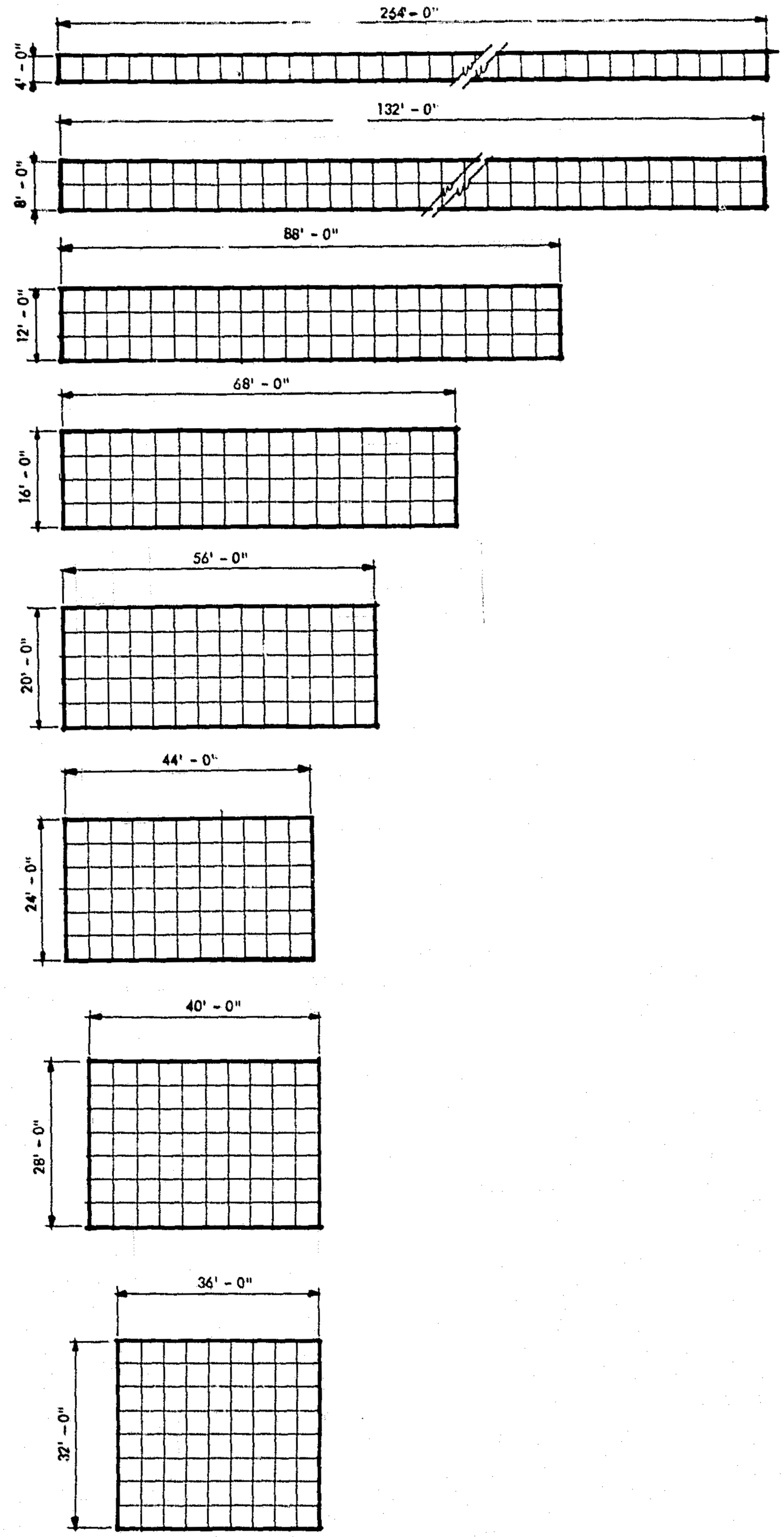
	Silicone Encapsulant / Glass Substrate																								

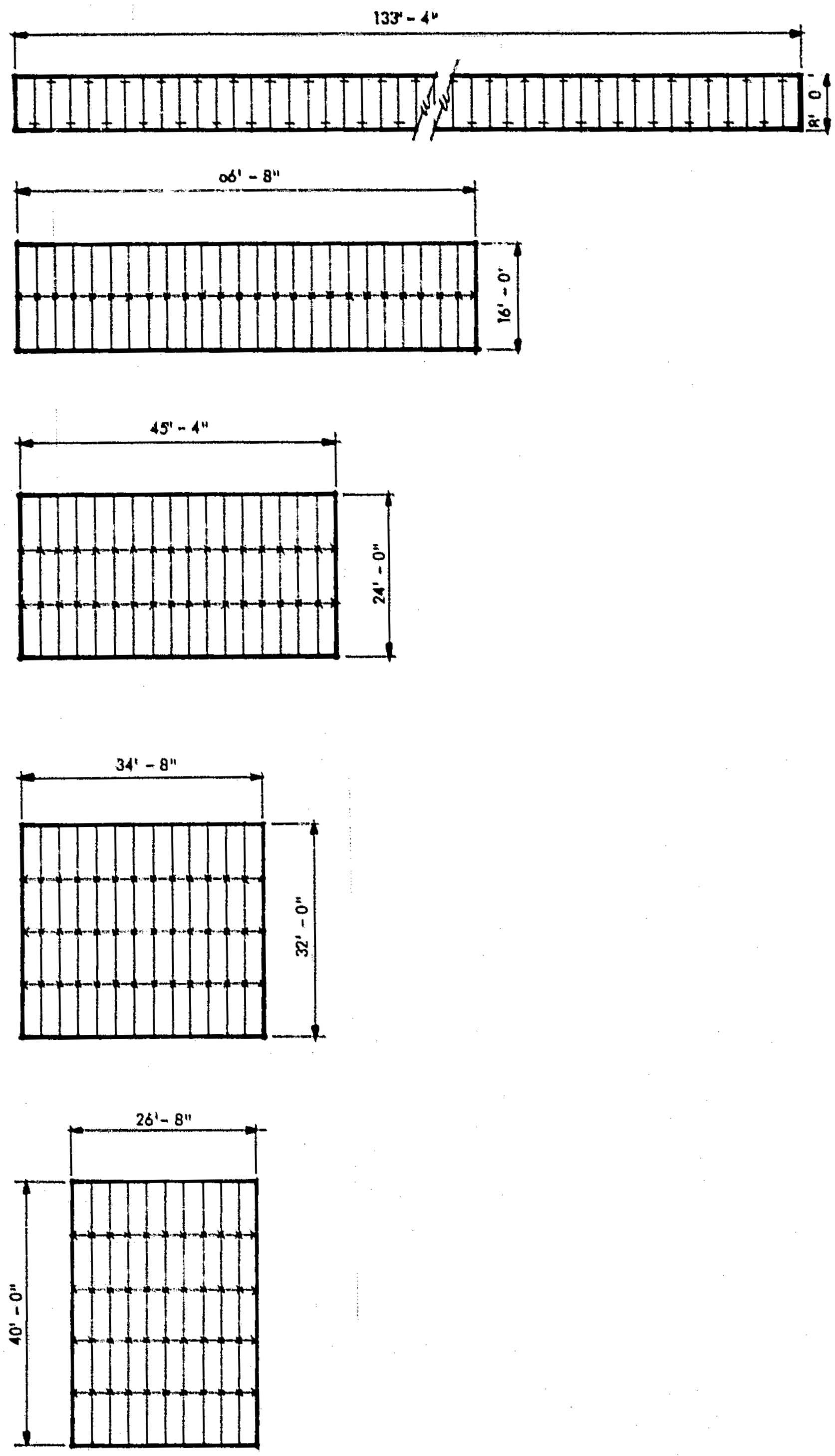
PANEL STUDY MATRIX

FIGURE 12-1



ARRAY CONFIGURATIONS 48" x 48" PANEL MODULE

FIGURE 12-2



ARRAY CONFIGURATIONS 32" x 96" PANEL MODULE

FIGURE 12-3

tion of the array with the building. We have addressed these by identifying four generic mounting configurations which represent the potential restrictions forced by the module.

The conclusions coming out of the studies depend on the way in which the panel or shingle module is incorporated into the residential design. There are basically four different techniques that define the full range of possible detailing. Each has its own particular restrictions and requirements, and advantages and disadvantages. These mounting types are: rack mount, standoff mount, direct mount and integral mount. Each of these mounting types may impose specific design requirements on the photovoltaic module. It is possible, therefore, to design a module around a given mounting type. It is also possible to design a module that can be utilized in all four mounting types. It will be necessary for the manufacturer to do a detailed mounting type cost analysis to determine whether he designs the module around the mounting type or designs a universal module for all mounting types.

APPENDIX 13 MOUNTING CONFIGURATIONS

PURPOSE: Four generic mounting types were established in order to perform the studies in the following appendices. The mounting types include rack mounting, standoff mounting, direct mounting, and integral mounting.

CONCLUSIONS: All module designs can be classified into one of the four generic mounting types or a combination of those types. Each mounting type has its own set of design requirements. The rack-mounted array is most suited for flat roofs. The maximum realistic slant height of the rack-mounted array is 16 ft. Aesthetics will play an important role in the mounting of residential roof-top arrays. Ground-mounted arrays may pose zoning ordinance problems and require fences. Direct mounting allows for a broad variety of module design possibilities for both architectural and engineering solutions to photovoltaic usage in residential applications. Integrally-mounted arrays (by the replacement of roofing materials) may realize cost credits of as much as $3.00 per square foot. However, potential problems with uneven heating of the array may occur.

RECOMMENDATIONS: Caution must be taken during the design phase of residential modules to ensure the proper use of the module in one or all of the generic mounting types.

Details for the four mounting types have been developed and are seen in Figures 13-1, 2, 3 and 4. Several important assumptions were made in order to develop adequately the four generic mounting types. First, the rack and standoff mounted modules need not form a watertight membrane, and the direct and integral mounted modules will be required to form a watertight membrane for the building structure. Secondly, 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 building roof design loads. Third, all module designs could be classified in one of the four generic mounting types. As previously mentioned each

BUILDING MODULES INTEGRATION TYPES

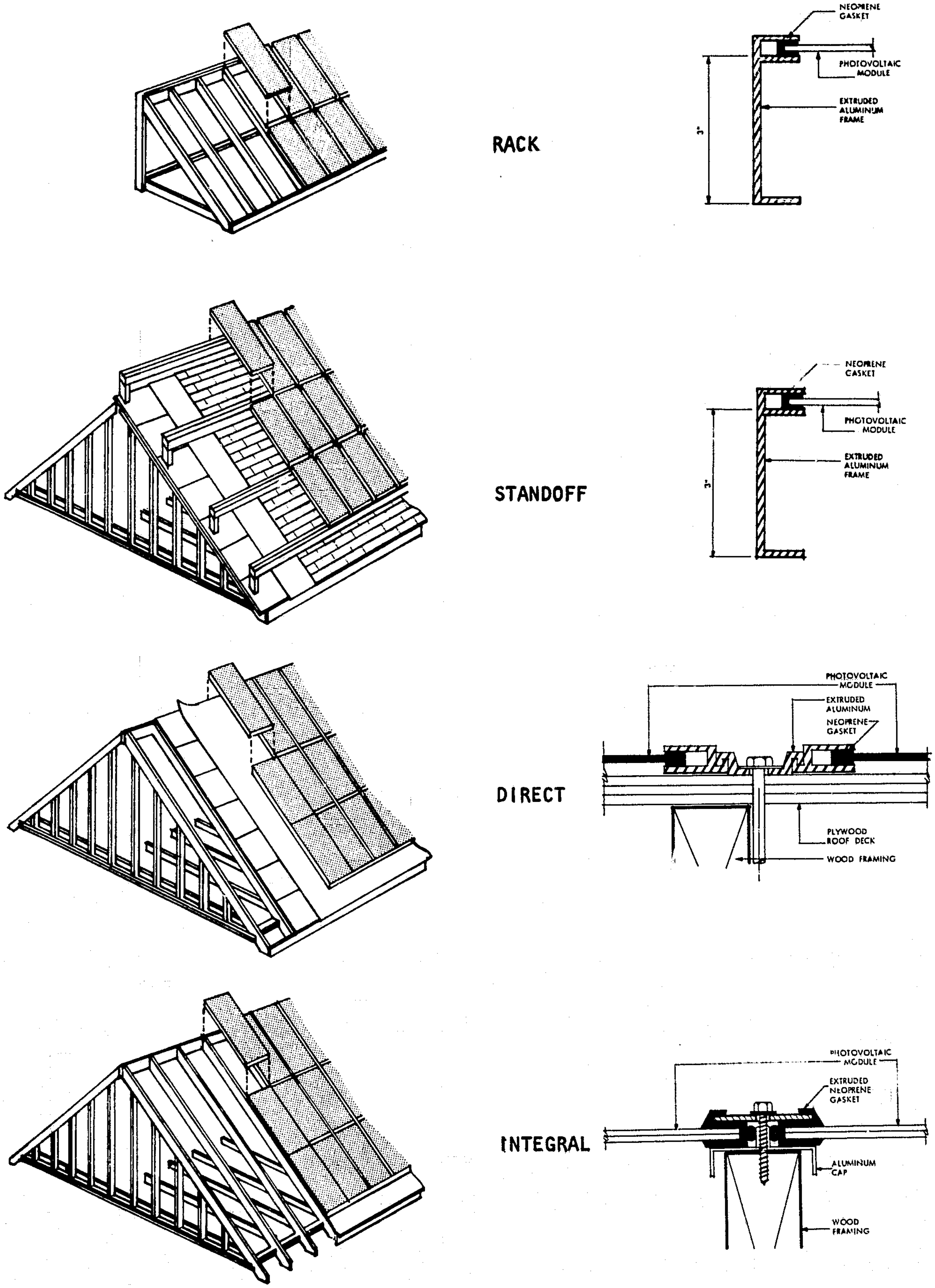
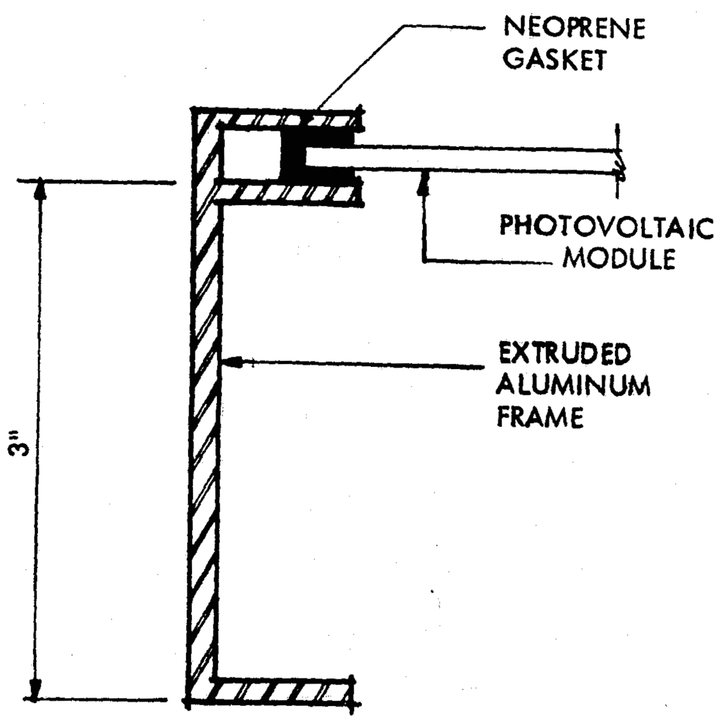


FIGURE 13-1

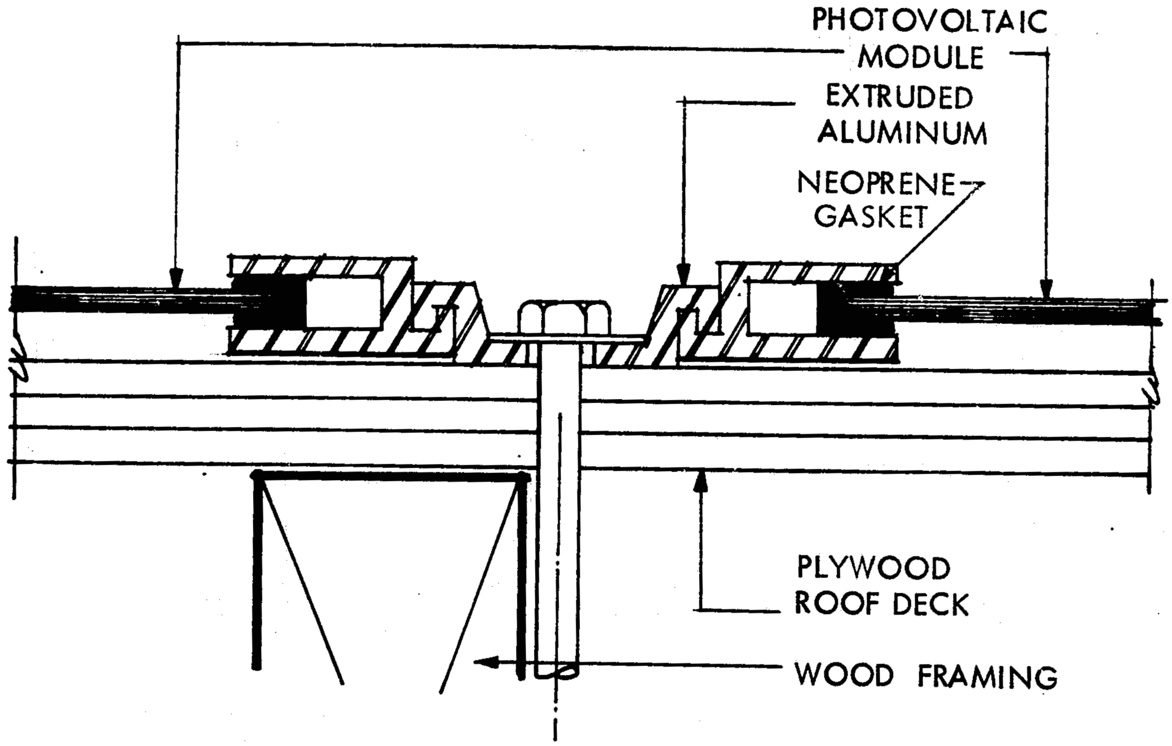
of the mounting types has its own benefits as well as disadvantages. The following describes each of the mounting types:

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 residence or on the roof of the residence. 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. Mainly, the module can be designed for the minimum amount of structural rigidity (i.e., resistance to dead loading and wind uplifts) and integrity, thus reducing the cost of



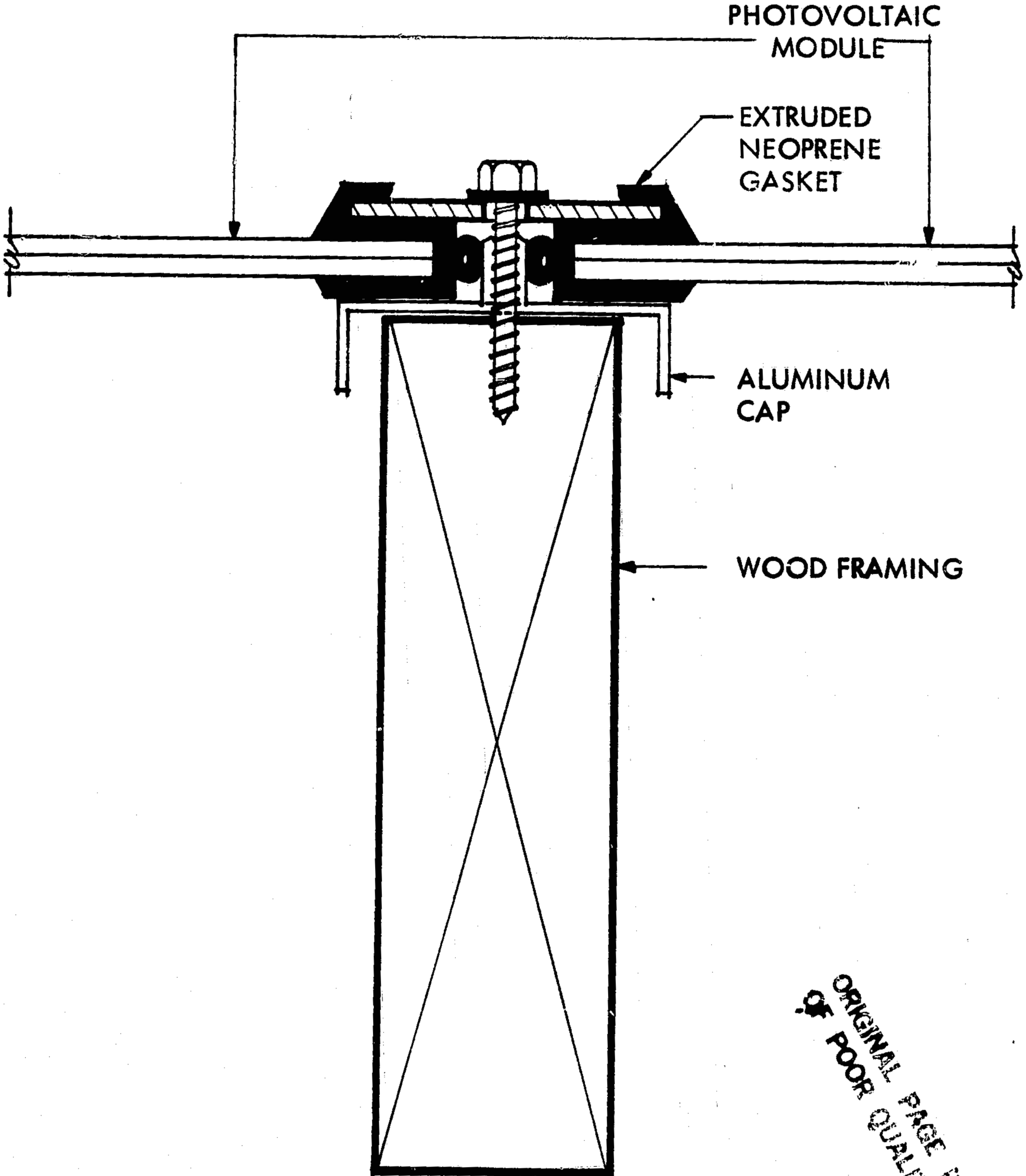
STAND OFF AND RACK MOUNT

FIGURE 13-2



DIRECT MOUNTING TECHNIQUE

FIGURE 13-3



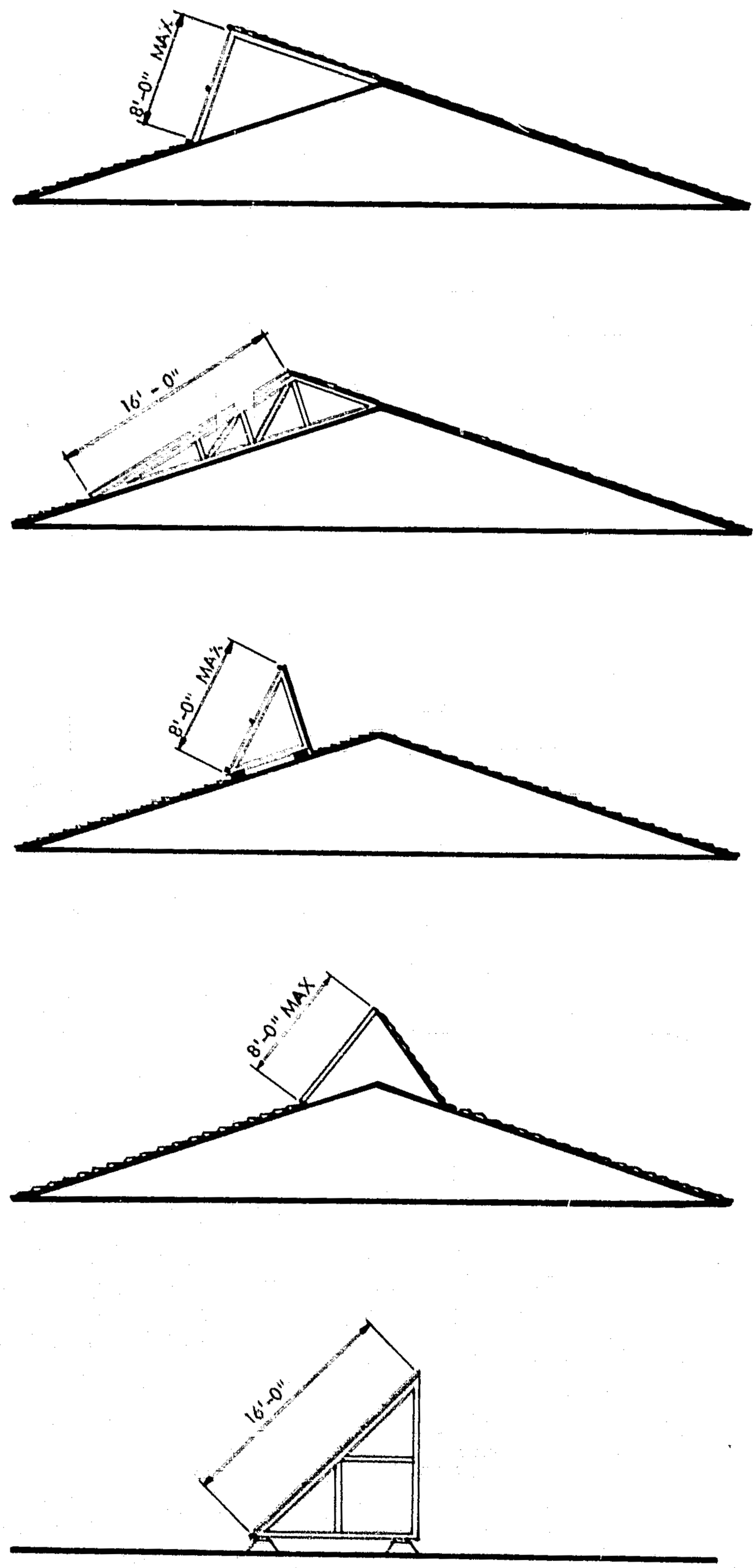
INTEGRAL MOUNTING TECHNIQUE

FIGURE 13-4

the module itself. Because of easy accessibility, maintenance and installation of the module and its electrical connections can be made quickly and with relative ease, allowing for reduction in both installation costs and maintenance costs.

There are, however, some serious drawbacks to 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 mounted arrays, causing additional cost to the system.

While ground mounted arrays pose special problems, rooftop installations of rack mounted modules also have their own inherent problems. Upon close inspection of the applications where roof mounted rack type arrays can be used, five configurations can be identified as seen in Figure 13-5. Examining these five details more closely, it becomes apparent that the last detail for the flat roof rack mounted array becomes the only reasonable choice for a 1,000 $ft.^2$ rack mounted array. This choice is apparent for several reasons. First, because of the height restrictions, i.e., aesthetic and structural limitations require the rack does not exceed 16 ft, space becomes a limitation for residential rooftop applications. Secondly, added material costs associated with the other details for roof rack-mounted arrays will drive the installed costs above those for other type mounting systems. Thirdly, aesthetic acceptability is important in residential applications. These rack mounted rooftop arrays give a tacked-on appearance and are grossly out of proportion with respect to residential design. Further, A-frame type details will impose extremely large point loads on the roof framing system. This would require sizeable increases in roofing members and a severe cost penalty.



ROOF MOUNTED RACK MOUNTING TECHNIQUES

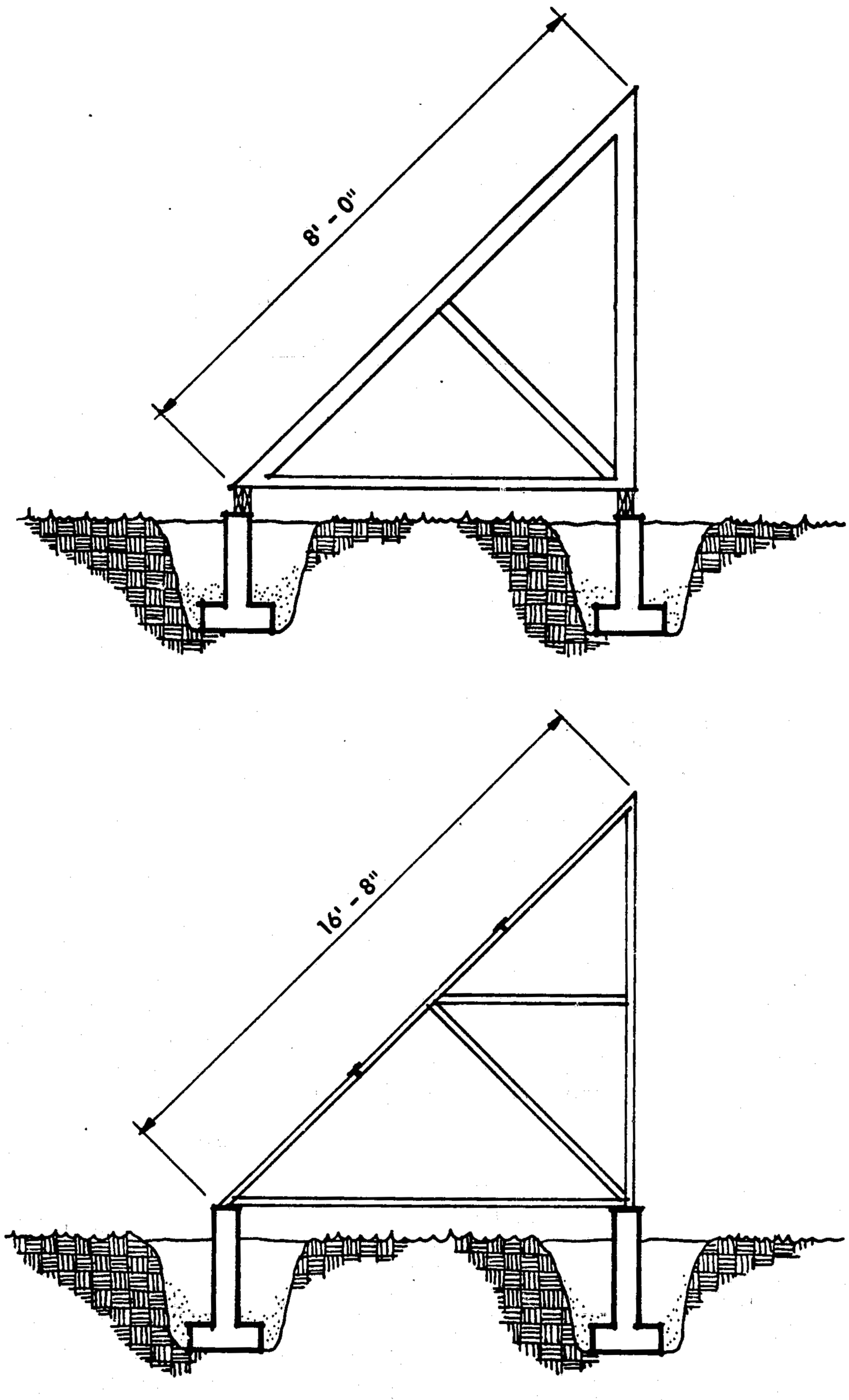
FIGURE 13-5

An example rack was designed to do detailed costing studies around. This rack can be seen in Figure 13-6. These costs were generated around both the roof mounted and the ground mounted rack using both wood and steel for the structural members. It will be shown in later sections that wood is far less expensive than steel for this type of application. Not only is cost an important consideration, but since this is a residential application, the materials used should be compatible with standard residential practices.

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 to an extent 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.

   Because of the close proximity of the module to the roof, maintenance will be more difficult than it was with rack mounted arrays. However, this slight installation disadvantage will not outweigh the reduction in materials and installation labor costs incurred by these standoff mounts over the rack mounted array. A comparison of labor and materials costs for the standoff mounted module and the rack mounted module can be seen in the cost analysis sections (Appendix 14). It should be noted that neither the rack mounted nor the standoff mounted array requires waterproofing, for neither acts as a watertight membrane over the roof structure.

3. Direct Mount. Installation of direct mounted modules is accomplished by anchoring the modules to the roof. The use of this mounting technique eliminates the need for additive structural supports. The



RACK MOUNT

FIGURE 13-6

modules will be placed on the waterproof membrane which is already on top of the roof sheathing. There will be a need for module-to-module and array perimeter waterproofing and, therefore, the array will act as a waterproof membrane. This is necessary in order to assure water does not collect under the modules causing mildew and rotting problems. There will, also, be a minimal credit for replacement of some roofing materials.

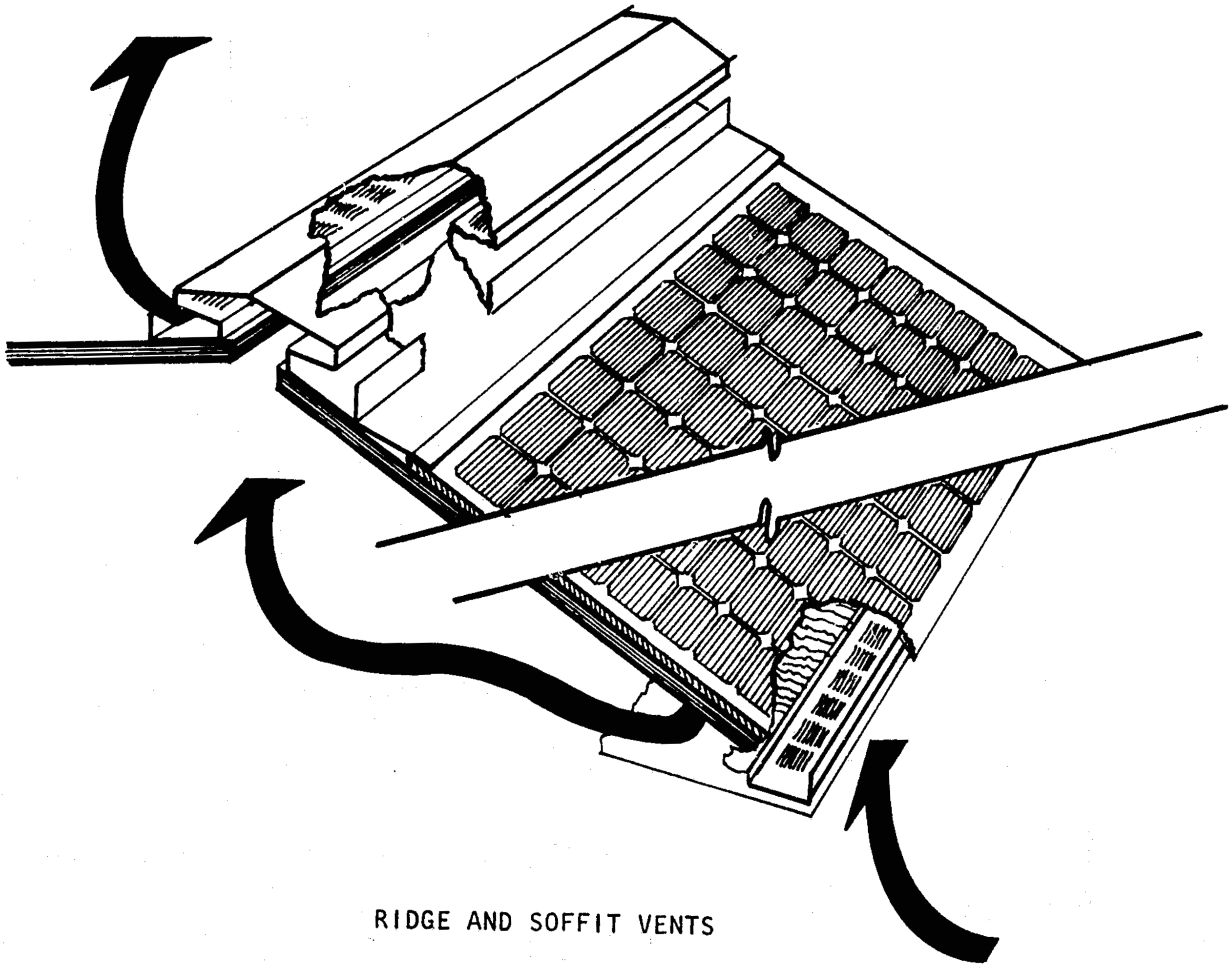
Because of the direct mount system's inherent contact with the roof, three major problems will exist. First, cooling of this type module will be a problem, for only the top surface will be cooled by convection. This will, of course, decrease the module efficiency. Second, electrical connections must be of a very unique type because the back surface of the module will not be exposed for interconnecting purposes; because of this, new and innovative techniques need to be developed for electrically connecting these 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 surface, module tilt is, therefore, dependent upon roof pitch and requires the roof be designed accordingly.

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 a 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 residential photovoltaic modules for direct mount applications.

4. Integral Mount. Integral mounting places the module within the roof construction itself. Modules are attached to and supported by the roof structural framing members and serve as the finished roof surface. Credits of approximately $0.94 per sq.ft. to $3.43 per sq. ft. may be realized by the replacement of the roof sheathing and shingles

by the integrated module. However, due to the structural support given by the roof sheathing, removal of that roof sheathing will require additional structural support be given to the roof framing system. Therefore, the above mentioned cost credits will be reduced accordingly. Watertightness is critical to avoid problems of water damage and mildew. Electrical connections and maintenance, if required, can be made from the attic area of the residence provided the modules are not attached above a cathedral ceiling (a cathedral ceiling is an area of the roof where a finished ceiling is applied to the bottom of the sloping roof rafters). As with the direct mounted module, the integral mounted module's tilt angle is determined by the roof pitch and again requires the roof to be designed accordingly.

Likewise, module area is restricted to the roof area. Modules to be used integrally must be constructed to the standard building tolerances. Because the array now becomes the roof structure, modules must be designed to withstand all live loads that are specified for residential applications. This mounting technique allows for venting of the back side of the module. However, uneven heating of the array may occur in the event that improper venting occurs in the attic space. This problem may stem from improper packing of insulation, dead space, or improper ventilating detailing. A soffit to ridge vent system is recommended as seen in Figure 13-7. This heating problem requires additional study in order to determine the severity and probable solutions to the problem.



RIDGE AND SOFFIT VENTS

FIGURE 13-7

APPENDIX 14 MODULE/PANEL SIZE AND SHAPE COST ANALYSIS

PURPOSE: Examination of the size and shape of module/panel as effected by the residential building industry. Also examined are the associated costs of materials and labor on installation of module/panels.

CONCLUSIONS: Panel size and shape should be of convenient size to allow ease of handling by one or two installers. Module mounting type also effects size and shape, and a module size of 32" x 96" appears to be an appropriate size for use in the residential market. Excluding roof credits, installation costs are the least expensive for direct mounted modules (see Appendix 16 for final costs). Examination of rack mounting indicates steel as a structural support is prohibitively expensive. A maximum width of 40" and 50 to 60 lbs. would be adhered to.

RECOMMENDATIONS: It is recommended that further studies be undertaken to establish the optimum size of residential photovoltaic modules. Much design work is required to establish an optimum module design which incorporates the inexpensive installation techniques of a direct mounted module and the cost credits achieved by using an integrally mounted module.

INTRODUCTION

There will be many factors which will influence the installation and materials costs with regards to photovoltaic modules. These factors include mounting type, particular detail used for each mounting type, panel size and module size. Other factors which may influence these costs are module voltage and terminal location. These latter topics will be discussed in Appendix 15.

In order to accomplish the task of costing materials and labor for installation of PV modules, it was necessary to make several assumptions. First, the panel size was established at 32" x 96" and 48" x 48". A further breakdown of panel size included the investigation of 16" x 24" and 16" x 48" modules configured into the above mentioned panel sizes. Reasons for choosing these panel sizes are discussed in the following sections. Secondly, knowing that for each mounting type there is virtually an infinite number of possible designs related to edge details, it becomes necessary to define module edge details for each mounting type. Many details were examined; however, due to the time requirements for this study, one detail for each mounting type was established for the costing analysis. These details related to the specific requirements of each mounting type and costs for material and labor for installation were generated. Figures 13-1, 2, 3 and 4 show details of the edge mountings studied. Costs were generated using values from Means Building Cost Data [1] and Building Cost File [2] for materials used in module framing and mounting systems and their installation. As PV modules are not included in these costing catalogs, installation costs for glazing panels were used. Thirdly, it was assumed that each mounting type would utilize identical modules, i.e., the same module construction would be used in each of the framing techniques. It was necessary to make these assumptions in order to eliminate the literally millions of possibilities that could be generated for module design configurations.

PANEL SIZE AND SHAPE EFFECT ON COST OF INSTALLATION

The residential construction industry, as an average, possesses a rather reduced degree of technology in equipment, materials and methods used to manifest a particular architectural solution. Construction costs will rise and fall reflecting the degree of complexity, familiarity with the task required, and departure of materials required for that task from commonly used industry accepted sizes and shapes. The PV module/panel must, therefore, be uncomplicated and versatile in size and shape to allow adaptation to these solutions with optimum expenditure of labor and materials. It follows, then, that the panels must also interface with accepted construction industry materials and dimensions. The following are based on these assumptions.

- Panels must be easily handled by one or two workmen.
- Integral mounted panels must adapt to commonly used materials and framing dimensions.
- Panel will be integral part of an optimum residential array size of 1,000 ft.^{2} - 220 Volts dc.
- Size of glass cover/superstrate must be within limits of glass manu-

facturing technology.

- Where possible, it would be advantageous to cover the most area with the least effort.

Size and shape can have a significant impact on the PV panel installation. The PV module/panel was investigated to determine the most appropriate standard size to give the total array the increased flexibility and closer compatability with existing building practices. Primary consideration with regard to size and tolerance can be determined by examining current glazing system techniques and requirements. Commonly, economic considerations are the driving force for the practiced dimensions for glazing systems. The best economies, as well as the most widespread application of photovoltaic panels, may be realized by close adherence to current glazing module sizes.

The obvious first choice would be to make the panel as large as possible, approaching the total array area as the limit. This would, however, be an extremely naive approach. Handling, weight, and flexibility to variations in the supporting surface would suggest a smaller panel. Most residential tasks are accomplished by one or two men, each with a hand-to-hand comfortable grip span of 36 to 40 inches and individual lifting capacity of 50 to 60 pounds, as can be seen in Figure 14-1. This would suggest for ease of handling, shipping and installation that each PV panel or bundle of shingle type modules be within these limits, that is, with a maximum 40" dimension in at least one direction.

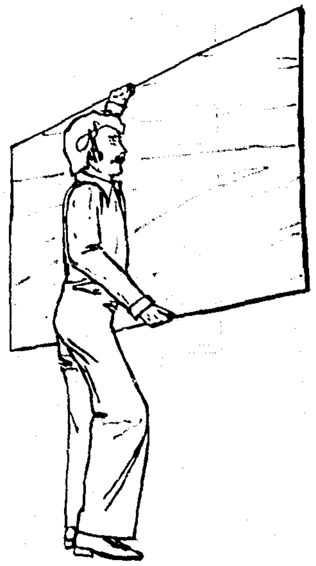


Figure 14-1

If, for example, glass were to be used as a superstrate material, the primary limitation in the panel becomes the cover itself. The present limitations of the glass industry will, then, influence size and shape of the panel. By examining Table 14-1, the maximum available size of various types and thicknesses of glass can be determined. A first approximation of maximum glass area under a given wind loading condition can be obtained from Figure 14-2. An optimization study can be performed to determine the glass size and thickness which will resist approximately 38 psf of wind loading, which will exceed all national building code requirements while minimizing glass transmission losses and cost. Returning to Figure 14-2 it can be seen that under 38 psf wind loading, glass areas can be 12, 20 or 30 $ft.^2$ for 1/8, 3/16 and 1/4" thick glass respectively.

Another item which now must be considered is standard building dimensional requirements for residential applications. Most of these fall within three groups: 16, 24 and 36 inch nominally. It may be advantageous for the module manufacturer to fabricate one size module which can be used universally in all mounting types. Only after a comprehensive manufacturing costing analysis can this decision be made. Recognizing this, the dimensions of PV panels could be one of these dimensions or a multiple of the same. This becomes particularly important for an integral or rack mounted array where each module would be nested within the framing of a roof structure, or interfaced with an adjacent roof unit covering. This limitation may not apply as rigidly to direct or standoff mounted arrays where array structures may help span any roof dimensional characteristics.

As the scope of this contract addresses residential photovoltaic applications, consideration must be given to personnel, material and equipment found on a residential job site. Typically, the majority of tasks undertaken on a residential job site, can be accomplished by the use of one or two men. Deviation from this may occur during the installation of pre-fabricated roof trusses. These trusses may be placed with the use of a crane. This operation will require a minimum of three men, a crane and a crane operator. Although additional manpower is required to install the truss system in this manner, the economies are favorable as the entire system can be placed in only several hours. A similar technique can be employed for the installation of photo-

TABLE 14-1

AVAILABILITY TABLE

PRODUCT	THICKNESS Nominal Inches	THICKNESS Tolerance Inches	WEIGHT Approx. lb./sq.ft.	MAXIMUM SIZE[1] Standard Inches
Clear				
Photo	1/16	0.058 to 0.068	0.81	36 x 50
Picture	5/64	0.070 to 0.080	1.01	36 x 50
Single Strength[3]	3/32	0.085 to 0.101	1.22	40 x 50
Double Strength[3,4]	1/8	0.115 to 0.134	1.65	60 x 80
3/16 Sheet[3,4]	3/16	0.182 to 0.200	2.45	120 x 84
7/32 Sheet[4]	7/32	0.212 to 0.230	2.88	120 x 84
1/4 Sheet[4]	1/4	0.240 to 0.260	3.24	120 x 84
3/8 Sheet	3/8	0.357 to 0.384	4.86	60 x 84
7/16 Sheet	7/16	0.400 to 0.430	5.67	60 x 84
Greenhouse[5]	1/8	0.115 to 0.134	1.65	20 x 20

FLOAT GLASS
To Meet Wind Load Requirements

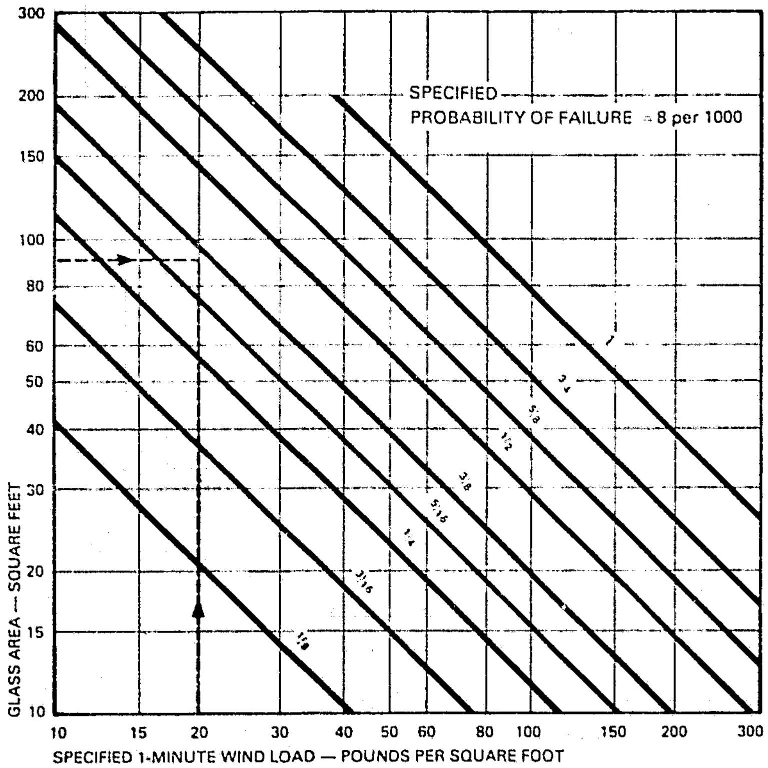


FIGURE 14-2

voltaic panels. This would imply no limiting size requirements for installation and handling. However, due to the high rental and operating costs of cranes, the use of cranes on residential job sites must be kept to a minimum. Should cranes be needed for hoisting panels to roofs, the photovoltaics modules must be designed for rapid installation. Examining costs may provide some insight to the module designer. Rental costs for a crane and operator will be on the order of $400 per day. Noting the need for additional ground personnel, this figure must be increased another $50 to $80 per day, bringing the total additional cost to $450 to $500 per day. If the photovoltaic array can be installed in one day with the use of a crane, the total additional cost for the system installation would be comparable to the addition of two additional construction personnel for two and a half to three days. In light of this, it is not economically advantageous to use cranes for installation unless the operation can take place in one day or when installation without cranes takes longer than three days.

The panel dimensions can be determined using the above described criteria. Keeping in mind the requirement for comfortable hand to hand gripping span of 40", an individual's lifting capacity of 50 to 60 pounds, coupled with the standard building dimensions of 16, 24, and 36 inches nominally, suggests a module of 32 inches nominally. This 32 inch dimension fits well with the 16 inch nominally on center roof truss spacing, allowing easy integration of the photovoltaic panels onto or into the roof structure. By fixing this dimension as the width, and considering the appropriate limitations imposed by the glass industry technology, the height dimension can now be determined. It is also important to consider again the ease of handling for both shipping and installation. It should be noted that one of the larger residential building components are the 4 by 8 foot sheets of plywood. These plywood sheets are easily handled by one workman. By choosing the eight foot length for the PV module, we can maximize area by still allowing the workmen to easily handle one unit. The standard module then becomes 32 by 96 inches nominally.

Having established a standard panel size, it is now appropriate to examine that panel with respect to the four established mounting types. The following assumptions must be made in order to fully analyze effects each of the mounting types will have on the panel size. 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 small crane or ladder hoist. (See Figure 14-3)
   - Arrays must comply with local zoning laws with regard to height, property line setback and obstruction of views or visual access by adjacent residential units.
   - Waterproofing of array connections will not be a major problem.

2. Standoff Mount
   - Above ground lifting to be accomplished by small crane or ladder hoist.
   - Panels must be easily handled by one or two men.
   - Panel must present favorable aspect ratio for convenient inclusion in a 1,000 ft.^{2}, 220 Vdc array.
   - Waterproofing of array connections will not be a major problem.
   - Approaches closely the considerations of a roof support, rack mounted array.

3. Direct Mount
   - Panels must be easily handled by one or two men.
   - Limitation of size to total area as a function of flammability of PV panel materials as stipulated by applicable building Code(s). (See Code Review Appendix 3).
   - Panel must present favorable aspect ratio for efficient inclusion in a 1,000,ft.^{2}, 220 Vdc array.
   - Mildew and rot under panel may be a problem. Panels can be directly fastened and flashed to the roof sheathing.

4. Integral Mount
   - Panels will be nested within customary spaced roof framing members.
   - Waterproofing of array will be a major factor.
   - Panels must be easily handled by one or two men.

Using these assumptions and the above generated discussion on the standard panel size, considerations can now be given to the individual mounting techniques.

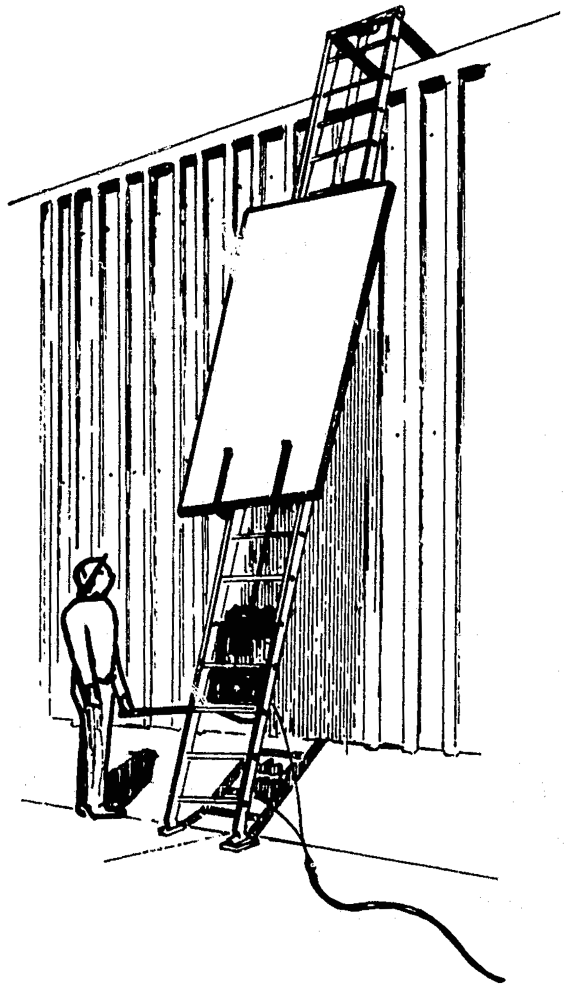


FIGURE 14-3

1. Rack Mount

Ground Support

Residential sized framing materials for this type mounting generally fall within three inch to four inch steel angles and 2 by 4 inch, 2 by 6 inch, and 2 by 8 inch wood framing. The most effective installation would be one with support material being used to optimum safe spans and with a minimum number of foundations. To this end, it would seem that due to visual and access height considerations, an 8 to 10 foot vertical height array would be a limit. It would follow, then, that the first limiting dimension would be a function of the structural capacity of the P.V. panel substrate or superstrate, or frame in the long dimension. Design wind loads, and probable module and panel constructions should comfortably allow a span of 96 inches. This, then, determines the distance between support points leaving the last dimension of width to efficient use of the support structure materials and connections. For reasons previously stated regarding handling, lifting, versatility and manufacturing economy, a constant width of 40 inches should not be exceeded. The width could be determined more closely depending upon the method of handling expected during shipping and installation. Compared costs for ground supported racks using steel or wood as a support material, can be seen in Table 14-3. Also included in Table 14-12 is a comparison of the costs for a 48 by 48 inch panel. It becomes quickly evident by examining the Tables that steel racks for residential applications are economically disadvantageous. This, again, stresses the need to use conventional residential building materials.

Flat Roof or Deck Support

Many of the considerations mentioned in the above applies for this type support. However, because of existing substructures such as roof or deck framing, the cost and size considerations for rack support foundations, soil conditions, etc., are not serious factors. Capacities and framing dimensions inherent in the design considerations for the roof or deck will impose their own parameters on the photovoltaic panel. It would appear, however, that the 96 inch length listed previously would remain valid for this type mounting application. Interfacing the photovoltaic panel with customary residential framing dimensions defines the panel rack structure, namely that the rack supporting structure must be a multiple of the 16 inch roof framing system. However, this does not put any size restrictions on the module. Size will, therefore, be restricted by handling during installation and shipping. In the interest of uniformity it is again advisable to use the standard 32 by 96 inch module.

It can be seen by examining Table 14-3 that the rack mounted rooftop array will be more costly than the ground mounted array. This is due to the increased costs of roof flashing material. As with the ground mounted array, wood framing would be the most obvious choice for residential applications.

2. Stand Off Mount

This type of support, although freed from the restrictions of property line setback, visual access requirements and foundations, is still limited by the size of appropriate roof area. Even though consideration need not be given to the waterproofing of the array, the size of the panel determines how many penetrations of the roof membrane are required for mounting support points. For this reason, consideration should be given to either the largest practical panel with a rigid structure, or a more elaborate support beam to span longer distance, in order to minimize the roof penetrations and, therefore, the chance for leaks. One or two workmen will still have to handle the panel, probably without the assistance of a crane. It would seem that the 32 by 96 inch panel would be optimum since it provides a reasonable span in the long direction under normal wind loading conditions, and uses standard metal extrusions for structural panel support. Although large quantities of structural material have been eliminated by the use of a standoff mounting type, the costs for installation are still high. This is due to the labor costs required for installation of a 1,000 $ft.^2$ array. Table 14-3 shows comparative costs of materials and installation for all mounting types associated with a 32 by 96 inch panel. Table 14-12 shows a similar breakdown for a 48 x 48 inch panel.

3. Direct Mount

Optimum areas of flashing of the panel to the roof membrane will be a significant factor in determining the size of a panel in a system requiring waterproofing. Although a panel mounted directly to the roof surface either on or close to the waterproofing membrane eliminates the need for any supplemental structural framing, it now requires that the perimeter and common edge connections be watertight or watershedding to prevent water from collecting under the panel and contributing to fungus, rot or roof leakage. The panel design should be such to allow for minimum edge sealing and flashing while maximizing active area; easy interfacing with other roofing materials, and easy handling by one or two workmen without use of a crane.

The designer of a direct mounted photovoltaic module is in a unique position to design a new and innovative product. While certain electrical requirements must be met, which are similar to those required for all photovoltaic modules, structural requirements for direct mounted modules are very lenient. With the existing roof structure acting as the structural support for the photovoltaic panel, extreme structural flexibility can be experienced. The shingle type photovoltaic module is an excellent example of a design approach which addresses the need or lack of need for structural rigidity. With the module being directly attached to the structure, the only size limitation placed on the module is the roof area. However, to avoid the need for custom made panels, size must be defined using other criteria.

The limiting factors become shipping and handling concerns, and installation concerns. It can, therefore, be concluded that the direct mounted module could range in size from a small shingle type to a large rolled type which could have three to five foot widths with varying lengths. (See Figure 14-4) This latter example does imply an extremely advanced technology, but does exemplify the broad-scope of design possibilities for this type application.

In light of the requirements to make some costing determinations, it was necessary to use an example module. A conventional flat plate module was used and edge details were generated as seen in Figures 13-2 thru 4. It can be seen in Table 14-3 that even with this very restrictive approach, the overall installation, materials and labor costs are considerably lower than those incurred by using other mounting types. These costs were generated for both a 32 by 96 inch and a 48 by 48 inch panel. No real significant cost difference appears for these two panel types. It is felt, however, that with new and innovative techniques these costs can be substantially reduced by eliminating edge details and gasketing material for waterproofing and designing a watershedding device.

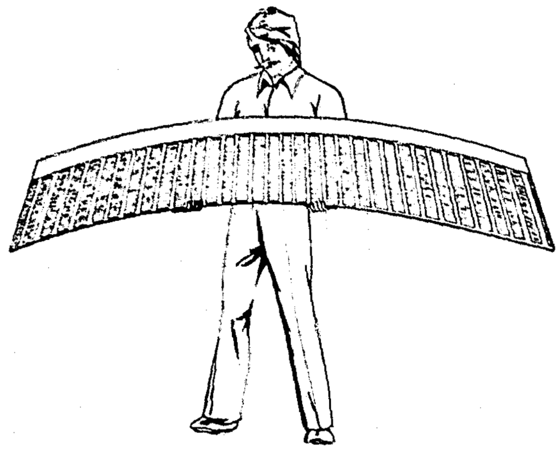


FIGURE 14-4

4. Integral Mount

This mounting technique utilizes the photovoltaic panel as the actual roof membrane. This places special demands on the construction of the module and will influence to some extent the mounting details. The size of the module becomes critical for this mounting type. The majority of roofing materials and framing dimensions commonly used in residential construction range from 16 inch on center to 36 inch on center with most falling in the 16, 24, and 36 inch on center size. With roof framing members 16 inch on center, a 32 inch module will, upon installation, be intersected at the center by a truss. Experience indicates local heating problems will arise if the module is in direct contact with the truss. To overcome this problem may require redesign of the truss to use a special truss system consisting of 2 by 6 inch main trusses with intermittent 2 by 4 inch trusses placed at truss-module intersection points to assure adequate and even cooling. Coupled with the arguments given in the standard panel size discussion, this indicates that a 32 by 96 inch panel will be the optimum size to meet all of the criteria for an integrally mounted PV array. Table 14-3 shows the material and labor costs for panels of 32 by 96 inch while Table 14-12 shows similar costs for the 48 by 48 inch panel. These costs are higher than those experienced for direct mount and standoff mount, however, they are lower than those experienced for rack mounted using steel or wood structural elements.

Having examined the design requirements for the four generic mounting types, there are some interesting observations. It becomes apparent that in order to reduce costs of both materials and installation, quick and easy installation of modules will be a prime requirement. Replacement of building materials will also further reduce costs. With this in mind, it is apparent that a combination of direct and integral mount would be an ideal design concept. Large areas and lightweight modules would facilitate installation as well as reduce installation materials cost. Extensive design must continue in this direction in order to reduce costs for the ultimate goals of 1986.

It is desirable to cover large areas with direct or integrally mounted panels; examples in the following costing sections will show this to be the case. Having established a standard panel of 32 by 96 inches and comparing this to a 48 by 48 inch panel, a starting point has been established. Further breakdown of these panels into modules can be used as an example of smaller module installations. Two sizes were established - 16 by 48 inches and 16 by 24 inches. These module sizes were established as both can be used in the two established panel sizes.

COST ANALYSIS

Having established the standard panel at 32 by 96 inches, cost comparisons can now be made with the 48 by 48 inch module. For residential applications, 1,000 ft.^{2} arrays with a 220 Vdc output were investigated. Using the two above mentioned panel sizes, a number of 1,000 ft.^{2} arrays were generated. Figures 12-2 and 12-3 illustrate these arrays. A review of the array characteristics and a comparison of the 32 by 96 inch panel shows a wide variation of the number of panels and subsequent interconnects to achieve the same nominal size array. These factors will influence the cost of materials and installation for 1,000 ft.^{2} arrays.

Consideration must be given to the average overall dimensions of a single family residence. At approximately 2,000 $ft.^2$ of floor area on one floor, reasonable roof dimensions might be approximately 30 by 60 feet. When one half of this roof area is facing south, an available amount of approximately 15 by 60 feet is presented. Similar dimensions will occur for a flat roof, since aesthetic height limitations and shading suggest only one row of approximately 15 feet in height. As seen in Figures 12-2 and 12-3, 1,000 $ft.^2$ arrays which most closely fit 15 by 60 foot model roof area, will be 16 by 66 feet, 8 inches, and 24 by 45 feet in the 32 by 96 inch panel configuration, and 16 by 68 feet and 20 by 56 feet in the 48 by 48 inch panel configuration.

With the mounting designs and array shape configurations established, detailed costing studies were performed. Tables 14-3 through 14-16 show a breakdown of material and labor costs for the various array shape configurations and the two chosen panel sizes. Remembering from previous discussions, rack mounted arrays are limited to two sizes; the 8 by 132 feet and the 16 by 68 feet for the 48 by 48 inch panel configuration, and the 8 by 133 feet and the 16 by 66 feet array configuration for the 32 by 96 inch panels. These six array configurations are realistic for a standard residential application. In these cases, the following array characteristics are listed:

TABLE 14-2

	32 by 96 inch panel			48 by 48 inch panel		
Array Size, Feet	8x133	16x67	24x45	8x132	16x68	24x44
No. of Panels	50	50	51	66	68	66
Array Parameter	282 ft	265 ft	139 ft	280 ft	168 ft	136 ft
Adjacent Lengths	392 ft	450 ft	474 ft	388 ft	428 ft	460 ft
Total Lineal Feet of Collector	674	715	613	668	596	596

From these array characteristics and the costing tables it is seen that no direct relationship exists between any of the characteristics and the corresponding variations in cost. Costs are extremely sensitive to mounting designs as well as the mounting types. For example, the 48 by 48 inch direct mount configuration is less costly than the corresponding array size configurations for the 32 by 96 inch panel when based on materials and labor cost.

However, the integrally mounted 32 by 96 inch panel configurations are less costly than the 48 by 48 inch integral mount configuration.

A somewhat different approach was taken to evaluate the costs of smaller modules. As previously stated, two module sizes were determined as useful for both the 32 by 96 inch and 48 by 48 inch panels and those are 16 by 48 inch and 16 by 24 inch modules. In the cost analysis, the mounting details around the edge of the panels were maintained as previously discussed while details were drawn up, as seen in Figure 14-5, to form panels using the two smaller modules sizes. As could be expected, the costs for these panels are slightly higher than those for panels consisting of one module. Full breakdowns of the costs for the addition of these modules can be seen in Table 14-21. Also available is the costing information for the various array sizes using both 48 by 48 inch and 32 by 96 inch panels and the 16 by 48 inch and 16 by 24 inch modules.

Examination of the relative cost differences, Figures 14-7 and 14-8, between the four mounting types indicates several basic conclusions. Most important is that considerable cost differences exist between the four generic mounting types. These differences arise due to the differences in materials and time requirements for installation. It must be noted that these costs are equally influenced by the details used for the costing analysis. It is conceivable, therefore, that had different details been used for this analysis, considerably different costs could have been obtained. Finally, because photovoltaic modules are a new innovation in the building industry, it was necessary to use examples of materials in the building industry that most closely relate to photovoltaic modules. It was difficult to anticipate any problems that may arise in the installation of PV modules and, therefore, any cost differentials between the existing building product and the modules. As the industry matures, the installation and materials costs will likewise mature and be reduced directly with respect to the products penetration into the building market.

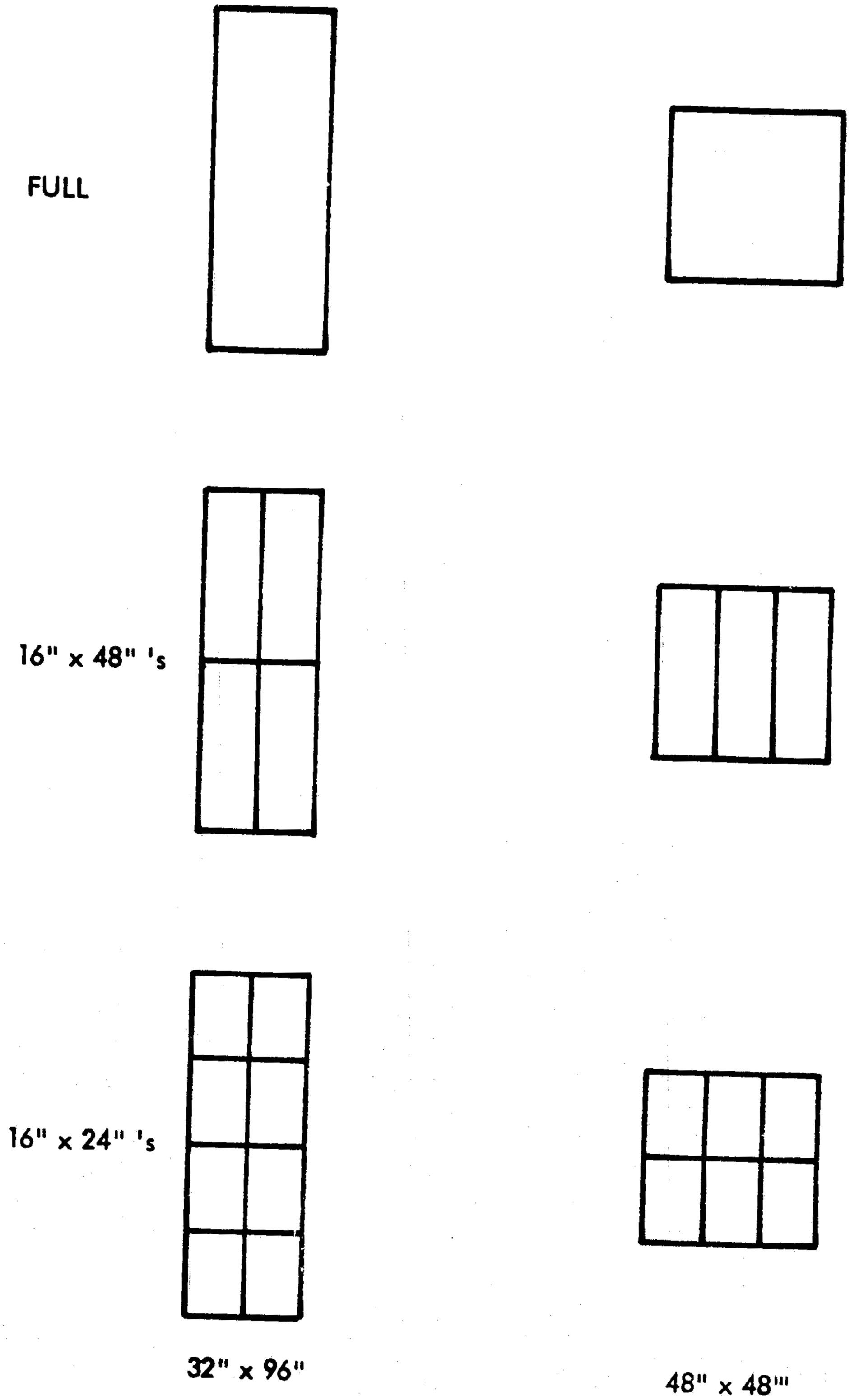


FIGURE 14-5

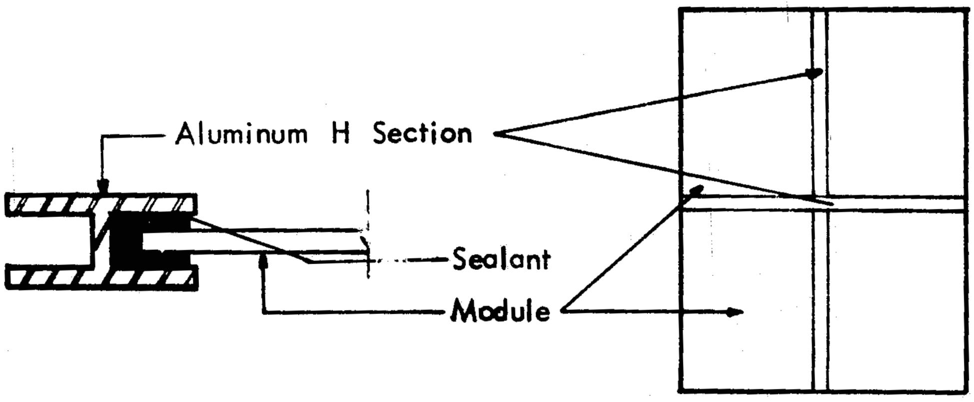


FIGURE 14-5 (cont)

Tolerance

Until recently, tolerance presented no great problem to the building industry, except in certain specialized fields such as structural engineering. However, an increasing number of components are being prefabricated away from the building site. Tolerance, the degree of inaccuracy that is accessible, becomes acute, if the functional element, such as a photovoltaic module which is composed of factory-made or prefabricated components, is to be satisfactorily assembled. For example, when factory-made windows are set in masonry wall construction, inaccuracies in the size, shape or position of the windows are taken up by the masonry and only inaccuracies in the masonry units themselves are adjusted by the mortar joints.

There is a sequentially decreasing inaccuracy that can be tolerated in the construction of a building. For example, building excavation can be expected to be accurate to within 0.2 feet. Concrete foundations can be held accurate to ± 0.25 inches, concrete slabs can be accurate to ± 0.125 inches. Masonry work and wood framing can be expected to be accurate ± 0.06 inches, structural steel accuracy varies with the size of the steel structure and is specified in standards of the American Institute of Steel Construction. While door frames can be set in rough openings with an allowed tolerance of ± 0.25 inches, door hardware is installed to ±0.015 inches. Glazing systems are installed to various tolerances which are a function of the panel size and framing system employed.

The above examples are intended to show the relative tolerances which can be achieved in various procedures in the construction industry, and the conditions of which a designer must be aware when attempting to mate or join different materials. Obviously, the direct glazing of a poured concrete opening must be given special consideration or extremely expensive operations will result.

The installation of photovoltaic module/panels into an array has already been likened to the installation of a glazing system in the building industry and that analogy will be continued for illustration purposes. The dimensional tolerances required of a particular module/panel must be calculated for a specific design. The various tolerances which must be calculated are as follows:

- Width Tolerance. The total overall tolerance of the width of the panel is comprised of four separate tolerances being size, squareness, plumbness, and position. The overall tolerance for the width of the panel is the square root of the sum of the squares of the four separate tolerances. Size, squareness and plumbness are manufacturing tolerances.

- Height Tolerance. Height tolerance is calculated exactly like the width tolerance if the array is to be more than one panel in height.

- Joint Tolerance. Joint tolerance is entirely a function of the design of the framing system. As a general rule, however, most joint tolerances are held to plus or minus 1/8 inch.

The first tolerance to be determined will be the width variance. By establishing a module consisting of glass and a neoprene gasket glazing system a closer look at tolerances can be undertaken. Having established a glass module, the amounts for each aspect of tolerance are:

tpw = Total Overall Tolerance of the Width of the Panel

tsi = Size Tolerance = ± 0.09375"

tsq = Square Tolerance = ± 0.09375"

tpl = Plumbness Tolerance = ± 0.09375"

tpo = Position Tolerance = 0.0328175"

The square root of the sum of the squares is the overall tolerance for the width of the panel. The squareness and plumbness are, because of the interaction that occurs between them within the array, arbitrarily reduced to 0.75 of 6/32 and 3/32 respectively for the calculation of the total overall tolerance (tpw). Therefore, the total overall tolerance of the width of the panel according to "Modular Coordination of Low Cost Housing" is:

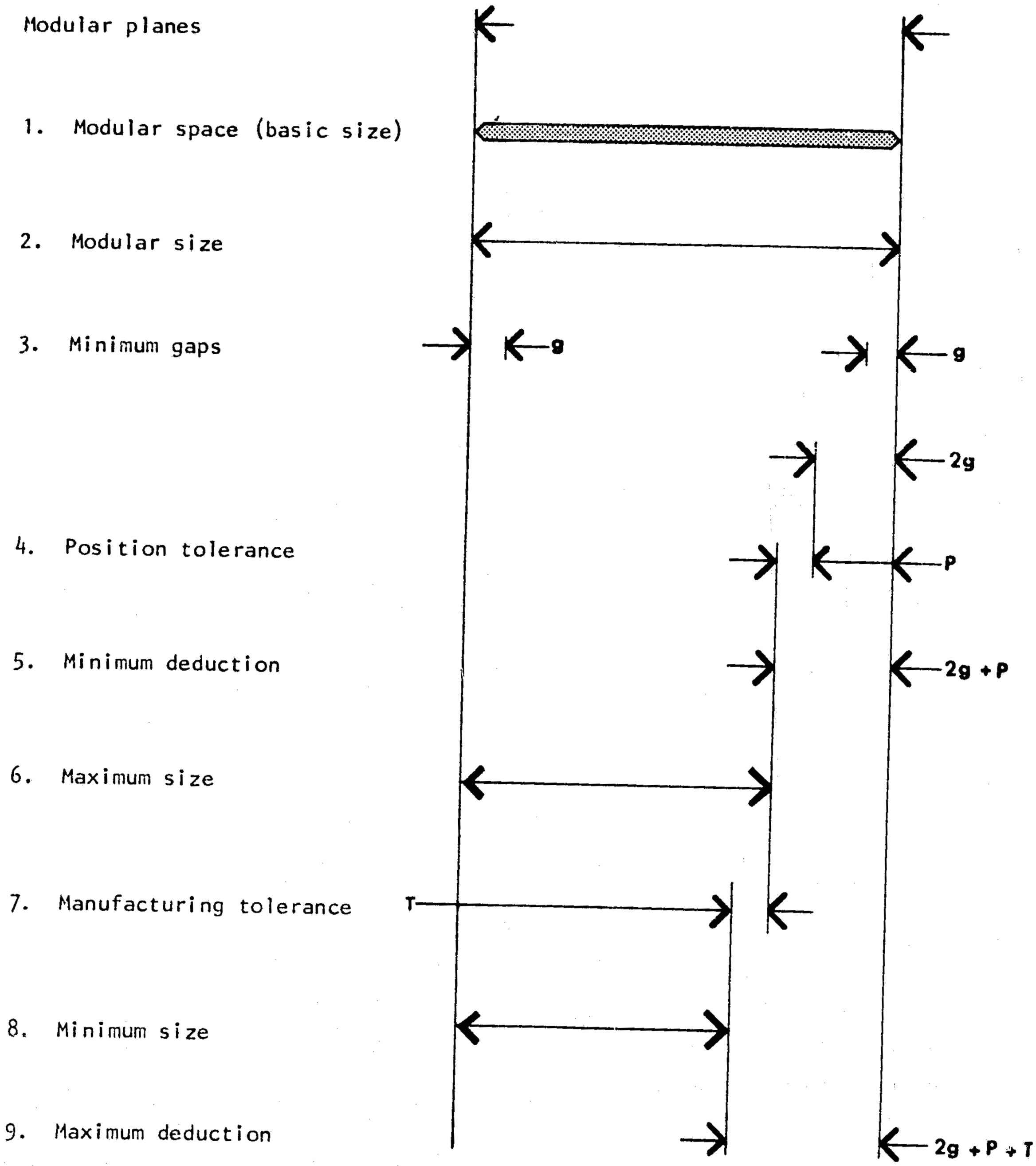
$$tpw = (tsi)^2 + (0.75tsq)^2 + (0.75tpl)^2 + (tpo)^2$$
$$= 0.035'' + 0.0197'' + 0.0049'' + 0.1076$$
$$= 0.1672''$$

The height tolerance considerations are exactly the same as the width tolerance in this case because all interfaces are between identical modules. Therefore, the total overall tolerance of the height of the panel is:

$$tph = (tsi)^2 + (0.75tsq)^2 + (0.75tpi)^2 + (tpo)^2$$
$$= 0.35'' + 0.0197'' + 0.0049'' + 0.1076''$$
$$= 0.1672''$$

Figure 14-6 illustrates the process used to determine the overall system dimensions. The standard module 32 x 96 inch, defines the module size. The minimum gap or joint used is 1/2 the center web of the glazing gasket used plus the allowable joint tolerance. If for example, the web is 0.1719" thick, half of that is 0.0859" and the allowable joint tolerance for the entire width or length is plus or minus 0.125" or 0/25" total. The maximum size shown in Figure 14-6 is:

Maximum Width	=	32" - 2(0.0859" + 0.125")
	=	31.5782
Maximum Height	=	96" - 2(0.0859" + 0.125)"
	=	95.5782



APPLICATION OF THE SYSTEM OF TOLERANCES TO A MODULAR COMPONENT

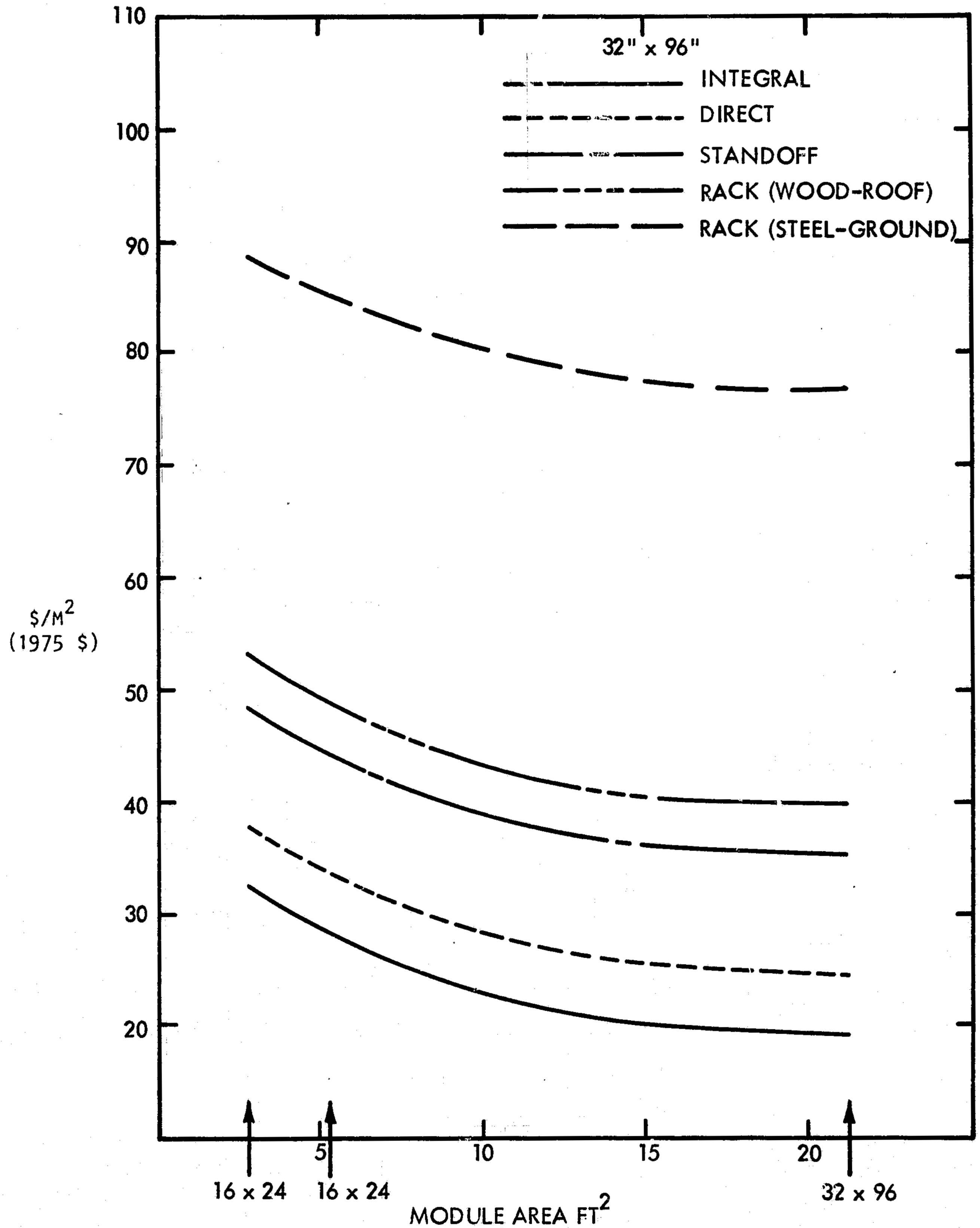
FIGURE 14-6

It is necessary to further reduce these dimensions by subtracting the maximum manufacturing tolerance which is 0.162" in both the width and length directions; therefore, the minimum panel size is:

Minimum Wdith = 31.5782 - 0.1672 = 31.4110

Minimum Height = 95.5782 - 0.1672 = 95.4110

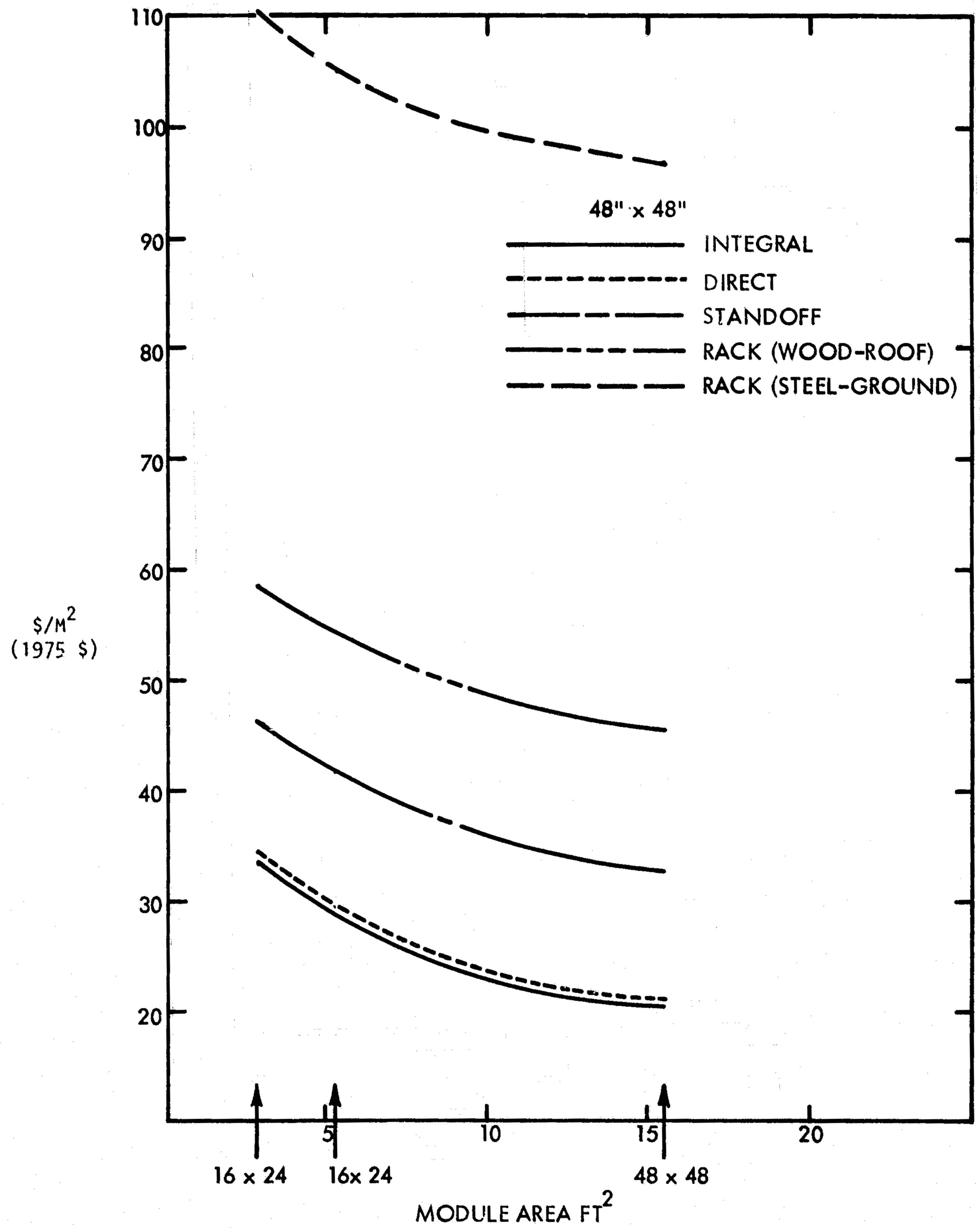
Tolerances become most critical in applications using integral type mounting systems and least critical in systems which do not require module edge to edge contact. This latter technique may be accomplished in specially-designed direct mounted module systems.



INSTALLATION COSTS LESS WIRING
32" x 96" PANEL

Figure 14-7

C-4



INSTALLATION COSTS LESS WIRING
48" x 48" PANEL

Figure 14-8

MATERIAL AND LABOR COSTS

32" x 96" PANELS (1975 DOLLARS)

NOMINAL ARRAY SIZE	NO. OF PANELS	MODULE SIZE	INTEGRAL	DIRECT	STANDOFF	RACK W/R	RACK S/R	RACK W/G	RACK S/G
133' x 8'	50	32" x 96"	$3,827	$3,501	$3,441			$4,020	$6,490
		16" x 48"	4,707	4,381	4,321			4,900	7,370
		16" x 24"	5,147	4,821	6,761			5,340	7,810
66' x 16'	50	32" x 96"	$3,702	$3,479	$3,534	$3,938	$6,383	$3,467	$5,911
		16" x 48"	4,582	4,359	4,414	4,818	7,263	4,347	6,791
		16" x 24"	5,022	4,799	4,854	5,258	7,703	4,787	7,231
45' x 24'	51	32" x 96"	$3,815	$3,616	$3,623				
		16" x 48"	4,712	4,513	4,520				
		16" x 24"	5,161	4,962	4,969				
34' x 32'	52	32" x 96"	$3,510	$3,696	$3,590				
		16" x 48"	4,425	4,611	4,505				
		16" x 24"	4,883	5,069	4,963				
26' x 40'	50	32" x 96"	$3,664	$3,572	$3,700				
		16" x 48"	4,544	4,452	4,580				
		16" x 24"	4,984	4,945	5,020				

KEY

W - Wood Frame Rack
S - Steel Frame Rack
R - Roof Mounted Rack
G - Ground Mounted Rack

TABLE 14-3

MATERIAL AND LABOR COSTS

PANEL 32" x 96" INTEGRAL

ARRAY SIZE	MATERIAL	QUANTITY	LABOR RATE	COST LABOR	MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL	666 ft.	$ 0.60/ft.	$ 399.60	$0.53/ft.	$ 352.98	$ 753.00	$ 627.00
133' x 8'	GASKET	666 ft.	1.20/ft.	799.20	1.00/ft.	666.00	1465.00	1220.00
	SCREWS	400	0.12/scr	48.00	0.12/scr	48.00	96.00	80.00
	MODULE	50 @ 21.33/ft^2	2.14/ft^2	2282.31			2282.00	1900.00
TOTAL				$3499.11		$1066.98	$4596.00	$3827.00
	AL	616 ft.	0.60/ft.	369.60	0.53/ft.	326.48	696.00	580.00
66' x 16'	GASKET	616 ft.	1.20/ft.	739.20	1.00/ft.	616.00	1355.00	1128.00
	SCREWS	470	0.12/scr	56.40	0.12/scr	56.40	113.00	94.00
	MODULE	50 @ 21.33 ft^2	2.14/ft^2	2282.31			2282.00	1900.00
TOTAL				$3447.51		$ 998.88	$4446.00	$3702.00
	AL	613.33 ft.	0.60/ft.	368.00	0.53/ft.	325.06	793.00	660.00
45' x 24'	GASKET	613.33 ft.	1.20/ft.	736.00	1.00/ft.	613.33	1349.00	1123.00
	SCREWS	470	0.12/scr	56.40	0.12/scr	56.40	113.00	94.00
	MODULE	51 @ 21.33/ft^2	2.14/ft^2	2327.36			2327.00	1938.00
TOTAL				$3487.76		$ 994.79	$4582.00	$3815.00
	AL	517.33 ft.	$ 0.60/ft.	$ 310.40	$0.53/ft.	$ 274.18	$ 584.00	$ 486.00
34' x 32'	GASKET	517.33 ft.	1.20/ft.	620.80	1.00/ft.	517.33	1137.00	947.00
	SCREWS	500	0.12/scr	60.00	0.12/scr	60.00	120.00	100.00
	MODULE	52 @ 21.33/ft^2	2.14/ft^2	2373.60			2374.00	1976.00
TOTAL				$3364.80		$ 851.51	$4215.00	$3510.00
	AL	600 ft.	0.60/ft.	360.00	0.53/ft.	318.00	678.00	565.00
26' x 40'	GASKET	600 ft.	1.20/ft.	720.00	1.00/ft.	600.00	1320.00	1099.00
	SCREWS	500	0.12/scr	60.00	0.12/scr	60.00	120.00	100.00
	MODULE	50 @ 21.33/ft^2	2.14/ft^2	2282.31			2282.00	1900.00
TOTAL				$3422.31		$ 978.00	$4400.00	$3664.00

TABLE 14-4

MATERIAL AND LABOR COSTS

ARRAY SIZE	MATERIAL	QUANTITY	PANEL LABOR RATE	32" x 96" COST LABOR	DIRECT MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL F	400 ft.	$0.60/ft.	$240.00	$1.18/ft	$472.00	$712.00	$593.00
	AL S	384 ft.	0.60/ft.	230.40	0.52/ft	199.68	430.00	358.00
133' x 8'	GASKET	400 ft.	1.20/ft.	480.00	0.24/ft	96.00	576.00	480.00
	SCREWS	410	0.12/scr	49.20	0.10/scr	41.00	90.00	75.00
	SEALANT	266.66 ft	0.20/ft.	53.40	0.23/ft	61.41	115.00	96.00
	MODULE	50 @21.33 ft^2	2.14/ft^2	2282.31			2282.00	1900.00
TOTAL				$3335.31		$870.09	$4205.00	$3501.00
	AL F	400 ft.	$0.60/ft.	240.00	1.18/ft	472.00	712.00	593.00
	AL S	368 ft.	0.60/ft.	220.80	0.52/ft	191.36	412.00	343.00
66' x 16'	GASKET	400 ft.	1.20/ft.	480.00	0.24/ft	96.00	576.00	480.00
	SCREWS	500	0.12/scr	60.00	0.10/scr	50.00	110.00	92.00
	SEALANT	200 ft.	0.20/ft.	40.00	0.23/ft	46.00	86.00	72.00
	MODULE	50 @21.33 ft^2	2.14/ft^2	2282.31			2282.00	1900.00
TOTAL				$3323.11		$855.36	$4178.00	$3479.00
	AL F	432 ft.	$0.60/ft.	259.20	$1.18/ft	509.76	769.00	640.00
	AL S	384 ft.	0.60/ft.	230.40	0.52/ft	199.68	430.00	358.00
45' x 24'	GASKET	432 ft	1.20/ft.	518.40	0.24/ft	103.68	622.00	518.00
	SCREWS	525	0.12/scr	63.00	0.10/scr	52.50	116.00	97.00
	SEALANT	182 ft.	0.20/ft.	36.40	0.23/ft	41.86	78.00	65.00
	MODULE	51 @21.33 ft^2	2.14/ft^2	2327.96			2328.00	1938.00
TOTAL				$3435.36		$907.48	$4343.00	$3616.00
	AL F	448 ft.	$0.60/ft.	268.80	$1.18/ft	528.64	797.00	664.00
	AL S	384 ft.	0.60/ft.	230.40	0.52/ft	199.68	430.00	358.00
34' x 32'	GASKET	448 ft.	1.20/ft.	537.60	0.24/ft	107.52	645.00	537.00
	SCREWS	540 ft.	0.12/scr	64.80	0.10/scr	54.00	119.00	99.00
	SEALANT	174 ft.	0.20/ft.	34.80	0.23/ft	40.02	75.00	62.00
	MODULE	52 @21.33 ft^2	2.14/ft^2	2373.60			2374.00	1976.00
TOTAL				$3510.00		$929.86	$4440.00	$3696.00

TABLE 14-5

MATERIAL AND LABOR COSTS

ARRAY SIZE	MATERIAL	QUANTITY	PANEL LABOR RATE	32" x 96" COST LABOR	DIRECT MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
26' x 40'	AL F	440 ft.	$0.60/ft.	$264.00	$1.18/ft.	$519.20	$783.00	$652.00
	AL S	360 ft.	0.60/ft.	216.00	0.52/ft.	187.20	403.00	336.00
	GASKET	440 ft.	1.20/ft.	528.00	0.24/ft.	105.60	634.00	528.00
	SCREWS	540	0.12/scr	64.80	0.10/scr	54.00	119.00	99.00
	SEALANT	160 ft.	0.20/ft.	32.00	0.23/ft.	36.80	69.00	57.00
	MODULE	50 @21.33 ft^2	2.14/$ft.^2$	2282.31			2282.00	1900.00
TOTAL				$3387.11		$902.80	$4290.00	$3572.00

TABLE 14-5 (Cont)

MATERIAL AND LABOR COSTS

PANEL 32" x 96" STANDOFF

ARRAY SIZE	MATERIAL	QUANTITY	LABOR RATE	COST LABOR	MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL SH	800 ft.	$0.60/ft.	$480.00	$ 1.24/ft.	$992.00	$1472.00	$1226.00
	AL H		0.60/ft.		0.225/ft.			
133' x 8'	GASKET	800 ft.	1.20/ft.	960.00	0.12/ft.	96.00	1056.00	879.00
	SCREWS	1100	0.12/scr	132.00	0.03/scr	33.00	165.00	137.00
	SEALANT		0.20/ft.^{2}		0.23/ft.^{2}			
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.^{2}	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	50 @ 21.33 ft^2	0.75/ft.^{2}	799.88			800.00	666.00
TOTAL				$2739.08		$1393.00	$4132.00	$3441.00
	AL SH	800 ft.	$0.60/ft.	480.00	1.24/ft.	992.00	1472.00	1226.00
	AL H	66.67 ft.	0.60/ft.	40.00	0.225/ft.	15.00	55.00	46.00
66' x 16'	GASKET	800 ft.	1.20/ft.	960.00	0.12/ft.	96.00	1056.00	879.00
	SCREWS	1100 ft.	0.12/ft.	132.00	0.03/scr	33.00	165.00	137.00
	SEALANT	133.34 ft.^{2}	0.20/ft.^{2}	26.67	0.23/ft.^{2}	30.67	57.00	47.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.^{2}	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	50 @ 21.33 ft.^{2}	0.75/ft.^{2}	799.88			800.00	666.00
TOTAL				$2805.75		$1438.67	$4244.00	$3534.00
	AL SH	816 ft.	0.60/ft.	489.60	1.24/ft.	1011.84	1501.00	1250.00
	AL H	90.67 ft.	0.60/ft.	54.40	0.225/ft.	20.40	75.00	62.00
45' x 24'	GASKET	816 ft.	1.20/ft.	979.20	0.12/ft.	97.92	1077.00	897.00
	SCREWS	1100	0.12/scr	132.00	0.03/scr	33.00	165.00	137.00
	SEALANT	181.33 ft.^{2}	0.20/ft.^{2}	36.27	0.23/ft.^{2}	41.71	78.00	65.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.75/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.^{2}	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	51 @ 21.33 ft.^{2}	0.75/ft.^{2}	815.87				
TOTAL				$2874.54		$1476.87	$4351.00	$3623.00

TABLE 14-6

MATERIAL AND LABOR COSTS

PANEL 32" x 96" STANDOFF

ARRAY SIZE	MATERIAL	QUANTITY	LABOR RATE	COST LABOR	MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL SH	800 ft.	$0.60/ft.	$480.00	$1.24/ft.	$ 992.00	$1472.00	$1226.00
	AL H	106.68 ft.	0.60/ft.	64.00	0.225/ft.	24.00	88.00	73.00
40' x 26'	GASKET	800 ft.	1.20/ft.	960.00	0.12/ft.	96.00	1056.00	879.00
	SCREWS	1100	0.12/scr	132.00	0.03/scr	33.00	165.00	137.00
	SEALANT	213.36 ft	0.20/ft.	42.67	0.23/ft.	49.07	92.00	77.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272/LF	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	50 @ 21.33 ft.^{2}	0.75/ft.^{2}	799.88			800.00	666.00
TOTAL				$2845.75		$1466.07	$4312.00	$3590.00
	AL SH	832 ft.	0.60/ft.	499.20	1.24/ft.	1031.68	1531.00	1275.00
	AL H	104 ft.	0.60/ft.	62.40	0.225/ft.	23.40	86.00	72.00
34' x 32'	GASKET	832 ft.	1.20/ft.	998.40	0.12/ft.	99.84	1098.00	914.00
	SCREWS	1120	0.12/scr	134.40	0.03/scr	33.60	168.00	140.00
	SEALANT	208 ft.	0.20/ft.	41.60	0.23/ft.	47.84	89.00	74.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	52 @ 21.33	0.75/ft.^{2}	831.87			832.00	693.00
TOTAL				$2935.07		$1508.36	$4443.00	$3700.00

TABLE 14-6 (Cont.)

MATERIAL AND LABOR COSTS

PANEL 32" x 96" RACK

ARRAY SIZE	MATERIAL	QUANTITY	LABOR RATE	COST LABOR	MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL	800 ft.	$0.60/ft.	$480.00	$1.24/ft.	$992.00	$1472.00	$1226.00
	SEALANT	800 ft.	0.20/ft.	198.40	0.23/ft.	184.00	382.00	318.00
	SCREWS	200	0.15/scr	30.00	0.10/scr	20.00	50.00	42.00
133' x 8'	MODULE	50 @ 21.33 ft.^{2}	0.75/ft.^{2}	799.88			800.00	666.00
TOTAL				$1508.28		$1196.00	$2704.00	$2252.00
	AL	800 ft.	0.60/ft.	480.00	1.24/ft.	992.00	1472.00	1226.00
	SEALANT	800 ft.	0.20/ft.	198.40	0.23/ft.	184.00	382.00	318.00
66' x 16'	SCREWS	200	0.15/scr	30.00	0.10/scr	20.00	50.00	42.00
	MODULE	50 @ 21.33 ft.^{2}	0.75/ft.^{2}	799.88			800.00	666.00
TOTAL				$1508.28		$1196.00	$2704.00	$2252.00

TABLE 14-7

MATERIAL AND LABOR COSTS

ARRAY 8' x 133'

PANEL 32" x 96"

RACK - STEEL

GROUND MOUNT	QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
STEEL ANGLES	3.38T	$774/T	$2616.12	$504/T	$1703.52	$4320.00	$3597.00
STEEL TEES	---	---	---	---	---	---	
CONCRETE PIERS	1.58 YDS	16.62/YD	26.26	32.56/YD	51.44	78.00	65.00
PIER STEEL	0.16 T	244/T	39.04	422/T	67.52	107.00	89.00
CONCRETE FOOTINGS	3.6 YDS	14.32/YD	51.55	32.66/YD	117.58	169.00	141.00
FOOTING STEEL	0.13 T	336/T	43.68	580/T	75.40	119.00	99.00
EXCAVATION	43 YDS	1.42/YD	61.06	1.45/YD	62.35	123.00	102.00
BACKFILL	43 YDS	2.00/YD	86.00	2.05/YD	88.15	174.00	145.00
TOTAL			$2923.71		$2165.96	$5090.00	$4238.00

TABLE 14-8

MATERIAL AND LABOR COSTS

ARRAY 8 x 133

PANEL 32 x 96

RACK WOOD

GROUND MOUNT	QUALITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
WOOD FRAME 2x4, 2x6, 2x8	1.224 MBF	300/MBF	367.20	339/MBF	414.94	782.00	651.00
WOOD FRAMING 2x10	0.89 MBF	291/MBF	258.99	352/MBF	313.28	572.00	476.00
CONCRETE PIERS	1.58 YDS	16.62/YD	26.26	32.56/YD	51.44	78.00	65.00
PIER STEEL	0.16 T	244/T	39.04	422/T	67.52	107.00	89.00
CONCRETE FOOTING	3.6 YDS	14.32/YD	51.55	32.66/YD	117.58	169.00	141.00
FOOTING STEEL	0.13 T	336/T	43.68	580/T	75.40	119.00	99.00
EXCAVATION	43 YDS	1.42/YD	61.06	1.45/YD	62.35	123.00	102.00
BACKFILL	43 YDS	2.00/YD	86.00	2.05/YD	88.15	174.00	145.00
TOTAL			$933.78		$1190.66	$2124.00	$1768.00

TABLE 14-9

MATERIAL AND LABOR COSTS

ARRAY 66' x 16'

PANELS 32" x 96"

RACK - STEEL

GROUND MOUNT	QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
STEEL ANGLES Incl. Paint	1.63 Tons	$774/T	$1262.00	$504/T	$821.52	$2084	$1735.00
STEEL TEES	1.4 Tons	796/T	1114.40	518/T	725.20	1840	1532.00
CONCRETE PIERS	1.224 YDS	16.62/Y	20.34	32.56/YD	39.85	60	50.00
PIER STEEL	0.075 Tons	244/T	18.30	422/T	31.65	50	42.00
CONCRETE FOOTINGS	2.76 YDS	14.32/Y	39.52	32.66/YD	90.14	130	108.00
FOOTING STEEL	0.09 Tons	336/T	30.24	580/T	52.20	82	68.00
EXCAVATION	21.4 YDS	1.42/Y	30.39	145/YD	31.03	61	51.00
BACKFILL	21.4 YDS	2.00/Y	42.80	2.05/YD	43.87	87	72.00
TOTAL			$2558.00		$1836.00	$4394.00	$3659.00
ROOF MOUNT							
STEEL ANGLES	1.63 Tons	774/T	$1262.00	504/T	821.52	2084	1735.00
STEEL TEES	1.40 Tons	796/T	1114.40	518/T	725.20	1840	1532.00
STEEL ANGLES	0.13 Tons	854/T	111.02	516/T	67.08	178	148.00
WOOD BLOCK	0.27 MBS	364/MBF	98.28	452/MBF	122.04	220	183.00
FLASHING	272 $Ft.^2$	$0.77/Ft^2$	209.44	$0.70/ft^2$	190.40	400	333.00
STRIP	272 Ft.	0.58/LF	157.76	0.30/LF	81.60	239	199.00
TOTAL			$2952.90		$2007.84	$4961.00	$4131.00

TABLE 14-10

MATERIAL AND LABOR COSTS

ARRAY 66' x 16'
PANEL 32" x 96"
RACK - WOOD

GROUND MOUNT	QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
WOOD FRAME 2 x 4 / 2 x 6	1.013 MBF	$300/MBF	303.90	$339/MBF	343.41	647	539.00
WOOD FRAME 2 x 12	0.53 MBF	291/MBF	154.23	352/MBF	186.56	341	284.00
CONCRETE PIER	0.8 YDS	16.62/YD	20.34	32.56/YD	39.85	60	50.00
PIER STEEL	0.075 T	244/T	18.30	422/T	31.65	50	42.00
CONCRETE FOOTING	2.76 YDS	14.32/YD	39.52	32.66/YD	90.14	130	108.00
FOOTING STEEL	0.09 T	336/T	30.24	580/T	52.20	82	68.00
EXCAVATION	21.4 YDS	1.42/YD	30.39	1.45/YD	31.03	61	51.00
BACKFILL	21.4 YDS	2.00/YD	42.80	2.05/YD	43.87	87	72.00
TOTAL			$639.81		$818.71	$1459.00	$1215.00
ROOF MOUNT							
WOOD FRAMING 2x4 / 2x6	1.013 MBF	300/MBF	303.90	339/MBF	343.41	647	539.00
WOOD FRAMING 2x12	0.53 MBF	291/MBF	154.23	352/MBF	186.56	341	284.00
STEEL ANGLES	0.13 T	854/T	111.02	516/T	67.08	178	148.00
WOOD BLOCKS	0.27 MBF	364/MBF	98.28	452/MBF	122.04	220	183.00
FLASHING	272 Ft.	0.77/Ft.^{2}	209.44	0.70/Ft.^{2}	190.40	400	333.00
STRIP	272 Ft.	0.58/LF	157.76	0.30/LF	81.60	239	199.00
TOTAL			$1034.63		$991.09	$2026.00	$1686.00

TABLE 14-11

MATERIAL AND LABOR COSTS

48" x 48" PANELS (1975 DOLLARS)

NOMINAL ARRAY SIZE	NO. OF PANELS	MODULE SIZE	INTEGRAL	DIRECT	STANDOFF	RACK W/R	RACK S/R	RACK W/G	RACK S/G
132' x 8'	66	48" x 48"	$3,852	$3,077	$3,217			$4,630	$7,755
		16" x 48"	4,723	3,948	4,088			5,501	8,626
		16" x 24"	5,157	4,382	4,522			5,935	9,060
88' x 12'	66	48" x 48"	$3,714	$3,067	$3,217				
		16" x 48"	4,585	3,938	4,088				
		16" x 24"	5,019	4,372	4,522				
68' x 16'	68	48" x 48"	$4,482	$3,156	$3,303	$4,584	$7,658	$4,095	$7,186
		16" x 48"	5,379	4,053	4,200	5,481	8,555	4,966	8,057
		16" x 24"	5,827	4,501	4,648	5,929	9,900	5,400	8,491
56' x 20'	70	48" x 48"	$3,853	$3,249	$3,384				
		16" x 48"	4,776	4,172	4,307				
		16" x 24"	5,238	4,634	5,692				
44' x 24'	66	48" x 48"	$3,540	$3,070	$3,221				
		16" x 48"	4,411	3,941	4,092				
		16" x 24"	4,845	4,375	4,526				
40' x 28'	70	48" x 48"	$3,831	$3,257	$3,384				
		16" x 48"	4,754	4,180	4,307				
		16" x 24"	5,216	4,642	4,769				
36' x 32'	72	48" x 48"	$3,938	$3,357	$3,465				
		16" x 48"	4,888	4,307	4,415				
		16" x 24"	5,362	4,781	4,889				

KEY

W - Wood Frame Rack
S - Steel Frame Rack
R - Roof Mounted Rack
G - Ground Mounted Rack

Table 14-12

MATERIAL AND LABOR COSTS

PANEL 48" x 48" INTEGRAL

ARRAY SIZE	MATERIAL	QUANTITY	LABOR RATE	COST LABOR	MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL	668 ft.	$0.60/ft.	$ 400.80	$0.53/ft.	$ 354.04	$ 754.00	$ 678.00
132' x 8'	GASKET	668 ft.	1.20/ft.	801.60	1.00/ft.	668.00	1470.00	1224.00
	SCREWS	340	0.12/scr	40.80	0.12/scr	40.80	82.00	68.00
	MODULES	66 @ 16 ft.^{2}	2.14/ft.^{2}	2259.84			2260.00	1882.00
TOTAL				$3503.04		$1062.84	$4566.00	$3852.00
	AL	628 ft.	0.60/ft.	376.80	0.53/ft.	332.84	710.00	592.00
88' x 12'	GASKET	628 ft.	1.20/ft.	753.60	1.00/ft.	628.00	1382.00	1151.00
	SCREWS	450	0.12/scr	54.00	0.12/scr	54.00	108.00	90.00
	MODULES	66 @ 16 ft.^{2}	2.14/ft.^{2}	2259.84			2260.00	1882.00
TOTAL				$3444.24		$1014.84	$4460.00	$3714.00
	AL	628 ft.	0.60/ft.	376.80	0.53/ft.	332.84	710.00	592.00
68' x 16'	GASKET	628 ft.	1.20/ft.	753.60	1.00/ft.	628.00	1382.00	1151.00
	SCREWS	460	0.12/scr	55.20	0.12/scr	55.20	110.00	92.00
	MODULES	68 @ 16 ft.^{2}	2.14/ft.^{2}	2328.32			2328.00	1939.00
TOTAL				$3513.92		$1016.04	$4530.00	$3774.00

Table 14-13

MATERIAL AND LABOR COSTS

PANEL 48" x 48" INTEGRAL

ARRAY SIZE	MATERIAL	QUANTITY	LABOR RATE	COST LABOR	MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL	636 ft.	$ 0.60/ft.	$ 381.60	$0.53/ft.	$ 337.08	$ 719.00	$ 599.00
56' x 20'	GASKET	636 ft.	1.20/ft.	763.20	1.00/ft.	636.00	1399.00	1165.00
	SCREWS	470	0.12/scr	56.40	0.12/scr	56.40	112.00	94.00
	MODULE	70 @ 16 ft.^{2}	2.14/ft.^{2}	2396.80			2397.00	1996.00
TOTAL				$3598.00		$1029.48	$4627.00	$3853.00
	AL	596 ft.	0.60/ft.	357.60	0.53/ft.	315.88	673.00	560.00
44' x 24'	GASKET	596 ft.	1.20/ft.	715.20	1.00/ft.	596.00	1211.00	1008.00
	SCREWS	450	0.12/scr	54.00	0.12/scr	54.00	108.00	90.00
	MODULE	66 @ 16 ft.^{2}	2.14/ft.^{2}	2259.84			2260.00	1882.00
TOTAL				$3386.64		$ 965.88	$4252.00	$3540.00
	AL	628 ft.	0.60/ft.	376.80	0.53/ft.	332.84	710.00	591.00
40' x 28'	GASKET	628 ft.	1.20/ft.	753.60	1.00/ft.	628.00	1382.00	1151.00
	SCREWS	470	0.12/scr	56.40	0.12/scr	56.40	113.00	94.00
	MODULE	70 @ 16 ft.^{2}	2.14/ft.^{2}	2396.80			2397.00	1996.00
TOTAL				$3583.60		$1017.24	$4601.00	$3831.00
	AL	644 ft.	0.60/ft.	386.40	0.53/ft.	341.32	728.00	606.00
36' x 32'	GASKET	644 ft.	1.20/ft.	772.80	1.00/ft.	644.00	1417.00	1180.00
	SCREWS	500	0.12/scr	60.00	0.12/scr	60.00	120.00	100.00
	MODULE	72 @ 16 ft.^{2}	2.14/ft.^{2}	2465.28			2465.00	2053.00
TOTAL				$3684.48		$1045.32	$4730.00	$3938.00

Table 14-13 (Cont.)

MATERIAL AND LABOR COSTS

ARRAY SIZE	MATERIAL	QUANTITY	PANEL LABOR RATE	48" x 48" COST LABOR	MATERIAL RATE	DIRECT COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL F	272 ft.	$0.60/ft	$163.20	$1.18/ft	$320.96	$484.00	$403.00
	AL S	256 ft.	0.60/ft	153.60	0.52/ft	133.12	287.00	239.00
132' x 8'	GASKET	272 ft.	1.20/ft	326.40	0.24/ft	65.28	392.00	326.00
	SCREWS	470	0.12/scr	56.40	0.10/scr	47.00	103.00	86.00
	SEALANT	396 ft.	0.20/ft	79.20	0.23/ft	91.08	170.00	142.00
	MODULE	66 @16 ft^2	2.14/ft^2	2259.84			2260.00	1882.00
TOTAL				$3038.64		$657.44	$3696.00	$3077.00
	AL S	276 ft.	$0.60/ft	165.60	1.18/ft	325.68	491.00	409.00
	AL S	252 ft.	0.60 ft.	151.20	0.52/ft	131.04	282.00	235.00
88' x 12'	GASKET	276 ft.	1.20/ft.	331.20	0.24/ft	66.24	397.00	331.00
	SCREWS	460	0.12/scr	55.20	0.10/scr	46.00	101.00	84.00
	SEALANT	352 ft.	0.20/ft.	70.40	0.23/ft	80.96	151.00	126.00
	MODULE	66 @16 ft^2	2.14/ft^2	2259.84			2260.00	1882.00
TOTAL				$3033.44		$649.92	$3683.00	$3067.00
	AL F	288 ft.	$0.60/ft.	172.80	$1.18/ft	339.84	513.00	427.00
	AL S	256 ft.	0.60/ft.	153.60	0.52/ft	133.12	287.00	239.00
68' x 16'	GASKET	288 ft.	1.20/ft.	345.60	0.24/ft	69.12	415.00	346.00
	SCREWS	460	0.12/scr	55.20	0.10/scr	46.00	101.00	84.00
	SEALANT	340 ft.	0.20/ft	68.00	0.23/ft	78.20	146.00	122.00
	MODULE	68 @16 ft^2	2.14/ft^2	2328.32			2328.32	1939.00
TOTAL				$3123.52		$666.28	$3790.00	$3156.00
	AL F	300 ft.	0.60/ft.	180.00	$1.18/ft	354.00	534.00	445.00
	AL S	260 ft.	0.60/ft.	156.00	0.52/ft	135.20	291.00	242.00
56' x 20'	GASKET	300 ft.	1.20/ft.	360.00	0.24/ft	72.00	432.00	360.00
	SCREWS	470	0.12/scr	56.40	0.10/scr	47.00	103.00	86.00
	SEALANT	336 ft.	0.20/ft.	67.20	0.23/ft	77.28	144.00	120.00
	MODULE	70 @16 ft^2	2.14/ft.^{2}	2396.80			2397.00	1996.00
TOTAL				$3216.40		$685.98	$3902.00	$3249.00

Table 14-14

MATERIAL AND LABOR COSTS

ARRAY SIZE	MATERIAL	QUANTITY	PANEL LABOR RATE	48" x 48" COST LABOR	MATERIAL RATE	DIRECT COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL F	288 ft.	$0.60/ft.	$172.80	$1.18/ft	$339.84	$513.00	$427.00
	AL S	240 ft.	0.60/ft.	144.00	0.52/ft	124.80	269.00	224.00
44' x 24'	GASKET	288 ft.	1.20/ft.	345.60	0.24/ft	69.12	415.00	346.00
	SCREWS	450	0.12/scr	54.00	0.10/scr	45.00	99.00	82.00
	SEALANT	308 ft.	0.20/ft.	61.60	0.23/ft	70.84	132.00	110.00
	MODULE	66 @16 ft^2	2.14/ft^2	2259.84			2260.00	1882.00
TOTAL				$3037.84		$649.60	$3687.00	$3070.00
	AL F	308 ft.	$0.60/ft.	184.80	$1.18/ft	363.55	548.00	456.00
	AL S	252 ft.	0.60/ft.	151.20	0.52/ft	131.04	282.00	235.00
40' x 28'	GASKET	308 ft.	1.20/ft.	369.60	0.24/ft	73.92	444.00	370.00
	SCREWS	470	0.12/scr	56.40	0.10/scr	47.00	103.00	86.00
	SEALANT	320 ft.	0.20/ft.	64.00	0.23/ft	73.60	138.00	115.00
	MODULE	70 @16 ft^2	2.14/ft^2	2396.80			2397.00	1996.00
TOTAL				$3222.80		$689.00	$3912.00	$3257.12
	AL F	320 ft.	$0.60/ft.	192.00	$1.18/ft.	377.60	570.00	475.00
	AL S	256 ft.	0.60/ft.	153.60	0.52/ft.	133.12	287.00	239.00
36' x 32'	GASKET	320 ft.	1.20/ft.	384.00	0.24/ft	76.80	461.00	384.00
	SCREWS	500	0.12/scr	60.00	0.10/scr	50.00	110.00	92.00
	SEALANT	324	0.20/ft.	64.80	0.23/ft	74.52	139.00	116.00
	MODULE	72 @16 ft^2	2.14/ft^2	2465.28			2465.00	2053.00
TOTAL				$3319.68		$712.04	$4032.00	$3357.00

INDEX

AL F - Aluminum factory installed
AL S - Aluminum site installed

Table 14-14 (Cont.)

MATERIAL AND LABOR COSTS

ARRAY SIZE	MATERIAL	QUANTITY	PANEL LABOR RATE	48" x 48" COST LABOR	STANDOFF MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL SH	528 ft.	$0.60/ft.	$316.80	$1.24/ft	$654.72	$972.00	$809.00
	AL H	528 ft.	0.60/ft.	316.80	0.225/ft	118.80	436.00	363.00
132' x 8'	GASKET	528 ft.	1.20/ft.	633.60	0.12/ft	63.36	697.00	580.00
	SCREWS	710	0.12/scr	85.20	0.03/scr	15.84	101.00	84.00
	SEALANT	528 ft.	0.20/ft	105.60	0.23/ft	121.44	227.00	189.00
	FLASHING	272 ft.^{2}	0.77/ft^2	209.44	0.70/ft	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	66 @ 16 ft^2	0.75/ft^2	792.00			792.00	659.00
TOTAL				$2617.20		$1246.16	$3863.00	$3217.00
	AL SH	528 ft.	0.60/ft.	316.80	1.24/ft	654.72	972.00	809.00
	AL H	528 ft.	0.60/ft.	316.80	0.225/ft	118.80	436.00	363.00
88' x 12'	GASKET	528 ft.	1.20/ft.	633.60	0.12/ft.	63.36	697.00	580.00
	SCREWS	710	0.12/scr	85.20	0.03/scr	15.84	101.00	84.00
	SEALANT	528 ft.	0.20/ft.	105.60	0.23/ft.	121.44	227.00	189.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	66 @ 16 ft^2	0.75 ft.^{2}	792.00			792.00	659.00
TOTAL				$2617.20		$1246.16	$3863.00	$3217.00
	AL SH	544 ft.	0.60/ft.	326.40	1.24/ft	674.56	1001.00	833.00
	AL H	544 ft.	0.60/ft.	326.40	0.225/ft.	122.40	449.00	374.00
68' x 16'	GASKET	544 ft.	1.20/ft.	652.80	0.12/ft.	65.28	718.00	598.00
	SCREWS	730	0.12/scr	87.60	0.03/scr	21.90	110.00	92.00
	SEALANT	544 ft.	0.20/ft.	108.80	0.23/ft.	125.12	234.00	195.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	68 @ 16 ft.^{2}	0.75/ft.^{2}	816.00			816.00	679.00
TOTAL				$2685.20		$1281.26	$3966.00	$3303.00

Table 14-15

MATERIAL AND LABOR COSTS

PANEL 48" x 48" STANDOFF

ARRAY SIZE	MATERIAL	QUANTITY	LABOR RATE	COST LABOR	MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL SH	560 ft.	0.60/ft.	336.00	1.24/ft	694.40	1030.00	858.00
	AL H	560 ft.	0.60/ft.	336.00	0.225/ft	126.00	462.00	385.00
56' x 20'	GASKET	560 ft.	1.20/ft.	672.00	0.12/ft	67.20	739.00	615.00
	SCREWS	750 scr	0.12/scr	90.00	0.03/scr	22.50	113.00	94.00
	SEALANT	560 ft.	0.20/ft.	112.00	0.23/ft	128.80	241.00	201.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	70 @ 16 ft.^{2}	0.75/ft.^{2}	840.00			840.00	699.00
TOTAL				$2753.20		$1310.90	$4064.00	$3384.00
	AL SH	528 ft.	0.60/ft.	316.80	1.24/ft	654.72	972.00	809.00
	AL H	528 Ft.	0.60/ft.	316.80	0.225/ft.	118.80	436.00	363.00
44' x 24'	GASKET	528 ft.	1.20/ft.	633.60	0.12/ft.	63.36	697.00	580.00
	SCREWS	710	0.12/ft.	85.20	0.03/scr	21.30	107.00	89.00
	SEALANT	528 ft.	0.20/ft.	105.60	0.23/ft.	121.44	227.00	189.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	66 @ 16 ft.^{2}	0.75/ft.^{2}	792.00			792.00	659.00
TOTAL				$2617.20		$1251.62	$3869.00	$3221.00
	AL SH	560 ft.	0.60/ft.	336.00	1.24/ft.	694.40	1030.00	858.00
	AL H	560 ft.	0.60/ft.	336.00	0.225/ft.	126.00	462.00	385.00
40' x 28'	GASKET	560 ft.	1.20/ft.	671.00	0.12/ft.	67.20	739.00	615.00
	SCREWS	710	0.12/scr	90.00	0.03/scr	22.50	113.00	94.00
	SEALANT	560 ft.	0.20/ft.	112.00	0.23/ft.	128.80	241.00	201.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	70 @ 16 ft.^{2}	0.75/ft.^{2}	840.00			840.00	699.00
TOTAL				$2753.20		$1310.90	$4064.00	$3384.00

Table 14-15 (Cont.)

MATERIAL AND LABOR COSTS

ARRAY SIZE	MATERIAL	QUANTITY	PANEL LABOR RATE	48" x 48" COST LABOR	STANDOFF MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL SH	576 ft.	0.60/ft.	345.60	1.24/ft.	714.24	1060.00	888.00
	AL H	576 ft.	0.60/ft.	345.60	0.225/ft.	129.60	475.00	396.00
36' x 32'	GASKET	576 ft.	1.20/ft.	691.20	0.12/ft.	69.12	760.00	633.00
	SCREWS	770	0.12/scr	92.40	0.03/scr	23.10	116.00	97.00
	SEALANT	576 ft.	0.20/ft.	115.20	0.23/ft.	132.48	248.00	207.00
	FLASHING	272 ft.^{2}	0.77/ft.^{2}	209.44	0.70/ft.^{2}	190.40	400.00	333.00
	STRIP	272 ft.	0.58/LF	157.76	0.30/LF	81.60	239.00	199.00
	MODULE	72 @ 16 ft.^{2}	0.75/ft.^{2}	864.00			864.00	719.00
TOTAL				$2821.20		$1340.54	$4162.00	$3465.00

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AL SH = ALUMINUM SITE INSTALLED
AL H = ALUMINUM FACTORY INSTALLED

Table 14-15

MATERIAL AND LABOR COSTS

ARRAY SIZE	MATERIAL	QUANTITY	PANEL LABOR RATE	48" x 48" COST LABOR	RACK MATERIAL RATE	COST MATERIAL	1978$ TOTAL	1975$ TOTAL
	AL	1056 ft.	$0.60/ft.	$633.60	$1.24/ft.	$1309.44	$1943.00	$1618.00
	SEALANT	1056 ft.	0.20/ft.	211.20	0.23/ft.	242.88	454.00	378.00
132' x 8'	SCREWS	530	0.15/scr	79.50	0.10/scr	53.00	133.00	111.00
	MODULE	66 @ 16 ft.^{2}	0.75/ft.^{2}	792.00			792.00	659.00
TOTAL				$1716.30		$1605.32	$3322.00	$2766.00
	AL	1088 ft.	0.60/ft.	652.80	1.24/ft.	1349.12	2002.00	1667.00
	SEALANT	1088 ft.	0.20/ft.	217.60	0.23/ft.	250.24	468.00	390.00
68' x 16'	SCREWS	550	0.15/scr	82.50	0.10/scr	55.00	138.00	115.00
	MODULE	68 @ 16 ft.^{2}	0.75/ft.^{2}	816.00			816.00	679.00
TOTAL				$1768.90		$1654.36	$3423.00	$2850.00

Table 14-16

MATERIAL AND LABOR COSTS

ARRAY 8' x 132'
PANEL 48" x 48"
RACK - STEEL

GROUND MOUNT	QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
STEEL ANGLES	3.5 T	$774/T	$2709.00	$504/T	$1764.00	$4473.00	$3724.00
STEEL TEES	0.57 T	796/T	453.72	518/T	295.26	749.00	624.00
CONCRETE PIERS	1.58 YDS	16.62/YDS	26.26	32.56/YD	51.44	78.00	65.00
PIER STEEL	0.16 T	244/T	39.04	422/T	67.52	107.00	89.00
CONCRETE FOOTINGS	3.6 YDS	14.32/YD	51.55	32.66/YD	117.58	169.00	141.00
FOOTING STEEL	0.13 T	336/T	43.68	580/T	75.40	119.00	99.00
EXCAVATION	43 YDS	1.42/YD	61.06	1.45/YD	62.35	123.00	102.00
BACKFILL	43 YDS	2.00/YD	86.00	2.05/YD	88.15	174.00	145.00
TOTAL			$3470.31		$2521.10	$5992.00	$4989.00

Table 14-17

MATERIAL AND LABOR COSTS

ARRAY 8' x 132'
PANEL 48" x 48"
RACK - WOOD

GROUND MOUNT	QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
WOOD FRAMING 2x4/2x6/2x8	1.404 MBF	$300/MBF	$421.20	$339/MBF	$475.96	$897.00	$747.00
WOOD FRAMING 2x10	0.89 MBF	291/MBF	258.99	352/MBF	313.28	572.00	476.00
CONCRETE PIER	1.58 YDS	16.62/YD	26.26	32.56/YD	51.44	78.00	65.00
PIER STEEL	0.16 T	244/T	39.04	422/T	67.52	107.00	89.00
CONCRETE FOOTINGS	3.6 YDS	14.32/T	51.55	32.66/YD	117.58	169.00	141.00
FOOTING STEEL	0.13 T	336/T	43.68	580/T	75.40	119.00	99.00
EXCAVATION	43 YDS	1.42/YD	61.06	1.45/YD	62.35	123.00	102.00
BACKFILL	43 YDS	2.00/YD	86.00	2.05/YD	88.15	174.00	145.00
TOTAL			$987.78		$1251.68	$2239.00	$1864.00

Table 14-18

MATERIAL AND LABOR COSTS

ARRAY 68' x 16'
PANELS 48" x 48"
RACK - STEEL

GROUND MOUNT	QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
STEEL ANGLES	1.63 T	$774/T	$1261.62	$504/T	$821.52	$2083	$1734.00
STEEL TEES	2.02 T	796/T	1607.92	518/T	1046.36	2654	2210.00
CONCRETE PIERS	1.224 YDS	16.62/YD	20.34	32.56/YD	39.85	60	50.00
PIER STEEL	0.075 T	244/T	18.30	422/T	31.65	50	42.00
CONCRETE FOOTINGS	2.76 YDS	14.32/YD	39.52	32.66/YD	90.14	130	108.00
FOOTING STEEL	0.09 T	336/T	30.24	580/T	52.20	82	68.00
EXCAVATION	21.4 YDS	1.42/YD	30.39	1.45/YD	31.03	61	51.00
BACKFILL	21.4 YDS	2.00/YD	42.80	2.05/YD	43.87	87	72.00
TOTAL			$3050.97		$2156.79	$5208.00	$4336.00
ROOF MOUNT							
STEEL ANGLES	1.63 T	774/T	1261.62	504/T	821.52	2083	1734.00
STEEL TEES	2.02 T	796/T	1607.92	518/T	1046.36	2654	2210.00
STEEL ANGLES	0.13 T	854/T	111.02	516/T	67.08	178	148.00
WOOD BLOCKS	0.27 MBF	364/MBF	98.28	452/MBF	122.04	220	183.00
FLASHING	272 Ft.^{2}	0.77 Ft.^{2}	209.44	0.70/Ft.^{2}	190.40	400	333.00
STRIP	272 Ft.	0.58/LF	157.76	0.30/LF	81.60	239	199.00
TOTAL			$3446.04		$2329.00	$5775.00	$4808.00

Table 14-19

MATERIAL AND LABOR COSTS

ARRAY 68' x 16'
PANEL 48" x 48"
RACK - WOOD

GROUND MOUNT	QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	1975$ TOTAL
WOOD FRAMING 2x4 / 2x6	1.103 MBF	$300/MBF	$330.90	$339/MBF	$373.92	$705.00	$587.00
WOOD FRAMING 2x12	0.53 MBF	291/MBF	154.23	352/MBF	186.56	341.00	284.00
CONCRETE PIER	0.8 YDS	16.62/YD	13.30	32.56/YD	26.05	39.00	32.00
PIER STEEL	0.075 T	244/T	18.30	422/T	31.65	50.00	42.00
CONCRETE FOOTINGS	2.76 YDS	14.32/YD	39.52	32.66/YD	90.14	130.00	108.00
FOOTING STEEL	0.09 T	336/T	30.24	580/T	52.20	82.00	68.00
EXCAVATION	21.4 YDS	1.42/YD	30.39	1.45/YD	31.03	61.00	51.00
BACKFILL	21.4 YDS	2.00/YD	42.80	2.05/YD	43.87	87.00	72.00
TOTAL			$659.68		$835.41	$1495.00	$1245.00
ROOF MOUNT							
WOOD FRAMING 2x4 / 2x6	1.103 MBF	300/MBF	330.90	339/MBF	373.92	705.00	587.00
WOOD FRAMING 2 x 12	0.53 MBF	291/MBF	154.23	352/MBF	186.56	341	284.00
STEEL ANGLES	0.13 T	854/T	111.02	516/T	67.08	178	148.00
WOOD BLOCKS	0.27 MBF	364/MBF	98.28	452/MBF	122.04	220	183.00
FLASHING	272 $Ft.^2$	$0.77/Ft.^2$	209.44	$0.70/Ft.^2$	190.40	400	333.00
STRIP	272 Ft.	0.58/Ft.	157.76	0.30/Ft	81.60	239	199.00
TOTAL			$1061.63		$1021.57	$2083.00	$1734.00

Table 14-20

MATERIAL AND LABOR COSTS

PER PANEL COST

			QUANTITY	LABOR RATE	LABOR	MATERIAL RATE	MATERIAL	1978$ TOTAL	19[illegible] TOTAL
	32" x 96"								
16 x 48	16" x 24"								
		Aluminum H	16 ft.	.60/ft.	9.60	.52/ft.	8.32	$17.92	$14.90
		H Seal	32 ft.	.20/ft.	6.40	.23/ft.	7.36	13.76	11.50
		Butt Seal	--						
		Total			$16.00		$15.68	$31.68	$26.40
16 x 24	16" x 48"								
		Aluminum H	10.67 ft.	.60/ft.	6.40	.52/ft.	5.55	11.95	10.00
		H Seal	21.33	.20/ft.	4.27	.23/ft.	4.91	9.18	7.70
		Butt Seal							
		Total			$10.67		$10.45	$21.12	$17.60
	48" x 48"								
16 x 48	16" x 24"								
		Aluminum H	12 ft.	.60/ft.	7.20	.52/ft.	6.24	13.44	11.20
		H Seal	24 ft.	.20/ft.	4.80	.23/ft.	5.52	10.32	8.60
		Butt Seal							
		Total			$12.00		$11.76	$23.76	$19.80
16 x 24	16" x 48"								
		Aluminum H	8 ft.	.60/ft.	4.80	.52/ft.	4.16	8.96	7.50
		H Seal	16 ft.	.20/ft.	3.20	.23/ft.	3.68	6.88	5.70
		Butt Seal							
		Total			$ 8.00		$ 7.84	$15.84	$13.20

Table 14-21

REFERENCES:

1. Means, Robert Snow, Company, Inc., Construction Consultants and Publishers, Duxbury, Mass. 1977.

2. McKee-Berger-Mansueto Inc., Van Nostrand Reinhold Co., New York, New York, 1977.

APPENDIX 15. GROUNDING, WIRING, TERMINAL AND VOLTAGE STUDIES

PURPOSE: This appendix includes four separate but related studies concerning the electrical requirements for residential photovoltaic modules and array branch circuit wiring. In general, this section identifies grounding, wiring, and terminal requirements as specified by the National Electrical Code (NEC) and Underwriters Testing Laboratory (UL), and studies the effect of voltage level on array branch circuit wiring cost.

CONCLUSIONS: Grounding will be required for those metal framed panels that use the frame as a conductor raceway or enclosure. However, panel designs that do not use an integral metal raceway can expect to be granted an exception. Module design requirements for this grounding exception would be determined by a recognized electrical testing laboratory.

Conductors for general use are limited to #14 AWG copper. Wiring for lighting fixtures can be as small as #18 AWG copper. This implies the possibility of using #18 AWG for the wiring between PV modules, if NEC officials view modules as being similar to lighting fixtures. The most economical cable or conductor/conduit systems are Non-metallic Sheathed Cable (NM), and Armored Cable (AC or BX) for wiring in dry locations. and Underground Feeder Cable (UF) for wiring in wet locations. Both the NEC and UL establish safety requirements for connections, terminals, and splices that are general enough to allow the module manufacturer to choose from a variety of terminal designs specifically suited to any particular module or panel designs. There are, however, several specific NEC and UL requirements concerning use of aluminum conductors, type of connector or contact material allowed for quick connect terminals, allowable ampacity for quick connect terminals, and minimum allowable junction box volume for any combination of conductors, that should be referred to by the module manufacturer before using them.

Array branch circuit wiring costs increase greatly as module size is reduced. Electrical wiring costs do not vary significantly among the three array configurations considered in the voltage study. Terminal costs, i.e., combined labor and material costs for making connections between conductors and modules/panels, are the principle drivers for array branch circuit wiring. A modular quick connect wiring system can be significantly less expensive than the traditional junction box wiring system particularly when the array branch circuit wiring is exposed to the weather as with a rack or standoff mounting type. Electrical wiring costs are inversely proportional to array branch circuit voltage level; however, there is little to no difference between the 100 and 220 volt dc system costs, as unit costs for this study were established.

RECOMMENDATIONS: The module manufacturer should assume grounding will be required, especially if a metal frame is used for the panel. However, an electrical testing laboratory should be consulted concerning possible module/panel designs which could eliminate the need for a grounding conductor. The module manufacturer should refer to NEC Sections 250-72 and 250-92 for approved grounding techniques.

The module manufacturer could assume that the #14 AWG minimum can be extended to #18 AWG, and follow that assumption with an inquiry to a cable manufacturer concerning the likelihood of developing, or using an existing cable other than those commonly used in the building industry, that is specially applicable to residential photovoltaic modules. It is unlikely, however, that any new cable can be cost competitive with Nonmetallic Sheathed Cable and Underground Feeder Cable.

For specific information on material performance specifications, and manufacturing processes related to minimizing cost, individual terminal manufacturers should be contacted. A quick connect terminal, in particular, should be heavily investigated.

The cost difference between 100 and 30 volt dc array branch circuit wiring system is significant enough to rule out consideration fo collection systems less than 100 volts unless some other total system consideration makes it economical.

* * * * *

GROUNDING REQUIREMENT STUDY

A study was done establishing grounding requirements for residential photovoltaic modules and panels. The purpose of this study was to identify those design features which would require the use of a grounding conductor for photovoltaic modules and panels. All requirements have been based on National Electrical Code (NEC) general and equipment-specific grounding requirements. The study starts with NEC definitions for grounding and grounded conductors, and a tabular summary of NEC sections reviewed as part of the study. Following the table are commentaries elaborating on important sections in the Code. Finally, conclusions are drawn.

The NEC distinguishes between grounded and grounding. The conductor connected to ground is called the "grounded" conductor. Whereas the "grounding" conductor is the conductor used to connect noncurrent-carrying conductive parts of equipment to ground to prevent these parts from acquiring a potential above ground resulting in a hazardous condition.

GROUNDING REQUIREMENTS REVIEW SUMMARY

TABLE 15-1

Topic	Reference	Discussion
Definitions	NEC Article 100	This study contains several terms and equipment which may require definition.
General	NEC 250-1	Defines the scope of Article 250, Grounding.
DC Systems	NEC 250-3	Gives two and three-wire systems grounding requirements.
Point of Connection	NEC 250-22	Specifies connection point for system grounding conductor.
Enclosure Grounding	NEC 250-32, -33	Gives requirements for service raceways and other metal enclosures.
Equipment Grounding	NEC 250-42, -43, -44, -46	Requirements for fixed equipment, and non-electric equipment, and requirements for spacing from lightning rods.
Methods	NEC 250-50, -51, -57, -58, -61	Requirements for equipment connections and grounding paths, and defines equipment considered grounded.
Bonding	NEC 250-70, -71 -72, -75, -77, -78	Gives general information, bonding for service equipment, and bonding methods.
Grounding Conductors	NEC 250-91 through -99	Gives materials and installation requirements for grounding and equipment conductors.
Grounding Conductor Connections	NEC 250-111, -113, -117, -118	Gives examples of typical grounding connections.

NEC Section 250-3, DC Systems, requires grounding for all three wire DC systems and for two wire DC systems except those below 50 V-DC and above 300 V-DC. (The exceptions for two wire systems needs explanation. The 50 volt exception is easily understood; low voltage means lower safety hazard. The 300 volt exception is not so easily understood, and has been the subject of minor controversy within the NEC committees. It is a hold over from the late 1940's and early 50's when DC was available in some cities. At that time, equipment that operated on 300 volts was limited to permanent equipment such as overhead cranes. The equipment was grounded but the system was not. The 300 volt exception should not be expected to stay in effect.) In any case, this code section does not impose a grounding requirement on the module or panel assuming the system is designed so that power is bussed to a collection box from which the system could be grounded. This section covers grounded systems rather than grounding of equipment.

NEC Section 250-3, Point of Connection for DC Systems, specifies grounding at supply stations rather than individual services. The section states "DC systems to be grounded shall have the grounding connection made at one or more supply stations. A grounding connection shall not be made at individual services nor at any point on premises wiring." One reason for the "point of connection" requirement, suggested by a NEC Committee member, is because of underground water line corrosion problems believed to be caused by earth currents. Pipe corrosion was frequently a problem with electrically driven trolleys which used the rail as the grounded conductor. Relative to PV residential applications, which would typically use the city water supply line for the grounding conductor, earth currents may not be great enough to cause any problems. In any case, this section does not impose any grounding requirements on the module or panel, as, again, it is a systems concern.

NEC Sections 250-32 and 250-33 suggest that the panel will require grounding if the panel frame is used as a conductor raceway or enclosure. Section 250-32 states that "metal enclosures for service conductors on equipment shall be grounded." Section 250-33 states that "metal enclosures for other than service conductors shall be grounded." From this it can be assumed that all metal enclosures which carry conductors require grounding.

Section 250-42 also suggests grounding; it states that "equipment fastened in place or connected by permanent wiring methods and with exposed noncurrent-carrying parts of fixed equipment likely to become energized shall be grounded." However, exception #2 of 250-42 and the exception to 250-43 suggest that a well designed PV module that effectively isolates live parts from metal frames may be granted exception from grounding. Section 250-42, exception #2 states that "metal frames of electrically heated devices in which frames shall be permanently and effectively insulated from ground shall be exempted by special permission from this grounding requirement." The exception to 250-43 states: "Generators and motor frames in an electrically operated organ (musical type) shall be grounded except where the generator is effectively insulated from ground and from the motor driving it." From these two exceptions, it can be assumed that a well designed PV module or panel would be granted a similar exception.

Conclusions

In summary. It appears as though grounding will be required for those metal framed panels that use the frame as a conductor raceway or enclosure. However, panel designs that do not use an integral metal raceway can be granted an exception from grounding if properly designed. Module design requirements for this grounding exception would be determined by a recognized electrical testing laboratory.

(NEC approved techniques for grounding are: 1) bonding of metal frames and; 2) use of grounding conductors. These techniques are described in 250-72 and 250-92. Refer to the NEC Review, Appendix 4, for more information.)

WIRING REQUIREMENTS AND COST STUDY

A study was undertaken establishing wiring requirements for photovoltaic modules and array branch circuits identifying those wiring systems that best meet these requirements. The purpose of this study was to arrive at a least expensive wiring system that meets all the necessary performance requirements. Performance requirements were based on a review of the wiring requirements established by the National Electrical Code (NEC), and Underwriters Laboratories (UL) Standard 57 for Electrical Lighting Fixtures. (Wiring for lighting fixtures have several things in common with PV panels, namely, operating voltage, operating temperature, and raceways integral with the metal frame.) The cost study was based on Robert Snow Means' Mechanical and Electrical Cost Data, Pittsburgh-area wholesale electrical suppliers' quotes, and several electrical wiring manufacturers suggested wholesale prices.

The report presents a general summary of the results, the NEC and UL reviews, followed by a tabular listing of requirements and references. The approved wiring methods best suited for residential photovoltaic application are then listed and briefly described. The report ends with the summary table and some general concluding statements.

Review of the NEC and UL Standard 57 resulted in: 1) general requirements for protection, operating voltage, wire size, application and ampacity; 2) specific installation and application requirements for NEC-approved wiring systems; and 3) a partial listing of UL wire classification information identifying insulation type, maximum operating temperature, and approved application for conductors and cable.

NEC and UL references for the above mentioned requirements are given in the following table. All of the references except the tables are included in the NEC Review - Appendix 4.

WIRING STUDY REVIEW SUMMARY

TABLE 15-2

REQUIREMENTS	REFERENCES
General:	NEC Article 110
. Protection	NEC Sections 230-52, 230-54, 300-4
. Voltage	NEC Section 300-2 and Table 402-3
. Wire Size	NEC Sections 310-5, 400-12, 410-23
. Application	NEC Sections 225-4, 225-10, 230-43, 230-52, 230-54, 310-7, 310-8, 310-5(2)
. Ampacity	NEC Sections 310-19, 402-5 and Table 402-15
Wiring Systems	NEC Articles 320, 324, 328, 330, 333, 336, 339, 345, 346, 347, 348, 350, 352, and UL 57-Sec. 16
Wire Classification	NEC Tables 110-13 and 402-3

From the Code and UL reviews, it was determined that the wiring systems meeting the requirements for a residential PV installation are: 1) Insulated Conductors (Type THW) in conduit or in approved raceway; 2) Nonmetallic Sheathed Cable (NM); 3) Underground Feeder and Branch-Circuit Cable (UF); 4) Armored Cable (AC, commonly referred to as BX); and 5) a prewired, module system (similar to the Wiremold Co., ODS-Overhead Distribution System). A brief description and discussion of each of these wiring types as follows:

- Insulated Conductors in Conduit or Approved Raceway

  The insulation conductors-in-conduit or in-approved raceway wiring system would typically use THW conductors. (THW is not the only conductor suitable for this system but it is the type most often used for wiring in conduit). THW is a moisture and heat resistant thermoplastic conductor, rated at 70 and 90^{o}C, applicable for dry and wet locations. It is available in sizes 14 AWG through 2000 MCM. (MCM = Thousand Circular Mils, AWG = American Wire Gauge)

  Protection for wet locations with an Insulated Conductor System would be provided by Intermediate Metal Conduit (IMC). IMC is a metal raceway of circular cross section, constructed from galvanized steel or aluminum. (Steel is less expensive than aluminum and was used for the costing study.) IMC is thinner walled than Rigid Metal Conduit (See NEC Article 346, and Article 345 for IMC) and is less expensive than Rigid Metal.

  Electrical Metallic Tubing (EMT, see Article 348), commonly called "thin wall", is usually used indoors for branch circuiting and would be used with an Insulated Conductor System for dry locations only in a residential PV system. EMT can be treated for use in wet locations but is seldom used this way.

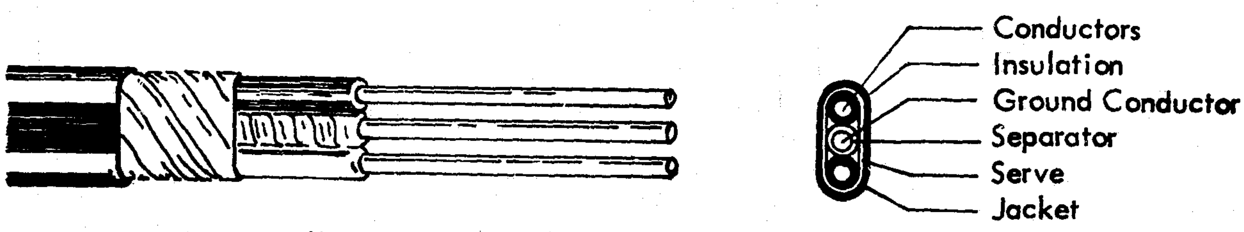
  It is possible that an approved raceway can be integrated into metal framed panels. This raceway could be used for wet or dry locations, if proper finishes and/or metals were used. An aluminum, galvanized steel, or enamel-coated frame (based on UL requirements for Rigid Metal Conduit) would be required for outdoor application. The integral raceway must allow for access to connections and must provide a means for running the wiring. (In flourescent light fixtures this is done by way of a snap-in metal pan or panel.)

Insulated Conductor
(Type THW)

FIGURE 15-1

- Nonmetallic Sheathed Cable (NM)

Nonmetallic Sheathed Cable (NM) is a factory assembly of two or more insulated conductors having an outer sheath of moisture resistant, flame retardant, nonmetallic material (usually PVC). (See Article 336 for reprint of NM requirements). NM is approved for use in dry locations only, rated for 60°C, and permitted for use "in one or two family dwellings, or multi-family dwellings, and other structures not exceeding three floors above grade." Use of NM without conduit or raceways assumes that the array branch circuit wiring will not be required to meet the wiring requirements for service conductors. See Commentary following NEC 230-43 for further explanations.

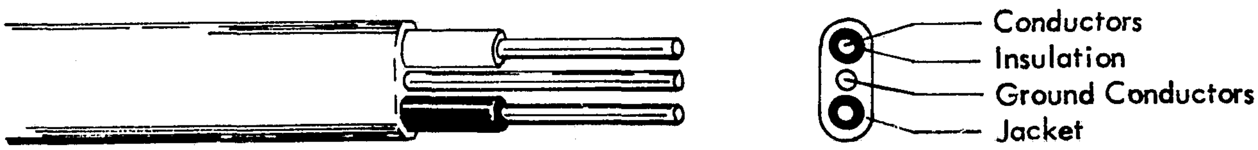


Nonmetallic Sheathed
Cable (NM)

FIGURE 15-2

Underground Feeder and Branch Circuit Cable (UF)

Underground Feeder and Branch Circuit Cable (UF) is similar to NM but is approved for underground use, wet locations, and where exposed to sunlight. UF is rated for 60°C maximum operating temperature. UF has replaced NMC as the Nonmetallic Sheathed Cable approved for wet locations (NMC is the designation used for a type of Nonmetallic Sheathed Cable that was specially approved for wet locations; cable with the NMC label is no longer available), and does not have the three-story, residential limitation that NM has. Use of UF without conduit or raceways assumes the array branch circuit wiring will not be required to meet the wiring requirements for service conductors. See NEC 230-43 for further explanation.

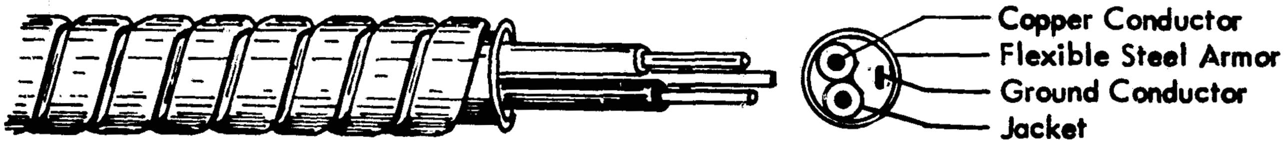


Underground Feeder
Cable (UF)

FIGURE 15-3

Armored Cable (AC)

Armored Cable (NEC designated AC, but commonly called BX) is a factory fabricated assembly of insulated conductors in a flexible metallic enclosure. AC is permitted in dry locations, and is rated at 60°C. It is typically used in commercial or other buildings as a replacement for NM. It is actually a factory fabricated insulated conductor-in-conduit type wiring system. Use of BX without conduit or raceways assumes the array branch circuit wiring will not be required to meet the wiring requirements for service conductors. See NEC 230-43 for further explanation.



Flexible Armored Cable
(BX)

FIGURE 15-4

- Prewired Modular System

  The prewired modular wiring system used for the cost study is the ODS Overhead Distribution System manufactured by the Wiremold Co., of West Hartford, Connecticut. The ODS System is used for lighting and communications systems in commercial buildings. It is UL approved and meets NEC requirements. Components include a

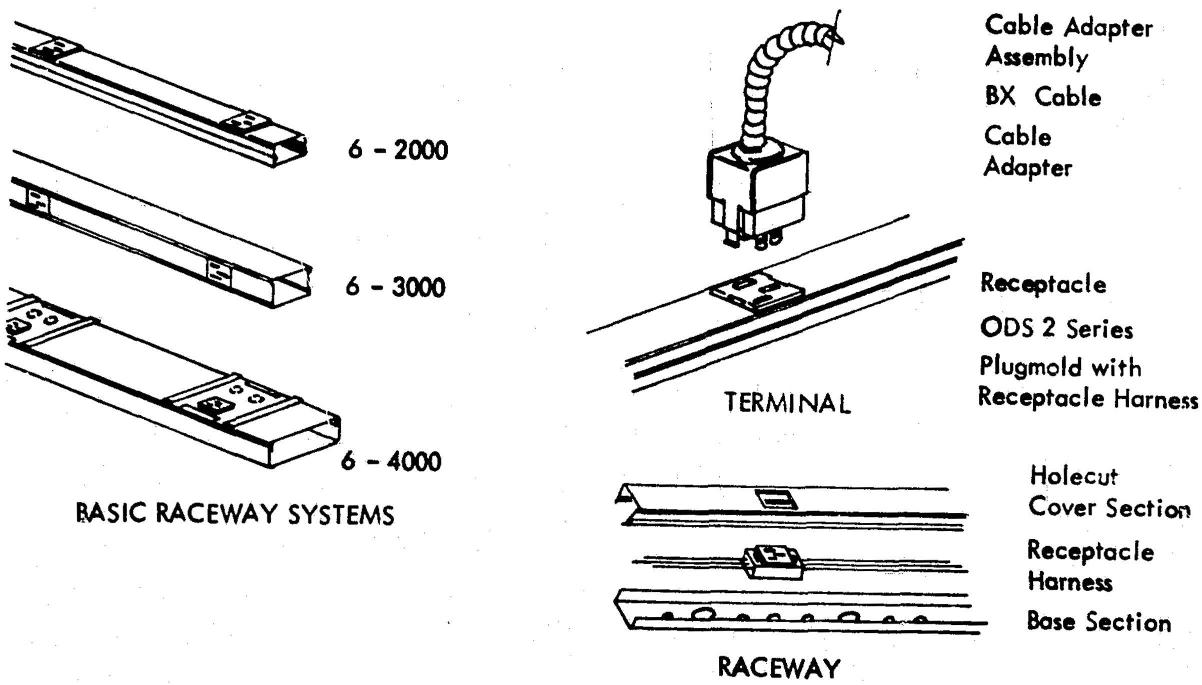


FIGURE 15-5

raceway system and a cable adapter assembly. The raceway is comprised of a base section, prewired receptacle harness, and a cover section with receptacles located every 24 or 30 inches. Four raceway sizes are available. The raceway is typically wired with #12 AWG but can be specially ordered prewired with other size conductors. The system has the capability of alternately wiring receptacles to add current capacity; up to four circuits are standard. The cable adapter is made up of a three-pronged terminal, similar to a standard plug, and a six foot piece of BX cable. The system is approved for indoor use only. It is covered by NEC Articles 545 and 353.

The wiring cost summary table with associated notes follow. From this summary, it is apparent that the most economical cable or conductor systems suitable for residential photovoltaic systems are the Nonmetallic Sheathed Cable, (NM) and Armored Cable (BX) for wiring in dry locations and Underground Feeder and Branch Circuit Cable (UF) for wiring in wet locations.

** M = Material Cost
L = Labor Cost
T = Total Cost

WIRING COST SUMMARY
TABLE 15-3
1975 DOLLARS/100 FT

SYSTEM * TYPE	THW W/O CONDUIT			THW W/EMT			THW W/IMC			NM			UF[4]			BX			ODS		
# OF WIRES[1]	3			2			2			3			3			2			3 or 4		
COST ** BREAKDOWN	M	L	T	M	L	T	M	L	T	M	L	T	M	L	T	M	L	T	M	L	T
AWG/CONDUIT DIAMETER																					
#14 CONDUCTOR	7	21	28	5	14	19	5	14	19	10	38	48	12	38	48	16	38	54			
(1/2") CONDUIT[2]		53	53[3]	13	53	66	28	92	120												
TOTAL ($/100 FT)	7	74	81	18	67	85	33	106	139	10	38	48	12	38	50	16	38	54	--	--	--
#12 CONDUCTOR	10	25	35	7	17	24	7	17	24	14	42	56	18	42	60	19	40	59	116	122	238[5]
(1/2" CONDUIT)		53	53	13	53	66	28	92	120												
TOTAL	10	78	88	20	70	90	35	109	144	14	42	56	18	42	60	19	40	59	116	122	238
#10 CONDUCTOR	16	27	43	10	18	28	10	18	28	20	51	71	26	51	77	30	46	76	133	122	255[5]
(1/2") CONDUIT		53	53	13	53	66	28	92	120												
TOTAL	16	80	96	23	71	94	38	110	148	20	51	71	26	51	77	30	46	76	133	122	255
#8 CONDUCTOR	27	34	61	18	22	40	18	22	40	44	61	105	57	61	118	[illegible]	56	100	--	--	--
(1") CONDUIT		53	53	32	79	111	50	131	181												
TOTAL	27	87	114	50	101	151	68	153	221	44	61	105	57	61	118	44	56	100	--	--	--
#6 CONDUCTOR	32	42	74	22	28	50	22	28	50	58	70	128	76	70	146	--	--	---	--	--	--
(1") CONDUIT		53	53	32	79	111	50	131	181												
TOTAL	32	95	127	54	107	161	72	153	221	58	70	128	76	70	146	--	--	---	---	---	---

* THW W/O CONDUIT = Type THW Conductors With Panel Frame Used As Raceway
THW W/EMT = Type THW Conductors With Electrical Metal Tubing (Suitable For Dry Locations)
THW W/IMC = Type THW Conductors With Intermediate Metal Conduit (Suitable For Wet Locations)
NM = Nonmetallic Sheathed Cable (Dry Locations)
UF = Underground Feeder Cable (Wet Locations)
BX = Armored Cable (Dry Locations)
ODS = Prewired Modular System Called Overhead Distribution System (Dry Locations)

TERMINAL STUDY

This study was conducted to establish requirements for photovoltaic module/panel terminals and array branch circuit interconnects.

The study is based on NEC requirements for splices, terminals, and connections and requirements for quick-connect terminals as established by UL Standard 310. NEC requirements are summarized in Table 1. References are made to NEC sections that can be found in the NEC Review, Appendix 4, of this document.

Following the NEC and UL Standard Requirements is a general discussion of PV terminal and interconnect design requirements. The study concludes with a description and discussion of two quick connections currently manufactured.

TERMINAL REQUIREMENTS REVIEW SUMMARY
TABLE 15-4

Requirements	NEC Reference	Discussion
General	110-14	Establishes general requirements for terminals and splices to include pressure connectors. See commentary following 110-14(a).
Outdoor Application	225-4	Establishes requirements for conductor covering
	230-26	Specifies clearances for point of attachment to the building.
	230-43	Specifies installation requirements
	230-52	Specifies installation details for entering a building.
	230-54	Specifies raintight service head for service raceways.
Boxes and Fittings	300-15	General requirements for boxes and fittings.
	370-5	Specific boxes for damp or wet locations. Weatherproof defined.
	370-6	Number of conductors allowed in junction boxes.
Safety	110-17 (430-132)	Requirements for guarding of live parts - see commentary.

NEC REQUIREMENTS

The NEC for the most part establishes very general, nonspecific requirements for terminals. For example, NEC Section 110-14 requires that connection "devices such as pressure terminal or pressure splicing connectors and soldering lugs shall be suitable for the material of the conductor and shall be properly installed and used", and warns against use of conductors of dissimilar metals unless the terminal, connector, or "device is suitable for the purpose and conditions of use". Section 110-14 (a) requires that "connection of conductors to terminal parts ... shall be made by means of pressure connectors (including set-screw type), solder lugs, or splices to flexible leads. More specific requirements are given in the NEC Handbook Commentary following Section 110-14 which states that "pigtailing, either field- or factory-wired, is recognized by the NEC."

NEC Section 300-15 (a) establishes requirements for boxes and fittings. It states: "A box or fitting shall be installed at each conductor splice connection point, outlet, switch point, junction point, or pull point for the connection of conduit, electrical metallic tubing, surface raceway, or other raceways." An exception to this, allows conductors splices in surface raceways, wireways and other similar enclosures having removable covers which make the splice accessible after installation.

NEC Section 300-15 (b) establishes requirements for boxes only. It states: "A box shall be installed at each conductor splice connection point, outlet, switch point, junction point, or pull point for the connection of Type AC cable, Type MC cable, mineral insulated metal-sheathed cable, nonmetallic-sheathed cable, or other cables, at the connection point between any such cable system and a raceway system and at each outlet and switch point for concealed knob-and-tube wiring." Exception is granted "for insulated outlet devices supplied by nonmetallic-sheathed cable" and "where accessible fittings approved for the purpose are used for straight-through splices in mineral insulated metal-sheathed cable.

NEC Section 370-5 gives requirements for connections in wet or damp locations. It states: "In damp or wet locations, boxes and fittings shall be so placed or equipped as to prevent moisture from entering or accumulating within the box or fitting. Boxes and fittings installed in wet locations shall be approved for the purpose."

NEC Section 370-6 gives minimum cubic inch capacity requirements for junction boxes, so sufficient free space for conductors is provided.

<u>UL Standard 310 - Quick Connect Terminals</u>

"For the purpose of this standard", quoting directly from Standard 310, UL defines the following terms:

> "Quick-Connect Wiring Termination - An electrical connection consisting of a male tab and female connector that can be readily engaged or disengaged without the use of a tool - hereinafter referred to as a terminal."
>
> "Production Tab - The part of a terminal that is to be inserted in a connector, manufactured to specified tolerances, and intended to mate properly with a connector when employed in a circuit for a functional purpose other than the tests described in Section 7 - 13."
>
> "Test Tab - A tab made to specified tolerances for conducting electrical, mechanical, and temperature-rise tests. Test tabs are used to provide an accurate base for test measurements."
>
> "Connector - The part of a terminal that receives a tab."

Review of this standard resulted in two important limitations in regard to materials and ampacity. UL excerpts indicating these limitations follow.

- Material Limitations

  Connector Materials - A connector shall be plated or unplated copper alloy.

  Tabs - A production tab shall be plated or unplated copper alloy. Exception: A production tab intended for use in an appliance or equipment that complies with the requirements for such appliance or equipment may be plated steel or unplated steel if of a corrosion resistant alloy.

For the mechanical tests, a test tab shall be unplated brass, CDA Alloy 260, as identified in the Copper Development Association Standard Handbook, 1973; and for the temperature-rise tests, shall be tin plated or corrosion resistant steel having a hardness of 62 $\pm$ 7 on the Rockwell 30T scale.

Exception: An unplated brass test tab, CDA Alloy 260, may be used for the temperature-rise test of a connector intended for use only with production tabs of copper alloy.

- Ampacity Limitation

Ampacity - These requirements apply to quick-connect terminals designed for use with Nos. 22 - 10 AWG copper conductors for internal wiring connections in electrical equipment and for the field termination of conductors to electrical equipment.

UL representative Mr. Hames of the Northbrook, UL Labs mentioned in conversation that the #22-10 AWG range for quick connect has resulted from manufacturers' requests rather than from physical connector constraint, and that changes in existing standards to include larger conductors are possible.

General PV Terminal and Interconnect Design Requirements

Based on the NEC and UL requirements for connections, general PV terminal requirements were established. They are as follows:

1. Safety

Module/panels shall be designed to ensure safety by guarding of live wires against accidental contact that might occur during installation and replacement. In one technique now being used, terminals are shorted during installation by a conductor connected to the positive and negative terminals. Disconnection is made by cutting the conductor after the array is wired.

A simpler solution to prevent against accidental contact seems to be a recessed terminal similar to that used in standard receptacles. This terminal design is currently used in an overhead lighting distribution system that meets UL standards and is recognized as safe by the NEC (see wiring study for a description of the Wiremold ODS). It was learned from J. Russo of Wiremold Co., that some quick connect systems were having trouble receiving UL approval and NEC recognition because of the possibility of exposing live tabs (male contacts) upon relocation of lighting fixtures. (One of the main selling points of a quick connect Overhead Distribution-type-System is that lighting fixture location can be easily changed if for example the furniture layout of the office space below were changed. The Wiremold ODS requires hard wiring of 6 foot length of BX cable to the lighting fixture conductors followed by insertion of the plug or tab assembly (male contacts) into a receptacle. Rearrangement of the lighting fixtures would be done by detachment of the plug cutting power to the fixture - resulting in no hazard.)

Relative to PV systems, this no hazard requirement presents a problem. However, this dangerous or hazardous condition, actually resulting from ignorance or carelessness, can be remedied by proper labeling of the equipment and connectors as to the hazard involved.

2. Flexibility

Because of the variety likely to be encountered in residential applications (roof size, shape, and construction detail), terminals should be designed to allow series/parallel connections such that any desired array configuration can be accommodated. Ideally, this shall be done with a minimal number of terminal and interconnect types.

3. Ease of Installation

Simple connections are desirable, that is connections requiring one or no tools.

Terminals, interconnects and conductors could be color coded to insure proper series/parallel connection. A "fool proof" installation system is conceivable where pre-cut cable and factory fabricated terminals need only be snapped together requiring no understanding of the basic electrical principles involved. This would eliminate the need for the electrician thereby reducing installation costs.

A word of caution however -- if a quick connect system as described above is developed, areas of labor jurisdiction must be defined. A modular school construction system (School Construction System Development, SCSD) developed in the 1960's experienced early failures partly because of initial jurisdictional problems associated with a ceiling system integrating the lighting fixture, air conditioning terminal, and ceiling panels. Installation cost savings with this integrated system were not realized where envisioned each of the three labor disciplines performed in the work in areas not originally anticipated.

4. Replacement

Terminals should be designed to minimize repair and replacement costs. This means terminals shall be designed so that engagement and disengagement can be easily achieved and require no replacement of parts.

Accessibility at the point of connection -- whether it be the junction box, enclosure, or raceway -- is necessary for maintenance of the system.

In general, accessibility, regardless of mounting types, requires that either (1) the point of connection must be accessible from the face or side of the panel (which may decrease net collector area), (2) the panels must be removed for access to the electrical connections, or (3) the point of connection is accessible from the rear.

5. Dı.ability and Stability

The terminal should be environmentally and physically stable. If totally exposed to the outdoors, it must be designed to protect against penetration by water, degradation by sunlight, ozone, and any other environmental hazards present. The terminal should also be protected from physical damage, and the connection should remain stable for the life of the system.

6. Cost

Minimum cost yet maximum performance terminals and interconnects are required.

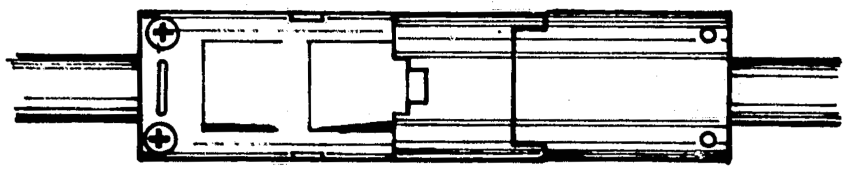
A combined function system may be the best approach to low costs. A structural system which also serves to conduct electricity and an electrical terminal which also connects the panel to the structure could minimize both materials and labor. Further research into the technical and economical feasibility of an integrated system should be performed.

Quick Connectors - Examples

. Nonmetallic Sheathed Cable Connector. (Figures 15-6 and 15-7)
Amp Inc. of Harrisburg, PA manufactures a connector intended for use in modular or manufactured building (as defined in NEC Article 545). It is a hermaphroditic terminal design limited for use with #12 and #10 AWG NM Cable. The connector is designed such that the cable does not have to be stripped to connect the terminal contacts to the conductors. This is done by knife contacts that pierce the conductor insulation. The connector is intended for use in dry locations only. No other performance specifications were available at the time of final printing of this document. The connector wholesales for $1.00/ mated pair. (1978 prices)

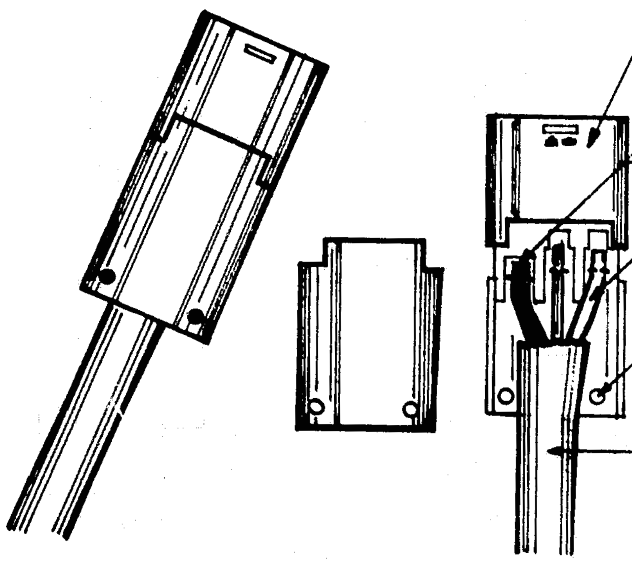
. Sure Seal Connector (Figure 15-8)
ITT Cannon of Santa Ana, CA has developed a "low cost environmental connector tailored to fit into such areas as marine, recreation, household appliance, solar energy, and agricultural applications. These sealed connectors satisfy all the parameters defined by automotive/industrial standards for shock, vibration, temperature cycling, salt water spray and immersion, and low millivolt drop and low contact resistance." Although wire range is limited to #14 through #18 AWG, the manufacturer indicated larger sizes can be manufactured at slightly increased costs.

Quoting from Bechtel Corporations' "Engineering Study of the Module/Array Interface for Large Terrestrial Photovoltaic Arrays", June 1977, Final Report,



The nonmetallic sheathed cable connector shown in Figure 545 2 after being joined together (Amp Inc)

FIGURE 15-6



Non Metallic Sheathed Cable Connector
Amp Inc.

FIGURE 15-7

(ERDA/JPL/954698-77/1), Sure Seal "environmental performance was generally good except that the connector bodies (composed of a nitrile rubber and PVC compound) were attacked harshly in ozone and ultra violet environments." The manufacturer has been contacted by NASA - Lewis Research Center, Cleveland, OH, about development of a Ethylene Propylene Diene Monomer (EPDM ozone and UV resistant) version of the Sure Seal. The EPDM version is expected to increase cost by 8 - 10% over the PVC - nitrile composition. Conservative cost estimates for the EPDM connector from conversations with manufacturers representative are: #14 - 18, $1.50/three pronged mated pair; #10 - 12, $2.50/three pronged mated pair; and #4 - 8, $3.00/three pronged mated pair. These are 1978 prices.

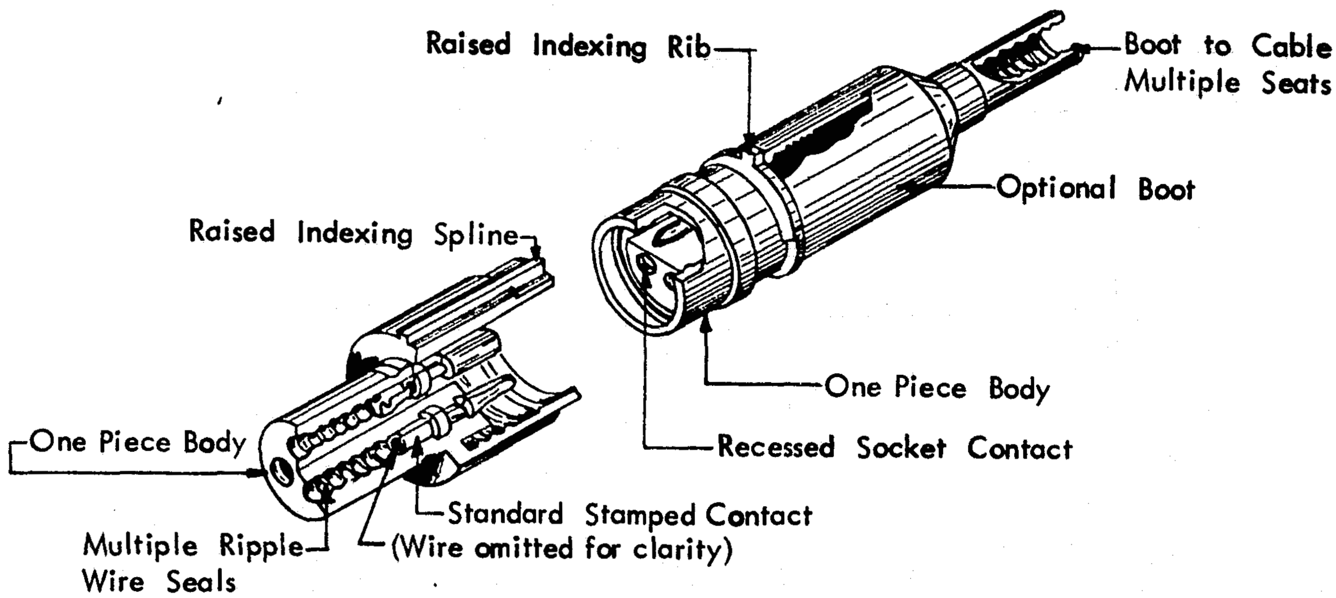


FIGURE 15-8

CONCLUSIONS

Both the NEC and UL establish safety requirements for connections, terminals, and splices that are general enough to allow the module manufacturer to choose from a variety of terminal designs for any specific module or panel design. For example, the NEC requires the use of boxes or fittings at connection points, splices, etc. However, a fitting is generally defined as "an accessory such as a locknut, bushing, or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function." Also, the NEC requires that boxes and fittings used in damp or wet locations must be equipped or so placed to prevent moisture from entering or accumulating.

However, there are several specific requirements that the module manufacturer should be aware of. These requirements, referenced and elaborated on in the text, relate to the use of aluminum conductors, the type of connector or contact materials for quick connect type terminals, ampacity for quick connect terminals, and minimum volume for junction boxes. For more specific information on what options exist, in regards to materials availability, capabilities, limitations, and manufacturing processes and cost, the module manufacturer would do better to contact a terminal manufacturer.

VOLTAGE STUDY

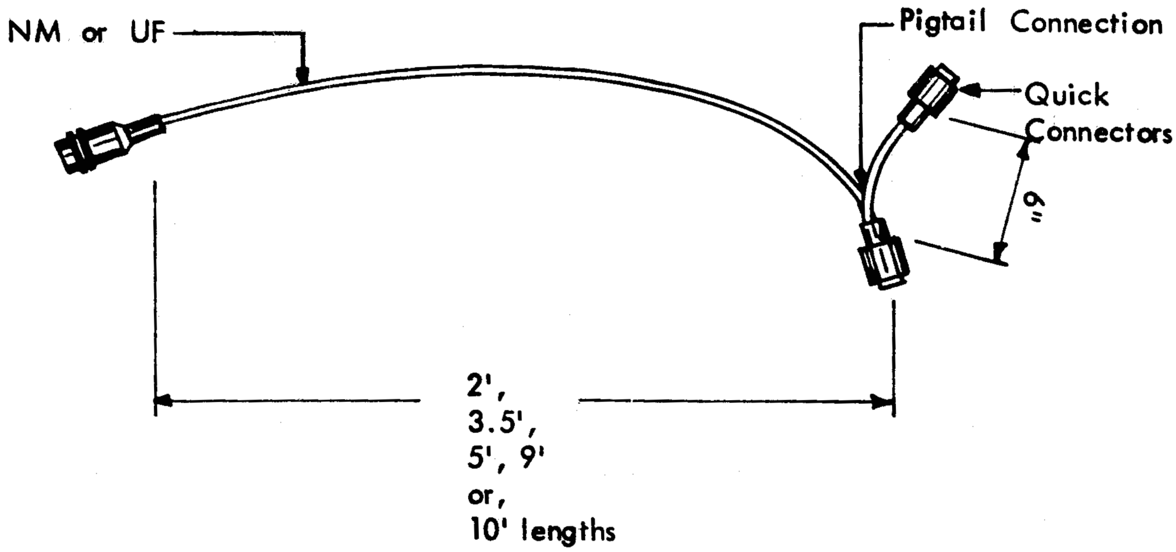
This study was conducted to determine the effect of voltage level on electrical wiring costs for residential photovoltaic arrays. The three voltage levels studies were 30, 100 and 220 Volts dc.

Wiring, connection, and grounding requirements were established in the preceeding wiring, terminal, and grounding studies. From these studies, two least expensive wiring systems meeting the requirements of the Code were identified and are used in this study. These are: 1) nonmetallic sheathed cable in junction boxes and 2) a modular quick connect system. A brief description of these wiring systems follow.

- The J-Box system uses Nonmetallic Sheathed Cable (NM) in nonmetallic junction boxes for wiring in dry locations, and Underground Feeder Cable (UF) in weatherproof boxes for wet locations. This system requires a junction box to be installed at each panel with all connections for array branch circuit wiring being made within boxes. The basic components of each box connection are the box, box cover, fittings, and wire connection devices. Wire connection devices typically used in junction boxes are wire nuts (other, more expensive types are also widely used, but have not been considered in this study). Labor involved includes attachment of the box, fastening of the fittings to the box, stripping of the wires and/or cable sheathing, insertion of the wires through the fittings, and connection of the wires by way of wire nuts.

- The modular quick connect (MQC) system uses factory-fabricated cable/quick connector assemblies. (See Figure 15-9) This system is a conceptual modification of the Wiremold Overhead Distribution System (ODS). (For a description of ODS, see Wiring Study.) Rather than a receptacle harness in a metallic raceway, the MQC system uses nonmetallic sheathed cable and quick connectors. A modified ODS was used for two reasons: 1) NM cable is less expensive than the metallic raceway while still meeting NEC requirements for residential applications, and 2) ODS is not approved for wet locations.

  The components of the assembly as developed for this study, are a 2, 3.5, 5, 9 or 10 foot cable (cable length dependent on module and panel sizes) and three, three-conductor quick connector halves -- two male halves and one female half. (See Figure 15-9) Total connector materials per assembly would be two mated pairs (if an additional female receptacle for the panel terminal is included, i.e., three half terminals and one half terminal makes two mated pairs). Factory fabrication would involve three conductor to contact connections for each connector half. The assembly could be rated #18 - #4 AWG and approved for dry and/or wet locations if the proper cable and connectors are used. Site labor involves quick connect attachment of assemblies to the panels. Assemblies would be rated for a maximum number of parallel electrical connections. The number of panels which could be "strung" together would be dependent on the output and operating voltage of the panel. Also required with this system is the wiring of quick connect male terminals to the array branch circuit conductors that bus power to a central collection point.



MODULAR WIRING SYSTEM ASSEMBLY

FIGURE 15-9

Units costs for material and labor used for both of these systems are shown in Tables 15-8 and 15-9. Wiring costs for two array configurations - a 16' x 67' array comprised of 50 - 32 by 96 inch panels and a 16' x 68' array comprised of 68 - 48 by 48 inch panels are shown in Tables 15-6 and 15-7. The wiring costs for the MQC, both wet and dry systems, and the J-box, both wet and dry, are calculated at array voltages of 220, 100 and 30 Vdc.

In addition to the systems shown, wiring costs for two other array configurations were calculated to determine the effect of configuration on cost. The arrays studied were an 8' x 132' and a 24' x 44' - both comprised of 66 - 48" x 48" panels. As is seen in Figure 15-12 and Table 15-7, array configuration has little effect on total cost. Calculations for the 8' x 132' and 24' x 45' arrays made up of 32 by 96 inch panels yield similar results as seen in Figure 15-11 and Table 15-6.

Also shown in Table 15-5 and Figure 15-10 are wiring costs for the arrays assuming each panel is made up of smaller modules. The two module sizes assumed are 16" x 24" and 16" x 48". The internal wiring system is assumed to be a quick connect system similar to the MQC system described. The purpose of this portion of the study was to estimate the added electrical costs associated with smaller modules.

Some general notes follow. These notes are intended to further clarify the study by explaining additional assumptions that were made.

1. Electrical specifications for panels used in this study are given in Figures 15-13 through 15-18.

2. Ampacity for cable and conductors is based on NEC Ampacity Table 310-16. Conductors were assumed rated for 60 degree C corrected by a 0.88 factor for an assumed operating temperature of 31 - 40 degrees C (86 - 104 degrees F). (See NEC Review, Article 310, Table 310-16.)

3. All array branch circuit conductors were bussed to a collection point located directly above the center line of each array configuration.

4. Where possible, it was attempted to match array configuration and load with conductor size so that each conductor was used most efficiently. This seemed particularly important with the MQC system.

5. ONE PARTICULARLY SENSITIVE ASSUMPTION WAS THAT USED FOR THE LABOR COSTS INVOLVED IN MANUFACTURING THE MQC ASSEMBLY. The figure used was arrived at through a series of assumptions based on wiring costs found in the 1978 Mechanical and Electrical Cost Data Book published by the Robert Snow Means Company of Duxbury, Massachusetts. These assumptions resulted in a #14 AWG, 5' assembly cost of $13.85. This cost was compared to the

$9.00 cost of a similar but simpler assembly manufactured by Wiremold for use in their ODS. Assuming the MDQ system to be more labor intensive, the $13.85 to $9.00 rate seems reasonable. However, to show the significance of this assumption, several MQC system costs for 16' x 67' arrays using 48" x 48" panels were calculated using a $9.00 MQC assembly. THE RESULTS: 220 - MOD. - DRY DROPPED FROM $821 to $566; and 100 - MOD - DRY DROPPED FROM $846 to $608. ALTHOUGH THE FINAL TABLULATIONS, AS ORIGINALLY ASSUMED, SHOW THE MQC SYSTEM TO BE LESS EXPENSIVE THAN THE J-BOX SYSTEM, THIS DIFFERENCE MAY BE UNDERSTATED.

6. Labor costs used for installation of the J Box can be considered more accurate than those used for the MQC System. Both Means and the 1978 Building Cost File book compiled by McKee-Berger-Mansueto Inc. list installation of outlet boxes at approximately $20/box. (This figure is slightly higher than that used in this study for total box, including box, fittings and wiring, installation cost.) J-Box prices used in Means and Building Cost File are deduced from actual building construction cost experience and are therefore assumed to be accurate.

7. Unit labor costs for wiring with #14 - #12 AWG are taken from Means 1978. This number is deduced from the difference in total labor costs for wiring a 15 amp three-way toggle switch ($4.77) and a 15 amp single-pole switch ($2.74). The difference in labor is the wiring of one conductor. The difference in cost is roughly two dollars. Assuming the use of wire nuts rather than a screw pressure connector, the cost per conductor was estimated to decrease from $2.00 to $1.50.

   Furthermore, the labor cost for wiring of #12 AWG was assumed equal to that for #14 AWG, for the J-Box method. It was assumed, from the outset, that labor and material costs increase as wire size increases. However, it seems logical to assume that at some point labor costs for smaller size wires begin to equal and then exceed the labor costs of larger wires because of the increased difficulty in working with the smaller wires. Therefore, it was assumed that the labor involved in wiring #14 AWG and #12 AWG were equal. This assumption becomes fairly significant in determining the slope of the voltage level vs. cost curve. As the J-Box wiring study developed, typically, #14 AWG was used for the 220 Volt-dc systems where #12 AWG was used for the 100 Volt-dc system. Since there essentially was no difference in labor cost (material cost for wiring is different) this tended to decrease the total cost difference between 220 and 100 volt dc wiring systems. To indicate the magnitude of these differences, a $1.25 labor cost for #14 AWG rather than the $1.50 would decrease the 200 volt total of $610 in the 16 x 67' array, 32 x 96 inch module, J-Box wiring method, dry application by $31 to $579. (The wet would decrease from $1,259 to $1,228.) A similar $1.25 cost for #14 AWG in the 16 x 68 array, 48 x 48 inch module, J-Box, dry would decrease the $940 by $42 to $898. (The wet decreases by $42 to $1,653.) With these decreases in total cost the negative slope of the voltage level vs. cost curve would remain approximately constant rather than tending toward zero.

CONCLUSIONS

1. Array branch circuit wiring costs increase greatly as module size is reduced. This is illustrated by Figure 15-10.

2. Electrical wiring costs do not vary significantly with array configuration.

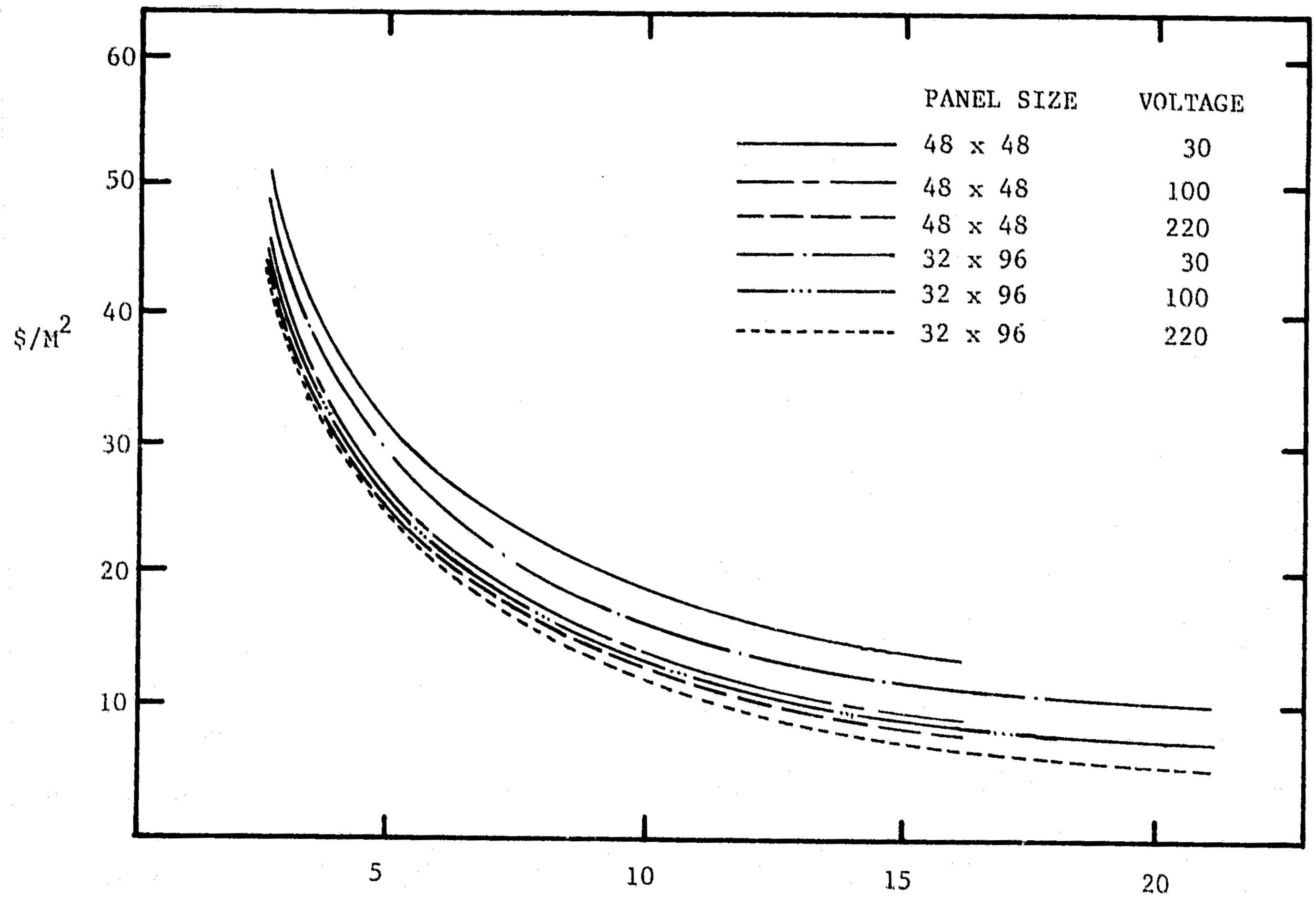
3. Terminal costs are the principle drivers for total wiring costs. Total conductor or cable cost (i.e., materials and labor) ranges from 7% (at 220 V-dc) to 40% (at 30 V-dc) of the total electrical branch circuit wiring costs.

4. A modular quick connect system (as defined in this study) can be significantly less expensive than a J-Box system particularly when the array wiring is exposed to the weather as with a rack or standoff mounting type. However, this cost difference, as shown in Figures 15-11 and 15-12 may be understated. (See general notes number five.)

5. Electrical wiring costs are inversely proportional to array branch circuit voltage level. This relationship is shown in Figures 15-12 and 15-13. From these figures it can be seen that there is very little to no differ-

ence between the 100 and 220 volt dc systems array branch circuit costs. This is due primarily to equal labor cost assumptions for #12 and #14 AWG conductors (see general notes number seven) and secondarily to the #14 AWG minimum conductor size limitation that inhibited using a more efficient wiring diagram with smaller conductors. (This #14 AWG minimum conductor size limitation proved less significant than originally anticipated because of the dominance of the terminal cost. This is especially true of the MQC system where the quick connect terminal used had a capacity range from #18 AWG to #14 AWG in which case the use of #18 AWG rather than #14 AWG nonmetallic sheathed cable would have made very little difference in total cost.)

PANEL/MODULE SIZES		VOLTAGE COSTS, 1975 $/M^2$		
PANEL	MODULE	30 Vdc	100 Vdc	220 Vdc
48 x 48	48 x 48	14.00	8.38	8.12
	16 x 48	28.98	23.35	23.10
	16 x 24	51.44	45.82	45.58
32 x 96	32 x 96	10.42	6.34	5.90
	16 x 48	27.35	23.27	22.83
	16 x 24	48.95	45.71	45.28



MODULE AREA Ft^2

ELECTRICAL WIRING COSTS

16 x 67' and 16 x 68' Arrays
Modular Wiring Method
Dry Location

FIGURE 15-10

Table 15-6 Wiring Costs for 32 by 96 Inch Panel/Modules

Condition/ Termination	WIRING COSTS, 1975 $/m^2								
	8 x 133 (99.1 m^2) Array			16 x 67 (99.1 m^2) Array			24 x 45 (101.1 m^2) Array		
	30 Vdc	100 Vdc	220 Vdc	30 Vdc	100 Vdc	220 Vdc	30 Vdc	100 Vdc	220 Vdc
DRY Modular	11.90	6.70	6.10	10.40	6.30	5.90	9.60	6.10	6.00
J-Box	11.40	6.70	6.30	9.90	6.90	6.20	10.00	6.60	6.40
WET Modular	12.40	7.20	6.60	10.90	6.70	6.40	9.90	6.60	6.40
J-Box	17.40	13.20	12.80	16.40	13.40	12.70	16.70	13.10	12.90

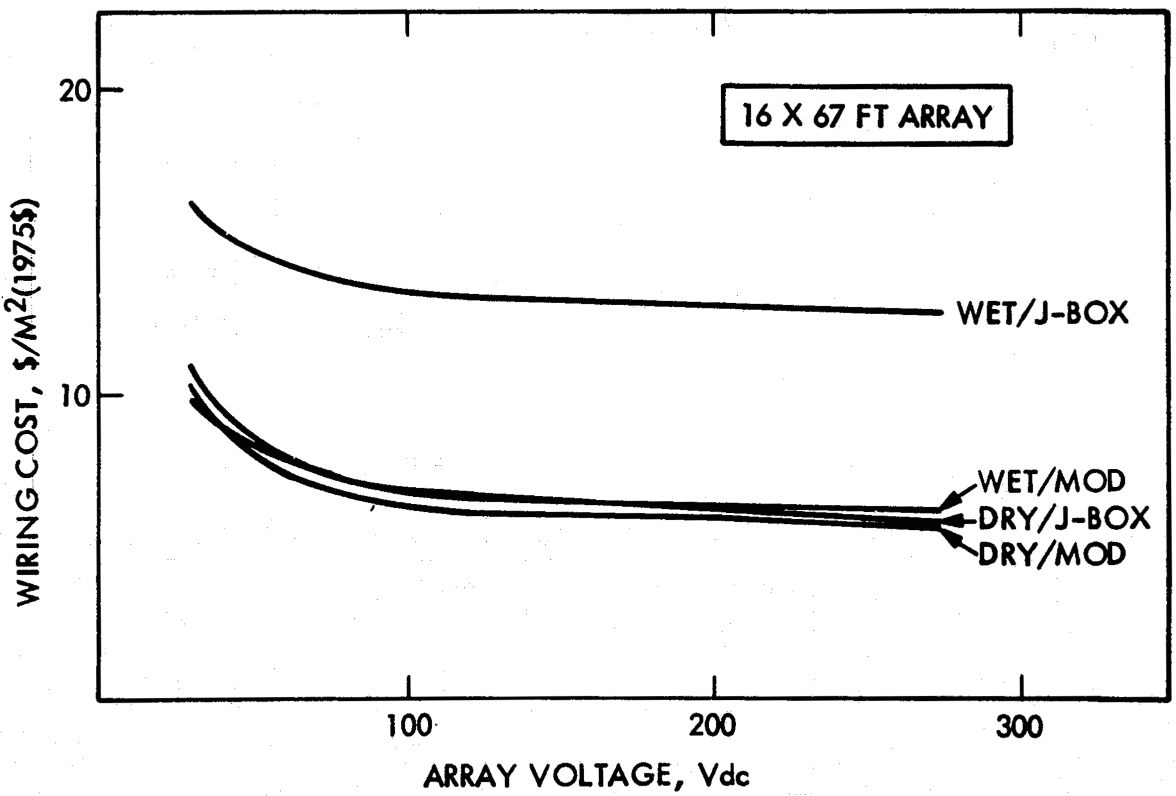


Figure 15-11 Wiring Costs Versus Array Voltage for 32 by 96 Inch Panel/Modules in 16 by 67 Foot Array

Table 15-7 Wiring Costs for 48 by 48 Inch Panel/Modules

Condition/ Termination	WIRING COSTS, 1975 $\$/m^2$								
	8 x 132 (98.1 m^2) Array			16 x 68 (101.1 m^2) Array			24 x 44 (98.1 m^2) Array		
	30 Vdc	100 Vdc	220 Vdc	30 Vdc	100 Vdc	220 Vdc	30 Vdc	100 Vdc	220 vdc
DRY Modular	15.27	8.83	8.27	14.00	8.37	8.12	13.94	8.24	7.62
J-Box	14.95	9.58	9.43	13.00	9.30	9.30	12.94	9.10	8.86
WET Modular	16.21	9.52	8.49	14.83	9.00	8.75	14.78	8.86	8.76
J-Box	24.27	17.65	16.94	21.13	17.29	16.77	21.39	16.79	16.44

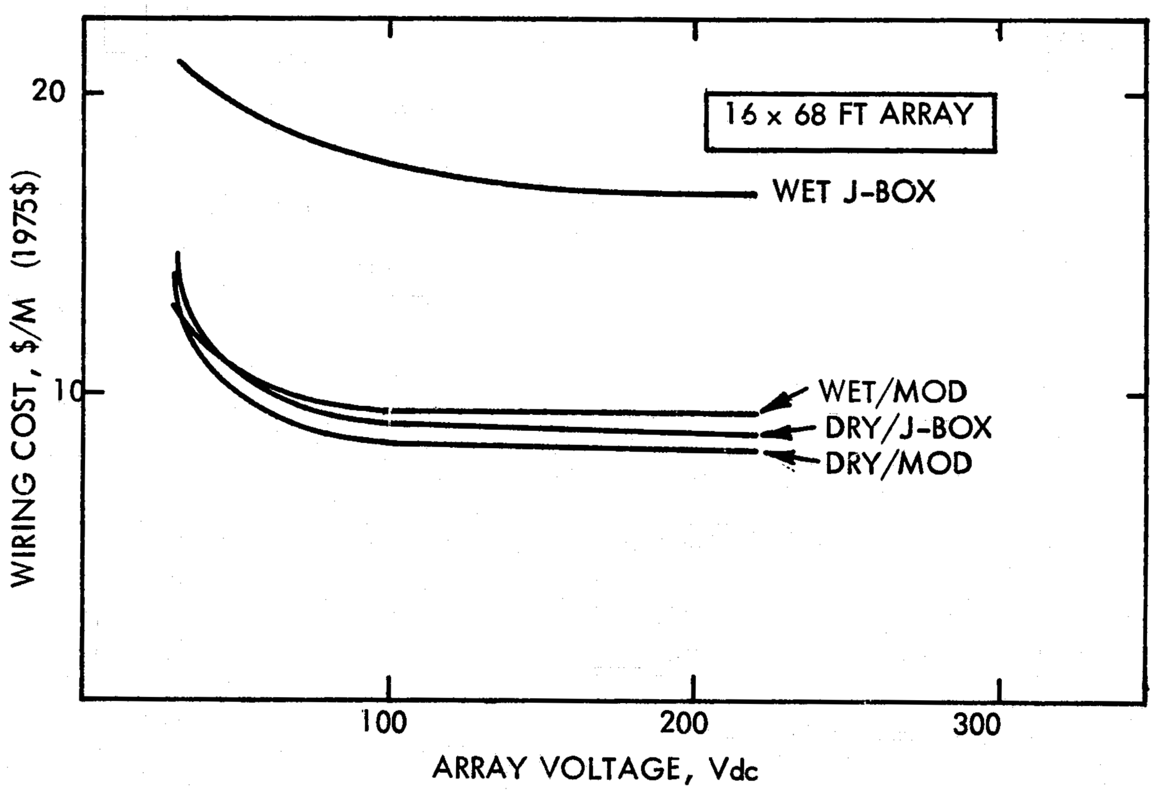


Figure 15-12 Wiring Costs Versus Array Voltage for 48 by 48 Inch Panel/Modules in 16 by 68 Foot Array

TABLE 15-8 LABOR COSTS - UNIT PRICES

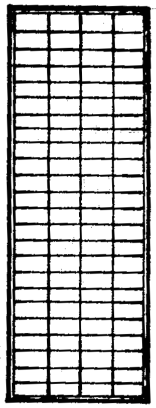
TASK	COST 1978 DOLLARS	SOURCES/COMMENTS
Install Box, dry	$ 7.60	78 Means: box; $5.50, p.228, line 20. cover; $2.07, p.228, line 45.
Install Box, wet	9.15	78 Means: box and cover; p.228, line 165
Install Cable	Varies	78 Means: See Wiring Study for various costs
Install Fittings, dry	0	Plastic boxes used with NM only require stapling within 6" of box
Install Fittings, wet	2.78	78 Means: assumed equal to plastic bushing cost p.208, line 113
Wiring with #14 - #12 AWG conductors	1.50	78 Means: deduced from p.228, lines 40 and 60
Wiring with #10 AWG conductors	2.80	78 Means: deduced from p.228, lines 220, 230, 240, 250; assumes $1.30/wire size greater than #12 AWG.
Site Connection of #14-12 AWG conductors to quick connect terminal	7.50	#14 - 12 AWG: 3 @ $2.50/conductor = $7.50/terminal; assumes labor involved for stripping conductor, crimping contact to conductor, and insertion into quick connect terminal housing to be approximately twice that of the required for wire nut attachment in a J-Box. (Wire nut = $1.30/conductor.)
Site Connection of #10 AWG	11.40	#10 AWG: 3@ (@.50 + 1.30)/conductor = $11.40
MQC Assembly attachment #14	.50	Estimate: $0.50/13.70 x 60 min/hr = 2 min/assembly
MQC Assembly attachment #10	.66	Estimate: .50 x 61/46; ration based on the difference in cost of wiring #14 and #10 NM Cable
48 x 48 Internal Wiring of 3 - 16" x 48" Modules	22.50	Estimate: assumes a quick connect assembly; 9 conductors/assembly x 1.25/conductor = $11.25 2 assembly/panel x $11.25/assembly = $22.50/panel
32 x 96 Internal Wiring of 4 - 16" x 48" modules	33.75	Estimate: $11.25/assembly x 3/panel = $33.75
48 x 48 Internal Wiring of 6 - 16" x 24" modules	56.25	Estimate $11.25/assembly x 5/ panel = $56.25
32" x 96" Internal Wiring of 8 - 16" x 24" modules	78.75	Estimate: $11.25/assembly x 7/panel - $78.75

TABLE 15-9 MATERIAL COST - UNIT PRICES

Material	Cost 1978 Dollars	Source/Comment
Box dry (20 cu. in.)	$ .36	Distributers quote (D.Q.)
Box wet	4.08	D.Q.
Cable	Varies	78 Means, see wiring study for various costs
Fittings, dry	0	Plastic boxes used with NM require stapling within 6" of box
Fittings, wet	.75	D.Q. for use with NM/UF, uses "O" ring seal
Wiring Nut dry and wet	.03	D.Q. for #10 - #12 AWG rated (varies insignificantly with wire size)
5'-Assembly- #14 AWG, dry	13.85	#14 NM 5' x $.12/ft. = .60 Terminals #14 - 18 AWG, 2 @ $1.00/ mated pair = $2.00 Labor (factory) $1.25/conductor x 9 = $11.25
5'-Assembly- #14 AWG, wet	15.00	#14 UF 5' x $.15/ft. = $.75 Terminals #14 - 18 AWG, 2 @ $1.50/ mated pair = $3.00 Labor (factory) $1.25/conductor x 9 = $11.25; assumes labor rate to be one/half of the $13.70/hour 1978 electricians rate. See site connection labor cost.
48" x 48" Internal Wiring for (3) 16" x 48" modules - dry	4.24/Panel	Wiring: ($0.02/conductor ft. x 2 ft.) x (3 conductors) = $0.12 Terminals: 2 @ $1.00 = $2.00 Total: $2.12/assembly x 2 assemblies/panel = $4.24
48" x 48" Internal Wiring for (3) 16" x 48" modules - wet	6.36/Panel	Wiring: ($0.03/conductor ft. x 2 ft.) x (3 conductors) = $0.18 Terminals: 2 @ $1.50 = $3.00 Total: $3.18/assembly x 2 assemblies/panel = $6.36
48" x 48" Internal Wiring for (6) 16" x 24" modules - dry	10.60/Panel	Wiring: ($0.02/conductor ft. x 2 ft.) x (3 conductors) = $0.12 Terminals: 2 @ $1.00 = $2.00 Total: $2.12/assembly x 5 assemblies/panel = $10.60
48" x 48" Internal Wiring for (6) 16" x 24" modules - wet	15.90/Panel	Wiring: ($0.03/conductor ft. x 2 ft.) x (3 conductors) = $0.18 Terminals: 2 @ $1.50 = $3.00 Total: $2.12/assembly x 5 assemblies/panel = $15.90

TABLE 15-9 (Cont.) MATERIAL COST - UNIT PRICES

Material	Cost 1978 Dollars	Source/Comment
32" x 96" Internal Wiring for (4) 16" x 48" modules - dry	6.55/Panel	Wiring: ($0.02/conductor ft.) x (4 ft. + 5 ft.) x (3 conductors) = $0.54 Terminals: 6 @ $1.00 = $6.00 Total: $0.54 + $6.00 = $6.54
32" x 96" Internal Wiring for (4) 16" x 48" modules - wet	9.81/Panel	Wiring: ($0.03/conductor ft.) x (4 ft. + 5 ft.) x (3 conductors) = $0.81 Terminals: 6 @ $1.50 = $9.00 Total: $0.81 + $9.00 = $9.81
32" x 96" Internal Wiring for (8) 16" x 24" modules - dry	14.93/Panel	Wiring: ($0.02/conductor ft.) x (7.5 ft. + 8 ft.) x (3 conductors) = $0.93 Terminals: 14 @ $1.00 = $14.00 Total: $0.93 + $14.00 = $14.93
32" x 96" Internal Wiring for (8) 16" x 24" modules - wet	22.40/Panel	Wiring: ($0.03/conductor ft.) x (7.5 ft. + 8 ft.) x (3 conductors) = $1.40 Terminals: 14 @ $1.50 + $21.00 Total: $1.40 + $21.00 = $22.40



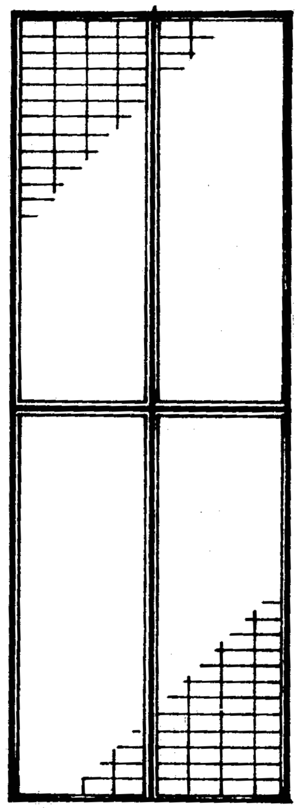
MODULES

16" x 48"

62.1 Volts Peak

57.4 Volts Nominal

1.07 Amps



PANEL

32" x 96"

4-16" x 48" Modules Series

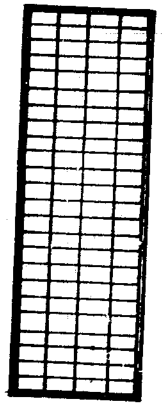
248.4 Volts Peak

213.6 Volts Nominal

1.07 Amps

32" x 96" ARRAY OUTPUT 220 VOLTS

FIGURE 15-13



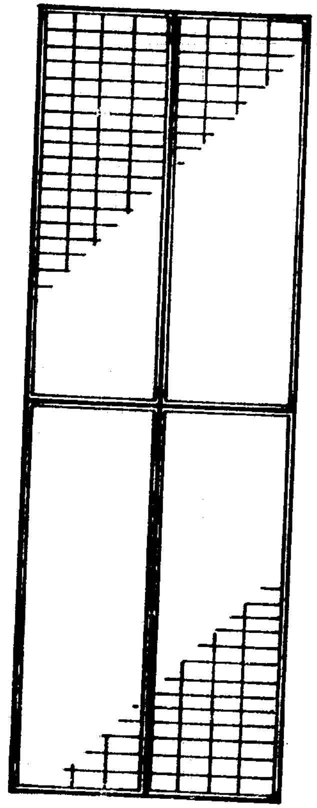
MODULE

16" x 48"

62.1 Volts Peak

53.4 Volts Nominal

1.07 Amps



PANEL

32" x 96"

4-16" x 48" Modules

2 Parallel
2 Series

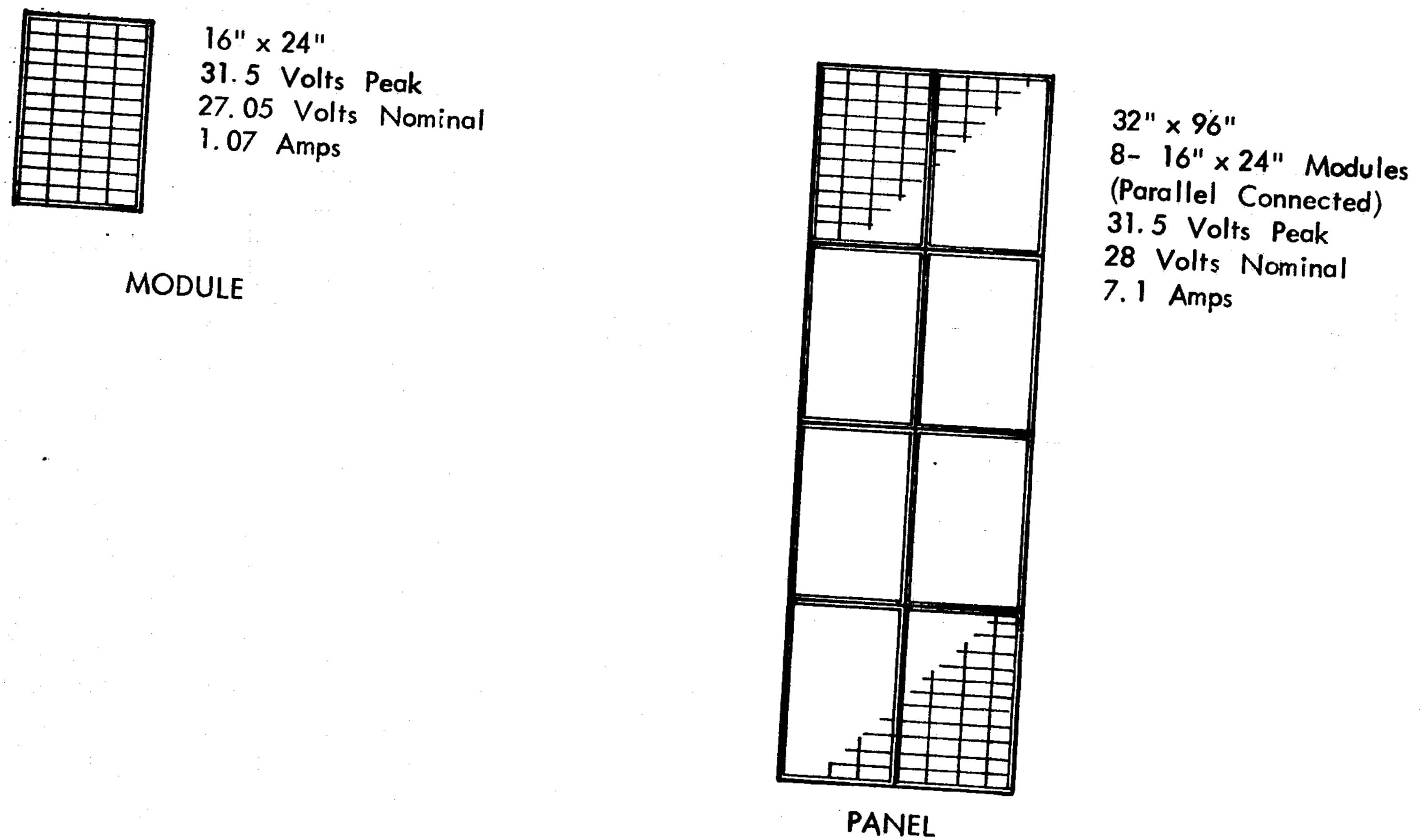
124.2 Volts Peak

106.8 Volts Nominal

2.14 Amps

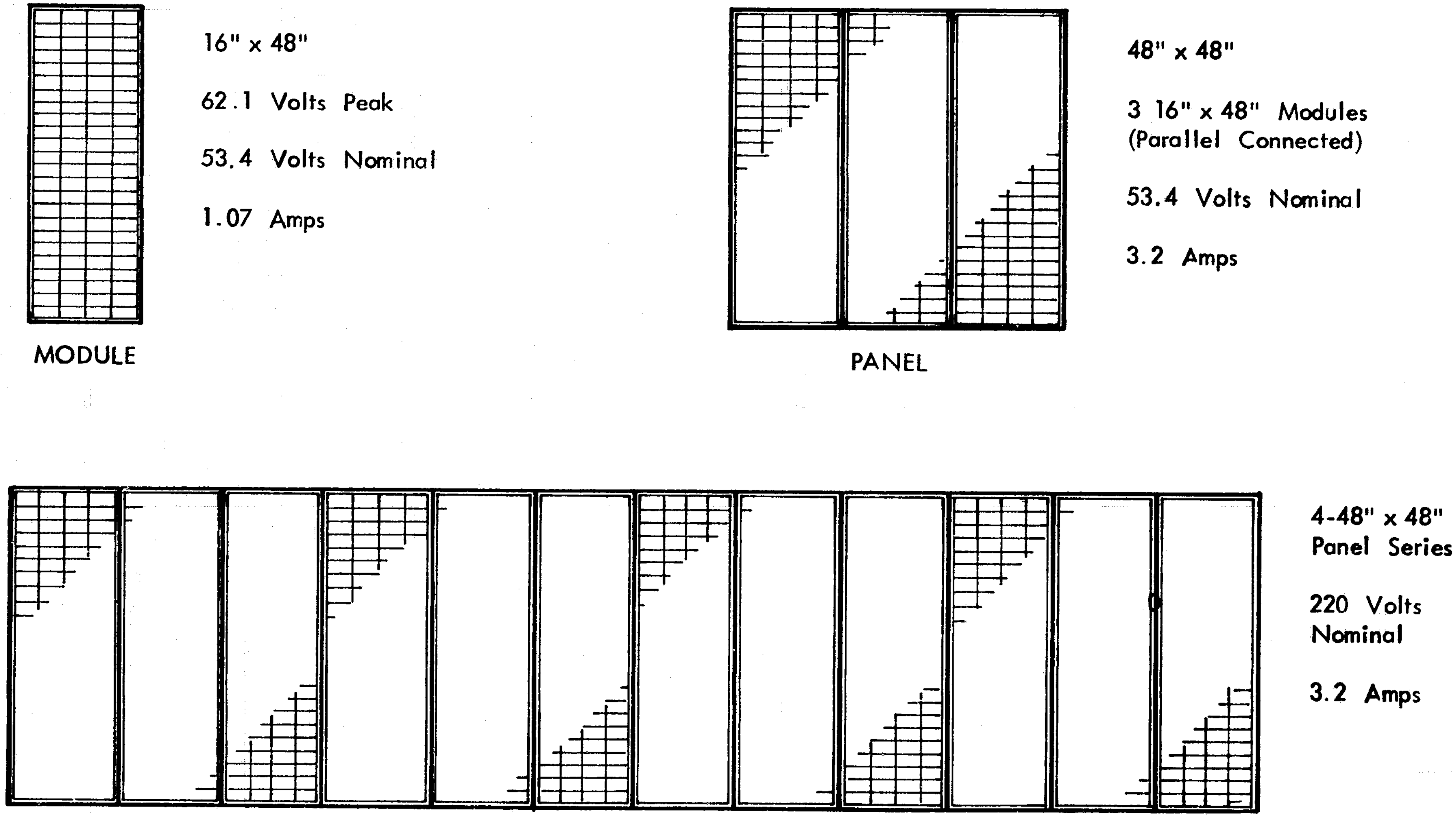
32" x 96" ARRAY OUTPUT 100 VOLTS

FIGURE 15-14



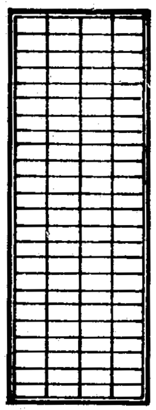
32" x 96" ARRAY OUTPUT 30 VOLTS

FIGURE 15-15



48" x 48" ARRAY OUTPUT 220 VOLTS

FIGURE 15-16



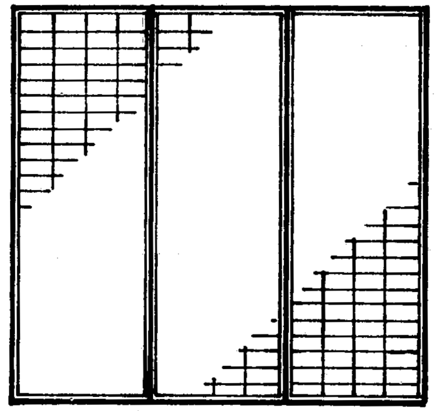
16" x 48"

62.1 Volts Peak

53.4 Volts Nominal

1.07 Amps

MODULE



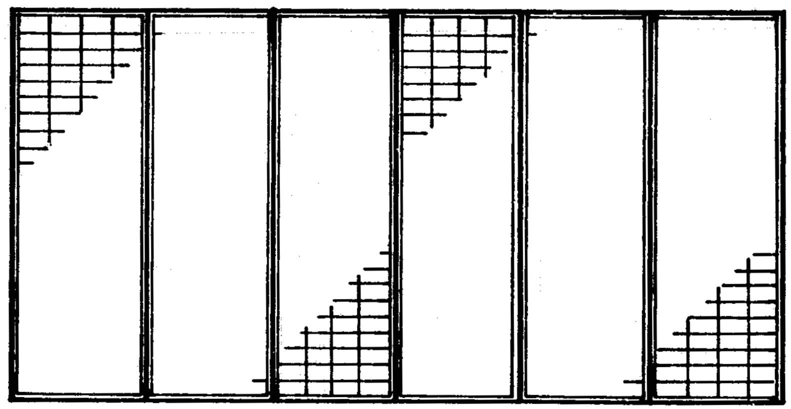
48" x 48"

3-16" x 48" Modules
(Parallel Connected)

53.4 Volts Nominal

3.2 Amps

PANEL



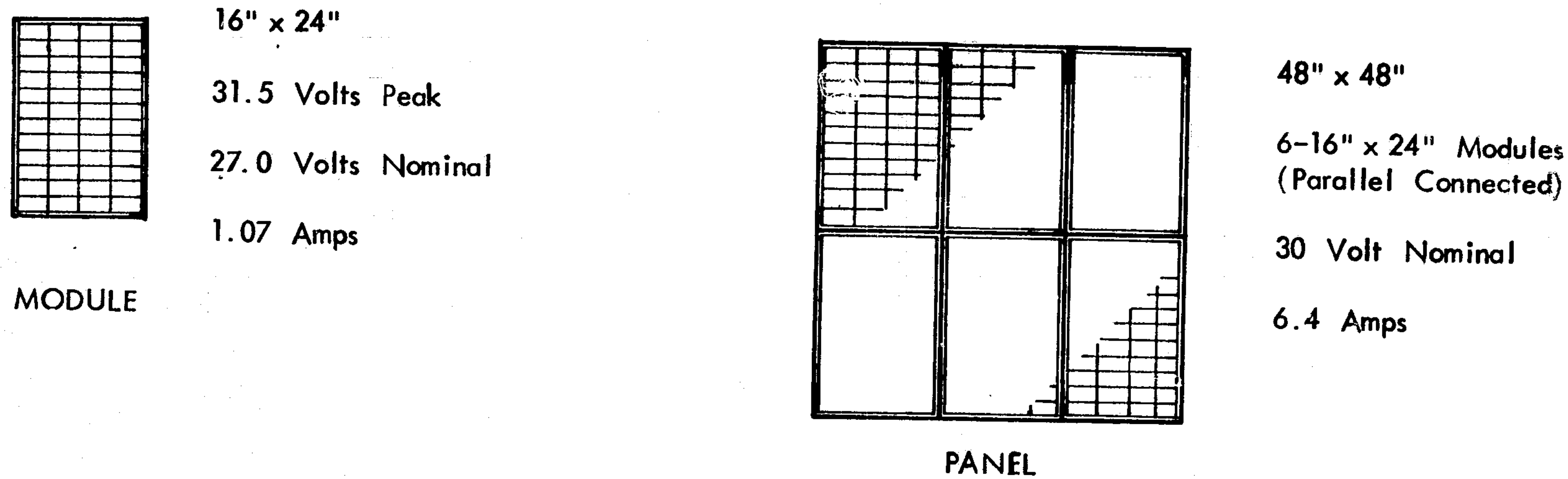
2-48" x 48" Panels Series

110 Volts Nominal

3.2 Amps

48" x 48" ARRAY OUTPUT 100 VOLTS

FIGURE 15-17



48" x 48" ARRAY OUTPUT 30 VOLTS

FIGURE 15-18

APPENDIX 16. ARRAY INSTALLATION COST SUMMARY

PURPOSE: A summary of installation costs has been made and cost drivers identified.

CONCLUSIONS: All costs generated are extremely sensitive to module design and edge detailing. Therefore, these values are only appropriate for the given edge detailing. Integrally mounted PV modules are the least expensive with regard to overall installation costs with the 32 x 96 inch being less expensive than the 48 x 48 inch panel. With typical roof cost credits given for integrally mounted arrays, installation costs are less than those for direct mounted arrays. The least desirable installation mounting type, from a cost standpoint, is the rack mounted.

RECOMMENDATIONS: Cost evaluation of all module designs must be undertaken to ensure reasonably accurate installation cost projections. Module size should be optimized to ensure minimal materials and wiring costs.

COST SUMMARY

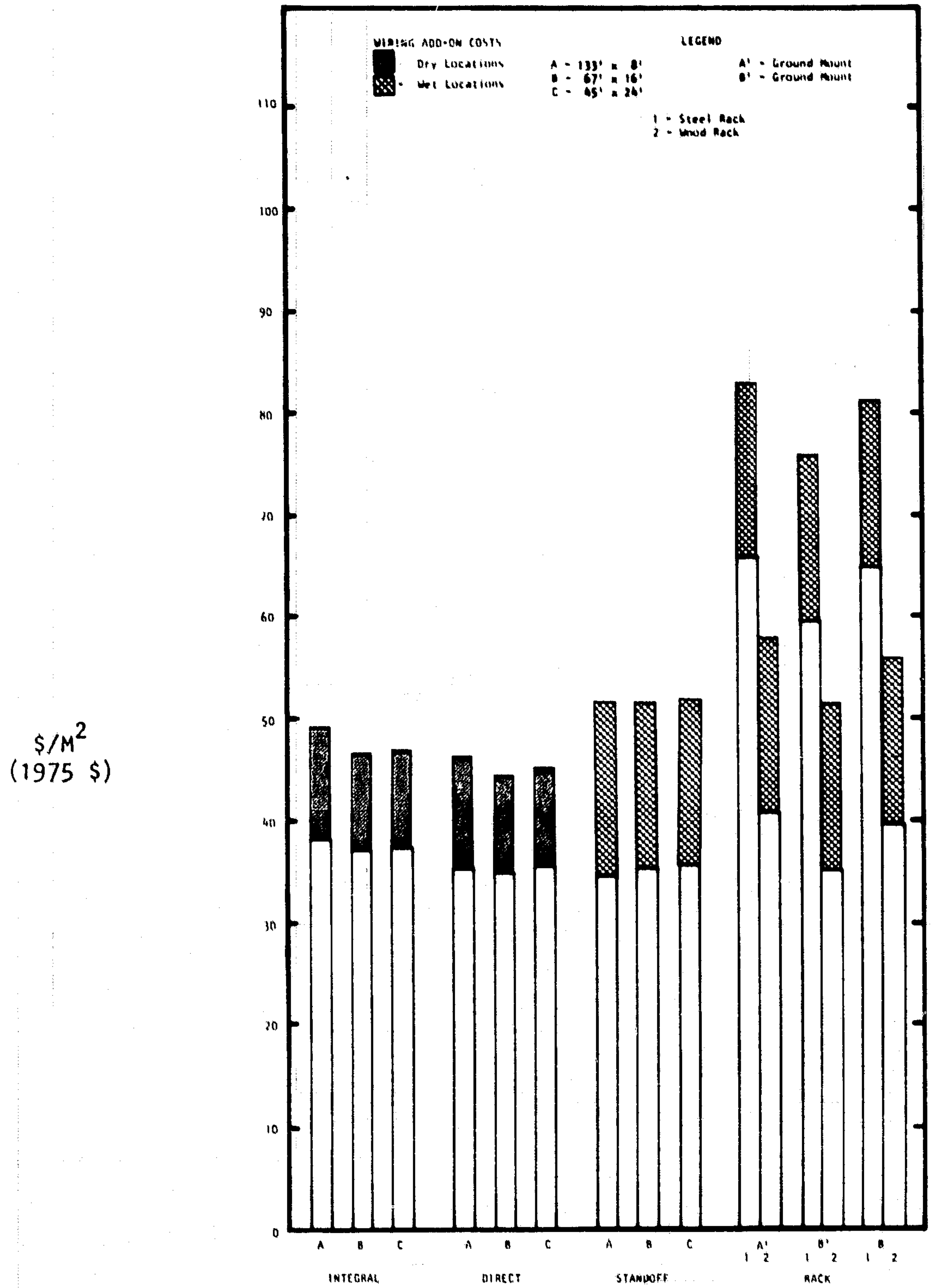
Having previously examined the material and labor costs for installation and wiring, a summary of total installation costs is presented. Three sets of figures follow showing total installation costs.

Figures 16-1 through 16-8 address installation costs with respect to voltage array output and wiring type. As previously seen in the Wiring Study, Appendix 15, voltages under 100 Vdc are not economically advantageous from a wiring cost standpoint. It should also be noted, that the array shape has little influence on the overall installation costs. Roofing credits associated with direct and integral panel installation are not shown, but values for such credits are found in Table 16-1.

Tables 16-2 and 16-3 are array mounting configuration installation cost summaries for the 32x96 panel/module and the 48"x48" panel/module respectively. These tables show cost breakdowns for the major components associated with the four mounting types or array installations. Also included are credits associated with replaced materials and a total installed cost in both 1975 dollars and 1980 dollars.

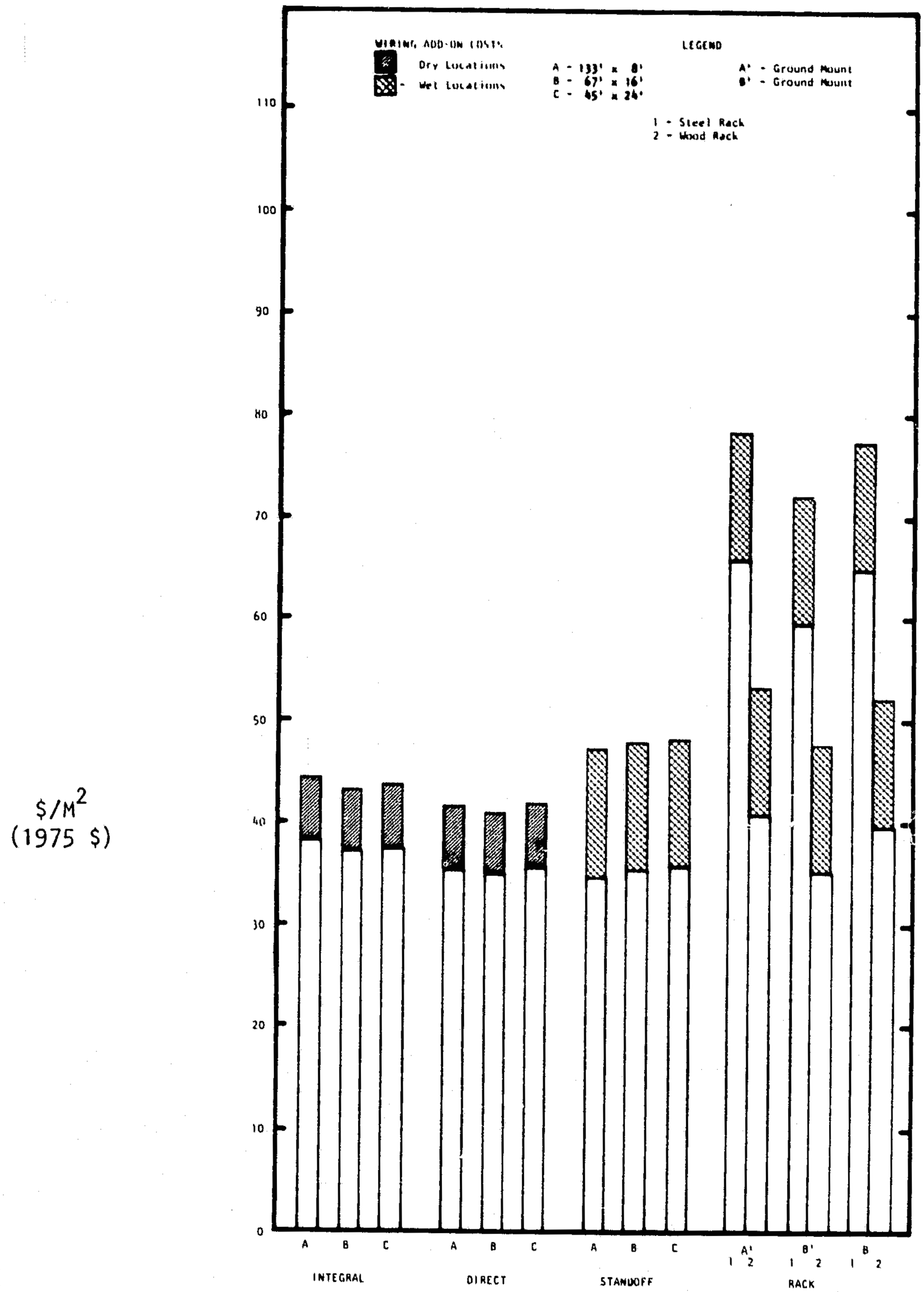
The final set of figures, Figures 16-10 through 16-16 attempt to identify cost drivers. Examination of these figures shows the major cost driver is the wiring when modules are less than 10 square feet in area. When a module area is greater than 10 square feet, the aluminum framing becomes a critical cost driver. Note that the associated roofing credits as given in Table 16-1 can be used to determine the final installation costs for integral and direct mounted panels.

It is important to note that these cost figures were obtained by first generating a detail for each particular mounting type; therefore, these costs are very detail specific. This indicates the need for cost analysis on all module designs. With this in mind, caution should be used when referencing these figures and this appendix.



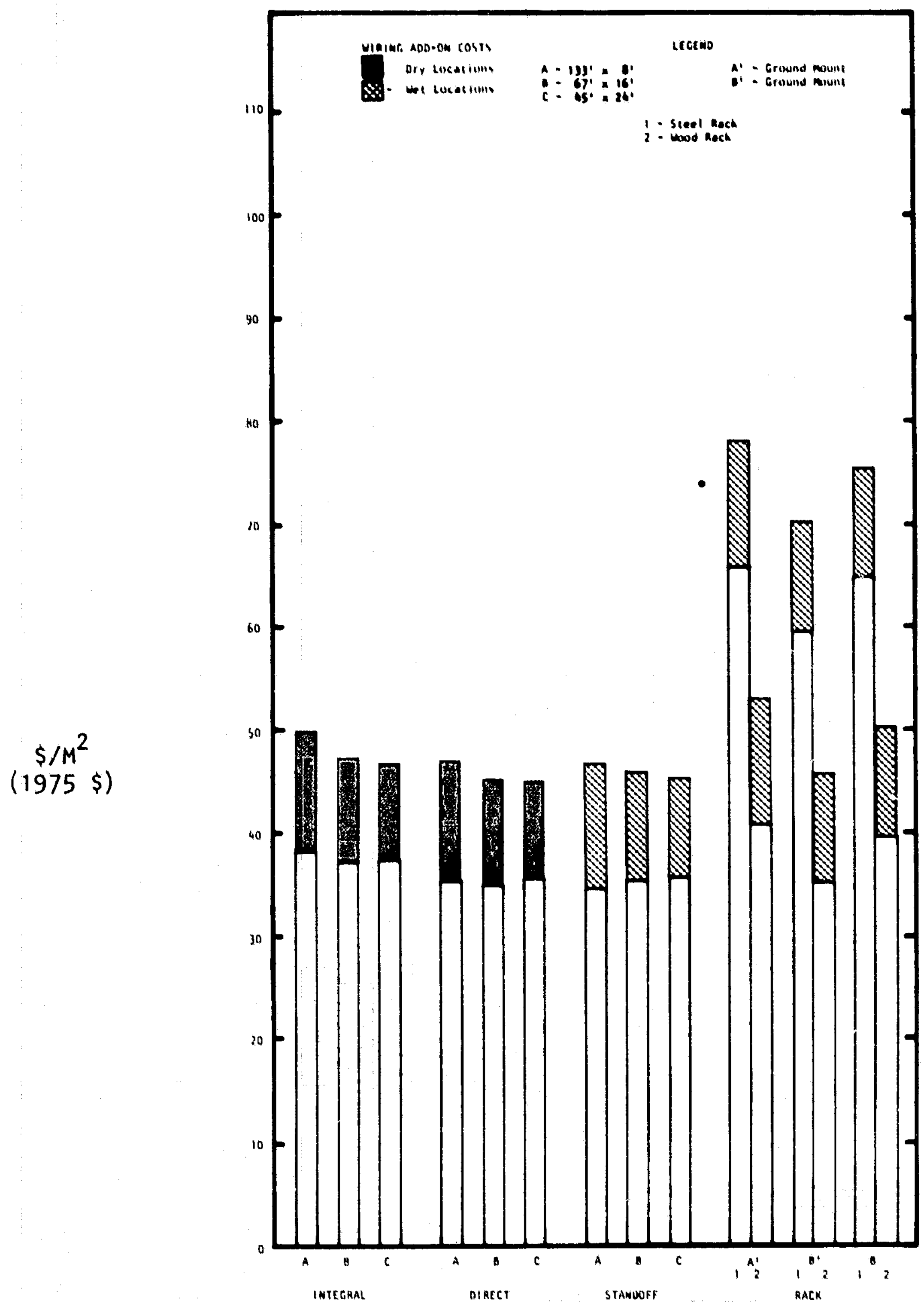
EFFECT OF J-BOX WIRING COSTS ON TOTAL INSTALLED COST
32"x96" PANEL/MODULE, 30 VOLTS ARRAY OUTPUT

FIGURE 16-1



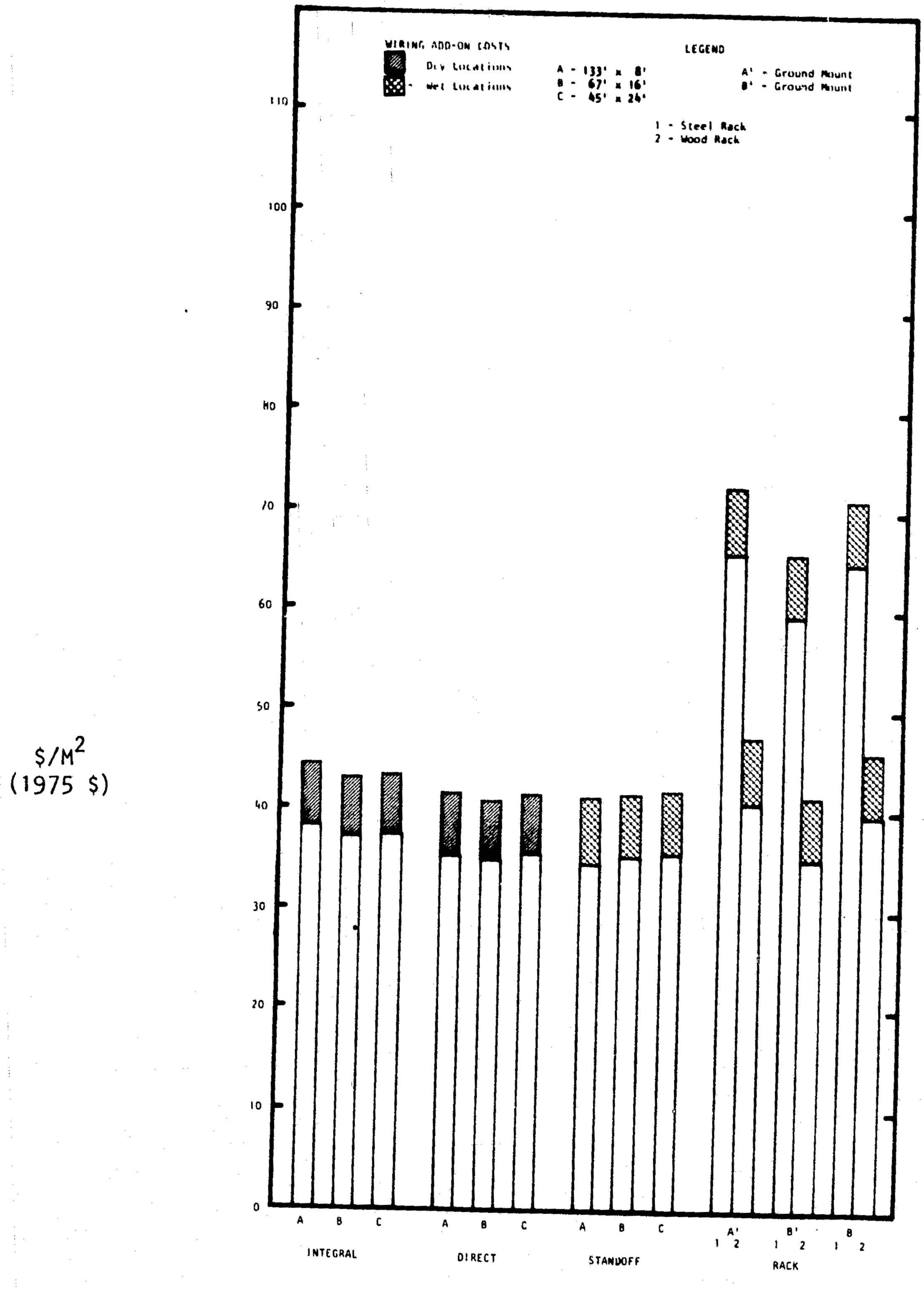
EFFECT OF J-BOX WIRING COSTS ON TOTAL INSTALLED COST
32''x96'' PANEL/MODULE, 220 VOLTS ARRAY OUTPUT

FIGURE 16-2



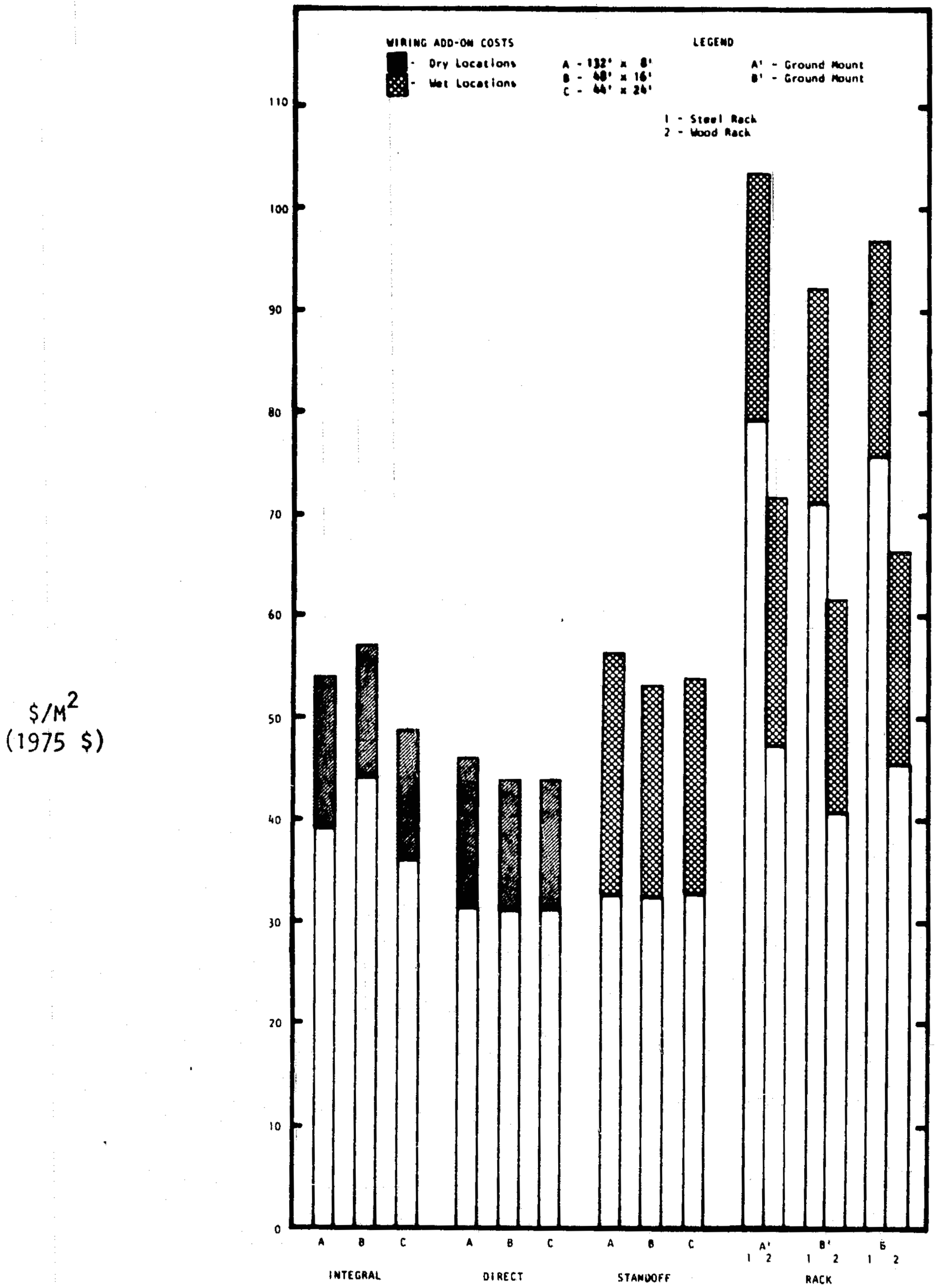
EFFECT OF MODULAR WIRING COST ON TOTAL INSTALLED COST
32"x96" PANEL/MODULE, 30 VOLTS ARRAY OUTPUT

FIGURE 16-3



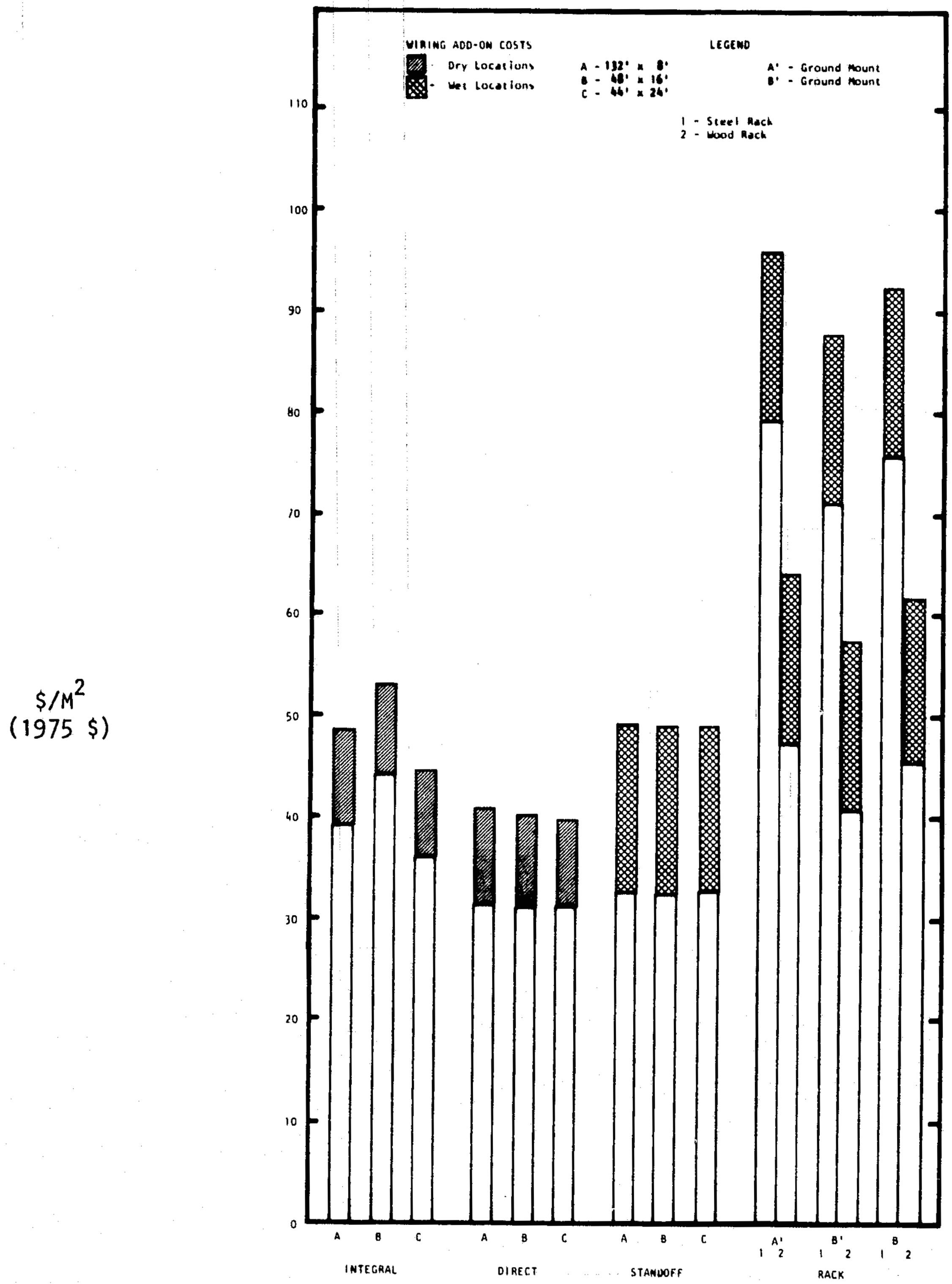
EFFECT OF MODULAR WIRING COST ON TOTAL INSTALLED COST
32''x96'' PANEL/MODULE, 220 VOLTS ARRAY OUTPUT

FIGURE 16-4



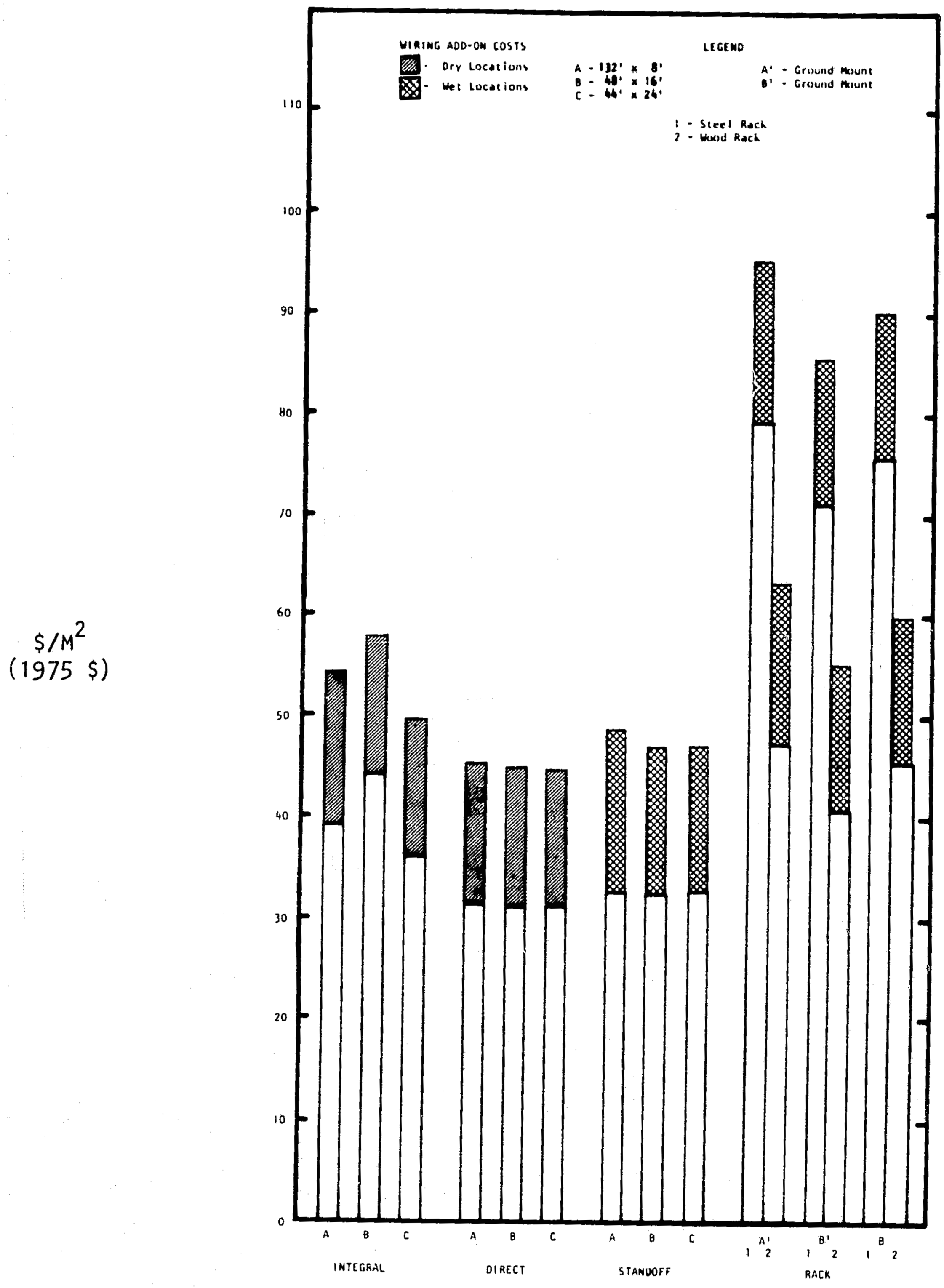
EFFECT OF J-BOX WIRING COST ON TOTAL INSTALLED COST
48"x48" PANEL/MODULE, 30 VOLTS ARRAY OUTPUT

FIGURE 16-5



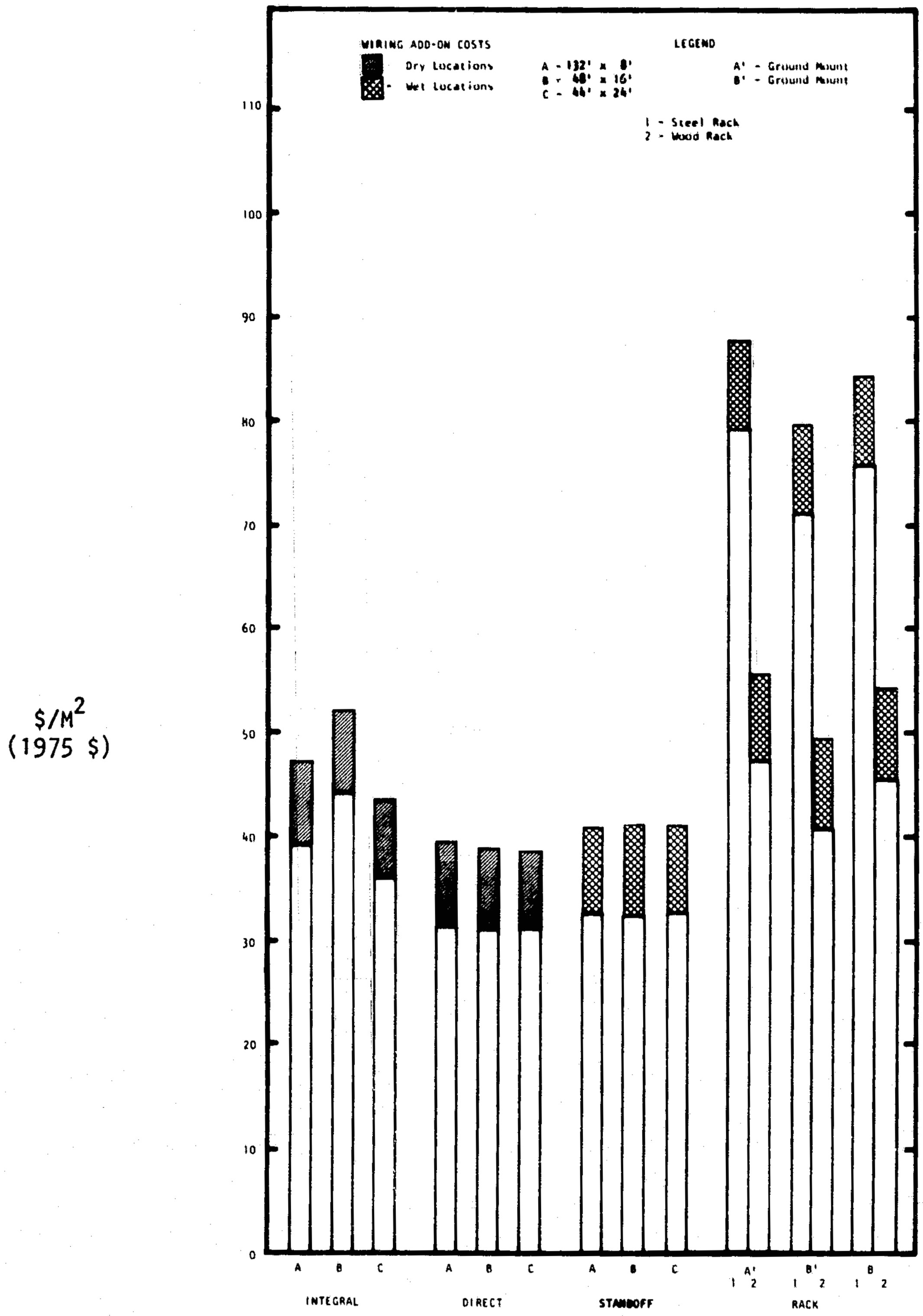
EFFECT OF J-BOX WIRING COST ON TOTAL INSTALLED COST
48"x48" PANEL/MODULE, 220 VOLTS ARRAY OUTPUT

FIGURE 16-6



EFFECT OF MODULAR WIRING COST ON TOTAL INSTALLED COST
48"x48" PANEL/MODULE, 30 VOLTS ARRAY OUTPUT

FIGURE 16-7



EFFECT OF MODULAR WIRING COST IN TOTAL INSTALLED COST
48"x48" PANEL/MODULE, 220 VOLTS ARRAY OUTPUT

FIGURE 16-8

TABLE 16-1

ROOF CREDITS	
Material	$\$M^2$ (1975 \$)
1/2" Plywood	5.97
15# Felt	0.65
240# Asphalt Shingles	5.06
325# Asphalt Shingles	10.44
540# Asphalt Shingles	21.53
Spanish Tile	18.84
Mission Tile	32.29
Concrete Tile	19.38
Slate	22.60
18" Red Cedar Shakes	13.99
w/Fire Retardant	17.55

Table 16-2 Array Mounting Configuration Installation Cost Summary for 32 by 96 Inch Panel/Modules

COST COMPONENT	ARRAY INSTALLATION COSTS, 1975 $/m²				
	INTEGRAL	DIRECT	STANDOFF	RACK	
				ROOF	GROUND
• Wiring[1]	5.90	5.90	6.40	6.40	6.40
• Panel/Module Support Frame	5.80	10.40	14.20	12.80	12.80
• Panel/Module Installation	19.60	19.20	6.70	6.70	6.70
• Mounting Gaskets	9.40	4.80	8.90	-	-
• Sealant	-	0.70	-	3.20	3.20
• Roof Bracing	1.70	-	-	-	-
• Flashing	-	-	5.40	5.30	-
• Rack Structure[2]	-	-	-	11.90	12.30
• Fence[3]	-	-	-	-	17.00
Installation Cost	42.40	41.00	41.60	46.30	58.40
Roofing Credit[4]	17.10	10.40	-	-	-
Total Installed Cost 1975 $/m²	25.30	30.60	41.60	46.30	58.40
(1980 $/m²)	(35.50)	(42.90)	(58.30)	(64.90)	(81.80)

NOTES:

1. 220 Vdc
2. Wood structure. Includes concrete footings for ground-mounted rack arrays.
3. Needed for safety.
4. Credit for normal roofing materials displaced by the photovoltaic array. For integral mounting, it includes the cost of ½ inch plywood, 15# felt paper, and 325# asphalt shingles. For direct mounting, it is the cost of 325# asphalt shingles.

TABLE 16-3

COST COMPONENT	ARRAY INSTALLATION COSTS, 1975 $/m^2$				
	INTEGRAL	DIRECT	STANDOFF	RACK	
				ROOF	GROUND
Wiring[1]	7.60	7.60	8.80	8.80	8.80
Panel/Module Support Frame	6.60	7.50	12.90	17.60	17.60
Panel/Module Installation	19.20	19.20	6.70	6.70	6.70
Mounting Gaskets	10.30	3.50	5.90	---	---
Sealant	---	1.10	1.90	3.90	3.90
Roof Bracing	1.70	---	---	---	---
Flashing	---	---	5.40	5.30	---
Rack Structure[2]	---	---	---	11.90	12.30
Fence[3]	---	---	---	---	17.00
Installation Cost	45.40	38.90	41.60	54.20	65.90
Roofing Credit[4]	17.10	10.40	---	---	---
Total Installed Cost 1975 $/m^2$	28.30	28.50	41.60	54.20	65.90
(1980 $/m^2$)	(39.70)	(40.00)	(58.30)	(75.90)	(92.30)

NOTES:

1. 220 Vdc
2. Wood structure. Includes concrete footings for ground-mounted rack arrays.
3. Needed for safety.
4. Credit for normal roofing materials displaced by the photovoltaic array. For integral mounting, it includes the cost of ½ inch plywood, 15# felt paper, and 325# asphalt shingles. For direct mounting, it is the cost of 325# asphalt shingles.

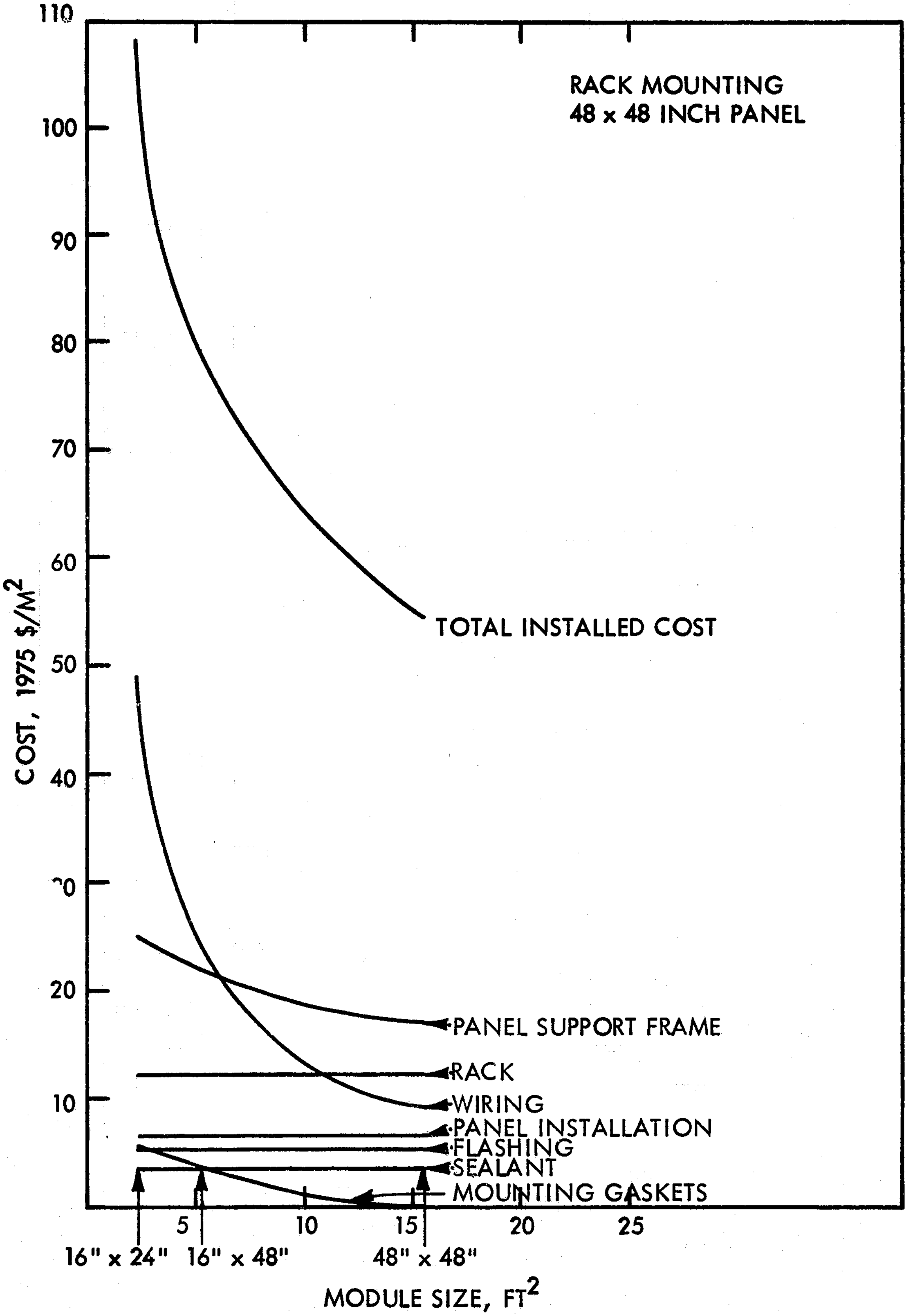


Figure 16-9 Rack Mounting - Array Costs Versus Module Size

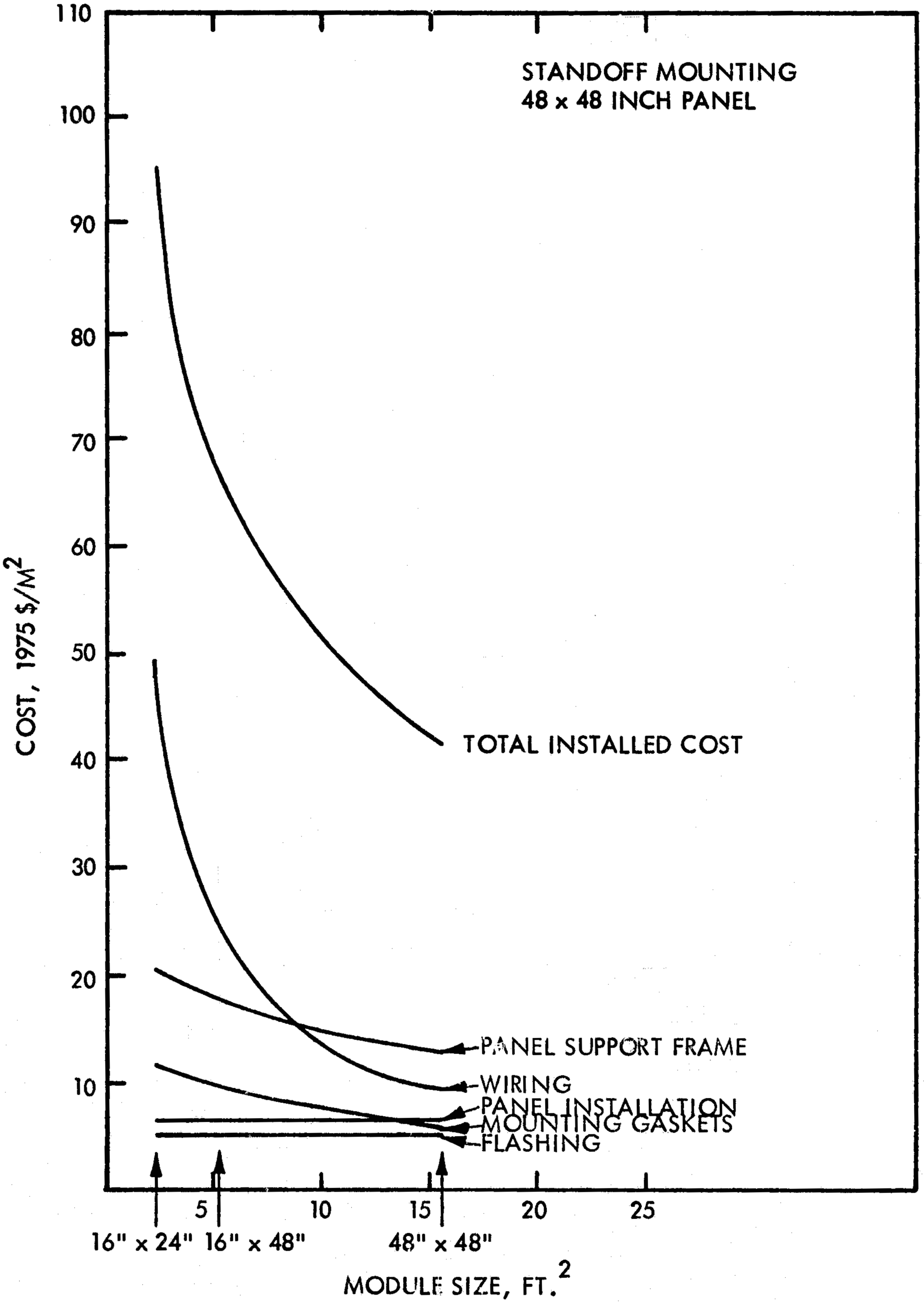


Figure 16-10 Standoff Mounting - Array Costs Versus Module Size

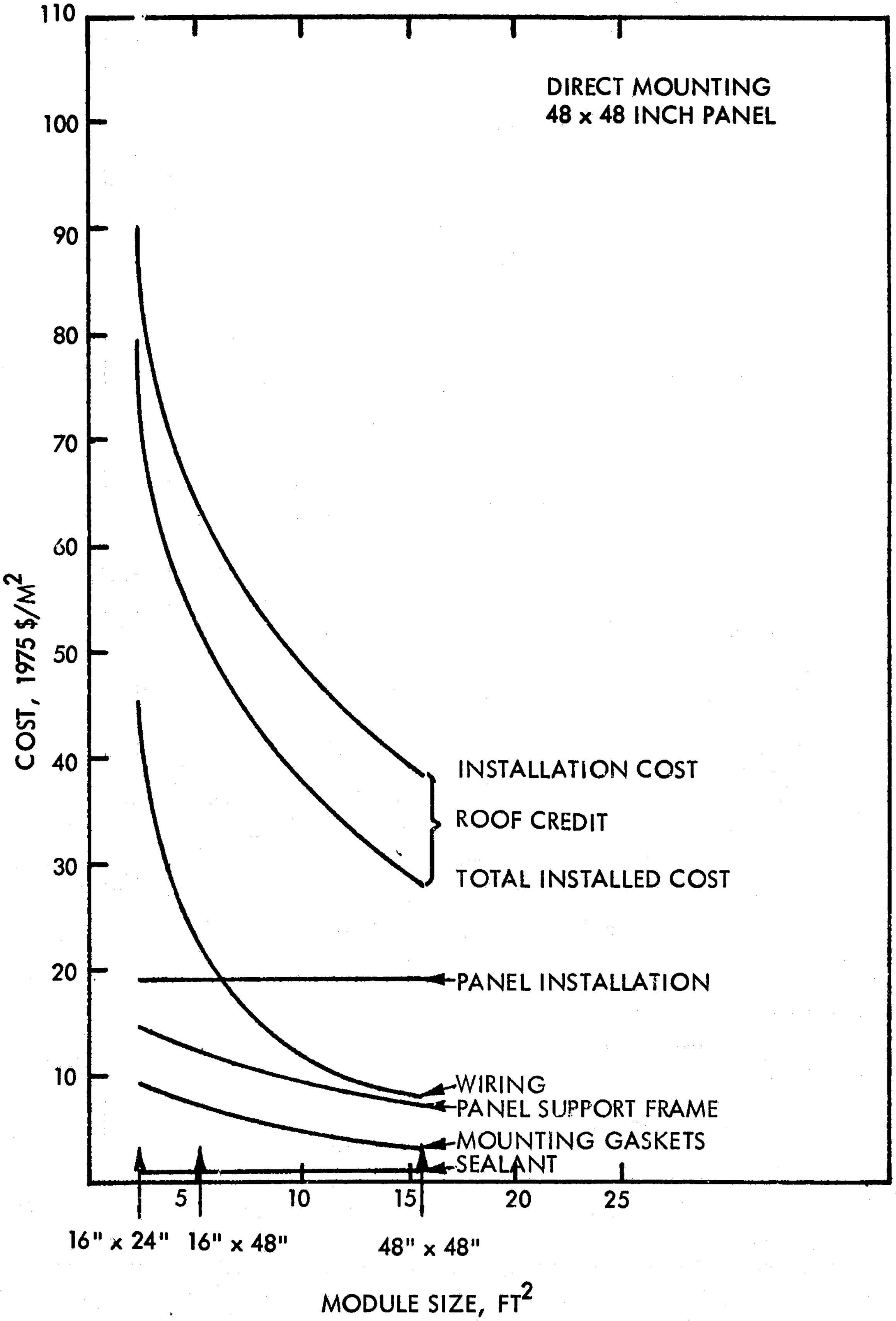


Figure 16-11 Direct Mounting - Array Costs Versus Module Size

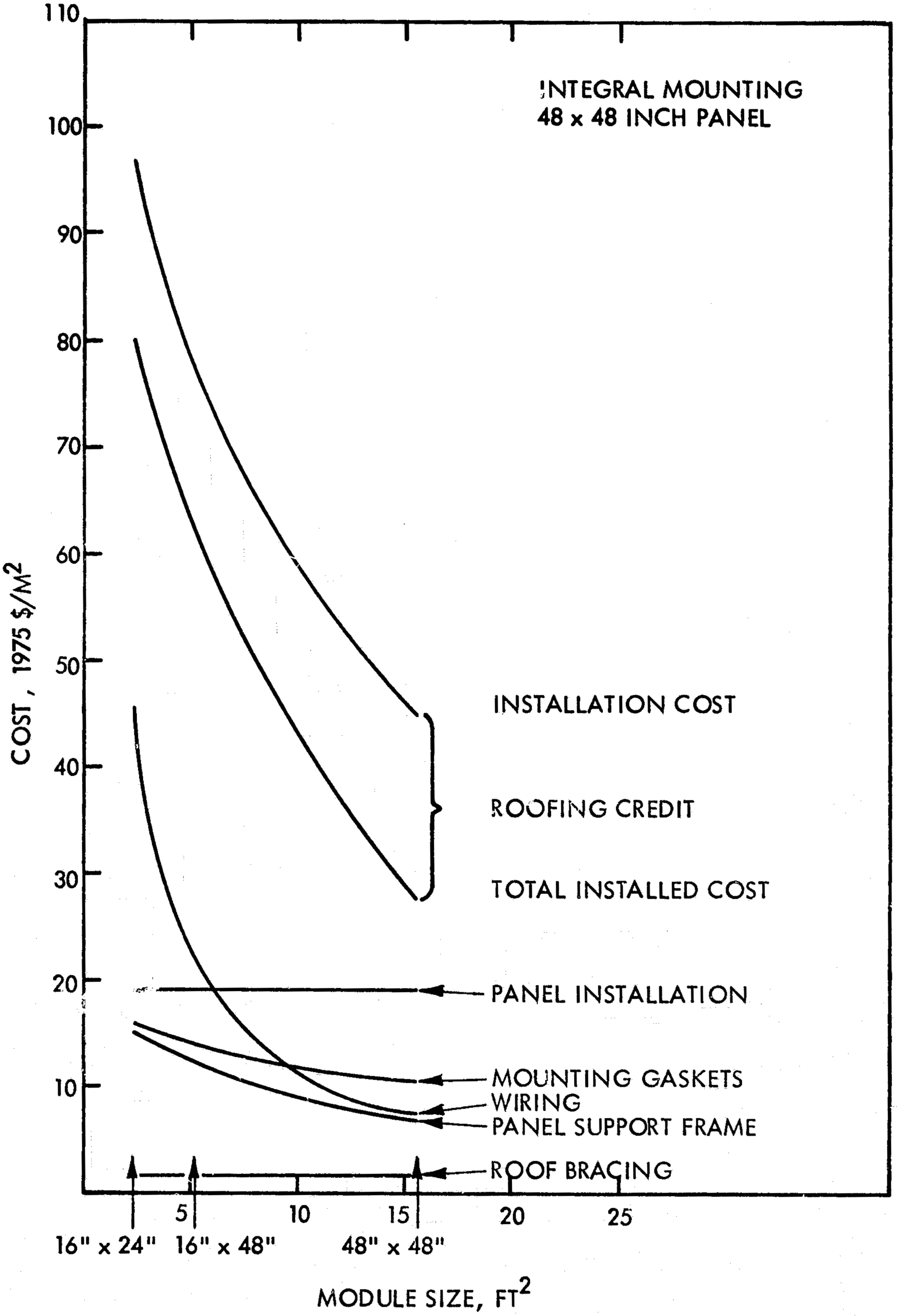


Figure 16-12 Integral Mounting - Array Costs Versus Module Size

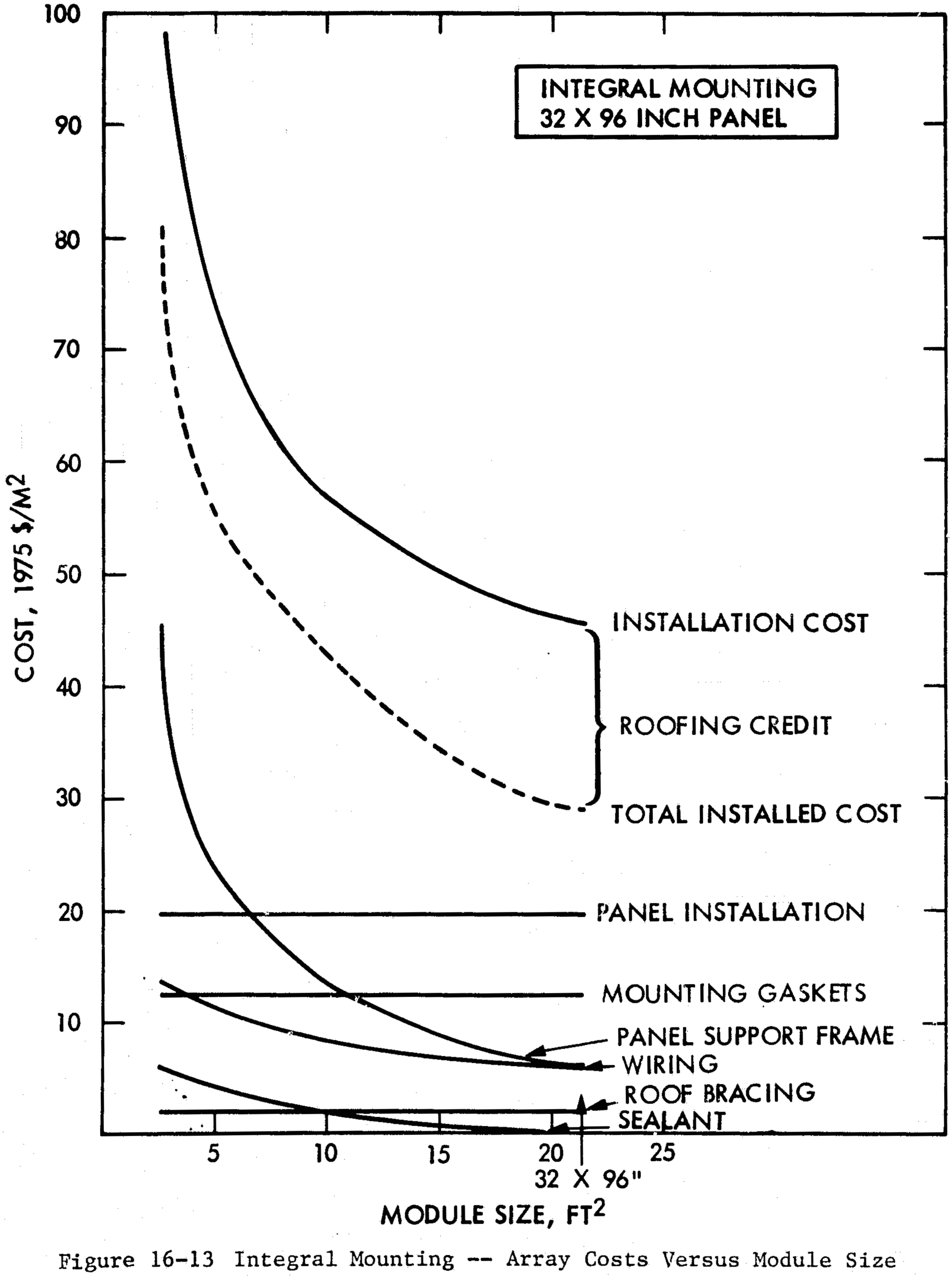


Figure 16-13 Integral Mounting -- Array Costs Versus Module Size

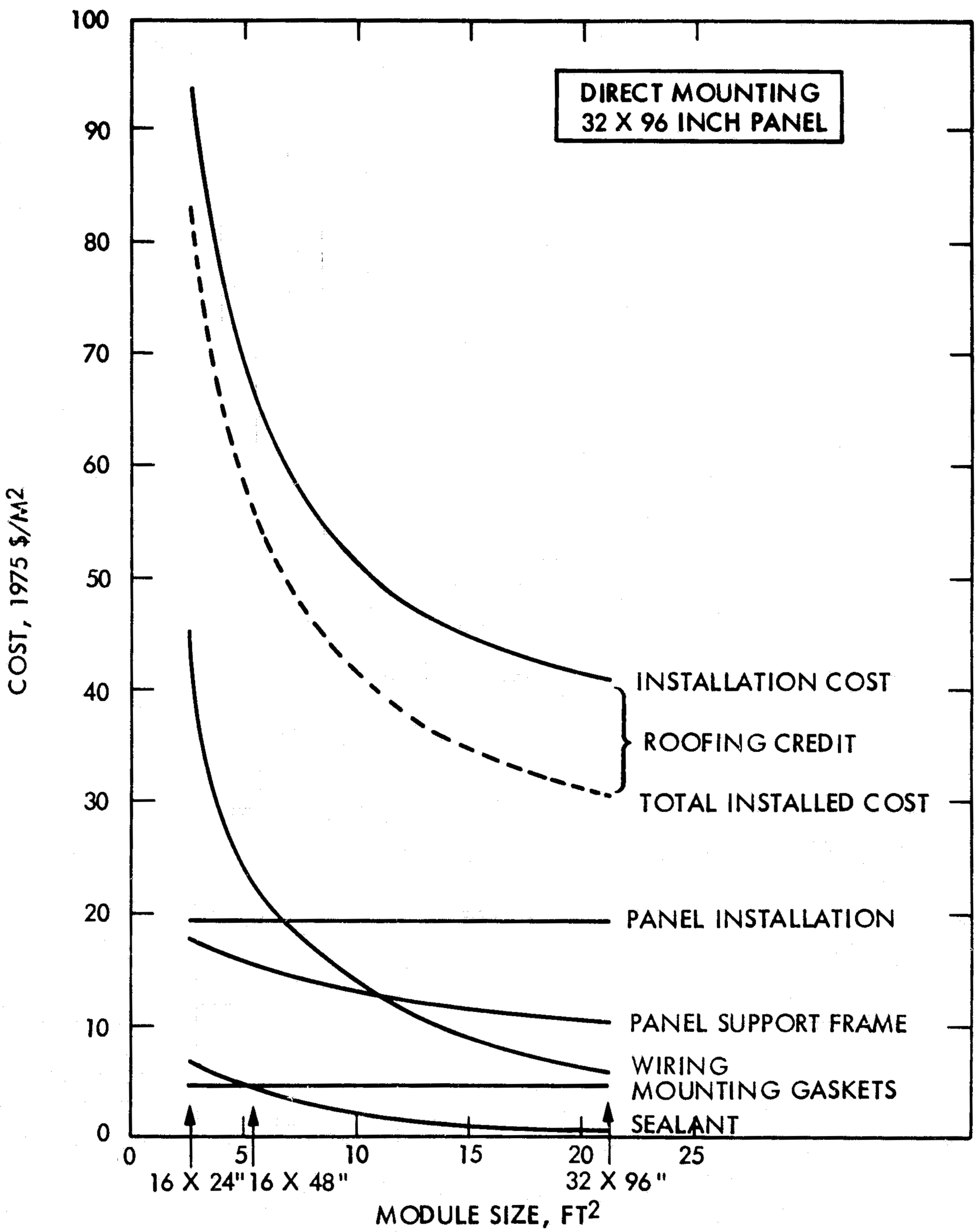


Figure 16-14 Direct Mounting -- Array Costs Versus Module Size

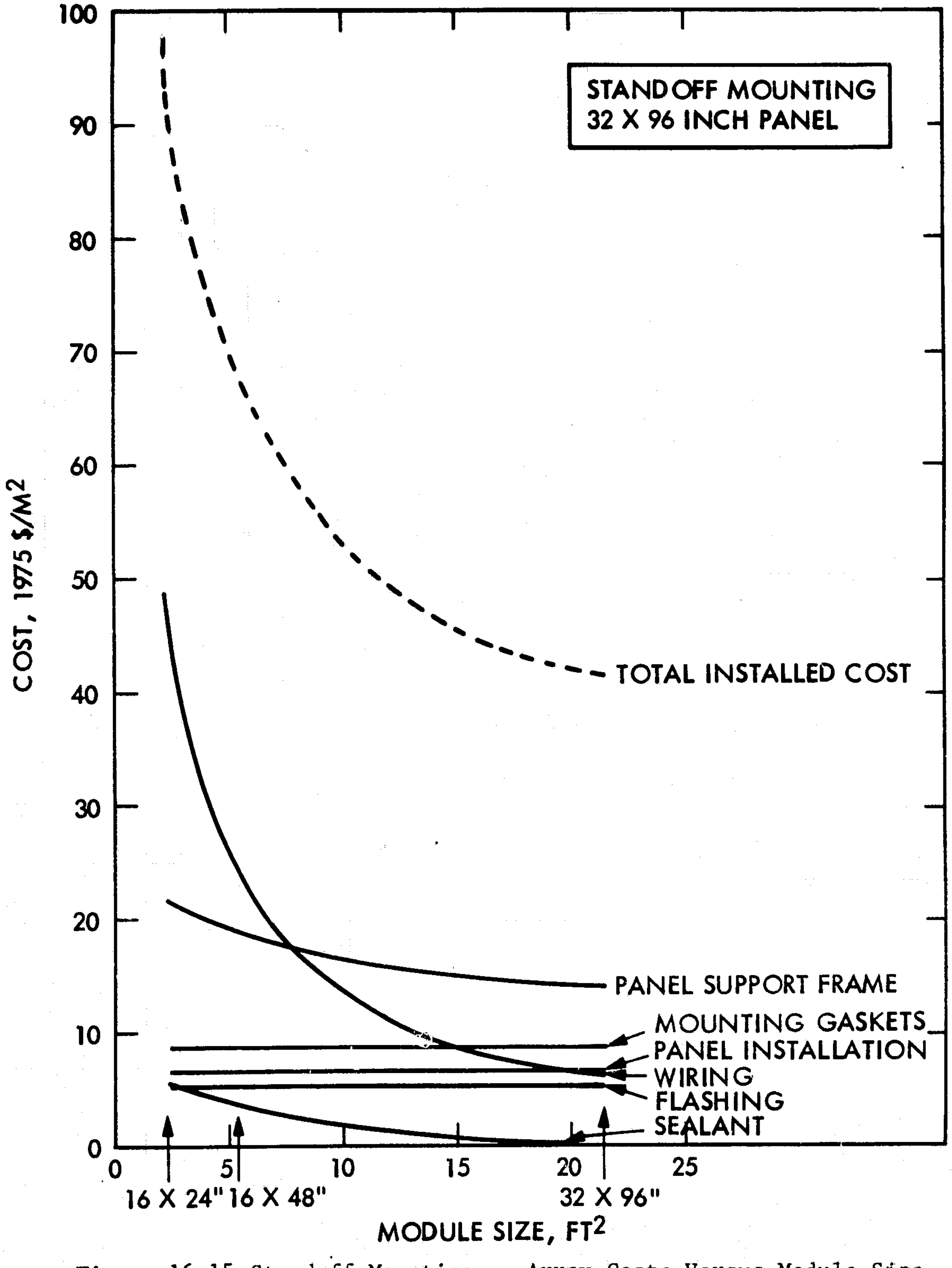


Figure 16-15 Standoff Mounting -- Array Costs Versus Module Size

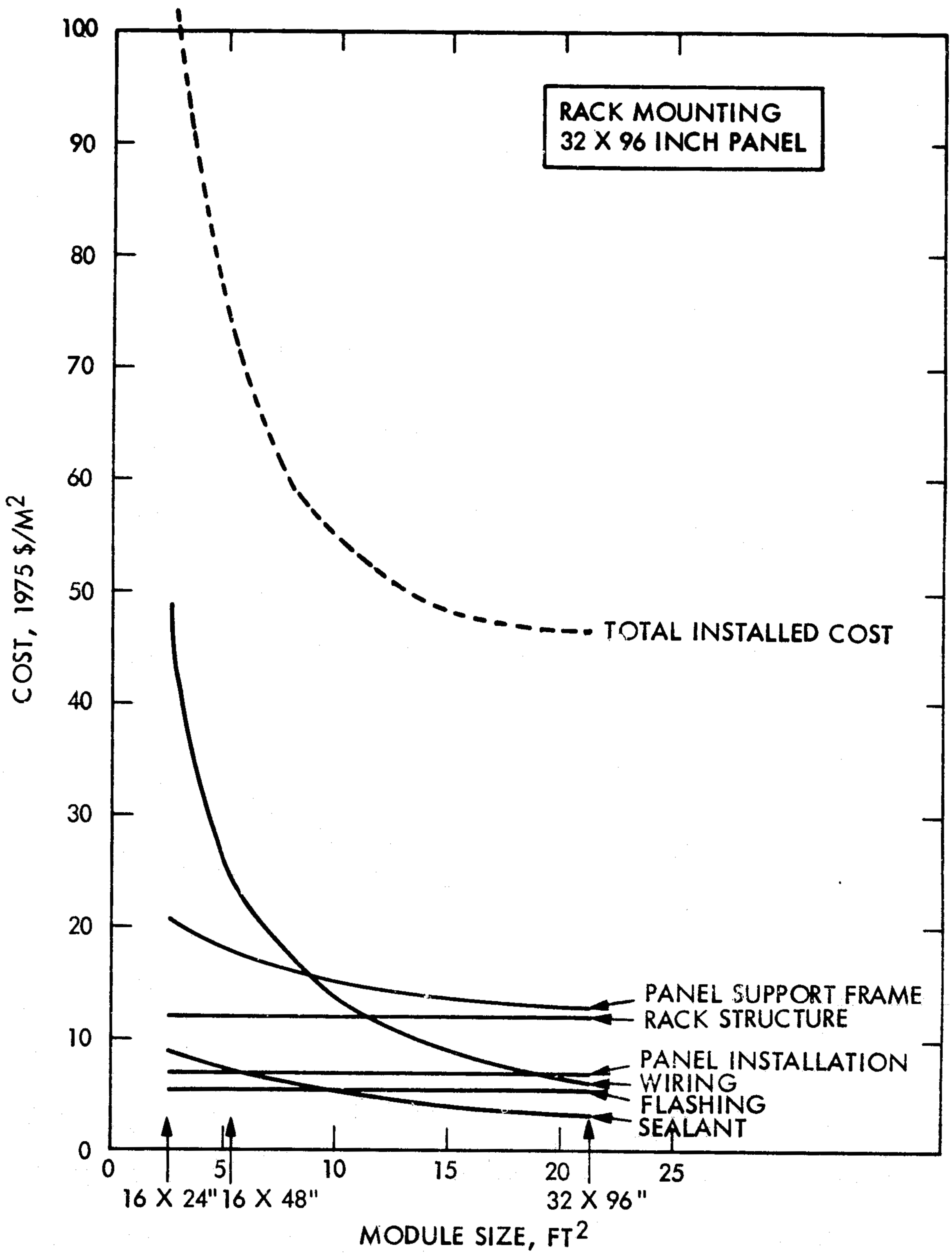


Figure 16-16 Rack (Roof) Mounting -- Array Costs Versus Module Size

APPENDIX 17. PHOTOVOLTAIC SHINGLE/PANEL COMPARISON

PURPOSE: To review the current R & D shingle module design with a view of the 1986 residential design requirements and the possibility of successful market penetration.

To compare the shingle style and panel style modules in one discussion to express the strengths and shortcomings of both concepts.

CONCLUSIONS: The current R & D module has shown proof of concept but additional development and testing or design variations are needed to improve the module and make it more responsive to relevant aspects of the residential building industry.

RECOMMENDATIONS: Refinement of the current R & D shingle module should be completed and demonstration projects erected for further testing of the design.

The current R & D shingle module should not be the final test of the general shingle concept because it is a specific design among many possible variations. The general shingle idea should remain as a central concept that is open to absorb new advancements in PV technology that might improve the current R & D design.

Since the general shingle module concept has great potential for residential applications, future R & D efforts should be directed toward the development of new shingle designs. The current R & D shingle is made from a combination of conventional PV materials and sub-assemblies which distort the simplicity of the original concept. The opposite design approach should be taken in future module designs.

All ideal shingle module characteristics should be identified and then the ideal shingle conceived. From this point, the new materials should be developed which achieve these characteristics.

The ultimate shingle module should be rectilinear, lightweight, pliant and sized for easy handling and fast installation with as few interconnections as possible. It should be durable to resist weathering and tough to withstand shipping and rough handling at the job site.

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INTRODUCTION

Although current module design has been of the flat plate or panel style, the increasing emphasis on residential applications has stimulated new module design concepts more in tune with the building industry. One R & D module, the shingle-style module, is being developed which produces electrical energy as its primary function but also forms a protective watertight roof covering. These new modules are similar in size to conventional asphalt shingles and are intended to be installed in a similar fashion. Their use in a housing project would replace conventional shingles on south facing roof slopes.

This new concept does not imply that current flat plate modules are restricted to the concept of self-contained tack-on units. If adequately sealed along their edges, flat plate modules could also be mounted on a sloping roof to form a watertight roof covering and replace conventional shingles in the area of the array. They could be made to replace the plywood substrate as well. Since flat plate modules can be formed into larger stiff panels that will not rack, warp or bend, they can be attached directly to the roof rafters or trusses to create a structural diaphragm in much the same way as conventional plywood sheathing.

There is a place in the residential building market for both PV modules concepts. The panel and shingle concepts can satisfy different functional requirements because of the distinct advantages each offers in the appropriate applications. However, both concepts, apart from any specific PV module design, have inherent liabilities that preclude their use under certain circumstances and, therefore, restricts their respective applications. A comparative discussion of both concepts with respect to building industry characteristics can help point out obstacles to successful market penetration for each but may also stimulate new developments in PV module design. Since residential photovoltaics is a new technology that requires new materials and techniques to achieve its primary function of electrical production, it is unlikely that a design that is strictly a panel or shingle can duplicate all the performance characteristics of the roofing materials they are intended to replace. Photovoltaic module design may evolve using the characteristics of both and thus may achieve wider application in the residential marketplace.

SHINGLE-STYLE PHOTOVOLTAIC MODULES

Shingles in Building Construction

The overlapping characteristics of shingles is a proven water shedding mechanism for sloped surfaces and appears in nature in the feathers of birds and hair of mammals as well as in building roof construction throughout thousands of years. The concept is a feature of common asphalt, wood and asbestos shingles, wood shakes, thatched roofs, and ceramic and cementitious tiles, most of which are common throughout the world. Shingle type roofing elements are conveniently sized products which can be lifted and placed with one hand, allowing free use of the other hand for attachment of the shingles to the substrate material underneath. The overlapping tabs shelter the upper part of the underlying shingles to form an open, air-tight system. Because of this characteristic, shingle materials only work on sloping surfaces.

As the degree of slope decreases, the overlapping coverage by the tabs should increase to guard against wind uplift and wind driven rain. In addition, minimal sloping roofs must be covered with more durable shingles to resist the effects of capillary action and wind uplift. Several manufacturers of asphalt shingles have solved the problem of wind uplift with an adhesive on the underside of the exposed tab.

By nature of their small size and numerous quantity in most applications, the units can be installed to conform to slight irregularities in squareness of the roof shape, and planar deviations across its surface. On the other hand, automated manufacturing processes and quality control at the plant creates units which are uniform enough to fit within close tolerances. Usually shingles are made from pliable material that is easily cut, or are manufactured from brittle material that can be intentionally broken along a scored line. This characteristic, in addition to the relative low cost of individual units, permit the roofer to quickly shape special units to fit into edge conditions which do not conform to the modular dimensions of the individual shingles. When the job is complete, the shingles form a dependable roof that is nearly maintenance free. An asphalt shingle roof can last from 15 to 20 years, and a slate roof can last as long as 100 years or more. Because of these advantages, shingle-type roofs are used throughout the residential building industry and all carpenters are familiar with their application. It necessarilv follows that the historv of success of shingle construction is a clear and logical influence in module design and that duplicating shingle features will enhance its function and marketability.

Shingle-Style Module Construction

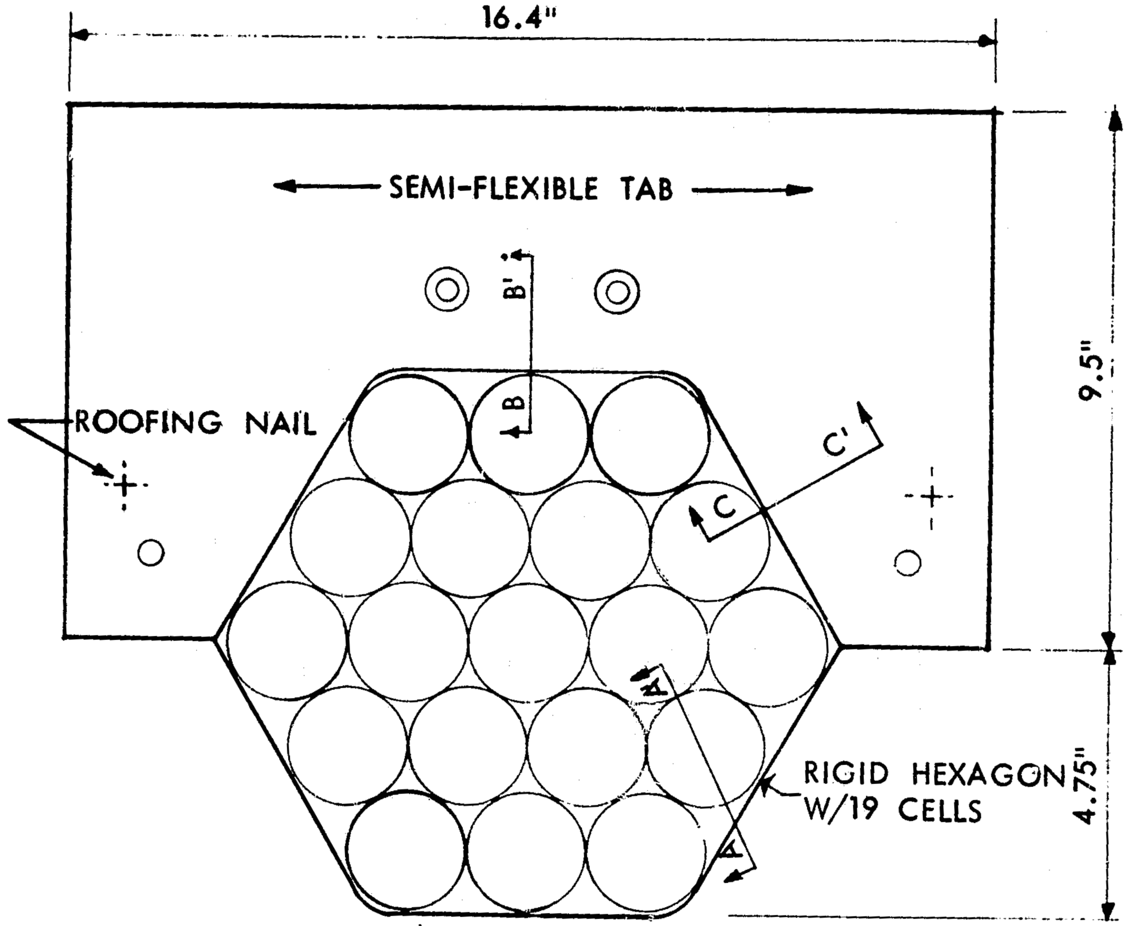
The current R & D shingle modules use a hexagonal shape on the exposed part of the shingle in order to accommodate close packing of current-production round solar cells. Even though the entire area is not covered with photovoltaic material, light falling on the white interstitial spaces between cells is internally reflected to enhance the power output of the module. As ribbon technology progresses and solar cells become rectangular rather than round, it is probable that future shingle modules may be rectangular.

Shingle

The particular R & D shingle module now under development consists of two major parts: the exposed rigid hexagon that contains the series-connected solar cells, and the rectangular semi-flexible part that holds the interconnection circuits and electrical terminals. (Figure 17-1)This semi-flexible tab is always overlapped and a part of its surface is used in anchoring the module to the underlying plywood sheathing.

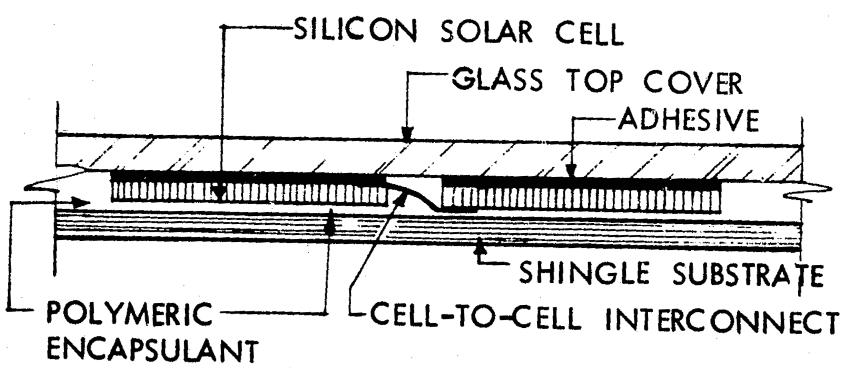
Constructing the rigid portion of the module takes several steps. The cells are bonded to the underside of a thermally-tempered hexagonal-shaped piece of glass approximately 3/16" thick and then cell-to-cell interconnects are made. Before a rigid fiberglass/epoxy protective sheet is attached to the back to sandwich the cells, the narrow leftover voids among the cells' edges caused by the cells thickness must be filled. To accomplish this, a squeegee is used to apply a silicone pottant that fills these voids. Additional pottant is laid over the cells to cover them with a thin coating. The pottant is then leveled off to create a smooth mounting surface for the back protective sheet. Once the back is adhered, the layers of glass, pottant, and rigid plastic form a solid construction that encapsulates the cells. (Figure 17-2).

The rigid hexagon is attached along its upper edges to the semi-flexible tab which is a composite laminate of tough, durable materials. It has two outer skins which sandwich a 1/8" thick, sponge-like core. The skins are made of



R & D SHINGLE MODULE

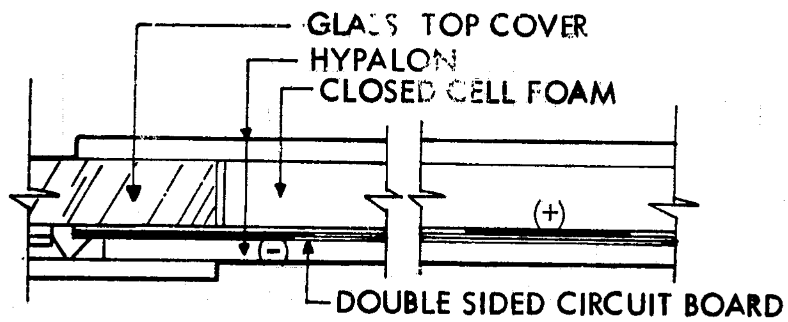
FIGURE 17-1



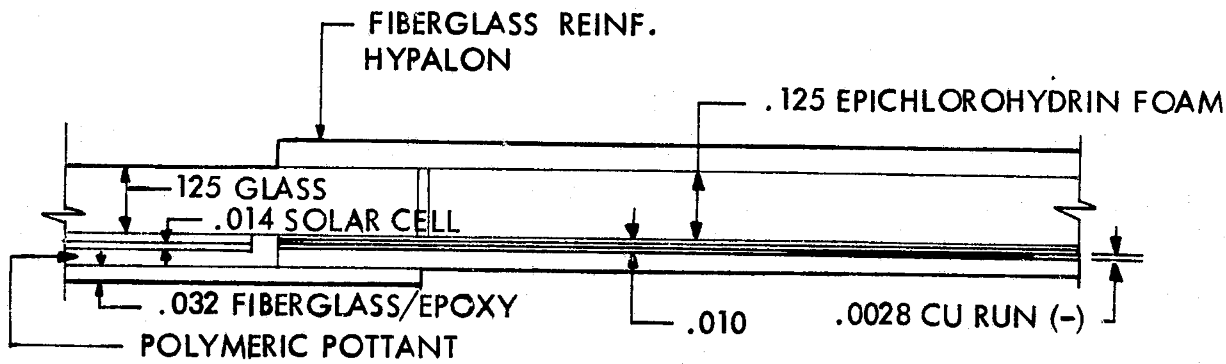
SECTION THROUGH HEXAGON (A-A)

FIGURE 17-2

HYPALON reinforced with an embedded polyester scrim and are glued to the compressible core made from closed-cell epichlorohydrim foam. The bottom skin must also sandwich a thin, two-sided flexible printed circuit board which carries the two positive and two negative terminals of the module. It is the core and the bottom HYPALON skin (Figure 17-3). Efforts are underway to



SECTION B-B' See Figure 17-1



SECTION C-C' See Figure 17-1

SECTIONS THROUGH HEXAGON AND TAB

FIGURE 17-3

reduce the cost of this flexible portion by redesign or substitution of materials. For instance, metal foil is under consideration to replace the printed circuit, and plastic impregnated cardboard is being tested to replace

C-5

the bottom rubber skin and the rigid fiberglass/epoxy sheet.

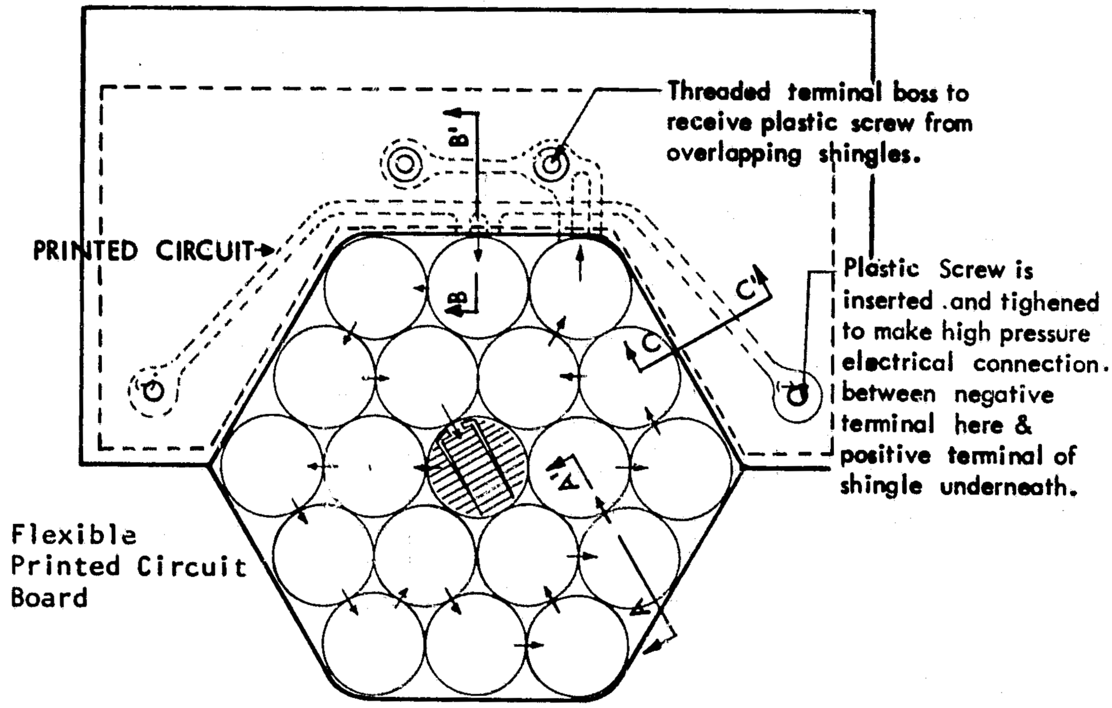
Much of the shingle design is predicated on the use of round cells with an efficient packing arrangement that produces the hexagonal shape. It is obvious that if square or rectangular cells were available, the present module design could change drastically. There would be less waste in cutting the sheet material, near 100% module packing efficiency, and many options for various sizes and proportions.

Module to Module Interconnections

Module to module electrical interconnections are accomplished with two positive threaded female terminals embedded in the flexible tab immediately above the rigid hexagon. Holes for the negative terminals are on either side of the hexagon. (Figure 17-4) As the shingles are overlapped, the two holes of the terminals of one shingle module register with two terminals of the modules underneath it (Figure 17-5). Flat-head machine screws with washers are then inserted and drawn down tightly to create a high pressure electrical contact between the two terminals. After the electrical connections are made, the module is anchored to the roof by two regular roofing nails driven through the shingle to the underlying plywood.

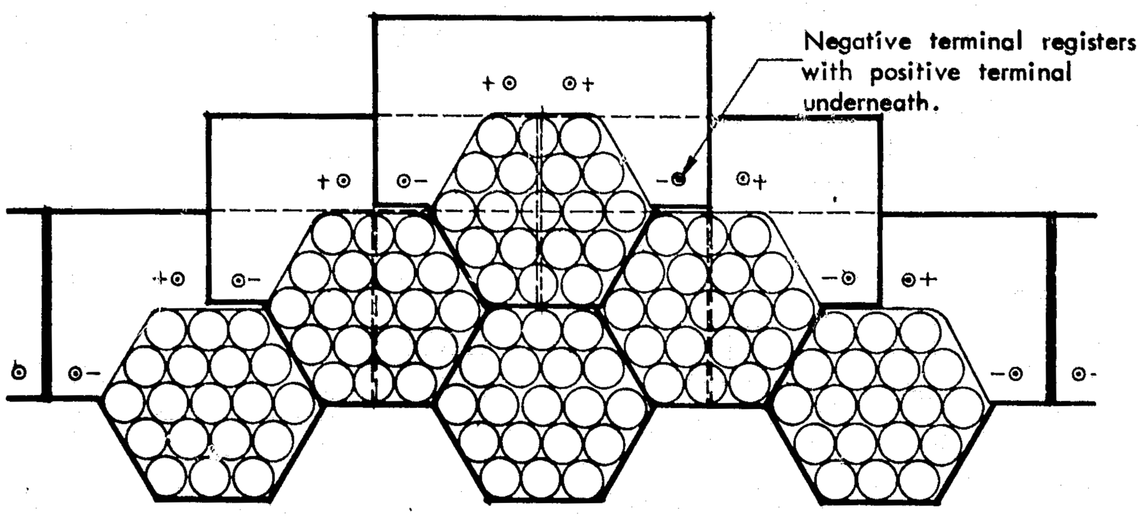
Figure 17-6 depicts an electrical schematic of module to module interconnections. As the shingles are installed to create an entire array, the interconnections between the overlapping layers form a series/parallel matrix interconnected modules. As modules are added in a parallel direction across the length of the roof from gable to gable the current increases. And as modules are added in a series direction along the slant of the roof from eave to ridge, the voltage increases. Unlike current flat plate modules which combine a large number of cells in series, the shingle interconnect configuration creates a series - parallel redundancy which eliminates the need for blocking or by-pass diodes -- the malfunctioning of one shingle module will not seriously interrupt the flow of current in this array.

At the bottom of the array near the eave, all the negative terminals of the first active course are connected using special starter shingles laid underneath along the length of the eave to form a common negative bus. This row of



ELECTRICAL CONDUCTORS WITHIN MODULE

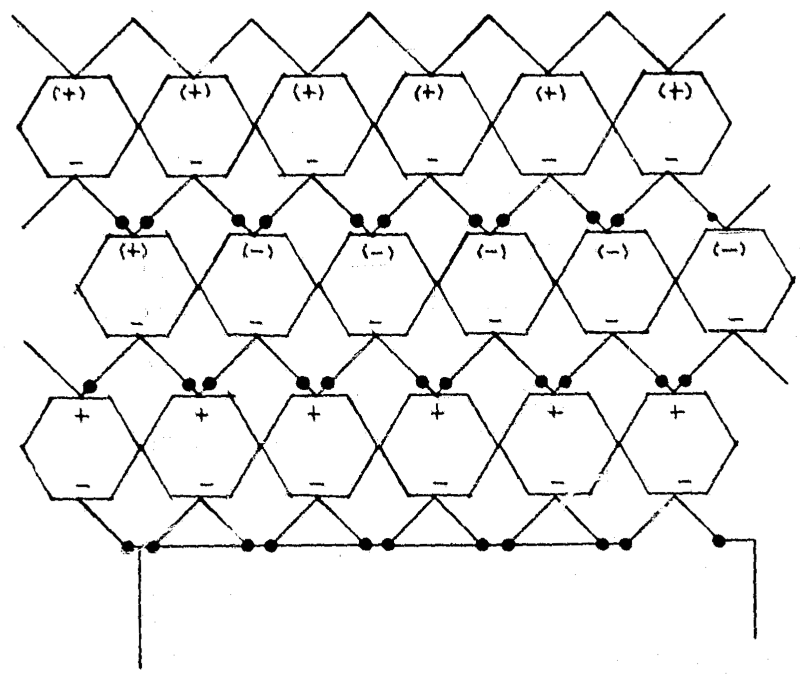
FIGURE 17-4



SHINGLE MODULE OVERLAP

FIGURE 17-5

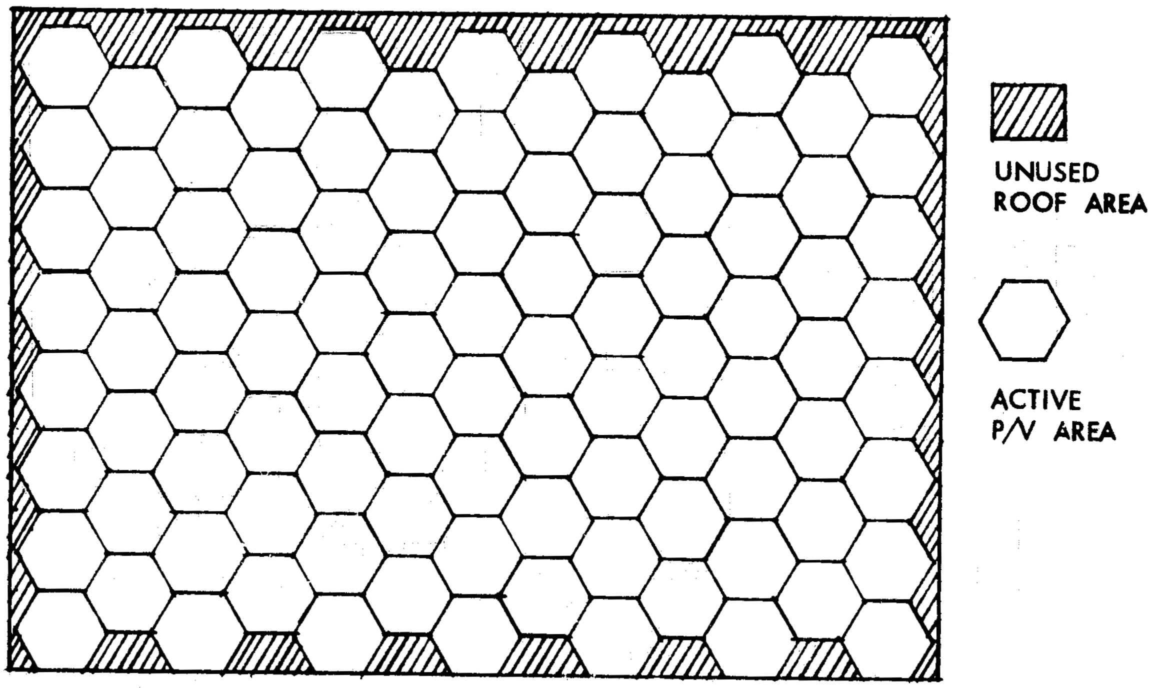
special shingles contains a built-in circuit board to make this jumper connection. Every fifth eave shingle is then tapped with a flat conductor cable which runs underneath the subsequent upper rows of shingles to the ridge of the roof. This arrangement is necessary to control the current density and series resistance losses for the overall installation. Similar terminations are required at the ridge and may be required at intermediate points along the slant height of the roof depending on the specific voltage requirements.



ELECTRICAL SCHEMATIC
FIGURE 17-6

Shingle Installation Area

Fig. 17-7 represents the plan of an array of PV shingles modules. The perimeter areas contain no active PV cells and must be filled with special "dummy" modules to finish the installation by completely covering the roof. Despite the close packing arrangement of the hexagon shapes, the loss of perimeter area diminishes the overall efficiency of the array. This loss becomes most critical in small installations but the effect diminishes as the array size increases.



AREA COVERAGE OF P/V SHINGLES

FIGURE 17-7

Installation Sequence

As with all shingle or slatework, PV shingle modules are laid over a plywood sheathing that has first been covered with one or two layers of roofing felts, and are installed beginning at the eaves and finishing at the roof ridge. Apart from the main electrical branches, the actual shingle installation begins with a one-third width starter strip to help form the necessary triple thickness characteristic of the entire installation. The second layer, a two-thirds width negative bus strip, is then placed along the eave length. These modules contain the first terminals. A special spacing tool is used to set them at the required distances so the first overlapping row of shingle modules can register exactly, and all subsequent interconnections can be made on target as the installation proceeds up the roof. Since the registration of all subsequent interconnecting terminals depend on the spacing of the terminals of this negative bus course, careful attention to its layout is required. After the first row is installed, the shingle modules then can be laid course by course from the eaves to the ridge at which point the positive terminals of the final course of modules are connected into a positive bus strip. The installation is finished when an additional layer of shingle material is added to the ridge to complete the triple thickness required by design. Since alignment tolerance of the interconnect terminals from shingle to shingle is less than 0.1 inch, careful manufacturing, installation, and material choice is mandatory. The shingle must remain dimensionally stable under changing temperatures and humidity conditions. The roof sheathing must be as square and even as possible, and quality control in the factory and on-site must be maintained.

A Comparison of Photovoltaic Shingle Modules and Asphalt Shingles

Shingle-style PV modules create a shingled roof covering when installed but these units have certain features unlike any roof covering in current use. To assess the material and installation characteristics of shingle modules, a comparison was drawn between it and asphalt shingles, which are widely used in the residential construction industry.

SIMILARITIES

1. Scale-like for shedding water.
2. Approximately the same size.

DIFFERENCES

Asphalt Shingles	PV Shingle Modules
1. Single function -- waterproofing	1. Double function -- electrical production and waterproofing.
2. Inexpensive materials -- asphalt impregnated organic or fiberglass felts with stone granules pressed into exposed tab.	2. Various materials and laminates.
3. Each individual shingle is waterproof and needs no sealing.	3. Much of the perimeter edge of each PV shingle needs to be sealed at the factory. The designers are allowing for the possibility of caulking the leading edge of shingle overlap at building site.
4. Rectangular in shape	4. Currently, partial hexagonal tab with rectangular substrate. (This may change with availability and recetangular solar cells).
5. Relatively thin	5. Thick, similar to slate roofing.
6. Pliable	6. Stiff like a shake or slate.
7. Can withstand rough handling	7. Must be handled carefully.
8. No special pieces needed	8. Dummy modules needed for ridge, sides and eaves of roof.
9. Cutting and fitting possible.	9. Cutting of PV shingles impossible. No roof penetrations can be permitted in the array area.
10. Approximately double coverage by overlapping	10. Approximately triple coverage by overlapping.
11. There is room for error in installation.	11. Tolerance of interconnection is close.
12. Nails only needed.	12. Nails and screws needed.
13. Average weight -- 2.4 lbs/ft^2	13. Average weight -- 4.0 lbs/ft^2
14. Installation of asphalt shingles is one of the simpler tasks a carpenter performs.	14. Installation requires more effort because of weight; more care because of glass and solar cells; more steps (nails and screws needed) and more skill (all interconnections must be made to conduct electricity.
15. Can be walked on with no significant damage. Carpenters can accidently drop their hammers on the finished shingles without puncturing them.	15. The weight of a workman may crack a glass cover. A dropped hammer will probably shatter the glass. Special protective pads may be needed during construction in high traffic areas on the roof.

16. Grit-like surface provides good footing during installation up to 6 and 12 pitch.	16. Slick glass covers offer no sure footing for workmen. Protective pads will offer better footing.

As may be expected, this point by point comparison demonstrates that the analogous relationship between the two products is weak. Because of its functional complexity, the shingle module has more the character of an electrical appliance than a building roof product. However, the study of current roofing practices by module designers should be instrumental in improving existing designs from an installation standpoint.

FLAT PLATE PHOTOVOLTAIC MODULES

Panelized Building Construction Materials

The panel concept in building roof products came into being when these products were required to perform other functions (usually with sheet glass) in addition to shedding water, such as collecting solar heat, letting in natural light or, in the case of photovoltaic panels, producing electrical energy. Compared to the age-old use of shingles, the general use of panelized building products is the result of relatively recent advances in materials and manufacturing technology. The ability to manufacture large sheets of glass, precise metal extrusions, and specialized synthetic rubber sealants has occurred only by the application of research and the development of precision manufacturing techniques which require heavy capital outlay.

Because large panels of glass, metal or stone can be machined rather than hand built, many identical units can be produced in the shop for later installation in the field. If the panels are to be used as exterior cladding or glazing, this implies that greater skill and precision is required in the assemblage of backup materials or anchor points that support the panels. Regardless of careful installation practices, field assembly is a less precise operation than quality-control manufacturing of building components. To compensate for small dimensional errors, loose tolerances can be designed into the joints between panels to allow the entire system to fit together.

Panelized products seem to work best when the entire system is controlled by a chain of automated processes from manufacture to final installation. This is especially true for large heavy panels that must be lifted in place with a crane, or with panelized building systems that, through high volume production and high speed erection, can readily amortize heavy capital equipment.

Flat Plate Photovoltaic Panel Type Module Construction

Photovoltaic panel type modules are shaped and sized according to the need to encase numerous cells in a large but manageable unit. Common panel construction uses a glass cover to protect the underlying brittle cells that are sandwiched between the cover plate and a plastic, glass, or metal substrate. An encapsulant is injected in the narrow space between the cover and the substrate to fill the voids and make the laminate one solid panel. The transparent glass cover and encapsulant slightly reduces the amount of sunlight striking the cells, but are critical elements that protect the cells. The cover plate is a barrier against mechanical damage, corrosive atmospheres and dirt. Encapsulant provides optical coupling between glass and cells and holds fast the cells and their electrical connections to prevent shifting among the cells and electrical shorts. Since it fills all voids, the cells are sealed against dirt and water intrusion.

The edges of the panels are usually finished with a small channel that fits over the thickness of the composite laminate construction. This protects the edge of the panels from minor damage. If the substrate materials have insufficient strength to support anchor points for attachment to the roof, then the panels must be clamped into a separate framing system that first attaches to the roof. The framing system helps stiffen the panels by continuously supporting their edges. The framing system also provides the opportunity for sealing the joints between the panels.

Mounting the Panels on the Roof

Most building products are for commercial applications and require the use of cranes for hoisting and maneuvering units into place.

Ideally, flat plate photovoltaic panels for single family applications should not require the use of a crane but should be light enough to permit one man to easily handle the panels. Each panel should be large enough in area to allow quick coverage of the roof without the hinderance of a complex anchoring and sealing system. Theoretically, one workman should be able to lift and carry a 4'-0" by 8'-0" panel weighing 50 to 60 pounds, but realistically, panels of this size and weight will require two men for carrying across narrow scaffolding and lifting in place on a sloped roof.

Before the panels are installed, the array area will either be sheathed with plywood or left open depending on the mounting type. With a "direct" mounting scheme, the panels are attached directly to the wood sheathing which may first be protected by a couple of layers of building paper or a complete shingle roof. If an integral mount is used, there is no wood sheathing in the area of the array and the panels are attached to the roof rafters or trusses. With this mounting scheme, the panels, when joined together, must create a watertight roof surface. The array should also act as a structural diaphram to stiffen the roof by tying together the underlying wood structural members.

The integral mounting usually will require a metal framing system similar to window wall construction. The framework is first attached to the structure and the PV panel then clamped tightly into the frame. A direct mounting scheme can use the same two part system of frame and panel or the PV panel manufacturer can eliminate the framing system by providing a structural edge detail on the perimeter of each panel with periodic anchor points. During installation, the joints between panels can then be sealed with a non-structural rubber gasket, or other dependable sealant.

Most panelized building products for exterior applications are intended to be installed vertically as glazing or wall cladding. In this way there are no bending stresses on the panels and little water can collect in the joints. If the panels are used in a sloping application typical of photovoltaic installations, the joints between the panels become vulnerable to water penetration, and as the slope decreases, the chance of leaks increases. Since the panels do not have the advantage of overlapping edges, but are butted together, their joints must be sealed with tightly fitting gaskets or durable sealants that are expensive because of their high quality. Most successful gasketing systems currently available are designed strictly for vertical window installations. Adapting them to a sloped application can cause problems. Stiff structural rubber gaskets that are supposed to hold glass panels in place are too pliable and can allow glass panels on a sloped surface to slip, thereby opening up the horizontal joints. The best rubber gasket details use a structural metal extrusion that holds the panels rigidly in place and in turn supports a rubber gasket for sealing the joint between panels.

It is also a good practice to weep the rubber gasket joints in order to conduct away any water that penetrates the seal. On a sloped application, water will invariably seep into the array at certain points and could collect within if not internally drained. Manufacturers of skylight framing systems have solved this problem to a certain extent. The metal frames which support the glass panes hold a continuous condensate gutter along their length on the interior side of the skylight. All airborne moisture from the interior that condenses on the top of the frame will drip down and be caught in the gutter. If any leaks develop in the joints between glass panes the gutter will also catch the water and conduct it to the edge of the skylight where it can be drained away. Since flat panel skylight systems are the closest product analogy to PV panel style module installations, an examination of their detailing will be important in the future evolution of mounting schemes.

Electrical Interconnections

Depending on the electrical requirements, a number of photovoltaic panels in an array are usually wired in series to increase voltage to a desired limit. This series of panels are then wired in parallel to other series connected panel groups. A panel to panel wiring is made with one electrical connection usually in a junction box or with a simple plug. In direct mount applications, these connectors would be hidden between the bottom side of the panel and the roof sheathing. With integral mounting, the electrical connections could be seen from outside the attic immediately under the exposed back side of the panels.

A Comparison of Conventional Panel Skylight Systems and Flat-Plate Photovoltaic Modules

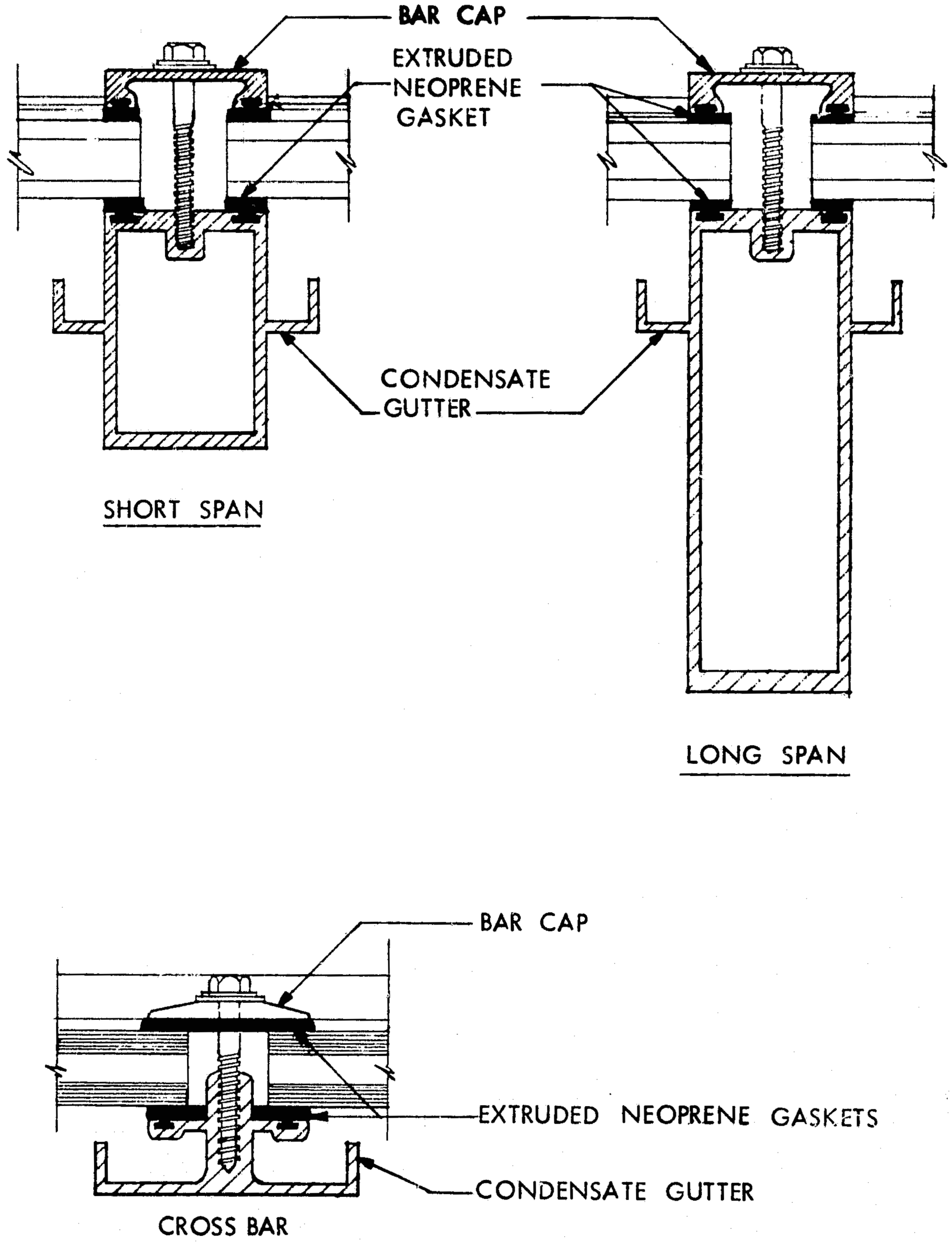
There are a number of manufacturers who market panel skylight systems for commercial buildings and greenhouse installations. These systems usually consist of structural metal framing usually extruded aluminum that is available in a number of depths and thicknesses for different spans. The framework is first erected before it received panes of glass that are ordered locally.

Some systems have been available for a number of years and provide dependable, watertight joints when the system is properly installed and maintained.

Since panel-style PV modules can be detailed in a similar fashion to double insulating glass panels, it is likely that a conventional skylight framing system would be used for an integral mount PV installation. Slight modifications to the frame may have to be performed to accommodate interconnections and receive wiring. Analyzing the details of these systems can aid the residential module designer searching for a dependable method of anchoring and waterproofing but it should be recognized that the success of these systems can be attributed to the design of the framing member and the high quality, high-cost materials involved. This level of quality appears in commercial applications where durability is essential to reduce maintenance. Common residential construction materials and techniques must rely on lesser quality. The following points of comparison outline some of the characteristics of skylight framing that should be considered in future PV panel design:

	Conventional Skylights		Panel PV Style Modules
1.	Success of system is achieved by stiffness of frame members, and the precision and uniformity of their dimensions. Glass panels are also manufactured to extremely close tolerances.	1.	Framing or detail system to receive PV modules must adapt to truss construction and compensate for irregularities in lumber dimensions, variable elevations of topchords of trusses and uneven spacing of trusses.
2.	Neoprene gaskets are used to create the waterproofing seal. Clamping pressure of bolted bar cap that holds down glass also compresses neoprene to close any slight openings along the joint. (Figure 17-8)	2.	A similar system could be devised for PV waterproofing.

3. Integral condensate gutters are usually included. (Figure 17-8)	3. If metal is used, condensate should be caught along length of frame. Conducting condensate out from the building will be a problem in detailing.
4. Systems are flexible and can adapt to different spans and different sized glass by using the appropriate size frame for the span. Details for holding glass panels usually remain the same.	4. PV integral panel systems for residential buildings will be largely restricted to the need for adapting to truss or rafter technology, if early market penetration is to be achieved.
5. Most panel skylight systems are used only in commercial and institutional applications and installed by skilled union workmen.	5. Installation of PV systems will be by non-union workmen. Skill level is more variable and must be compensated for.
6. Partial flashing at perimeter is usually provided by frame manufacturer.	6. Perimeter of PV panel array can be designed to be partially self-flashing for both integral and direct mounting type.



CONVENTIONAL FLAT GLASS SKYLIGHT SYSTEMS

FIGURE 17-8

CONSTRUCTION CONSIDERATIONS

The essential properties of both shingle and flat plate modules have been analyzed without detailed consideration of on-site installation procedures. An identification of these procedures and commentary on the implications that both PV module concepts will have on these procedures will alert module designers to aspects of construction that should be anticipated in the early design phase of PV modules.

These procedures appear in the list below and are arranged roughly in sequence by order of construction. Commentary on each appear in the following pages:

1. Comprehension by workmen (near term)
2. Receiving and unloading at the site
3. Storage of photovoltaic modules
4. Preparation of roof surface or structural support
5. Coordination with nearby roof or wall construction
6. Lifting and placing modules on roof
7. Scaffolding requirements
8. Effects of module size and number
9. Temporary roofing during construction
10. Work stoppage
11. Clearances and tolerances
12. Skilled labor required
13. Installation time
14. Stability during erection and installation
15. Extent of flashing
16. Hazardous conditions (non-electrical)
17. Electrical shock
18. Effects of rain and snow
19. Effects of sun and wind
20. Array inspection
21. Repair of module
22. Replacement of module
23. Allowance for pipe and flow penetration

CONSTRUCTION CONSIDERATIONS	SHINGLE	DIRECT PANEL	INTEGRAL PANEL
Comprehension by workmen (near term)	Drawings (layout & system schematic) and specifications necessary. Shingle type is system with some special parts. possible need for manufacturer's instruction book. Coordination with show drawings necessary. Shipment must be complete and organized on site for for correct installation. 1800 shingles is typical installation.	Bigger sizes mean fewer units and less confusion. Layout drawings simpler to understand. Fewer wiring connections mean less chance of omitting a connection.	Also applicable.
Receiving and unloading at the site.	Crates of shingle modules should be 80 lb. maximum and stiff to resist damage. All labeling should be clear and complete. Stack immediately on roof or designated storage area to reduce excessive handling. Two men per crate or hydraulic gate or fork-lift will ease unloading. Immediately inspect for damage.	More unwieldy and vulnerable to damage during unloading. Store on roof or logical storage area to prevent excessive handling.	Also applicable.
Storage of photovoltaic modules	Store under cover and away from vehicles or active materials handling areas. Store inside building. Block up 8" above floor or ground.	Store on edge in building under cover and away from active areas.	Also applicable.
Preparation of roof surface or structural support.	Planar deviation of roof sheathing not critical. Shingles are somewhat flexible. Cover plywood sheathing with one or two layers of building felts before installing modules.	Planar deviations of roof surface more critical. Shims may be necessary to correct surface.	Depending on detail, trusses must be precisely spaced. May be forcing rough carpentry into realm of unreasonable tolerances. Planar deviations in roof surface should be minimized.

CONSTRUCTION CONSIDERATIONS	SHINGLE	DIRECT PANEL	INTEGRAL PANEL
Coordination with nearby roof or wall construction	Chimneys and other roof penetration should be located on the north slope of the roof, but if this is not possible, the chimney must be bricked and flashed before installation of PV modules. Coordinate PV installation with masons.	Also Applicable	Also Applicable
Lifting and placing modules on the roof	Hoisting equipment depends on weight to be lifted. If crates of modules are too heavy to be carried up a ladder, crates should be broken on ground and only a manageable number carried up. A ladder hoist may be used or a small conveyer belt rented for a few hours. Stock flat on roof jacks.	Crane or ladder hoist needed. Unwieldy to handle while on roof. Sturdy scaffolding needed.	Without roof sheathing there is no area to stand except in attic. A crane could be used to maneuver panels in place or they can be lifted up through the attic space.
Scaffolding requirements	Roof jacks for scaffolding will probably be needed in the great majority of sloped roof applications. Jacks should be hung from ridge with special weight distributing pads to prevent glass cover breakage. Bundles of shingles should be stocked flat on scaffold near ridge or near area to be covered.	Depends on slope and weight of modules. Sheathed roof will provide opportunity for good footing and nailable surface for temporary scaffolds or roof jacks. Ground supported eave scaffold may be needed to stage modules for installation.	Working off attic floor can be a big advantage in stocking modules and positioning. Truss web members may be an inconvenience. Floor area will only be a temporary cover. Even with horizontal purlins, standing and walking over the outside of the open trusses can be hazardous.

CONSTRUCTION CONSIDERATIONS	SHINGLE	DIRECT PANEL	INTEGRAL PANEL
Effects of module size and number	1800 modules is typical installation resulting on more trips across roof surface and consequently more abuse. Each module easy to handle because of weight and size. Special edge modules will increase trips across the roof. There is a steady flow of work if the alignment is correct. With so many modules, the many inteconnections mean more chance of failure.	Good anchorage design and sealing methods could mean fast coverage with crane or good laborers. Because of fewer connections, individual worker skills are harder to build. Flow of work on each job may not be steady. Workload will fluctuate for each crew member.	Depending on details, installation sequence may be important. Work will be slower than direct mount because watertightness is critical, possibly involving extra installation steps.
Temporary roofing during construction	Roofing felts over plywood is adequate.	Roofing felts over plywood adequate.	Winter enclosure critical for housing starts in the fall. Install modules before November rains or securely rig temporary roof with plastic film or felts. Install modules in spring.
Work stoppage	Protection of leading edge, unfinished PV shingles easily accomplished. If work stops at mid-roof, protection of last installed row of shingles is easily accomplished.	1) Install modules first. If work stops, rain can flow underneath modules. 2) Flash array. 3) Shingle remaining area around array perimeter.	All open areas should be temporarily protected against water intrusion.

CONSTRUCTION CONSIDERATIONS	SHINGLE	DIRECT PANEL	INTEGRAL PANEL
Clearance and Tolerances	All alignment is determined by first row of modules at eaves. Interconnect tolerances are 0.1 inch. All modules must be identical.	Planar deviation must be small and alignment at two and four corner joints must be precise for good seal. Because of sheathing, panels and trusses do not have to be same modular spacing as modules.	Planar deviation and corner to corner alignment for good joint against water penetration. Coordinate truss spacing with panel width.
Skilled labor required	Installation by qualified electrician recommended. Installation at night recommended.	Carpenters or glazers can install and make interconnections. Can be electrically isolated allowing daytime installation.	Carpenters or glazers can install. Because of access from behind in attic, all electrical connections can be made at electrician's convenience.
Installation time	Because of 3600 electrical connections installation time is 2-3 times normal under the best conditions -- after initial layout is made. Repetitive nature of work can cause absentmindedness which cannot be tolerated here.	Size and fragility limit speed of installation. Skill levels increase more slowly. Perimeter flashing and surrounding roofing becomes a cut and fit operation.	Similar to direct mount, but more time consuming because of special care for joints and watertight integrity.
Stability during erection/installation	Plywood sheathing substrate makes entire house stiff. Minimal stability problems.	Similiar to shingle installation.	Without roof sheathing there is no diaphragm action on south side of roof. Integral modules should have diaphragm capabilities. Temporary bracing of roof rafters may be needed or light framing that ties together trusses.

CONSTRUCTION CONSIDERATIONS	SHINGLE	DIRECT PANEL	INTEGRAL PANEL
Extent of flashing	Similar to conventional roofing.	More flashing needed. Small wood curb may be needed to support perimeter flashing around array. Allow for weep holes at bottom of array.	Careful flashing necessary. Clips to receive roof flashing can be designed into details of panel system. Same amount of perimeter flashing needed as in direct mount.
Hazardous conditions (Non-electrical)	Glass cover plates are slippery and could cause falls. Danger increases with slope.	Weight and size of panels make installation awkward if work is not carefully planned. Maintaining balance will be difficult on sloping surface. Build scaffold at eaves for protection against bad falls.	Working off attic floor is a safety advantage if it is adequately covered. Working out on open trusses is dangerous. At least one hand is needed for balance. A fall, here, is limited to attic floor rather than completely off the roof.
Electrical Shock	The current and voltage level of a single shingle will not produce a noticeable shock. Shock of greater intensity is possible only by freak accident -- if a workman was grounded. This could happen if a workman was using a faulty electric drill with ground wire touching housing. Use battery power to eliminate all possibilities.	Because of size of panels a shock could be induced if a workman simultaneously grabbed a positive and negative terminal. Terminals should be shorted with a wire at the factory and then cut after final hookup, or one of the terminals should be inaccessible from outside of panel to safeguard against accidental shock.	Also Applicable

CONSTRUCTION CONSIDERATIONS	SHINGLE	DIRECT PANEL	INTEGRAL PANEL
Effects of rain and snow	Rain and snow may foul system if it is only partially installed. Wetness increases danger of falling.	Wetness causes hazardous working conditions. Small number of interconnections behind panels will probably be adequately but temporarily protected if a sudden rain storm hits.	Uncompleted sections of the roof with open trusses let the rain in. This situation must be solved if integral mounting is to become a possibility.
Effects of sun and wind	Should be installed at night. Special danger caused only by high winds.	Panels should not be installed during gusty winds. Depending on size they could pull workmen off balance if panels catch wind directly. Sun causes panels to heat up. May be a discomfort to workmen.	High winds may blow off temporary shelter. Partial array installation may be jeopardized if wind gets under the installed panels. Similar hazards as direct mount during gusty winds.
Array inspection	Scaffolds, roof jacks, and ladders must be specially designed to distribute weight across glass covers or span from panel edge to panel edge to facilitate close inspection across array area. Scaffolds should be adjustable to move up and down or across full length or width of array.	Also applicable	If panel substrate for integral panel is glass, most inspection can take place in the attic.
Repair of module	Replacement of a shingle module may be simpler and more expedient than repair.	Repair, if possible, cost is proportionate to panel size. Access to electrical connections almost impossible.	Repair if possible. Access to electrical interconnections from attic is ideal and will be a great advantage when trying to identify problems.

CONSTRUCTION CONSIDERATIONS	SHINGLE	DIRECT PANEL	INTEGRAL PANEL
Replacement of module	Replacement is possible but care and skill is needed. One man operation. Roofing nails are carefully snipped with special shears or cut with slater's tool. Interconnections which are close to nails must be preserved. A low profile socket wrench is used to reach under shingle and disconnect terminals. A new shingle is slipped into place and reconnections made. No nailing is needed.	More than one man needed. There must be adequate length of cable for interconnections so panel can be lifted and disconnection made. Breaking and remaking weather seals will be a problem.	Remove damaged panel only when replacement has been delivered. Electrical connections are no problem because of access from attic. Breaking and remaking weather seals will be problem.
Allowance for pipe and flue penetration	Keep south facing slope as free of obstructions as possible. Designing array around roofing elements is difficult if not impossible. Roof elements cause shading and therefore should be away from the modules.	Also applicable	Also applicable

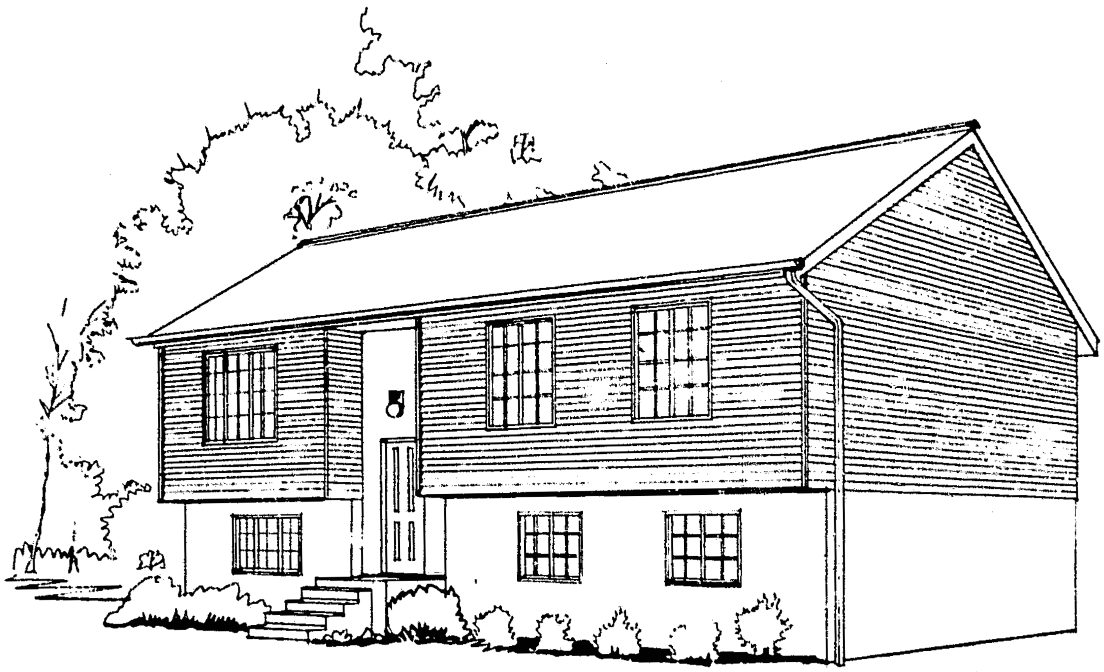
AESTHETIC CONSIDERATIONS

After the basic functional engineering requirements of a product or appliance is developed and satisfied, the design must be considered with respect to its aesthetic characteristics and marketability. The way in which aesthetics are considered in product design or in the way in which a product is incorporated into a building design is usually determined by four basic related influences:

- Intuitive Judgements
- Market Preferences
- Appropriateness
- Conservatism

Intuitive Judgements

Aesthetic choices during the design process sometimes arise from the intuitive judgements or experience of the designer. For instance, the choice of proper proportions for an object or a building are not usually made by formula, but are postulated by drawing and tested by simple inspection. The designer also knows that the relative scales of a building's masses and component parts are important. The grossest scale is the building itself, or its submasses (wings, stories, porticos or porches). The finest scaled parts are usually window mullion size. Successful composition usually balances a range of scaled parts from gross to fine to give the arrangement a fuller, more complete appearance. In the residential market, a simple example of good aesthetic judgement is the choice of narrow aluminum siding or wood clapboards over wide units on smaller homes. The scale or "texture" of horizontal lines on the wall surface is finer and more appropriate with respect to the size of the house. (Figure 17-9). The stylistic preferences of most home buyers may have a component of this type of basic intuition. For instance, the widespread use of snap-on window mullions that partition window panes may arise from a sentimental regard for Colonial impressions or from a basic feeling that the house design requires an intermediate level between window size and mullion size. Similar judgements of appropriate scale are made with respect to cedar shake siding, wood shake or various types of asphalt shingles available on the market. This concern for scale will have an impact on PV panel specification if a number of choices exist for the designer. The size of the grid pattern of the modules may be



The finer scale of clading materials is coordinated with the size of the wall areas.

Siding width and window pane areas are to large

SCALE COMPARISON OF BUILDING ELEMENTS

FIGURE 17-9

the deciding factor of one panel type over another. Photovoltaic shingle style modules also must be considered from this viewpoint.

Market Preferences

Knowing the preferences of the mass market and incorporating them into a product or building design encompasses the most important options on the field of aesthetic choices open to industrial designers and architects who may, in fact, have other tastes. Often, statistical analysis will show that tastes of the general public are not always based on costs or rational concerns. In fact, little of what is regarded as aesthetic is predicated on logic. For instance, much of the "styles" of architecture in suburbia and the commercial strip -- Colonial, Mediterranean, Spanish Mission, English Tudor -- are intended to induce fantasy rather than demonstrate the logic of construction. A more specific example of this is the garage window. It has become popular among builders to dress an integral garage with windows and curtains to create the illusion of a bigger house. This type of thinking will also have an impact on the module design. For instance, most homeowners prefer monochromatic roofs and the "polka dot" look of the current shingle module design deviates from that preferences. Even though the white insterstitial spaces along the round cells may improve electrical output, homeowners could forego the increase in efficiency for modules that match background color with PV cell material color. In the past, some asphalt shingle manufacturers have experimented with blends of higher contrast shingles but these color combinations have been eliminated from the market. The strong trend over a number of years has been toward muted tones with low contrast from shingle to shingle. The brighter colors have been eliminated in favor of shades of white, brown and black, although some greenish models are available. For instance, not one major asphalt shingle manufacturer was found to produce a blue shingle, the color of photovoltaic cells. All companies dropped that color from their lines in the early 1970's because sales were poor. From this, it is evident that the American public does not like blue shingled roofs. It is likely, however, that a photovoltaic array, when viewed from a distance, will not appear bright blue but may appear very dark or even black.

Appropriateness

The appropriate application of building products and appliances is borne out of respect for the cultural expectations ingrained in the general public. Thus, certain building products or design characteristics may imply "residential", "commercial" or "industrial". The hard, slick large-scale glass surfaces of solar thermal flat plate collectors or photovoltaic panels give them a more "commercial" impression which contrasts the softer textures and smaller scale residential walls and roof surfaces. This contrast can be noted by inspecting solar thermal arrays in operation around the country. The panels are packed into a tight array which usually has some conventional roofing surrounding it. This contrast is reinforced by the thick edge of the solar panels which are usually surface mounted rather than nested in the roof. This gives the look of an appliance. Photovoltaic panels fair better in this respect. Though surface mounted, the thinness of the panels will give a low profile and thus a more integrated appearance to the array. If the commercial look of the panels cannot be downplayed, then its detailing will have to be deftly handled by the designer. Since most of the south facing roof area will be required for the array, the photovoltaic modules and roof area should match and no narrow borders of differing roofing material used. Low profile parapet walls can be used to contain the array with a tight border. However, parapet walls are not ordinarily used as details in the mainstream of housing and other detailing methods should be devised to neatly finish the edges of the array.

Shingle type modules make stronger reference to residential roofs and therefore may seem more appropriate in the residential market. Because of this, the shingles may in fact, have a marketing advantage over panels despite other considerations, if they can be made to look more like shingles. But, the overlapping nature and similar size ends the list of similarities between photovoltaic shingles and conventional asphalt shingles. Most other visual characteristics differ, most notably the color, shape and texture. The south facing photovoltaic covered roof appearing shiny, dark bluish, and tile-like, will contrast the north slope which will probably be asphalt shingles that are matte, earth-tone and rectilinear. This difference in PV shingles and asphalt shingles can be an important one. Since the modules are shingle-like, consumers will have a basis for comparison, namely, regular asphalt or wood shingles. If the contrast is too great, the product may not gain acceptance. Panels, on the other hand, are a new product and may, in fact, gain acceptance as a novelty and thus may develop as a new aesthetic in housing.

Conservatism

It is generally true that the larger the investment an individual makes, the more conservative his attitude toward that purchase will be. Photovoltaic module design affects the appearance of the house which is directly related to its sale price. Since Americans move a number of times during their lifetime, the potential resale value of the home becomes a critical factor when choosing one home over another. Therefore, the visual characteristics of photovoltaic modules must definitely be considered if early market penetration is to be achieved.

IMPACT OF BUILDING CODES ON THE PHOTOVOLTAIC SHINGLE MODULE

Roof Coverings

Roof coverings are tested for their fire resistivity and rated according to whether they can pass one of three tests of increasing severity. These classifications, recognized among building industry officials and insurance underwriters, are labeled A, B, and C; A for resistance to severe fire exposure, B for resistance to moderate fire exposure, and C for resistance to light fire exposure. Unclassified roof coverings are those which cannot withstand the Class C test or have not been tested at all. For occupancy types or fire zones where risk of fire and panic are greater, Class A or B roofs are required in order to reduce risk. Where risk to life and property is less, Class C or unrated roofs are permitted.

The BOCA Code states that unclassified roof coverings may be used on buildings and structures of unprotected frame construction (that is, Type 4B), when the distance from any other building is not less than 12 feet. Since most one or two family dwellings fall within this exception, any type of RPM components would most probably be accepted by the Code. This study does not address townhouse or attached structure but there may be more incentive in the future to build these types of dwellings since they are energy efficient. If this trend occurs, then the code requirements for roof classifications will become more severe.

The UBC has a similar interpretation as BOCA for frame construction. Section 3203(f) lists materials which are acceptable and wood shakes and shingles are included (See Building Codes and Standards Review, Appendix 3). This suggests that RPM components could be combustible. The Standard Building Code is less specific but does not discourage the use of new materials. It also accepts wood shakes and shingles, again suggesting that RPM components could be combustible.

The National Fire Code is more stringent. It explicitly points out the fire hazards of wood shingles and shakes and specifically prohibits their use as well as other roof materials lacking a Class C rating.

Plastics are addressed separately by the three model codes, and accepts for use as roofing those materials from its list of approved plastics which are classified by their fire rating. Plastics for skylights and roofing are permitted in roofs for one and two family dwellings, but there are limitations. The maximum allowable area of plastic is usually 20 to 30% of the total floor area.

Roof Structures

Special interpretation by Code officials may be required for standoff or rack mounted modules. Since the modules mounted in these ways could not act as a roof covering, the standoff or rack mounted system may fall under the classification of a penthouse or more probably a roof structure. In some instances, a roof structure may be categorized as an additional story, thereby invoking stiffer requirements for construction type and roofing classification. These increased requirements most likely would apply only to standoff and rack mounted RPM's installed on two-story residences that are judged by code officials to be "three stories". It is unlikely that this situation would be a frequent occurrence.

Fire Ratings of Roof Coverings

For the great majority of applications, the physical composition of shingle photovoltaic modules will make little difference in that a fire rating is not ordinarily required for detached residences at least 12 feet apart. Despite this, application of the same module may be desired for a different occupancy or for use in a fire zone, and may therefore require a fire rating (determined by acceptable testing procedures). Conventional roof coverings are usually composed of layers of similar materials, forming a fairly uniform product. The shingle module currently under development is comprised of laminations of various materials both combustible and non-combustible. Making a judgement about the flame-spread of a shingle module based on its most or least combustible component has no meaning because of the test procedures incolved in the rating system. Candidates for an A, B, or C rating must withstand an intermediate flame test, a burning brand test, and a flame spread test, all of which require test samples composed of a number of shingle elements attached to wood decking representing a typical roofing installation. ASTM E-108, UL 790 and NFPA 256 tests are nearly identical and require test samples for the first two tests to be 3'-4" x 4'-4". The flame apread test requires a 4'-4" x 13'-0" sample. No single component of the roofing elements are tested separately but the entire in-place construction must withstand the test. Although PV shingle modules contain cellulosic and synthetic rubber materials which can burn, the hexagonal glass cover is the only material which is exposed on the roof surface other than the edge thickness of the flexible substrate which is ordinarily overlapped. Because of the incombustibility of the glass covers, the fire resistivity of the shingle elements could be largely enhanced. It must be recognized that the starter courses of the shingles has half hexagons of exposed hypalon. These small areas would be more vulnerable to fire and could more readily spread flame to the underlying wood deck.

The National Electrical Code

The design and materials chosen for the internal electrical conductors of the photovoltaic shingle module are out of the jurisdiction of the National Electric Code. Tests for electrical worthiness and fire safety of appliances are carried out by Underwriters Laboratories. Those appliances given U.L. labels are, in general, accepted by the NEC. The electrical connections from shingle to shingle could fall within the jurisdiction of the NEC. However, the threaded interconnects now under consideration are not addressed in the NEC Code and therefore not recognized. In addition, the exposed flat metal conductors running underneath terminals at the eaves and with the top row of positive terminals at the ridge are addressed in NEC Article 328, and are not allowed in residences. Formal interpretation regarding this specific application of flat conductor cables should be sought. (See NEC Review Article 328 for further discussion.)

MATERIALS STANDARD AND TEST METHODS FOR THE SHINGLE MODULE

Development of the photovoltaic shingle module can only advance by testing current designs, incorporating improvements suggested by test results, and then re-evaluating new designs by further testing. When the manufacturer is sufficiently satisfied with the performance of the product, he will contact one or more testing laboratories who can independently evaluate his product. If the module can withstand a series of tests established by the testing laboratories, it will gain an approval rating of the laboratory and thus become a legitimate safe product that a specification writer or designer can trust. When a new product to be introduced into the marketplace is slated for testing by a laboratory, a set of pre-established testing procedures usually cannot be applied immediately to the product. The type and methods of testing are established only through the judgement of laboratory engineers who must consider the function and the construction of the product by examining it and reviewing its intended function. The opposite is true for established products that are to be marketed by a company as a new line. For example, a new company wishing to manufacture and market asphalt shingles is entering an established competitive market whose product has established material standards and testing procedures. These standards and tests have been evolving over decades and are numerous as well as thorough in investigating all aspects of the manufacturing process. Producers of asphalt shingles who have contracted with Underwriters Laboratories or other testing groups, have an ongoing relationship with the laboratory that continues as long as the product is manufactured. Personnel from the laboratory can perform regular on-site inspections of both materials used in the product and also the process of manufacturing to ensure continuing high quality production.

No definitive set of test procedures or standards exist for new products such as the photovoltaic shingle module. These procedures would be assembled and carried out by laboratory engineers who through experience, sound judgement, and thorough inspection and understanding of the product's construction and function, propose a set of tests the product must undergo. After the request for testing has been made by the manufacturer, and the proper description of the item submitted, the manufacturer is assigned a Client Advisor who, in turn, assigns the product to the appropriate department for an initial evaluation. For instance, Underwriters Laboratories would test the shingle module in the Fire Protection Department and the Electrical Safety Department. If the product performs unsatisfactorily, design modifications are proposed or material substitutions suggested. If through subsequent testing the product performs to the satisfaction of the test officials, the test procedures are fixed and the materials and their level of quality are listed as the material standard for that model.

Some established tests are directly applicable to new products without any modifications in the procedures. For example, Underwriters Laboratories Fire Protection Department can perform two standards tests on the shingle module. The first test would be UL 790, Tests for Fire Resistance of Roof Covering

Materials. The test fixtures which hold the samples are 3'4" 4'4" or 3'4" x 10', depending on the test category and are quite adequate in size to simulate roof installation of PV shingle modules. These test methods are duplicated in NFPA 256. Another common fire test, UL 726 (ASTM E85), "Standard Method of Test for Surface Burning Characteristics of Building Materials" is not applicable to the shingle module. This test is used mostly to evaluate sheet and rolled material used on the interior surfaces of buildings. The second relevent test is UL 997, "Wind Resistance of Prepared Roof Covering Materials" (ASTM D3161). A 50 by 66 inch roof assembly is used in this procedure and can be adapted to test the effects of wind-driven rain by introducing water into the airstream.

Both the electrical components as well as the structure configuration of an electrical device are relevant to the product investigation by the Electrical Safety Department. The number and scope of test procedures can be considerably simplified if the device is constructed from previously approved components. If the conductors, plugs, switches, and terminals are adequate by previous testing, then the specific material or structural characteristics are investigated to determine if they could interfere with or damage the electrical system during normal operation and so cause risk of electrical shock or fire. In lighting fixtures, the wire entering the fixture must not abraid by contact with the sharp edges of the rough opening that accommodates the wire diameter. Usually a bushing is installed at points of penetration to protect the wire. A lack of such basic safety features in a new product will be exposed by visual examination rather than specific tests. Other standard tests may be performed on the device or entirely new tests designed and developed to evaluate the more novel features of the product.

One test that UL does not perform is a hail resistance test. The National Bureau of Standards, however, has established methods for determining the effects of hail in their test NBS-23, Hail Resistance of Roofing Materials. This standard describes methods for the manufacture of artifical hailstones to be loaded into a specially designed gun which fires them at a target of roof materials. The firing velocity is calibrated to simulate the various terminal velocities of different size diameter hailstones the roof covering may be subjected to in actual circumstances. (For further information see Appendix 20).

Temperature and humidity cycling tests (Appendix 20) are rather straightforward and would require little adaptation to accommodate the shingle module. There may be a need to determine the possibility of fungus growth around the edges of the shingle overlap or underneath the tabs. ASTM G-21, "Standard Recommended Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi" is a detailed 21-day test to determine if certain plastics will support the growth of fungus. In the case of the PV shingle module, the only materials exposed on the roof surface are the glass cover plates. It is unlikely that glass exposed to heavy UV radiation on the south slope of a roof will support fungus growth. In this instance, the concern is not with the materials involved but with fungus and the possibility of growth between the overlapping tabs. If laboratory engineers determine that such a possibility of fungus growth exists, a test procedure may have to be established that can adapt some of the ASTM-G-21 procedure.

A test of greater importance to shingle durability and longevity would be an accelerated aging or weathering test. Most conventional roofing materials are more singular in composition than the photovoltaic shingle module now under development. The difference is the variety of materials and number of laminations involved in its construction. In order to ensure that these materials and the adhesives joining them are capable of enduring long term cycles of adverse weather conditions while protecting the electrical conductors and terminals built into the shingle, ultraviolet radiation as well as air pollution tests should be carried out.

With every new product that is submitted for testing, the first investigation establishes the standards for materials of construction as well as the various tests for fire hazards or performance under normal or adverse conditions. These standards are under constant revision as materials, design, and production methods improve. While other developments are underway, certain materials produced years ago are still undergoing long term testing. For instance, fire treated wood shingles are tested at certain yearly intervals to determine if their fire retardant chemicals remain active. Asphalt shingles are tested at one, two, three, five and ten year intervals for fire resistance. It has been found that their resistance to fire improves with age.

In general, the establishment of test methods and standards cannot be carried out by simply selecting standard test numbers from a catalog supplied by the various testing laboratories. They are, first of all, decided through the judgement and experience of the laboratory engineers, and they continue to evolve as long as the product is produced and the manufacturer is under contract for ongoing inspection and testing.

The need for further product improvement may become apparent only through field experience. For instance, the resistance to snow and ice retention is difficult to simulate in a laboratory. Its impact on electrical performance may only be ascertained by exposure to snow and ice in different regions and at different degrees of slope. Such ambiguities as these will eventually be resolved throughout time by field experience, design revisions and further testing.

CONCLUSIONS

Exploration of a shingle concept in residential photovoltaics is a radical departure from flat plate module design and its associated problems of incomplete waterproofing, the weight of the individual panels and a "commercial" appearance in residential applications. The shingle module concept should imply reduced complexity, a proven watershedding method of overlapping units, and a low skill installation with easily manageable units that do not require hoisting equipment. The idea of a shingle style module also is a logical concept to develop because it could be readily accepted within mainstream building construction. However, investing the current R & D module with these characteristics has not been fully achieved.

The PV shingle designer has more than satisfied at least one requirement for weather protection. An installation of PV shingles provides triple instead of double the coverage of conventional shingles, a characteristic stemming from its hexagonal geometry. There is little doubt that these shingles will keep out the rain, although tests for wind driven rain and capillary action should be performed. In this respect, the final conclusions about PV flat plate and shingle concepts are counterposed. Large area panels may promote long term durability for PV cells, but inexpensive, dependable waterproofing at the joints is questionable. On the other hand, the shingle module, in solving the weather problem, may compromise the long-term electrical function.

Concern about the long-term success of the shingle stems from its relative small size and the durability and complexity of its construction. In a typical 1,000 ft^2 application, installers have to devote similar care to 1800 shingle modules as they would to only 63 - 48 x 48 inch or 47 - 32 x 96 inch panels. The greater number of interconnections on a shingle/module array increases the probability of failure either by omission, defective interconnect screws or busses, or by rain or ice infiltration over the years. The interconnects are not hidden deeply under the overlap, but are located near the lower edge of the overlapping shingle. To fully evaluate its long term performance, the designers should test the interaction of material durability and electrical output.

By visual inspection, it is apparent that the state-of-the-art development dilutes the strength of the original concept. Each unit is built from multiple laminations, sandwiched printed circuits or metal foil, and electrical terminals embedded in the flexible tab. Although the manufacture of the shingles can be rationalized by assembly line procedures, a lot of material and process steps have been devoted to producing and supporting a small active area of photovoltaic material. This inefficiency of size may extend to the field where the roof area could be covered more quickly if the modules were larger. The length of a shingle module could double and still be manageable, yet the active PV area could quadruple. This line of reasoning, however, does not necessarily hold true for roofing materials. Labor costs per ft^2 for installing wood shakes with individual exposed tab areas of 40 $inch^2$ are only slightly higher than labor costs for asphalt shingles with individual exposed tab areas of 216 $inch^2$. Slate shingle labor costs are nearly two and one half times higher. Other factors may be more critical than size such as weight and fragility of the units or the connection method as may be the case with the R & D shingle module. Unless other electrical connection is devised, the 3600 threaded interconnections in a typical residential application will probably hinder the speed of installation and costs will be prohibitive.

These conclusions are based on analysis of a product in its early stages of development. After successful functional testing, its fitness as a marketable competitive product will determine the extent of its application in the residential building market.

APPENDIX 18. RETROFIT APPLICATIONS

PURPOSE: Investigation of potential problems that may arise in retrofit applications for photovoltaic arrays was undertaken.

CONCLUSIONS: Each of the array mounting techniques has its own set of installation problems for retrofit applications. Most restrictive is perhaps the rack mounting technique for rooftop applications. Severe point stress problems may arise when attempting to use rack mounts on conventional roofs. Rack mounts may best be applied to flat roofs. Aesthetic considerations may require the addition of more living or work space, or extension rework of the existing structure to accommodate to proper integration of a PV array. Module weight should not present problems in retrofit applications, as typical roofing tiles and slate weigh in the range of 10-20 $lbs/ft.^2$ -- considerably less than typical PV modules. Area limitations will impose design restriction on PV retrofit applications. Individual applications must be examined for their own merits or problems.

RECOMMENDATIONS: Before attempting to design PV arrays for retrofit applications, extensive evaluation of the existing roof structures should be made in order to ensure the original design limits are not exceeded.

INTRODUCTION

The number of new homes being constructed in the United States every year is only a small percentage of the total number of existing homes. Since there are a large number of existing residences throughout the country, consideration must be given to module design requirements for retrofit applications. Examination of the millions of existing residences will show that a very small number are suited for the immediate application of photovoltaic modules. Although not serious, special problems do exist in the retrofit applications market, and consideration of these problems must be addressed.

General Description

The orientation of the photovoltaic modules is critical. Because of this, two restrictions become readily apparent in the retrofit market. First, the need for a southerly exposure; and second, the need for a proper tilt angle. The restrictions are probably the major problem in the photovoltaic retrofit market.

An examination of the four mounting types to the retrofit problem indicates that the problem can be overcome. Use of certain mounting types is one solution. But, in the long run, special installation systems for the integration of a solar system into a new or existing home which lack proper orientation or do not adapt easily to solar installations must be developed. Using the assumptions generated in the panel size and shape study (Appendix 14), consideration can now be given to the individual mounting techniques.

1. Rack mount, ground support: Due to the flexibility of this mounting technique, it is well suited for retrofit applications. Being located away from the structure and having its own structural system allows for any orientation and tilt angle to be achieved. However, problems using this technique are space, zoning ordinances and aesthetics, which may preclude the use of rack mounted support arrays.

   Rack mount, roof or deck support: Flat roofs are best suited for rack mounted rooftop arrays. This limits their use to residences located primarily in the southwestern part of the country. Structural problems may arise when placing rack mounted arrays on roofs. Severe point loading conditions may be encountered and close attention must be given to the design and possible redesign of roofing structural members. Flashing and waterproofing will be a problem and detailing of these areas must be given extensive evaluation.

2. Standoff mount: This mounting technique adapts itself well to retrofit applications. The problem of tilt angle is easy to overcome using this technique is that of tilt angle and orientation to a southerly exposure is not a major problem, provided that the angle from south is small. This technique may be aesthetically undesirable. Due to its likeness to rack mounting, similar problems exist.

Although, the structural members of the standoff array will impose less dead loading than with rack mounting.

3. Direct Mount: This technique, the direct application of PV module to the roof structure, does not lend itself well to retrofit applications where the roof is not facing south. In order to use direct mounted modules in a retrofit application, additional structure may be added to the existing building to accommodate tilt and orientation. This method is feasible and will be discussed later. On conventional sheathed roofs the installation of direct mounted arrays should impose no special requirements on the structural characteristics of the roof. For roofs without sheathing, those with perlins and tile, special modules may be required. However, weight will not be an overriding criteria, as typical tiles weigh in the range of 10-20 $lbs/ft.^2$ which is considerably less than a typical PV panel. Retrofit applications which utilize roofs constructed of tiles hung on perlins are specially suited to PV application if tilt angle and orientation are acceptable. Tiles could be replaced directed with specially designed PV modules. Module weight should not pose limitations as the tiles it will replace are two to three times heavier.

4. Integral Mount: The same problems that arose with the direct mount system can be expected with the integral mount technique. Additional shear bracing is also required which may rule out this approach except in special retrofit cases (complete remodeling).

<u>Addition Retrofit Systems</u>. Use of an addition such as a garage allows for the integration of a solar system into either new or existing homes which lack proper orientation, tilt, or do not adapt easily to solar installations. In such cases, the garage retrofit system would be able to assume the proper tilt, location, and orientation and would be adaptable to a variety of situations. The array can vary in size to meet a specified load demand and can utilize any of the four mounting techniques. The garage lends itself well to the installation of the PV array and all the variety of array options since it is a relatively open structure and does not produce some of the problems of instal-

lation and operation common to a residence. There are disadvantages, however. Often, additions such as garages are not possible due to land availability problems, or perhaps a garage already exists precluding the necessity for a second garage. However, this addition need not be limited to a garage space. Another and perhaps more critical disadvantage is the array area limitation, which may be experienced by a small addition.

Addition Options. The following options describe the way in which a standard garage addition may be modified to increase available roof area. Options include an addition with no increase to the roof area, an extension to the roof area, a side addition, and a combination of roof extension and side addition.

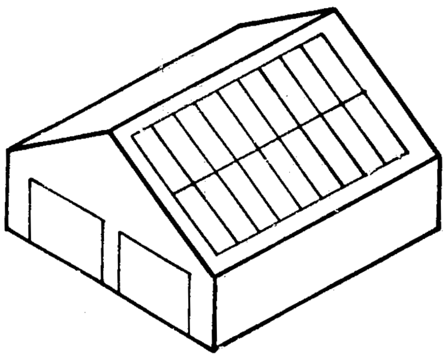
Option one, as seen in Figure 18-1, is a retrofit system requiring a minimum of construction. As seen, this option will allow 18 panels, 32x96 inch, without relying on additions or extensions of the garage roof area. This option would only yield 384 ft^2 of panel area, much less than the required 1,000 ft^2. If this addition is a garage, vehicular access is possible on all four sides.

Option two is a retrofit system containing 27 panels, 32x96 inch, an increase of 60% over option one through addition of a roof extension. This option yields 576 ft^2 of panel area, again much less than the required 1,000 ft^2. Vehicular access is again possible on all sides.

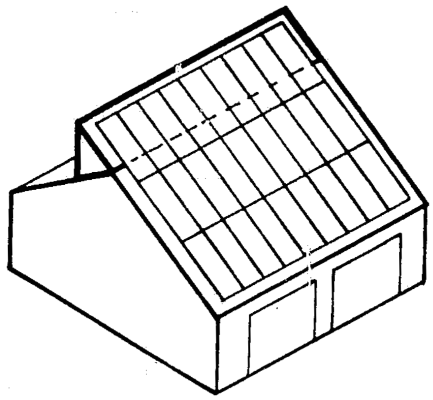
Option three is a retrofit system also containing 27 panels, 32x96 inch, by the installation of a side addition. However, by further extending this addition, 36 panels can be installed on the roof, giving 768 ft^2 of array area. Access to the garage will be limited to three sides, with no access on the south facade.

Option four is a retrofit system containing 36 panels, 32x96 inch. This increase is achieved by a roof extension and the installation of a side addition. By extending both additions, 54 panels, 32x96 inch, can be added to the roof structure yielding 1152 ft^2 of array area. This is in excess of 1,000 ft^2 requirement. This option would contain the largest array in the four options which meets the required 1,000 ft^2,200 Vdc requirement.

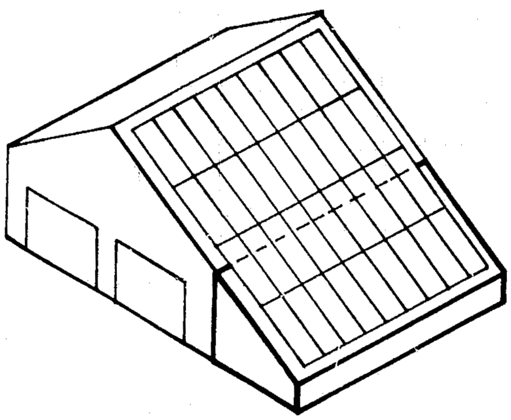
All the options and their various relationships to the adjoining residence are illustrated in Figure 18-2.



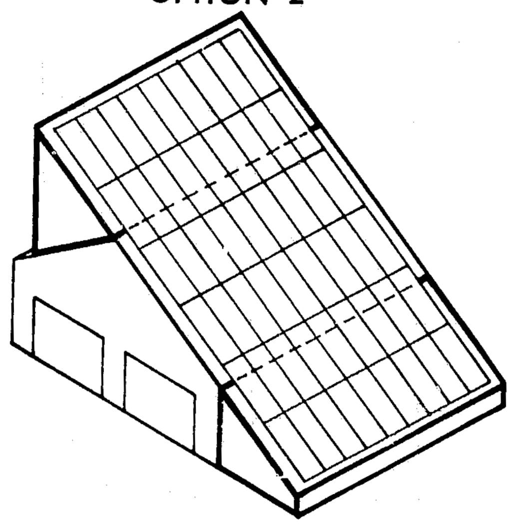
OPTION 1



OPTION 2

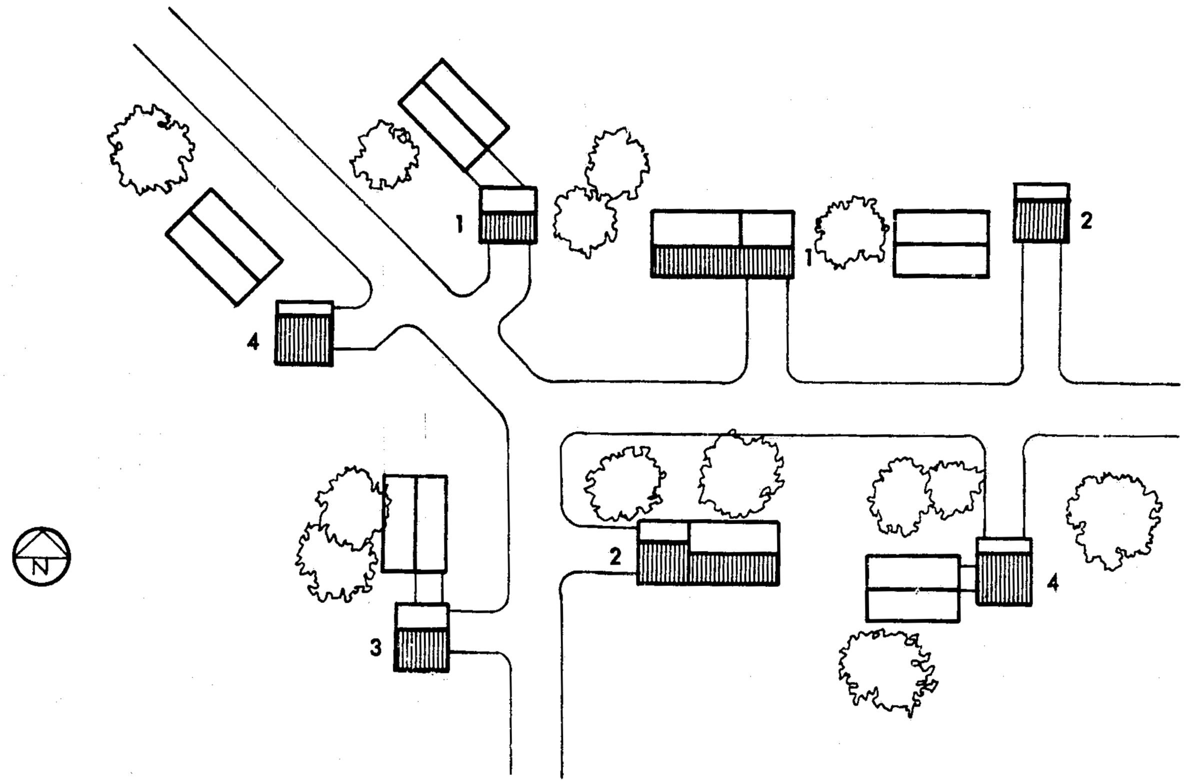


OPTION 3



OPTION 4

FIGURE 18-1



GARAGE RETROFIT LOCATION ON OPTIONS FOR THE RPS

FIGURE 18-2

APPENDIX 19. RESIDENTIAL PHOTOVOLTAIC MODULE PERFORMANCE CRITERIA

PURPOSE: The Residential Photovoltaic Module Criteria was developed to act as a guideline for the development of residential module requirements and also to act as a first draft of a future residential photovoltaic systems performance criteria document - this document covers the photovoltaic module only.

CONCLUSIONS: The need for a residential photovoltaic systems performance criteria document exists and the immediate development of such a document should be undertaken in order to ensure module and system performance, while not hindering product development.

RECOMMENDATIONS: A residential photovoltaic module performance criteria or more importantly a residential photovoltaic systems performance criteria should be developed in the very near future.

INTRODUCTION

The Interim Performance Criteria (RPMPC) document was drafted to outline all of the specific market related concerns the module manufacturer must resolve if he is going to produce a successful residential module. This document does not prescribe but instead references tests that determine compliance of the module to existing codes and standards. These tests, because they are not incorporated in the body of the RPMPC, can be updated as both the module and market mature. The RPMPC is not a final document but is, therefore, the first outline of an evolving study to be completed as both the module and the market mature.

RPMPC TABLE OF CONTENTS

RESIDENTIAL P. V. MODULE PERFORMANCE CRITERIA SUMMARY

APPLICATION

A - Applicable To Type Mounting Indicated
NA - Not Applicable

MOUNTING TYPE

R - Rack
S - Stand-Off
D - Direct
I - Integral

Residential Performance Criteria Paragraph	Mounting Type				Residential Performance Criteria Paragraph	Mounting Type			
	R	S	D	I		R	S	D	I
1.1.1 Nominal Operating Cell Temperature	A	A	A	A	2.1.1 Electrical Codes and Standards	A	A	A	A
1.1.2 Electrical Design Output	A	A	A	A	2.1.2 Safety and Health Standards	A	A	A	A
1.1.3 Minimum Power Output	A	A	A	A	2.2.1 Module Failure Prevention	A	A	A	A
1.2.1 Electrical Losses	A	A	A	A	2.3.1 Fire Codes and Standards	A	A	A	A
					2.3.2 Penetrations through Fire Rated Assemblies	A	NA	NA	NA
					2.3.3 Firestopping	NA	NA	A	A
					2.3.4 Protection Against Auto Ignition of Combustibles	A	A	A	A
					2.3.5 Integrated Construction	NA	NA	NA	A
					2.3.6 Penetrations	NA	NA	NA	A
					2.3.7 Roof Coverings	NA	A	A	A
					2.3.8 Flame Spread	A	A	A	A
					2.4.1 Generation of Smoke and Toxic Fumes	A	A	A	A

TABLE 19-1

RESIDENTIAL P. V. MODULE PERFORMANCE CRITERIA SUMMARY									
APPLICATION A - Applicable To Type Mounting Indicated NA - Not Applicable					**MOUNTING TYPE** R - Rack S - Stand-Off D - Direct I - Integral				
Residential Performance Criteria Paragraph	Mounting Type				Residential Performance Criteria Paragraph	Mounting Type			
	R	S	D	I		R	S	D	I
2.4.2 Flammable Materials	A	A	A	A	3.1.1 Dimensional Compatibility	NA	NA	NA	A
2.6.1 Protection from Heated Components	A	A	A	A	3.2.1 Vibration	A	A	A	A
2.7.1 Electrical Grounding and Safety	A	A	A	A					
2.8.1 Lightning Protection	A	A	A	A					

TABLE 19-2

RESIDENTIAL P. V. MODULE PERFORMANCE CRITERIA SUMMARY

APPLICATION

A - Applicable To Type Mounting Indicated
NA - Not Applicable

MOUNTING TYPE

R - Rack
S - Stand-Off
D - Direct
I - Integral

Residential Performance Criteria Paragraph	Mounting Type			
	R	S	D	I
4.1.1 Appliable Standards	A	A	A	A
4.1.2 Service Loads				
4.1.2.1 Dead Loads	NA	NA	NA	A
4.1.2.2 Live Loads	A	A	A	A
4.1.2.3 Wind Loads	A	A	A	A
4.1.2.4 Earthquake Loads	A	A	A	A
4.1.2.5 and 4.1.2.6 Constraint Loads	A	A	A	A
4.1.2.7 Ice Loads	A	A	A	A
4.1.2.8 Hail Loads	A	A	A	A
4.1.3 Maintenance Loads	NA	A	A	A
4.2.1 Resistance to Damage	A	A	A	A
4.3.1 Ultimate Load Combinations	NA	NA	NA	A

Residential Performance Criteria Paragraph	Mounting Type			
	R	S	D	I
5.1.1 Electrical Transport	A	A	A	A
5.1.2 Electrical Compatibility	NA	NA	A	A
5.2.1 Electrical Codes and Standards	A	A	A	A

TABLE 19-3

RESIDENTIAL P. V. MODULE PERFORMANCE CRITERIA SUMMARY

APPLICATION

A - Applicable To Type Mounting Indicated
NA - Not Applicable

MOUNTING TYPE

R - Rack
S - Stand-Off
D - Direct
I - Integral

Residential Performance Criteria Paragraph	Mounting Type				Residential Performance Criteria Paragraph	Mounting Type			
	R	S	D	I		R	S	D	I
6.1.1 Solar Degradation	A	A	A	A	7.1.1 Access for Maintenance	NA	A	A	A
6.1.2 Moisture	A	A	NA	NA	7.1.2 Impairment of Operation	A	A	A	A
6.1.3 Airborne Pollutants	A	A	A	A	7.2.1 Installation Instructions	A	A	A	A
6.1.4 Dirt Retention on Cover Plate Surface	A	A	A	A	7.2.2 Maintenance and Operation Instructions	A	A	A	A
6.1.5 Abrasive Wear	A	A	A	A	7.2.3 Maintenance Plan	A	A	A	A
6.1.6 Fluttering by Wind	A	A	NA	NA	7.2.4 Replacement Parts	A	A	A	A
6.1.7 Humidity	A	A	A	A	7.3.1 Servicing of P.V. Modules	A	A	A	A
6.1.8 Fungus Resistance	A	A	A	A	7.4.1 Labeling	A	A	A	A
6.1.9 Ice Dams and Snow Buildup	NA	NA	A	A	7.4.4 Technical Data Sheets	A	A	A	A
6.2.1 Thermal Degradation	A	A	A	A					
6.2.2 Thermal Cycling	A	A	A	A					
6.2.3 Transmission Losses Due To Outgassing	A	A	A	A					

TABLE 19-4

1. REQUIREMENTS: FUNCTION

1.1 MODULE PERFORMANCE

The module shall be capable of absorbing solar energy and converting it into electrical energy.

1.2 ENERGY TRANSPORT PERFORMANCE

The electrical transport components of the module shall transfer the required electrical energy at or above the design efficiency under full load conditions.

1.1	REQUIREMENT	PV MODULE PERFORMANCE. The module shall be capable of absorbing solar energy and converting it into electrical energy.
1.1.1	CRITERION	NOMINAL OPERATING CELL TEMPERATURE The PV Module's nominal operating cell temperature (NOCT) shall be determined when the following condition set forth in Appendix 1-A and stated where indicated in this document.
	EVALUATION	Review of drawings, specifications and calculations. Documentation will be obtained as outlined in Section 2 of Appendix 1-A.
	COMMENTARY	Since power output is directly related to operating or testing temperature, it is important to determine the nominal operating cell temperature in order to standardize or normalize power data.
1.1.2	CRITERION	ELECTRICAL DESIGN OUTPUT. The PV Module shall have an electrical power output rated at Air Mass 1.5 (100 mw/cm^2 or AM 1.5) and at the nominal cell operating temperature. The nominal cell operating temperature shall be determined for the particular module to roof mounting design.
	EVALUATION	Review drawing, specifications and calculations. Documentation will be obtained by utilizing the test procedure outlined in Section 1 of Appendix 1-A.
1.1.3	CRITERION	MINIMUM POWER OUTPUT. Manufactured PV Modules shall produce no less than 90% of the value as determined in Criterion 1.1.2.
	EVALUATION	Utilize the procedure as established in Criterion 1.1.2.
1.2	REQUIREMENT	ENERGY TRANSPORT PERFORMANCE. The electrical transport components of the module shall transfer the required energy at or above the design efficiency under full load conditions.

1.2.1	CRITERION	<u>ELECTRICAL LOSSES</u> Electrical losses shall not exceed the design values throughout the operating range or service life of the module.
	EVALUATION	Review of drawings, specifications, and calculations and test results.

APPENDIX 1-A

ELECTRICAL PERFORMANCE

Electrical performance measurements shall be referenced to Standard Operating Conditions (SOC) defined as 100 mW/cm^2 AM1.5 irradiance, Nominal Operating Cell Temperature. All procedures, equipment and standards related to measurements, shall conform to the latest revision to date of the contract of NASA TM 73702, Terrestrial, Photovoltaic Measurement Procedures, dated June 1977. The reference cell shall be the only irradiance used. Secondary standards or transfer modules shall not be used.

To provide for efficient module testing, module performance may be based on module output at either SOC conditions or at Optional Test Conditions (OTC) defined as 100 mW/cm^2 irradiance, and a cell temperature other than NOCT. When measurements are made at OTC, the power output (P) at NOCT cell temperature shall be determined as follows:

$$P = V_{NO} \, (I_{OTC} + I)$$

where

V_{NO} = Module nominal operating voltage at NOCT

I_{OTC} = Module current measured at OTC and at a voltage equal to (V_{NO} + V) volts.

I = Current temperature correction

= I@ (NOCT, V') - I @ (OTC, V = V + V)

V = Voltage temperature correction

= V @ (OTC, I = I' - I - I) - V @ (NOCT, I')

V' = Voltage 0.6 V_{oc} @ NOCT

I' = Current 0.9 I_{sc} @ NOCT

V_{oc} = Open circuit voltage

I_{sc} = Short circuit current

Determination of the temperature correction factors, I and V, in the above equation shall be based on actual measurements of a minimum of five prototype modules at both Optional Test Conditions and NOCT ± 2° cell temperature. The current-voltage (I-V) characteristics of each module shall be measured at both conditions. The corresponding I-V curves for the two temperatures may then be overpayed to determine the correction factors. A simultaneous translation of the curves along both current and voltage axes may be made until an accurate match of the curves is accomplished at two points near the maximum power point. The OTC curve should match the NOCT curve at a point where the NOCT current is approximately 90% of I_{sc} (I'), and at a second point where the NOCT voltage is approximately 60% of V_{oc} (V'). The current and voltage shift required to produce the curve match shall be determined for the exact cell temperature difference between tests. The change per degree C for each factor is then calculated and multiplied by the difference between NOCT and the temperature used for OTC. The resulting I and V shall be averaged for the modules tested to establish temperature correction factors to be used when testing modules at other than SOC. Alternate temperature correction procedures such as that provided by computer controlled Large-Area pulsed Solar Simulator (Xenon source) may be used.

APPENDIX 1-B

NOMINAL OPERATING CELL TEMPERATURE - RACK MOUNTED

1. PURPOSE

The purpose of this test is to acquire sufficient data to allow an accurate determination of the nominal operating temperatures of the solar cells of a terrestrial solar array module.

By definition, the original JPL Nominal Operating Cell Temperature (NOCT) is the module cell temperature under operating conditions in the Nominal Thermal Environment (NTE) which is defined as:

Insolation = 80 mW/cm^2

Air Temperature = 20^{o}C

Wind Average Velocity = 1 m/s

Mounting = Tilted, Open Back, Open Circuit

The NOCT test procedure is based on gathering actual measured cell temperature data via thermocouples attached directly to the cells of interest, for a range of environmental conditions similar to the NTE. The data is then presented in a way that allows accurate and repeatable interpolation of the NOCT temperature.

2. DETERMINATION OF NOCT

The temperature of the solar cell (T_{cell}) is primarily a function of the air temperature (T_{air}), the average wind velocity (V), and the total solar insolation (L)impinging on the active side of the solar array module. The approach for determining NOCT is based on the fact that the temperature difference (T_{cell} - T_{air}) is largely independent of air temperature and is essentially linearly proportional to the insolation level. Analyses indicate that the linear assumption is quite good for insolation levels greater than about 40 mW/cm^2. The procedure calls for plotting (T_{cell}-T_{air}), against the insolation level for a period when wind conditions are favorable. The NOCT value is then determined by adding T_{air} = 20^{o}C to the value of T_{cell}-T_{air}) interpolated for the NTE insolation level of 80 mW/cm^2, i.e., NOCT = T_{cell}-T_{air}) NTE + 20^{o}C.

The plot of T_{cell}-T_{air}) vs L shall be determined by conducting a minimum of two field tests in which the module being characterized is tested under terrestrial environmental conditions approximating the NTE in accordance with the testing guidelines which follow. Each test shall consist of acquiring a semicontinuous record of (T_{cell} -T_{air}) over a one- or two-day period, together with other measurements as required to characterize the terrestrial environment during the testing period. Acceptable data shall consist of measurements made when the average wind velocity is 1 m/s ± 0.75 m/s and with gusts less than 4 m/s for a period of 5 minutes prior to and up to the time of measurement. Local air temperature during the test period shall be 20^{o}C ± 15^{o}C. Using only acceptable data as so defined, a plot shall be constructed from a set of measurements made either prior to solar noon or after solar noon which defines the relationship between T_{cell} -T_{air}) and the insolation level (L) for L 40 mW/cm^2*.

When $(T_{cell}-T_{air})$ is plotted as a function of L for average wind velocities less than 1.75 m/s, results similar to those shown in Figure 4-1 are obtained. For the data shown, the local air temperature was 15.6°C ± 4.5°C and the wind speed varied from zero to less than 4 m/s with an average of 1 m/s. Using the plot of $(T_{cell}-T_{air})$ vs L, the value of $(T_{cell}-T_{air})$ at NTE is determined by interpolating the average value of $(T_{cell}-T_{air})$ for L = 80 mW/cm^2. Using the data in Figure 4-1 as an example, $(T_{cell}-T_{air})$ at NTE is determined to be 20.2°C. The preliminary value of NOCT is thus 20.2°C + 20°C = 40.2°C.

3. AIR TEMPERATURE AND WIND CORRECTION

A correction factor to the preliminary NOCT for average air temperature and wind velocity is determined from Figure 4-2. This value is added to the preliminary NOCT and corrects the data to 20°C and 1 m/s. $\overline{T}_{air}$ and $\overline{V}$ are the average temperature and wind velocity for the test period.

For the test data shown in Figure 4-1, $\overline{V}$ is 1 m/s and $\overline{T}_{air}$ is 15.6°C. From Figure 4-2, the correction factor is 0°C. The NOCT is therefore 40.2°C.

*The two sets of measurements can be combined into a single set provided the average air temperature of the two sets does not differ by more than approximately 5°C. If the average air temperature is sugnificantly different, the resulting effect appears as an increase in the scatter of the plotted data. As a result the data will be more difficult to fit and a less accurate result is possible.

4. TEST GEOMETRY

a. Tilt Angle. The plane of the module shall be positioned so that it is normal to the sun (±5°) at solar noon.

b. Height. The bottom edge of the module shall be 2 feet or more above the local horizontal plane or ground level.

c. Panel Configuration. The module shall be located in the interior of a 1.2 m x 1.2 m (4 ft. x 4 ft.) panel. Black aluminum panels or other modules of the same design shall be used to fill in any remaining open area of the panel structure. The back of the panel shall be exposed.

d. Surrounding Area. There shall be no obstructions to prevent full irradiance of the module beginning a minimum of 4 hours before solar noon and up to 4 hours after solar noon. The ground surrounding the module shall not have a high solar reflectance and shall be flat and/or sloping away from the test fixture. Grass and various types of ground covers, blacktop, and dirt are recommended for the local surrounding area. Buildings having a large solar reflective finish shall not be present in the immediate vicinity. Good engineering judgement shall be exercised to ensure that the module, both front and back sides, is receiving a minimum of reflected solar energy from the surrounding area.

e. Wind Direction. The wind shall not be predominantly from due east or due west; flow parallel to the plane of the array is not acceptable and can result in a lower-than-typical operating cell temperature.

f. Module Electrical Load. Data shall be obtained for a module open-circuit condition corresponding to zero electrical power output.

5. TEST EQUIPMENT

a. Pyranometer. The total solar irradiance on the active side of the module shall be measured by a pyranometer mounted on the plane of the module and within 0.3 m (1 foot) of the array. The pyranometer used shall have a traceable annual calibration to a recognized standard instrument and shall be either (1) a temperature-compensated unit which has less than ± 1% deviation in sensitivity over the range -20°C to +40°C, or (2) a unit which incorporates a temperature sensor and has a sensitivity-temperature correction supplied with its calibration.

b. Wind Measurement. Both the wind direction and wind speed shall be measured at the approximate height of the module and as near to the module as feasible.

c. Air Temperature. The local air temperature shall be measured at the approximate height of the module. The measurement shall be made in the shadow of the module and shall be accurate to ±1°C. (Note: An average local air temperature is desired. This is obtained satisfactorily by increasing the thermal mass of the thermocouple by imbedding the thermocouple in a solder sphere of approximately 1/4-inch diameter). The measurement must be appropriately shielded and vented.

d. Cell Temperature. The temperature of at least two representative interior solar cells shall be measured to ±1°C. Thermocouples shall be 36 gauge, and shall be soft-soldered directly to the back of the cells.

e. Substrate Surface Temperature. The exterior temperature of the rear of the solar module shall be measured to ±1°C beneath a representative cell and when practical beneath a representative space between cells. Thermocouples shall be 26 gauge, and shall be bonded down with 57-C epoxy or the equivalent.

6. DATA RECORDING

All data shall be printed out approximately every 2 minutes. In addition, solar intensity, wind speed, wind direction, and air temperature shall be continuously recorded.

7. CLEANING

The active side of the solar cell module and the pyranometer bulb shall be cleaned before the start of each test. Dirt shall not be allowed to build up. Cleaning with a mild soap solution followed by a rinse with distilled water has proven to be effective.

8. EQUIPMENT CALIBRATION

A calibration check shall be made of all the equipment prior to the start of the test.

2. REQUIREMENTS: SAFETY

2.1 HEALTH AND SAFETY. The design and installation of the P.V. Module shall be in accordance with applicable local and nationally recognized codes and standards.

2.2 FAIL-SAFE CONTROL. The module shall be fail-safe for operation under all anticipated conditions and in the event of damage.

2.3 FIRE SAFETY. The design and installation of the P.V. Module shall provide a level of fire safety consistent with applicable codes and standards.

2.4 TOXIC AND FLAMMABLE MATERIALS. The materials used in the P.V. Module shall not expose the installers or building occupants to hazards related to toxicity or flammability.

2.5 EXCESSIVE SURFACE TEMPERATURE. The P.V. Module shall not create a hazard to people due to excessive exterior surface temperatures, excessive being defined as 140°F (60°C) or above.

2.6 ELECTRICAL SHOCK. The module shall be designed to prevent shock hazard during installation and during normal and abnormal operation. Shock hazard must also be minimized in the event of natural or man-made disaster or accident.

2.7 SAFETY OF BUILDING AND SITE. The safe operation of the building or site shall not be affected by the P.V. Module.

2.1 SAFETY

HEALTH AND SAFETY. The design and installation of the P.V. Module shall be in accordance with applicable local and nationally recognized codes and standards.

2.1.1 CRITERION

ELECTRICAL CODES AND STANDARDS. Electrical materials and equipment and their installation shall be in accordance with applicable local and nationally recognized electric codes [1]*and with applicable standards of ANSI, NEMA, and UL. Electrical components, wiring, switching and protective devices shall be approved or listed by a nationally recognized testing laboratory.

EVALUATION

Review of drawings, specifications and testing to show compliance where necessary. Certifications from approved labs should be displayed.

COMMENTARY

Suitable standards are available for conventional equipment. Unique installation may require special consideration.

2.1.2 CRITERION

SAFETY AND HEALTH STANDARDS. The installation of the P.V. module shall comply with the Occupational Safety and Health Administration (OSHA) Standards [2].

EVALUATION

Review of drawings and specifications, inspection of construction site.

COMMENTARY

OSHA standards will apply mainly to the on-site construction and installation procedures surrounding the module. However, the manufacturer must be careful in his module design to assure that the OSHA standards can be adhered to with his particular module.

2.2 REQUIREMENT

FAIL-SAFE CONTROL. The P.V. module shall be fail-safe for operation under all anticipated conditions and in the event of damage to system components.

*References are indicated in brackets.

2.2.1 CRITERION

MODULE FAILURE PREVENTION. The module shall be designed to eliminate the possibility of damage to the system in the event of module failure. The device shall meet the requirements of one or more of the following organizations: NFPA, ASME, UL.

EVALUATION

Review of Drawings, Specifications and Design Calculations.

COMMENTARY

The excessive temperature and reverse biasing that may occur under shading or damage are important considerations. Considerations should be given during module design, as well as system design, to thermal shock which may cause cell damage in the event of module damage or failure.

2.3 REQUIREMENT

FIRE SAFETY. The design and installation of the P.V. Module shall provide a level of fire safety consistent with applicable codes and standards.

2.3.1 CRITERION

FIRE CODES AND STANDARDS. Modules and materials and their installation shall be in accordance with local and nationally recognized codes and standards for fire safety.

EVALUATION

Review of drawings and specifications for conformance with the local and nationally recognized codes and standards for fire safety including but not limited to applicable sections of NFPA 256 [3] and the National Electrical Code [1]. In cases where sufficient engineering information is not available, testing to show compliance may be required. Potential heat, rate of heat release, ease of ignition, and smoke generation will be considered in assessing potential fire hazards.

2.3.2 CRITERION

PENETRATIONS THROUGH FIRE-RATED ASSEMBLIES. Penetrations through fire-rated walls, partitions, floors, roofs, etc., shall not reduce the fire resistance required by local codes and ordinances.

EVALUATION

Review of drawings and specifications testing to show compliance in accordance with NFPA 251 4 .

COMMENTARY

It is the intent of this criterion to (1) prevent the passage of the module compartments through fire-rated assemblies from adversely affecting the fire endurance rating of the assembly, causing premature collapse of structural elements, and (2) ensure that proper techniques are employed in constructing these components so that adequate protection can be provided.

2.3.3 CRITERION

FIRESTOPPING. P.V. Modules that are integral parts of assemblies which normally require firestopping shall be firestopped on all sides. Firestopping shall be wood blocking of minimum 2 in. (5 cm) nominal thickness or of non-combustible materials providing equivalent protection.

EVALUATION

Review of drawings and specifications.

COMMENTARY

It is the intent of this criterion to ensure that P.V. Modules do not reduce the effectiveness of firestopping. For example, in the case where a module is an integral part of a wood framed wall which would normally be firestopped between studs, firestopping will be required in the wall above and below the P.V. Module.

2.3.4 CRITERION

PROTECTION AGAINST AUTO-IGNITION OF COMBUSTIBLES. Combustible solids used in P.V. modules shall not be exposed to elevated temperatures which may cause ignition.

EVALUATION

Review of calculations, drawings and specifications. Testing to show compliance where necessary.

COMMENTARY

Exposure of plastics as well as other combustible materials over an extended period of time result in the material reaching and surpassing its auto-ignition temperature. The ignition temperature of plastics may be above or below those of cellulosic materials. The most commonly accepted ignition temperature of wood is 392°F (200°C). However, studies have indicated that wood may ignite when exposed to a temperature of 212°F (100°C) for prolonged periods.

2.3.5	CRITERION	INTEGRATED CONSTRUCTION. The incorporation of P.V. Modules shall not reduce the fire resistance ratings required by MPS HUD 405-4 [5].
	EVALUATION	Evaluation of drawings and testing of materials. Compliance with ASTM E119 [6].
	COMMENTARY	Roof-mounted P.V. Modules which are an integral part of the roof construction shall not reduce the fire resistance rating of the roof assembly. Fire resistance ratings shall be determined by ASTM E119 test. Where E119 test results are not available a comparable test may be used.
2.3.6	CRITERION	PENETRATIONS. Penetrations through fire-rated assemblies shall not reduce the fire-resistance ratings as determined by ASTM E119.
	EVALUATION	Review of drawings and specifications.
2.3.7	CRITERION	ROOF COVERINGS. Installation of P.V. Modules on or as an integral part of the roof shall not reduce the fire retardant characteristics of the roof covering.
	EVALUATION	Review of drawings and specifications.
2.3.8	CRITERION	FLAME SPREAD. All materials in a P.V. Module shall be classified and meet codes pertaining to flame spread.
	EVALUATION	Review of specifications and tests.
	COMMENTARY	The ASTM E84 [7] flame spread test method shall be the basis for the evaluation of surface burning characteristics of module materials.
2.4	REQUIREMENT	TOXIC AND FLAMMABLE MATERIALS. The materials used in P.V. Modules, shall not expose the installer or building occupants to hazards related to toxicity or flammability.

2.4.1	CRITERION	<u>GENERATION OF SMOKE AND TOXIC FUMES.</u> The modules shall be designed to utilize material that in the presence of fire does not endanger the building occupants with excessive levels of smoke or toxic gasses, in accordance with nationally recognized codes.
	EVALUATION	Review of specifications and tests.
	COMMENTARY	Where adequate information is not available, ASTM E84 test or its equivalent shall be used.
2.4.2	CRITERION	<u>FLAMMABLE MATERIALS</u>. The design of the module shall, with regard to flammability of materials, be in accordance with nationally recognized codes.
	EVALUATION	Review of drawings and specifications.
	COMMENTARY	Where adequate information is not available, UL 263 [8] or its equivalent shall be used.
2.5	REQUIREMENT	<u>EXCESSIVE SURFACE TEMPERATURES</u>. P.V. Modules shall not create a hazard to people due to excessive exterior surface temperatures.
2.5.1	CRITERION	<u>PROTECTION FROM HEATED COMPONENTS</u>. Module components that are accessible or located in areas normally subjected to public traffic areas and which are maintained at elevated temperatures (temperatures in excess of 140°F or 60°C) shall be suitably isolated. Any surface which cannot be isolated shall be identified with appropriate warnings.
	EVALUATION	Review of drawings and specifications.
2.6	REQUIREMENT	<u>ELECTRICAL SHOCK HAZARD</u>. The P.V. Module shall be designed to prevent shock hazard during installation and during normal operation. In the event of emergencies, the life safety hazards which could occur as a result of a failure of the P.V. Module shall not be greater than those imposed by conventional electrical systems.
2.6.1	CRITERION	<u>ELECTRICAL GROUNDING AND SAFETY</u>. P.V.

		Modules shall be provided with grounding for all exposed external conductive surfaces not part of the module circuitry to minimize electrical hazard to personnel.
	EVALUATION	Review drawings and specifications. Test with suitable tester to determine continuity.
	COMMENTARY	Suitable standards are available for conventional equipment.
2.6.2	CRITERION	INSTALLATION SAFETY. The P.V. Module shall be so designed to comply with all existing OSHA standards about installation and maintenance protection of the workers.
	EVALUATION	Review of drawings and specifications.
2.7	REQUIREMENT	SAFETY OF BUILDING AND SITE. The safe operation of the building or site shall not be affected by the P.V. Module.
2.7.1	CRITERION	LIGHTNING PROTECTION. Lightning protection shall be provided in accordance with the NFPA 78 Lightning Protection Code. [9]
	EVALUATION	Review of calculations, drawings and specifications.
	COMMENTARY	There is a possibility that P.V. arrays, particularly array modules with plastic covers, increase the electrostatic potential between ground and air, and could induce increased lightning hazard in areas of high lightning incidence.

REFERENCES, SECTION 2

1. National Electrical Code, NFPA 70-1978, National Fire Protection Association, Boston, Massachusetts (1978).

2. Occupational Safety & Health Administration Standards, Occupational Safety and Health Administration, Washington, D.C.

3. Standard Methods of Fire Tests of Roof Coverings, NFPA 256-1976. National Fire Protection Association, Boston, Massachusetts.

4. Standard Methods of Fire Tests of Building Construction and Materials, NFPA 251-1972, National Fire Protection Association, Boston, Mass.

5. HUD Minimum Property Standards, One and Two Family Dwellings, (No. 4900.1), U.S. Department of Housing and Urban Development, Washington D.C.

6. Standard Methods of Fire Tests of Building Construction and Materials, ASTM E119, American Society of Testing and Materials, Philadelphia, Pennsylvania.

7. Standard Methods of Test for Surface Burning Characteristics of Building Materials, ASTM E84, American Society of Testing and Materials, Philadelphia, Pennsylvania.

8. Fire Tests of Building Construction and Materials, UL 263, Underwriters' Laboratories, Inc., Chicago, Illinois.

9. Lightning Protection Code, NFPA 78, National Fire Protection Association, Boston, Massachusetts.

3. REQUIREMENTS: MECHANICAL

3.1 SIZE AND SHAPE. The P.V. Module shall be designed for optimum performance while being compatible with standard building sizes and shapes.

3.2 VIBRATION. The P.V. Module shall be designed to withstand the vibrational loading that may be encountered during shipping, installation and operation.

3.1	REQUIREMENT	SIZE AND SHAPE. The P.V. Module shall be designed for optimum performance while being compatible with standard building sizes and shapes.
3.1.1	CRITERION	DIMENSIONAL COMPATABILITY. The P.V. Module shall be designed such that it will be compatible with building materials and practices.
	EVALUATION	Review drawing and specifications.
	COMMENTARY	Since many residential applications may require modules to be in some manner integrated into the building, the modules must be compatible with standard building design and construction practices.
3.2	REQUIREMENT	SHIPPING LOADS. The P.V. Module shall be designed to withstand the loads that may be encountered during shipping, installation and operation.
3.2.1	CRITERION	VIBRATION. The module shall be designed to withstand the vibrational loading that may be placed on it during shipping, installation and operation.
	EVALUATION	Review of drawings, specifications and tests.
	COMMENTARY	Although it is usually the practice of manufacturing companies to replace broken or damaged equipment when it is received at the building site, the P.V. module poses a separate problem. Small cell-to-cell electrical interconnects may be damaged and not readily detectable. In fact the module could be in service for some time before reverse bias problems might become obvious. At this point, the question of who should bear the cost of the labor required to replace the module is a serious question. Some protection to the buying public must be afforded. The manufacturer might utilize MIL-STD 810C Method 516.2 Procedure II, transit drop test, and Procedure V, bench handling test or its equivalent, should be performed to determine the module's ability to withstand shipping

shocks and its ability to withstand shocks during installation and maintenance, and ASTM 775 to evaluate shipping containers.

4. REQUIREMENTS: STRUCTURAL

4.1 STRUCTURAL DESIGN BASIS. The structural design of the P.V. module including connections and supporting structural elements shall be in accordance with nationally recognized codes and standards, and shall be based on anticipated load during the service life of the system.

4.2 FUNCTION AND OPERATION. The structural support of the P.V. Module shall not impair the function or operation of the P.V. Modules when exposed to service loads.

4.3 FAILURE LOADS AND LOAD CAPACITY. The structural elements and connections of the P.V. Module shall not fail under ultimate loads expected during the service life of the system.

4.1 REQUIREMENT

STRUCTURAL DESIGN BASIS. The structural design of the P.V. Module including connections and supporting structural elements shall be in accordance with nationally recognized codes and standards, and shall be based on anticipated load during the service life of the system.

4.1.1 CRITERION

APPLICABLE STANDARDS. The structural design and construction of P.V. Modules including connections and structural supports shall comply with the following provisions.

The elements of the module shall comply with the provisions of HUD-MPS 1 for single and multifamily housing or ANSI A119.1 [4], in the case of mobile homes.

EVALUATION

Review of drawings, specifications and structural calculations.

COMMENTARY

In addition to complying with the design and construction provisions of the MPS or ANSI A119.1 (for mobile homes), conventional elements and connections are required to comply with Criteria 4.1.2 (Service loads).

4.1.2 CRITERION

SERVICE LOADS. P.V. Module building interface. The following loads shall be used in the structural design of the P.V. Module, only when the module and its frame is considered an integral part of the roof. These loads shall also be used when designing module supports which attach to the building in any way.

1. Dead loads (D) shall be the "Design Dead Loads" stipulated in Section 601-3 of the MPS, or Section 2 of ANSI A58.1 [2].
2. Live Loads (L) shall be all applicable "Design Live Loads" stipulated in Section 601-4 and "Snow Loads" stipulated in Section 601-5 of the MPS or Section 3 & 7 of ANSI A58.1.
3. Wind loads (W) shall be "Wind Loads" stipulated in Section 601-6 of the MPS. In all cases consideration of local wind conditions shall be

assured by compliance with Section 6.3.3 of ANSI A58.1.

4. Earthquake or seismic loads (E) shall be those stpulated in Section 601-9 of the MPS which references the provisions of the Uniform Building Code (UBC) [3]. Additional references shall be found in Section 8 of ANSI A58.1. For non-conventional system components and connections, the value of "Cp" used in the UBC shall be taken as 2.0. See additional information in Appendix A.
5. Constraint loads (T) caused by the environment, normal functioning of the system and time-dependent changes within the materials of the system shall be taken as the most severe likely to be encountered during the service life.
6. Constraint loads (T) induced by differential foundation settlement shall be taken as those corresponding to a differential foundation settlement of the magnitude stated under Criterion 3.8.1.
7. Ice loads (I) shall be taken as those produced by the accumulation of ice on surfaces exposed to the natural environment. The thickness of ice shall be determined in accordance with Appendix B.
8. Hail loads (H) shall be taken as those produced by the impact of hail on surfaces exposed to the natural environment. Hail particle size and kinetic energy at impact shall be determined in accordance with Appendix C.

EVALUATION

Review of drawings, specifications and structural calculations.

COMMENTARY

All P.V. Modules which are mounted as an integral part of the roof watertight membrane and replace building materials which must meet certain criteria as stipulated under service loads. However, if the module is mounted to a rack or structure which complies with all building code requirements and the module replaces no building material and in its use places no risk to the life and safety of the building occupants it shall be exempt from section but shall be designed to comply with industry standards concerning its useful life and reliability. In addition to this, any P.V. Module mounted above the roof structure or on the ground should be carefully designed to resist any wind uplift.

4.1.3	CRITERION	MAINTENANCE LOADS. All components of a P.V. Array must be accessible for repair or replacement. Certain parts of the module must be designed to withstand normal service loads that would be incurred during repair or replacement.
	EVALUATION	Review of drawings and specifications.
	COMMENTARY	It would be expected that the module manufacturer should address this problem to the degree that notice should be given that the module either can or cannot be walked on or have any concentrated life loads imposed on it during maintenance or repair. The array designer or person specifying the use of the module in a particular application should address this question.
4.2	REQUIREMENT	FUNCTION AND OPERATION. The structural support of the P.V. Module shall not impair the function or operation of the P.V. Modules when exposed to service loads.
4.2.1	CRITERION	RESISTANCE TO DAMAGE. Under the effect of deflections caused by loads D,L,W and T as defined in Criterion 4.1.2, in addition to the anticipated creep deflections, the module connection or support thereof, shall not suffer permanent damage which would require replacement or repair, or which would impair its intended function during its service life.
	EVALUATION	Evaluation of documentation of data for design, tests, installation. Evaluation and/or testing of components and elements where deemed essential. Determination of compliance with

generally accepted standards and engineering and trade practices, where applicable.

The criterion is deemed satisfactory if it can be demonstrated that deflections caused by the specified loads can be accommodated by suitable details or adequate flexibility.

COMMENTARY

The intent of this criterion is to provide for the proper functioning of the module under service loading conditions without breakdown or permanent impairment beyond levels comparable to conventional roofing systems.

4.3 REQUIREMENT

FAILURE LOADS AND LOAD CAPACITY. The structural elements and connections of the P.V. Module shall not fail under ultimate loads expected during the service life of the system.

4.3.1 CRITERION

ULTIMATE LOAD COMBINATIONS. Non-conventional elements and connections shall comply with this criterion. (Conventional elements and connections are deemed to satisfy this criterion.)

Structural components, connections and supporting elements shall be designed for the following ultimate load combinations:

(1) 1.4 D + 1.7 L

(2) 0.9 D + 1.45 E

(4) 1.1 D + 1.3 L + 1.7 W

(5) 1.1 D + 1.3 L + 1.45 E

Where the multipliers are load factors and the letters are the service loads defined in Criterion 4.1.2.

EVALUATION

Review of structural calculations, specifications and drawings.

COMMENTARY

The intent of the criterion is to provide a minimum level of safety against loading situations which have a suitably low probability of occurrence during the service life. The load factors represent present-day design practice for residential building structures and are similar to the load factors used in Building Code Requirements for Reinforced Concrete, ACI 318-71 [5], American Concrete Institute, Detroit, Michigan (1971). These factors will produce ultimate loads comparable to those presently used in the design of steel structures. Adoption of similar levels of performance requirements for the P.V. systems will also permit the designer to explore the potential use of system components as structural elements for purposes of providing enclosure or diaphragm rigidity to the supporting structure in addition to their electrical function.

APPENDIX 4-A

SEISMIC LOADS

General

Seismic design requirements for the mechanical and electrical components of solar energy systems are covered in this section. Architectural and structural components shall be designed in accordance with MPS Section 601-9. The requirements of this section shall apply to the erection, installation, relocation, or replacement of, or addition to any mechanical or electrical component of a solar system. If elements of the solar energy system are attached to any existing structural element, or if parts of any existing structural element are modified or replaced with parts different in size and weight, the element, as well as its connections to the building shall be redesigned to comply with the seismic design requirements of Section 601-9 of the MPS.

Mechanical and Electrical Components

For those buildings required to be designed for earthquake by Section 601-9 of the MPS, mechanical and electrical components of solar energy systems shall resist seismic forces as specified for parts and portions of buildings in the latest edition of the "Uniform Building Code" (UBC)[1]. The value of C_p used in the UBC to establish the seismic force shall be taken from Table 1.

The design of all connections between the mechanical or electrical components and the structural frame shall allow for anticipated movements of the structure. The details of the connections shall be made a part of the contract documents.

COMMENTARY: Mechanical or electrical components of a solar system are subjected to seismic forces generated by their mass and may also be influenced by interaction with elements of the structural system.

(1) The "Uniform Building Code" is published by the International Conference of Building Officials, Whittier, California.

APPENDIX 4-A (Cont.)

TABLE 1

Part of System	Direction of Force	Value of C_p 1/ 2/
Storage tanks, pressure vessels, boilers, furnaces, absorption air conditioners, other equipment using combustible or high temperature energy sources, electrical motors and motor control devices, heat exchangers	any direction	0.12 when resting on ground 0.20 when connected to, or housed, elsewhere in the building.
Flat plate and concentrating solar collectors	any direction	0.20
Transfer liquid pipes larger than 2 1/2 in. diameter	any horizontal direction	0.12

1/ For flexible and flexibly mounted equipment and machinery, appropriate values of Cp shall be determined by a properly documented dynamic analysis, or by dynamic testing, using appropriate excitation spectra approved by HUD. Consideration shall be given to both the dynamic properties of the equipment and machinery and to the building or structure in which it is placed.

2/ WHEN LOCATED IN THE UPPER PORTION OF ANY BUILDING WHERE THE HN/D RATIO IS 5:1 OR GREATER THE CP VALUE SHALL BE INCREASED BY 50%

WHERE HN = HEIGHT IN FT, OF THE PART OF THE SYSTEM ABOVE THE BASE LEVEL OF THE BUILDING

D = THE DIMENSION OF THE STRUCTURE IN FEET IN A DIRECTION PARALLEL TO THE APPLIED FORCE

APPENDIX 4-B

ICE LOADS

(a) Above-ground installations of conventional elements for which ultimate design provisions apply, and all non-conventional elements, including connections and structural supports thereof, shall comply with Criterion 4.3.1 for load combinations (1) and (4) in which live load (L) shall be taken as that produced by the accumulation of ice on all surfaces exposed to the natural element.

(b) Above-ground installations of conventional elements for which working stress design provisions apply, including connections and structural supports thereof, shall comply with the following modification: load factors in load combinations (1) and (4) of Criterion 4.3.1 shall be taken as 1.0.

The radial thickness of ice around the circumference of exposed wires, pipes, and structural members shall be based on the annual frequency of occurrence of glaze shown in Figure 1 (see reference [6], and shall be computed as follows:

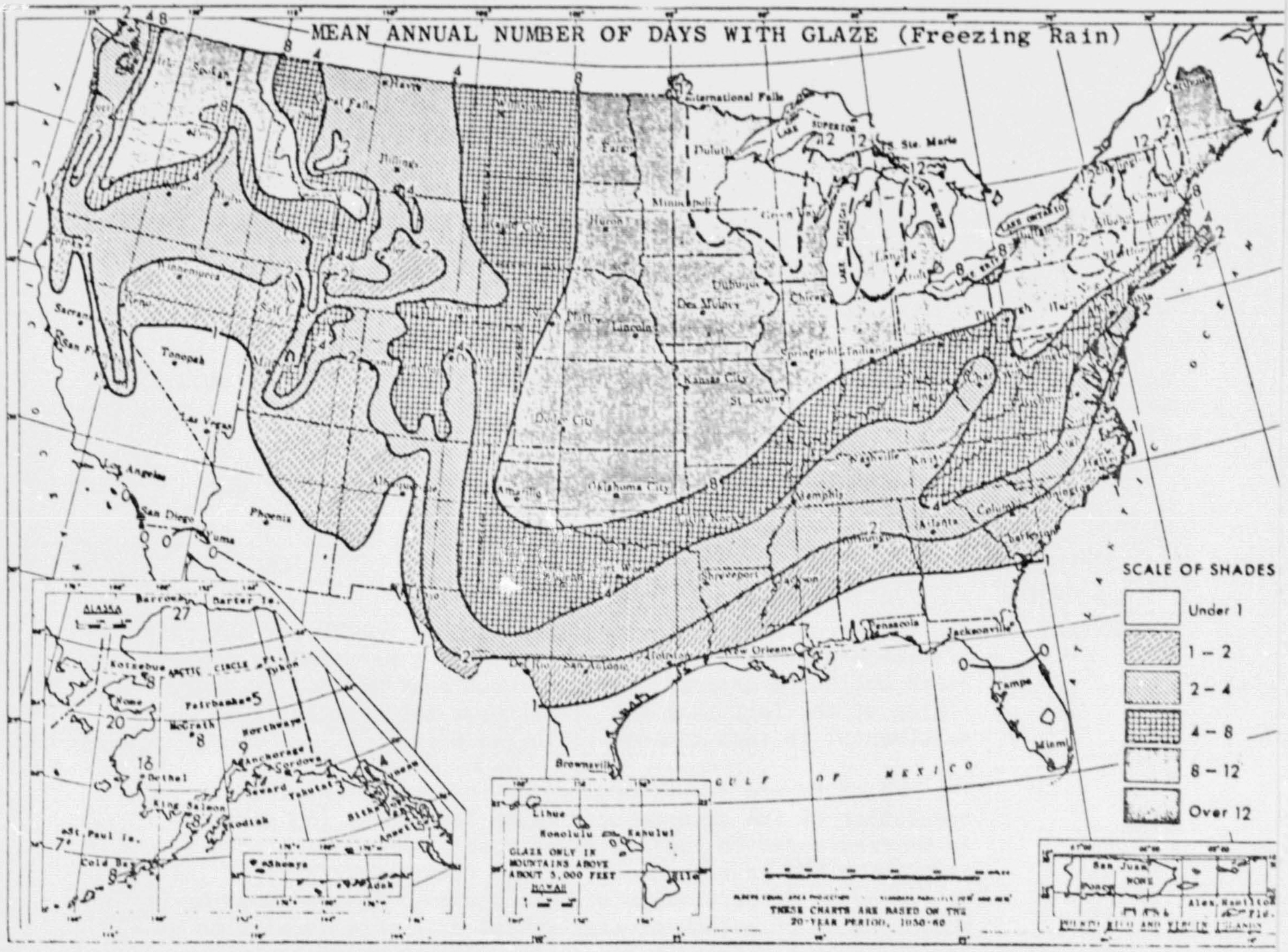
Mean annual number of days with glaze	under 1	1-4	4-8	Over 8
Thickness of ice (inches)	0	1/2	1/4	1.0

COMMENTARY The intent of this criterion is to account for the effect of ice loads primarily on wires, pipes, and other similar components which are exposed to the natural environment, in recognition of the fact that ice storms have been particularly detrimental to such components in the past.

The map of Figure 1 with documented information of the accumulation of ice recorded for major ice storms [6] and ice loads considered in the design of steel transmission pole structures [7] have been utilized to relate thickness of ice to frequency of occurrence of such storms. This assumption is made in view of a lack of statistical data on accumulation of ice and should result in a generally conservative practice even though it is recognized that thickness of ice cannot be solely expressed in terms of rate of occurrence.

APPENDIX 4-B (Cont.)

FIGURE 1



APPENDIX 4-C

HAIL LOADS

The cover plates of solar modules shall be protected against or resist the perpendicular impact of a single hailstone of the magnitude stipulated below falling at its terminal velocity.

Hail Size: $D = 0.3d$

in which D = hailstone diameter, inches
d = mean annual number of days with hail taken from Figure 1.

Terminal velocities for various hail sizes are given in Table 1. Compliance with this provision shall be based on documented past hail loading performance or testing using the procedures described in NBS Building Science Series BSS 23 (3) or equivalent.

Commentary: The correlation of hail size with mean annual number of days with hail was determined using data relating the probability of occurrence of hail particle size to the number of days with hail (tabulated in Ref. (4)), and limited statistical information relating the local area covered by a hailstorm, and the regional area for which statistical data are compiled. The hail size indicated has a 5 percent probability of being exceeded in any one year (estimated 20 year recurrence interval). The hail requirements in this section are based on available information which does not contain physical test data. Therefore, local hailstone loading performance should be considered in implementing the requirements of this section.

The impact from the vertical terminal velocity is used as a measure of the effect of hail falling with or without horizontal wind. It is possible that a larger impact could occur on surfaces sloped from 30° to 60° if the maximum particle diameter occurred simultaneously with high horizontal wind velocity perpendicular to the surface. It may be overly conservative for particles over 1.5" impacting on near vertical surfaces. However, due to the lack of information on this phenomenon and the low probability of its occurrence, it is assumed that the terminal velocity gives the best measure of impact force consistent with the present state-of-the-art.

The loadings specified in this section used to determine module structural performance compare closely with the loads used for the design of conventional asphalt shingles and built up roofing. These loads are those which are expected within the mid-continent hail belt.

(1) Baldwin, J.L., "Climates of the United States", U.S. Dept. of Commerce, Washington, D.C. (1973).
(2) Mathey, R.C., "Hail Resistance Tests of Aluminum Skin Honeycomb Panels for the Relocatable Lewis Building, Phase II", NBS Report 10193, National Bureau of Standards, Washington, D.C. (1970).
(3) Greenfield, H., "Hail Resistance of Roofing Products", Building Science Foundation Series 23, National Bureau of Standards, Wash. D.C. (Aug.'69).
(4) "Storm Data", U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (monthly periodical).

APPENDIX 4-C (Cont.)

FIGURE 1

ORIGINAL PAGE IS OF POOR QUALITY

APPENDIX 4-C (Cont.)

TABLE 1

Values of weight, terminal velocity, resultant velocity and kinetic energy computed for smooth ice spheres.

Diameter in	Weight gm	lb	Terminal Velocity ft/sec	Resultant Velocity ft/sec	Kinetic Energy 1/ ft-lb	
1/2	0.98	0.002	51	83	0.09	0.24
3/4	3.30	0.007	62	91	0.44	0.94
1	7.85	0.017	73	98	1.43	2.58
1 1/4	15.33	0.034	82	105	3.53	5.79
1 1/2	26.50	0.058	90	112	7.35	11.38
1 3/4	42.08	0.093	97	117	13.56	19.73
2	62.81	0.138	105	124	23.71	33.07
2 1/4	89.43	0.197	111	129	37.73	50.96
2 1/2	122.67	0.270	117	134	57.48	75.39
2 3/4	163.28	0.360	124	140	85.95	109.57
3	211.98	0.467	130	146	122.66	154.71

1/ First value corresponds to the terminal velocity and the second value corresponds to the resultant velocity.

APPENDIX 4-D

ULTIMATE LOAD DETERMINATION

Source Material: ANSI 58.1 1972
NBSIR 76-1187

Paragraph 3.1.2 of Chapter 3 of NBSIR states the following for determination of ultimate loading:

Ult. Load = $a_1D + a_2\ (a_3L + a_3Q + a_4T)$

Where Q = Wind (W) or Earthquake (E)

a_1 = 1.3 if parts along or adds to other loads
0.9 if it counteracts other loads

a_2 = 1.0 if one of L, Q or T is acting
0.75 if two are acting
0.6 if all three act

a_3 = 1.7 if load present

Example Calculation: a_4 = 1.3

Dead Load Characteristics:

Type F-41 Solar Cell w/Tedlar Film over Aluminum Substrate

Solar Cell w/Tedlar Film	1.7 lbs./sq. ft.
Aluminum Substrate	1.0
	2.7 lbs./sq. ft.

F-42 Solar Cell w/0.12" Tempered Glass over Aluminum Substrate

Solar Cell	1.6 lbs./sq. ft.
0.12" Temp. Glass	1.7
Aluminum Substrate	1.0
	4.3 lbs./sq. ft.

Use Avg. 3.5 lbs./sq. ft. for D.L.

Live Loading:

Wind (50 yr. Storm Occurrence) (Exposure B Suburban/Rural Areas)	110 MPH - Less than 50' in height 29 lbs./sq. ft.
Snow (50 yr. Storm Occurrence) Allow for 95% of Country Occurrence (All of USA but Northern Half of Maine)	50 lbs./sq. ft.
Earthquake (Zone 3)	0.201 Weight of Panel

Constraint loading will not be considered at this point due to the extensive analysis required to determine forces acting.

Ultimate Loading Possibilities:

1) DL + LL (Snow Only) U=1.3D + 1(1.7S + 0 + 0) = (1.3)(3.5) + (1.7)(50)

= 89.55 lbs./sq.ft. (Ult. Ld.)

53.5 lbs./sq.ft.(Working Ld.)

2) DL + LL (Wind Only) U=1.3D + 1(1.7W) = (1.3)(3.5) + (1.7)(29)

= 53.85 lbs./sq.ft. (Ult. Ld.)

32.5 lbs./sq.ft.(Working Ld.)

3) DL + LL (Wind (Northern) 90 MPH (19 lbs./sq.ft.) + Snow)

U = 1.3D + 0.75 (1.7S + 1.7W)

= (1.3)(3.5) + 0.75[(1.7)(50) + (1.7)(19)]

= 4.55 + 87.9

92.45 lbs./sq.ft.(Ult. Ld.)

72.5 lbs./sq.ft. (Working Ld.)

4) DL + LL (Wind + Earthquake)

U = 1.3D + 1[(1.7)(0.201 (Q))(3.5)]

U = 4.55 + (1.7)(0.201)(3.5)

= 1.2

5.75 lbs./sq.ft. (Ult. Ld.)

4.2 lbs./sq.ft. (Working Ld.)

Condition 3 Governs

Max. Ultimate Loading will occur between 89.55 and 92.45 lbs./sq. ft.

REFERENCES

1. HUD Minimum Property Standards, One and Two Family Dwellings (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1974) and HUD Minimum Property Standards, Multifamily Housing (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973).

2. Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, ANSI A58.1-1972, American National Standards Institute, New York, N.Y. (1972).

3. Uniform Building Code, International Conference of Building Officials, Whittier, California (1973).

4. Standard for Mobile Homes. ANSI A119.1-1974, American National Standards Institute, New York, New York (1974).

5. Building Code Requirements for Reinforced Concrete, AC1318-71, American Concrete Institute, Detroit, Michigan (1971).

6. Baldwin, J.L., Climates of the United States, U.S. Department of Commerce, Washington, D.C. (1973).

7. "Design of Steel Transmission Pole Structures." Task Committee on Steel Transmission Poles of the Committee on Analysis and Design of Structures, Journal of the Structural Division, American Society of Civil Engineers, New York, N.Y. (November 1974).

5. REQUIREMENTS: ELECTRICAL

5.1 SYSTEM DESIGN CONDITIONS. The P.V. Module shall be capable of functioning at its design output.

5.1	REQUIREMENTS	SYSTEM DESIGN CONDITIONS. The P.V. module shall be capable of functioning at its design output.
5.1.1	CRITERION	ELECTRICAL TRANSPORT. Design of the electrical elements of the module shall be in accordance with applicable recommendations of UL installation shall comply with NFPA standards.
	EVALUATION	Review of drawings and specifications.
5.1.2	CRITERION	ELECTRICAL COMPATABILITY. The external electrical interface components of the P.V. Module shall be designed to be compatible from module to module in order to facilitate interchangeability.
	EVALUATION	Review of drawings and specifications.
5.2	REQUIREMENTS	ELECTRICAL CODES. P.V. Modules shall be designed to meet all applicable codes and standards.
5.2.1	CRITERION	ELECTRICAL CODES AND STANDARDS. P.V. Modules shall comply with the National Electrical Code and with applicable standards of ANSI, NEMA and UL and shall be labeled and listed as applicable and tested by a qualified independent laboratory.
	EVALUATION	Review of drawings and specifications as well as testing by a qualified laboratory.
	COMMENTARY	The intent of this criterion is to assure for the proper testing of all P.V. module configurations by an independent testing lab.

6. REQUIREMENTS: DURABILITY/RELIABILITY

6.1 EFFECTS OF EXTERNAL ENVIRONMENT: The P.V. module shall not be affected by external environmental factors to an extent that will significantly impair its function during its design life.

6.2 TEMPERATURE. The module shall be capable of performing its intended function during its design life when exposed to temperatures that can develop during operation.

6.1 REQUIREMENTS

EFFECTS OF EXTERNAL ENVIRONMENT. The P.V. Module shall not be affected by external environmental factors to an extent that will significantly impair its function during its design life.

6.1.1 CRITERION

SOLAR DEGRADATION. Components or materials of P.V. Modules shall not be adversely affected by in-service exposure to sunlight to an extent that will significantly impair their function during their design life.

a. When P.V. Modules or materials of P.V. Modules are exposed to UV radiation with or without an intermittent water spray and at their maximum service temperature, there shall be no signs of excessive deterioration such as cracking, crazing, embrittlement, etching, loss in flexural strength, or any other changes that would significantly affect the performance of the components in the system.

b. P.V. modules shall be capable of providing its rated output after exposure to levels and intensities of solar radiation and temperatures equivalent to those expected in actual use over the life of the module.

EVALUATION

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where existing information is unavailable or inadequate, testing using either the methodology outlined in Appendix 6-A given at the end of this chapter or other methods which can be shown to meet the intent of the criterion.

COMMENTARY

The transmittance, emittance and absorptance data required to estimate the effects of degradation by solar radiation in reducing P.V. Module efficiency are available for most materials currently being used in modules.

6.1.2 CRITERION

MOISTURE. Components or materials of P.V. Modules shall not be adversely affected by exposure to moisture in service to an extent that will significantly impair the function of the module during its design life.

EVALUATION

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, methods which can be shown to meet the intent of the criterion will be used.

COMMENTARY

Moisture can exhibit itself in several forms, e.g., rainfall, melting snow and ice, or condensation. The intent of this criterion is to ensure adequate performance of the module, components, or materials that are expected to be exposed to moisture in service. Such components would not usually be expected to meet the intent of this criterion if moisture exposure could not occur, e.g., in P.V. modules that are hermetically sealed. If P.V. Modules are not hermetically sealed, the likelihood of moisture reaching and adversely effecting cells may be quite high depending upon the configuration used for module construction. The need for and extent to which a moisture barrier is established is a design problem. The barrier should be designed to minimize moisture attack when economically feasible.

One additional potential problem with P.V. Modules which are not hermetically sealed is that, in industrial atmospheres the introduction of dilutants in condensate solution may cause physical changes in the encapsulant. materials over a period of time. Such changes can permanently reduce the transmittance. When this possible condition exists, design considerations must be given to avoid the problem.

6.1.3 CRITERION

AIRBORNE POLLUTANTS. Components that are exposed to airborne pollutants such as ozone, salt spray, SO_2, NO_x, or HCl with or without the presence of moisture shall not be adversely affected by these factors to the extent that will significantly impair their function during their design life.

EVALUATION

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Appendix 6-B given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

The maximum pollutant levels in the areas where the system will be installed shall be used to determine the pollutant levels required for testing. If components are to be used in areas where they are not exposed to any or all of these pollutants, tests that are not applicable need not be conducted.

COMMENTARY

Ozone concentrations in normal dry air have been reported to range from 1-5 pphm volume. However, concentrations of 100 pphm/volume is known to degrade some organic materials but it has little effect on inorganic materials other than metals.

The effects of solar radiation in combination with airborne pollutants may also be an important consideration.

6.1.4 CRITERION

<u>DIRT RETENTION ON COVER PLATE SURFACE.</u> The module cover plate surface shall not collect and retain dirt to an extent that would significantly impair the function of the P.V. Module during its design life.

EVALUATION

Engineering analysis, documentation or satisfactory long-term performance under in-use conditions and review of plans and specifications.

COMMENTARY

Dirt retention may be a factor, in a reduction of solar transmittance. However, data is inconclusive at present. Despite the fact that dirt retention may be beyond the control of contractors or manufacturers, the owner of the system should be advised, if dirt is a potential problem, and a means to overcome or reduce the problem. If module cleaning is necessary, the manufacturer should supply the proper cleaning plan and cleaning solution. The retention of dirt may be affected by the tilt angle of the module. Rainfall and snow melt are generally sufficient to keep module cover plates clean. In areas of low rainfall or because of the nature of the cover plate surface, periodic washing may be required to remove dirt.

6.1.5 CRITERION

ABRASIVE WEAR. The ability of the module to function at its rated capacity shall not be significantly impaired by the abrasive wear to which its surface will be subjected during its design life.

EVALUATION

Engineering analysis, documentation of satisfactory long-term performance under in-use conditions, and review of surface hardness specifications for cover plate materials.

COMMENTARY

Test methods which are currently available for measuring abrasion resistance are believed to be too stringent for testing organic collector cover plates. Abrasive wear is expected to present a possible problem in areas subject to wind driven sand. Also, abrasive wear of cover plates resulting from periodic cleaning or scrubbing may have a significant effect on the ability of the cover plates to transmit sunlight.

6.1.6 CRITERION

FLUTTERING BY WIND. Modules and their components that are subject to fluttering by wind shall not degrade under in-use conditions to an extent that will significantly impair their function during their design life.

EVALUATION

Documentation of satisfactory long-term performance under in-use conditions, engineering analysis, or testing using an experimental verification procedure which can be shown to meet the intent of the criterion.

COMMENTARY

Thin films that increase in brittleness at low temperatures may be particularly susceptible to degradation by fluttering by wind.

6.1.7 CRITERION

HUMIDITY. The P.V. Module and its components shall not be adversely affected by exposure to humidity to an extent that will significantly impair its function during its design life.

EVALUATION

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate existing information is not available, test using the methodology outlined in Appendix 6-C. For module components which are structural rather than related to electrical production shall conform to ASTM 2247-D, Coated Metal Specimens at 100% Relative Humidity.

COMMENTARY

The known and well established effect of humidity on both electrical components and certain P.V. cell metalizations requires a detailed and extensive examination and evaluation.

6.1.8 CRITERION

FUNGUS RESISTANCE. The P.V. Module and its components shall not promote the growth of fungi, mold, or mildew.

EVALUATION

The design shall be capable of withstanding exposure to fungus as defined by Method 508 of MIL-STD 810C. All synthetic polymeric materials contained in the module assembly shall be tested to determine conformance to 6.1.8. by ASTM G21-70, Determining Resistance of Synthetic Polymeric Materials to Fungi.

COMMENTARY

Fungi can feed on some organic materials and generally thrive in warm, moist environments. They can be killed by sufficiently low wavelength ultraviolet radiation but much of this radiation may be absorbed by the earth's atmosphere. There is a high potential for fungus growth occurring under modules that are applied over a building watertight membrane and it may also be possible for fungi to grow on both the interior and exterior of the module and possibly affect module performance.

6.1.9	CRITERION	ICE DAMS AND SNOW BUILD-UP. The design of P.V. Module shall minimize the possibility of formation of ice dams and snow build-ups.
	EVALUATION	Review of drawings and specifications.
	COMMENTARY	In cold climates, water can flow off warm modules and freeze on cold surfaces thereby forming ice which could build up on the active module surface or under the module or roof. Snow could be prevented from sliding off modules by a physical constraint at the base of a module such as a lip or gutter and cause serious reduction of electrical output.
6.2	REQUIREMENT	TEMPERATURE RESISTANCE. The P.V. Module shall be capable of performing its intended function for its design life when exposed to temperatures that can develop during operation.
6.2.1	CRITERION	THERMAL DEGRADATION. Module components shall not thermally degrade to the extent that their function will be reduced below design levels during their design life when exposed to in-use temperatures.
	EVALUATION	Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. When adequate existing information is unavailable for module components, testing using either the methodology outlined in Appendix 6-D or other methods which can be shown to meet the intent of the criterion will be used.
	COMMENTARY	Some organic components which may be used in the modules may be particularly susceptible to thermal degradation under prolonged exposure. Module components of particular concern include organic cover plates, sealants and frames.
6.2.2.	CRITERION	THERMAL CYCLING STRESSES. The P.V. module shall be capable of withstanding the stresses induced by thermal

cycling for its design life.

EVALUATION

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis where adequate existing information is unavailable, testing using the methodology outlined in Appendix 6-E or other methods which can be shown to meet the intent of the criterion will be used.

COMMENTARY

This criterion is intended to identify potential problems that may occur as a result of differential thermal movement. Thermal compatability is especially critical in the case of modules with large expanses of glazing. Also critical in P.V. Modules is the need for adequate stress relief in cell-to-cell interconnects.

6.2.3 CRITERION

TRANSMISSION LOSSES DUE TO OUTGASSING. Outgassing of volatiles that will reduce module performance below specified design values shall not occur when the module is exposed to the maximum design tempratures.

EVALUATION

Documentation if satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing methods which can be shown to meet the intent of the criterion will be used.

COMMENTARY

Outgassing from components inside the module could lead to reduced transmissivity of the optical coupling between cells and cover plate by delamination of cells encapsulant and cover plate.

APPENDIX 6-A

TEST METHODOLOGY AGING

Components or materials shall be tested using at least one of three aging procedures and appropriate evaluation procedures as described.

The surfaces of components or materials shall be visually inspected before and after aging to ensure that no signs of excessive deterioration, such as dimensional changes, cracking, chalking, or other visually detectable changes which could significantly affect the performance of the components in the system, are present. In addition, other evaluation procedures shall be used, as necessary, to evaluate performance.

AGING PROCEDURE 1

ASTM reference methods for Aging Procedure 1 include G26-70 Operating Light and Water Exposure Apparatus (Xenon-Arc Type) for Exposure of Non-Metallic Materials, and D2565-75, Operating Xenon Arc-Type (Water-Cooled) Light and Water Exposure Apparatus for Exposure of Plastics.

Exposure components or materials to simulated solar radiation (such as xenon arc radiation) for a period of 2,000 equivalent sun hours. The exterior surfaces of components which are exposed to rainfall in service shall be subjected to a water spray for a period of 5 minutes during each 60 minutes of the light exposure. For components not exposed to railfall under normal operating conditions, the water spray shall not be included in the procedure.

AGING PROCEDURE 2

Expose components or materials to concentrated natural solar radiation using machines such as those referenced in ANSI 297.1-1975, paragraph 4.3.2, for a period of 2,000 equivalent sun hours. The exterior surfaces of components which are exposed to rainfall in service shall be subjected to a water spray for a period of 8 minutes during each 60 minutes of sunlight exposure. For components not exposed to rainfall under normal operating conditions, the water spray shall not be included in the procedure.

AGING PROCEDURE 3

ASTM reference methods for Aging Procedure 3 include:

G7-69T	Atmospheric Environmental Exposure Testing of Non-Metallic Materials
D1828-70	Atmospheric Exposure of Adhesive Bonded Joints and Structures
D1014-66 (1973)	Conducting Exterior Exposure Tests of Paints on Steel
D1006-73	Conducting Exterior Exposure Tests of Paints on Wood
G24-73	Conducting Natural Light Exposures Under Glass
D1435-69	Outdoor Weathering of Plastics

Expose components and materials to solar radiation outdoors for twelve months. The average daily flux of the solar radiation, as obtained by averaging the daily fluxes over the twelve month period of outdoor exposure, shall be at least 1,500 Btu/ft^2.

Evaluation techniques, in addition to those related to visual inspection, shall also be used. The methods below represent the types of evaluative techniques that should be used where applicable.

Vapor Transmission

E96-66 (1972)	Water Vapor Transmission of Materials in Sheet Form
C355-64 (1973)	Water Vapor Transmission of Thick Materials

Tensile Strength

D638-72	Tensile Properties of Plastics
D897-72	Tensile Properties of Adhesive Bonds
C297-61 (1970)	Tension Test of Flat Sandwich Construction in Flatwise Plane

Flexure Strength

D790-71	Flexural Properties of Plastics
C393-62 (1970)	Flexure Test of Flat Sandwich Constructions

Evaluations should be performed on both aged and unaged specimens to establish a basis of comparison.

COMMENTARY

The tests are intended to permit estimations to be made of the effect of solar radiation in degrading collector components and in reducing the collector efficiency. The 2,000 equivalent sun hours test time is considered to be equivalent to approximately 12 months of actual solar exposure with an average exposure time of 6 hours per day. The fact that the intensity of solar radiation varies with time of the day and time of the year should be considered in establishing the length of the exposure.

METHOD FOR EVALUATING THE EFFECTS OF SOLAR DEGRADATION ON THE PERFORMANCE OF THE P.V. MODULE (PRIMARILY FOR SPECTRALLY SELECTIVE MATERIALS)

TEST SPECIMENS

Test speciments shall consist of specimens of the materials to be tested.

Specimens of window materials for aging and evaluating shall consist of the number of windows used in the collector spaced and aligned as they would be in the collector.

AGING PROCEDURE

Specimens shall be exposed to simulated solar radiation with the spectral intensity in the 300 to 450 nm wavelength range equivalent to the air mass 2 solar spectrum (such as Xenon arc radiation) for a period of 1,000 hours at the maximum temperature to which they will be subjected in actual service. For collector windows, the exterior surfaces of the components shall be subjected to a water spray for a period of 5 minutes during each 60 minutes of the light exposure. For components not normally exposed to rainfall the water spray shall not be included in the procedure.

TEST PROCEDURES**

P.V. Module Cover Plate

1. Measure the total spectral transmittance (including both diffuse and normal radiation) of the windows from 300 to 1,820 nm.

2. Expose the cover to the aging procedure described above.

3. Repeat Step 1.

4. Calculate the solar transmittance (τ) determined from transmittance measurements from 300 to 1,820 nm for both unaged and aged specimens using the procedure described in ASTM E424.

TRANSMITTANCE OR REFLECTANCE BY ASTM METHOD E 424-71

An alternate calculation method is recented in ASTM Method E 424 for transmittance and reflectance. In ASTM E 424, solar energy transmittance or reflectance is calculated by integration using the solar energy distribution for sea level and air mass 2.0. Table A-1 contains twenty selected ordinates for use in the calculations.

Table A-1 Twenty Selected Ordinates for Evaluation of Solar Transmittance or Reflectance at Sea Level.***

Ordinate Number	Wavelength (nm)	Ordinate Number	Wavelength (nm)
1	390	11	745
2	444	12	786
3	481	13	831
4	511	14	877
5	543	15	959
6	574	16	1026
7	606	17	1105
8	639	18	1497
9	669	19	1497
10	705	20	1722

*Specimens shall be mounted perpendicular to the incident radiation.
**Other less sensitive test procedures which are directly integrating are given in ASTM E424-71 and E434-71.
***Extracted from ASTM Method E 424.

APPENDIX 6-B

TEST METHODOLOGY ENVIRONMENT

This section contains test methods to determine the resistance of components to airborne pollutants. Following the test, specimens shall exhibit no signs of deterioration that would significantly impair their performance.

Resistance to Ozone

Coupon specimens of components shall be exposed for 500 hours to an ozone atmosphere of 50 ± 5 pphm/volume in a test chamber at 23 ± 2°C (73.4 ± 3.6°F). The specimen shall be exposed under conditions which simulate in-use conditions. After the exposure, the surfaces of the specimens shall be visually examined for signs of deterioration such as cracking, blistering, or dimensional changes using a microscope with an eye-piece micrometer at 20X magnification. An ozone test chamber is described in ASTM D1149-64 (1970), "Accelerated Ozone Cracking of Vulcanized Rubber".

The extent of change of the specimens as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the characteristics of the same specimens before and after exposure.

Resistance to Salt Spray

Coupon specimens of components shall be evaluated in accordance with ASTM Standard Method B117-73. After exposure for 500 hours, with ASTM Standard Method B117-73. After exposure for 500 hours, the specimens shall be visually examined for signs of deterioration such as cracking, crazing, blistering, or pitting. The extent of the change as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the characteristics of the same specimens before and after exposure.

Resistance to SO_2, NO_x, and HCl

Coupon specimens shall be immersed for 500 hours in aqueous solutions containing 100 ppm of H_2SO_3, HNO_3 and HCl on a one component per test solution basis so that one half of the specimen is in the solution. During the immersion, the temperature of the test specimen shall be cycled repetitively as follows: one hour at the maximum service temperature, one hour at 23 ± 2°C (73.4 ± 3.6°F). Sufficient time shall be provided between each of the above cycles to allow the specimens to equilibrate at the test temperature. Test solutions shall not be heated above their boiling points or cooled below their freezing points during the tests and the concentrations of the solution shall be maintained at the desired levels. After exposure, the specimen shall be visually examined for signs of deterioration such as cracking, blistering or pitting. The extent of change of the specimens as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the same specimens before and after exposure.

APPENDIX 6-C

HUMIDITY TEST PROCEDURE

The module shall be subjected to the humidity cycling procedure per Figure 1. The module shall be tested in the open circuit condition, but with termination protected from water condensation. Electrical performance test, per Section A shall be performed within one hour after removal from the humidity chamber, or within another mutually agreed upon time period if the testing is subcontracted.

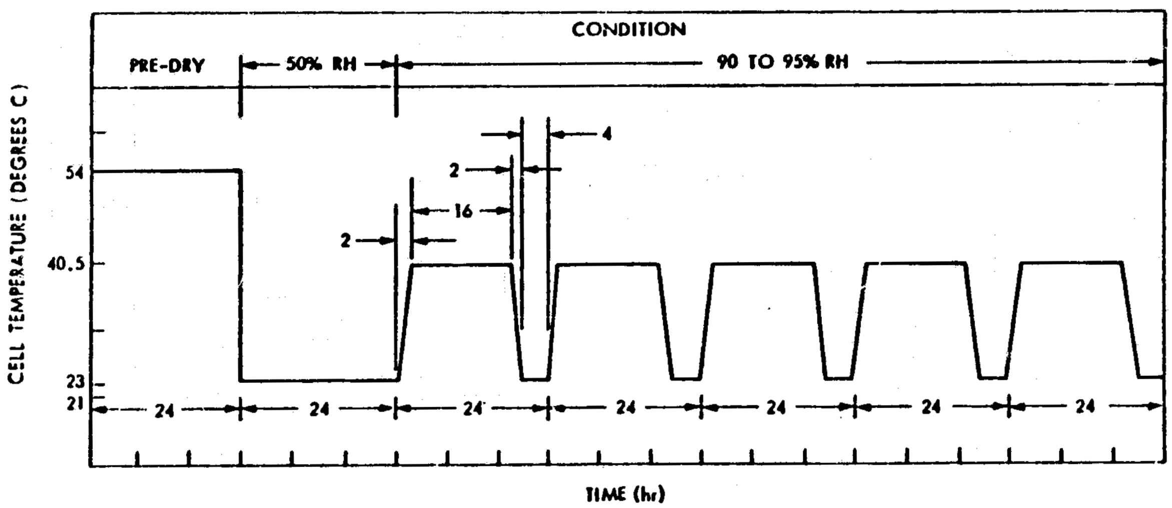


Figure 1. Humidity Cycle Test (Suitable procedures for accomplishing this test are described in MIL-STD-810C, Method 507.1, Procedure V.)

APPENDIX 6-D

TEST METHODOLOGY THERMAL DEGRADATION

This section contains information concerning methods to test for Thermal Degradation.

Complete components or coupon specimens shall be subjected to heat aging for a period of 500 hours at the maximum service temperature to which they will be exposed in actual service. Components and materials stressed in normal use should be stressed during the exposure. They shall be visually inspected both before and after aging.

When visually evaluated after exposure at the maximum service temperatures, there shall be no significant loss of strength as a result of the aging.

APPENDIX 6-E

THERMAL CYCLING TEST PROCEDURE

The module shall be subjected to the thermal cycling procedure per Figure 1, consisting of 50 cycles with the cell temperature carrying between -40°C and +90°C. The temperature shall vary approximately linearly with time at a rate not exceeding 100°C per hour and with a period not greater than 6 hours per cycle (from ambient to -40°C to +90°C to ambient). The module circuitry shall be instrumented and monitored throughout the test to verify that no open circuits or short circuits occur during the exposure.

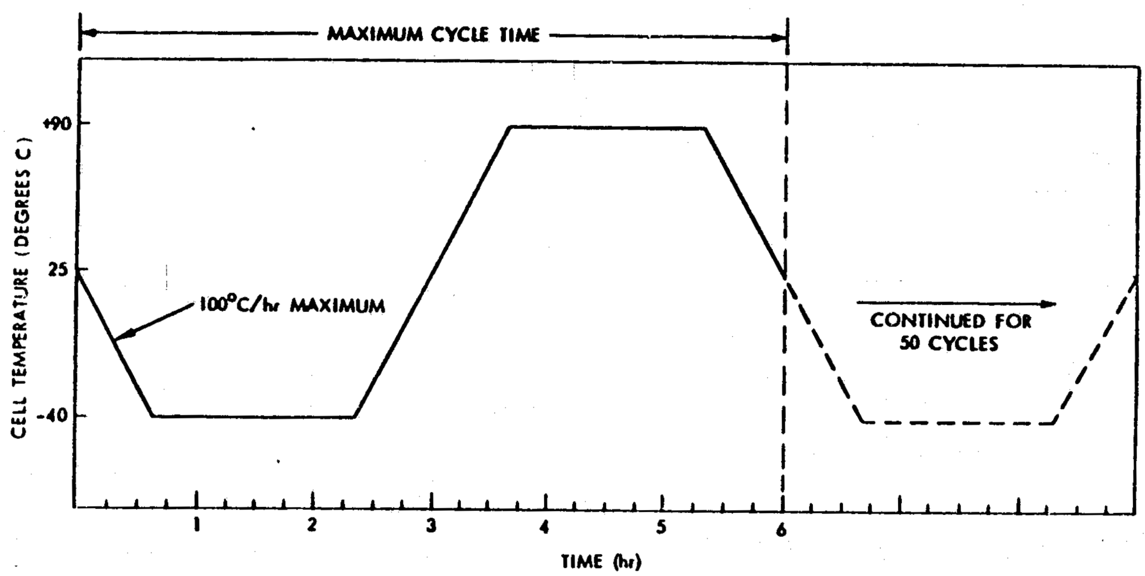


Figure 1. Thermal Cycle Test (Shorter cycle time is acceptable if 100°C/hr maximum rate of temperature change is not exceeded. Chamber may be opened at 25 cycles for visual inspection).

7. REQUIREMENTS: MAINTAINABILITY

7.1 ACCESSIBILITY FOR MAINTENANCE AND SERVICING. The P.V. Module shall be designed, constructed and installed to provide sufficient access for general maintenance, convenient servicing and monitoring of module performance.

7.2 INSTALLATION, OPERATION AND MAINTENANCE MANUAL. A manual shall be provided containing instructions for the installation, operation, and maintenance requirements of the P.V. Module.

7.1	REQUIREMENT	ACCESSIBILITY FOR MAINTENANCE AND SERVICING. The P.V. Module shall be designed, constructed and installed to provide sufficient access for general maintenance, convenient servicing and monitoring of module performance.
7.1.1	CRITERION	ACCESS FOR MAINTENANCE. Modules shall be replaceable or repairable without disturbing non adjacent modules in an array.
	EVALUATION	Review of drawings and specifications.
	COMMENTARY	Accessibility as a function of module life is an important consideration. Information on access provisions is provided in Uniform Mechanical Code, ICBO, 1973.
7.1.2	CRITERION	IMPAIRMENT OF OPERATION. The functional capability of the P.V. systems shall not be impaired to a greater extent than conventional systems when system repairs or modifications are being made.
	EVALUATION	Engineering review of specifications and drawings.
	COMMENTARY	Equipment that requires preventative maintenance shall be provided with complete instructions to maintain proper and efficient operation of the P.V. Module.
7.2	REQUIREMENT	INSTALLATION, OPERATION AND MAINTENANCE MANUAL. A manual shall be provided containing instructions for the installation, operation and maintenance of the module.
7.2.1	CRITERION	INSTALLATION INSTRUCTIONS. The instructions shall include physical, functional and procedural requirements for P.V. module installation. These instructions shall describe the interconnection requirements of the P.V. Module and its interface requirements with the buildings and site.
	EVALUATION	Review of isntallation instructions.

COMMENTARY

It is not the intent of this criterion to require complete, detailed module installation specifications. Such specifications would normally be project specific and part of the procurement process.

7.2.2 CRITERION

MAINTENANCE AND OPERATION INSTRUCTIONS

The manual shall completely describe the P.V. Module, its breakdown into components, its relationship to external systems and elements, its performance characteristics and its required parts and procedures for meeting specified capabilities.

The manual shall list all parts of the module by components, describing as necessary for clear understanding operation, maintenance, repair and replacement, such characteristics as shapes, dimensions, materials, weights, functions and performance characteristics. The manual shall include a tabulation of those specific performance requirements which are dependent upon specific maintenance procedures. The maintenance procedures, including ordinary, preventive and minor repairs, shall be cross-referenced for the module and its interface and with all subsystems and organized into a maintenance cycle. The manual shall fully describe operation procedures for all parts of the module including those required for implementation of specified planned changes in modes of operation. The manual shall provide warning against hazards that could arise in the maintenance of the module and shall fully describe precautions that shall be taken to avoid these hazards. The manual may consist in whole or in part of a series of instruction sheets provided by the various subsystem and component manufacturers.

EVALUATION

Review of maintenance and operating instructions.

COMMENTARY

Common malfunctions of P.V. Modules include cell cracking. It is necessary to fully describe and outline testing and identification methods of common malfunctions of P.V. Modules in the maintenance and operation manual.

7.2.3	CRITERION	MAINTENANCE PLAN. The manual shall include a comprehensive plan for maintaining the specified performance of the P.V. Module for their design service lives. The plan shall include all the necessary ordinary maintenance (e.g., cleaning) preventive maintenance and minor repair work, and projections for equipment replacement.
	EVALUATION	Review of maintenance plan.
7.2.4	CRITERION	REPLACEMENT PARTS. Parts, compoments, and equipment required for service, repair or replacement shall be commercially available from the P.V. Module Manufacturer or supplier.
	EVALUATION	Review of specifications for the availability of parts.
	COMMENTARY	This criterion is intended to preclude long periods of system inoperation due to the need for the repair or replacement of parts. It would be desirable to have a minimum one-year's supply of consumable parts and potential early failure items.
7.3	REQUIREMENT	REPAIR AND SERVICE PERSONNEL. The P.V. Module and system shall be designed in such a manner that they can be conveniently repaired by qualified service personnel.
7.3.1	CRITERION	SERVICING OF P.V. MODULES. The P.V. modules shall be capable of being serviced with a minimum amount of special equipment by a trained electrical service technician using a service manual.
	EVALUATION	Review of drawings, specifications, and service instruction manuals.
	COMMENTARY	The complexity and design of certain components may require their removal and replacement for repair of the system.

7.4	REQUIREMENT	LABELING AND TECHNICAL DATA SHEETS. Modules shall be properly labeled and be accompanied by a technical data sheet.
7.4.1	CRITERION	LABELING. P.V. Modules shall be labeled to show the manufacturer's name, model number, serial number, weight, electrical output, and any performance certifications.
	EVALUATION	Examine specifications.
7.4.2	CRITERION	TECHNICAL DATA SHEETS. Technical data sheets shall be provided which will include module efficiency, I.V. curves, and several normal operating cell temperatures, and proper warnings.
	EVALUATION	Review of specifications.
	COMMENTARY	Other data related to the installation and operating conditions or characteristics is desirable.

APPENDIX 20. CRITIQUE OF JPL'S SOLAR CELL MUDULE DESIGN AND TEST SPECIFICATIONS FOR RESIDENTIAL APPLICATIONS

PURPOSE: To critique, evaluate and re-write sections of the JPL specification to reflect the influence of building codes, standards and practices.

CONCLUSIONS: It is readily apparent that several sections in the JPL specification should be and will be adopted in an industry standard. This standard must be an industry consensus standard and will consist of testing methods and evaluations what will ensure module performance and integrity. Such a document may be generated by a standards writing organization such as ANSI or ASTM with the help of such testing organizations as Underwriters Laboratory.

RECOMMENDATIONS: Work should begin immediately to identify the proper organizations and laboratories necessary for the writing of an industry standard. Every effort must be made to allow manufacturers to generate new and innovative designs for their products by carefully writing industry standards.

INTRODUCTION

The following is a review of JPL's solar cell module design test specification for residential applications. The original JPL document was reproduced and commentary was added. This commentary which follows each section will be in *italics*. It should be noted that this specification is for a particular application, i.e., the government procurement of photovoltaic modules. In the future, sections of this document may be incorporated in an industry wide standard. Those sections which may be incorporated in that standard have been noted. The remaining areas are specific to the government specification and may indeed remain in the future for government procurements. Appendix 21 contains a specification which is of a format common to the building indsutry. This CSI format specification shows the general outline as well as a typical specification as it may be seen in the future for any building application.

Low-Cost Solar
Array Project

Solar Cell Module Design and Test Specification for Residential Applications

LSA Engineering

March 30, 1979

Prepared for
Jet Propulsion Laboratory
California Institute of Technology
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SECTION I
INTRODUCTION

A. SCOPE

This specification, a Jet Propulsion Laboratories Specification, provides near-term design, qualification and acceptance requirements for terrestrial solar cell modules suitable for incorporation in photovoltaic power sources (2 kW to 10 kW) applied to single family residential installations. Requirement levels and recommended design limits for selected performance criteria have been specified for modules intended principally for rooftop installation. Modules satisfying the requirements of this specification fall into one of two categories, residential panel or residential shingle, both meeting general performance requirements plus additional category peculiar restraints.

This is strictly a government specification for the procurement of R&D residential photovoltaic modules. This document is not meant to be an industry standard.

B. APPLICABLE DOCUMENTS

The following documentation is applicable to the extent specificed:

(1) Military: MIL-STD-810 C, Environmental Test Methods, March 10. 1975.

(2) Energy Research and Development Administration: TM 73702, ERDA/NASA/1022-77/16 "Terrestrial Photovoltaic Measurement Procedures" June 1977, Lewis Research Center, Cleveland, Ohio 44135.

(3) Underwriters Laboratory, Inc.: UL Standard No. UL 997, Wind Resistance of Prepared Roof Covering Materials," Latest Revision.

(4) Jet Propulsion Laboratories: 5101-19 "Cyclic Pressure-Load Developmental Testing of Solar Panels", February 1977, Pasadena, California.

(5) Underwriters Laboratories, Inc.: UL Standard No. 723, "Test for Surface Burning Characteristics of Building Materials", Chicago, Ill.

(6) Underwriters Laboratories Inc.: UL Standard No. 790, "Test for Fire Resistance of Roof Covering Materials", Chicago, Illinois.

(7) American Society of Testing and Materials: ASTM B117, "Standard Method of Salt Spray (Fog) Testing", Philadelphia, PA.

SECTION II

DESIGN AND PERFORMANCE REQUIREMENTS

Solar cell modules meeting the requirements of this document will be installed in arrays intended for residential applications ranging from 2kW to 10kW. In general these are intended as single-family dwelling applications. The use of concentrators or hybrid (combined thermal and photovoltaic) systems shall not be considered in meeting these requirements. The module designs shall satisfy the following general design considerations. Environments to be considered in assessing possible degradation of module electrical performance and physical properties include: solar exposure (particularly UV); thermal conditions, including freezing and thawing; effects of wind, rain, snow, ice, hail, salt mist, and atmospheric oxidants; dust and debris accumulation, especially nonremovable stains or contamination; and dynamic loading effects of wind, snow and hail. In addition to these general considerations, the following specific performance and design requirements shall be met by the modules.

A. PERFORMANCE REQUIREMENTS

The following standard performance measurement requirements shall be used:

(1) Average Module Output Power - Average module output power (P_{avg}) shall be determined for a suitable sized sample quantity of modules (not less than 10), at Standard Operating Conditions (SOC) and at Nominal Operating Voltage (V_{no}). Standard Opearting Conditions (SOC) are defined as AM1.5 irradiance level of 100 mW/cm^2 and cell temperature equal to the Nominal Operating Cell Temperature (NOCT). The power output (P) of individual modules shall be determined per Section IV, Paragraph A.

Determination of the average output power will be accomplished using a standard method of test established by a testing organization such as ASTM using NASA TM 73702, Terrestrial Photovoltaic Measurement Procedure as its basis. This test method will reference several other standard methods of test such as the Standard Method of Test for the Determination of the Nominal Operating Cell Temperature. In a specification document such as this, the test methods can be included or simply referenced by name and number.

(2) Minimum Individual Module Power Output - The minimum acceptable power output (P_{min}) for production modules shall be not less than 90 percent of the predetermined P_{avg}.

(3) Nominal Operating Voltage - The Nominal Operating Voltage (V_{no}) is the reference voltage at which modules are designed to provide maximum power output at Standard Operation Conditions (100 mW/cm^2, NOCT). For purposes of standardization, V_{no} shall be 15.0 Vdc, or a convenient fraction or multiple of 15 volts. In no case shall V_{no} exceed 60 Vdc.

This will be included in the above mentioned standard method of test. The value of the Nominal Operating Voltage can be specified here. As residential array systems become established, the 15 volt multiple requirement may be deleted.

(4) Nominal Operating Cell Temperature - The Nominal Operating Cell Temperature (NOCT) is the module cell temperature under ambient conditions equivalent to the Standard Thermal Environment (STE) which is defined as:

Insolation = 100 mW/cm^2

Air Temperature = 20^{o}C

Wind average velocity = 1 m/s

Mounting = Oriented normal to solar noon, mounted on structure typical of application

Electrical Load - Open circuit

The NOCT shall be determined by the procedure provided in Appendix A.

The Nominal Operating Cell Temperature is not a performance requirement. The determination of the Nominal Operating Cell Temperature, however, should be a standard test method. Reference to the method of determination should be made when obtaining the nominal operating voltage and not in the performance specification.

B. ELECTRICAL DESIGN REQUIREMENTS

The electrical design of the module shall meet the following requirements:

(1) Electrical Voltage Isolation - All module circuitry, including output terminations, shall be insulated from electrically conductive exter-

nal surfaces. The voltage isolation design shall provide capability to withstand an operating voltage resulting from series connection of modules to obtain a system voltage of 250 Vdc. This capability shall be demonstrated by successful completion of the 1500 Vdc high voltage withstanding test of Section III, paragraph B.2.

(2) Electrical Grounding and Safety - In order to minimize electrical hazard to personnel, all modules shall be provided with an external grounding terminal or stud serving as a common grounding point for all exposed external conductive surfaces not part of the module circuitry. A grounding connection is not required for modules without exposed conductive surfaces, unless removal of covers, mounting hardware, or adjacent modules, will expose such surfaces.

The above two electrical design requirements will ultimately be two of the requirements listed as an industry standard, e.g., a UL Standard for Safety 'Photovoltaic Modules for Residential Applications - Flat Plate Type'. This standard will reference any necessary test methods needed for determination of compliance.

(3) Module Electrical Interface - Each module shall be provided with redundant output terminations. The polarity of each termination shall be clearly marked in a permanent and legible manner. The terminations shall provide redundant connection to the module internal circuitry (cell strings) and shall have current handling capability compatible with module short circuitry current. If pigtails are selected as the output termination, they shall be of sufficient length to provide interconnection with adjacent modules. Output termination redundancy is not a requirement when direct module-to-module interconnections capability is provided.

Redundant output terminations may not be needed in all applications. However, as this is a specific specification used by JPL for its PV R&D procurement program, this requirement is legitimate. Polarity marking will be included in an industry standard as will circuitry current carrying capabilities.

(4) Cell String Circuit Reliability/Redundancy

Circuit redundancy features shall be incorporated where cost effective to enhance the reliability and manufacturing yield of completed modules. Design features may include, but are not limited to the following:

(a) Redundant interconnections between solar cells, including redundant cell attachment points

(b) Series/parallel interconnection of cells within the module

(c) Integral bypass diodes within each module

The decision to incorporate redundancy features shall be based on the expected percent improvement in lifetime/yield and replacement cost as contrasted with the percent increase in module cost/watt. Series/parallel circuit arrangements, when used, shall be designed so that "hot-spot" cell heating does not lead to further module degradation under worst-case-single-cell-failure conditions defined as follows:

(a) The module output is short circuited

(b) A single representative solar cell is open circuited to represent a single cell failure

(c) The incident irradiance is 100 mW/cm^2, AM1.5

(d) The thermal boundary conditions are adjusted so that the equilibrium solar cell temperature outside of the hot-spot region is equal to NOCT + 20°C.

This requirement should not be necessary since the manufacturer should strive to produce a reliable module in any manner he chooses. The reliability tests established in the industry standard will provide adequate incentive to incorporate reliability into the module design.

C. MECHANICAL DESIGN REQUIREMENTS

The mechanical design of the module shall meet the following requirements:

(1) Module Geometry - To meet the array/system requirements for mounting, each module shall meet the envelope, mechanical and interface requirements specified by an Interface Control Drawing to be prepared by the manufacturer.contractor, providing as a minimum the following information.

(a) Maximum envelope dimensions and tolerances.

(b) Location and configuration of output terminations

(c) Mounting hole or attachment provisions, dimensions, and tolerance

(d) Illuminated (active) surface dimensions and shadowing or view angle constraints

(e) Nominal electrical performance (P_{avg})

(f) Maximum weight

(g) Dimensioned cross-sectional view through cells and terminations

(h) Drawing of roof-top installation showing interface constraints

(i) Details of labeling and identification

To allow for convenient handling and testing of modules, no individual panel module shall exceed 1.2 meters x 1.2 meters (47.244 inches x 47.244 inches). Shingle modules shall be sized such that an integral number of modules will fit efficiently on a 1.2 m x 1.2 m mounting structure.

The size restriction is specific to this specification only and should be so indicated. If it is not the intent of JPL to limit size and this size restriction relates only to standardized testing, that should be so indicated.

(2) Interchangeability - All modules from a given manufacturer shall be physically and functionally interchangeable. Tolerances on all external module dimensions shall be maintained at a level consistent with module interchangeability. Surfaces, mounting holtes, and any attachment hardware associated with the attachment interfaces, shall be maintained within tolerances specified in the interface control drawing.

(3) Optical Surface Soiling - The illuminated optical surface(s) of the module shall be smooth, and generally free of projections which could promote entrapment of dust and other debris. Particular attention shall be given to selection of materials for the optical surface(s) which will minimize the accumulation of nonremovable contaminants, particulate matter and stains, and will promote self-cleaning by natural processes such as wind and rain.

This requirement is not necessary as it will be to the qualified *manufacturer's advantage to minimise soiling so as to maximise module output over time.*

(4) Module Labeling and Identification - Each module shall be identified in a permanent and legible manner with suitable labels or markings specifying the manufacturer's module model number (or drawing) and revision, sequential serial number, year and week of manufacture, and maximum system operating voltage for which the module is designed. Additional information may include the Nominal Operating Voltage and power of the module. The polarity of each electrical termination shall be marked in a permanent and legible manner in a position which is visible when accessing the electrical terminations in a completed array.

D. ENVIRONMENTAL DESIGN REQUIREMENTS

Environments to be considered in assessing possible degradation of module electrical performance and physical properties include: solar exposure (particularly UV); thermal conditions, including freezing and thawing; effects of wind, rain, snow, ice, hail, slat mist, and atmospheric oxidants; dust and debris accumulation, especially nonremovable stains or contamination; and dynamic loading effects of wind, snow and hail. As a minimum, the module design shall be capable of withstanding exposure to the following test environments:

(1) Thermal cycling from -40° to $+90^{\circ}$ per the test procedure in Section V, paragraph A.

(2) Humidity per the test procedure in Section V, paragraph B.

(3) Mechanical cycling loading per the test procedure in Section V, paragraph C. The test load level shall be ±1.7kPa (±35 pounds per square foot). This test is applicable only to panel type modules.

(4) Wind resistance test per the procedure in Section V, paragraph D. Shingle type modules only shall be capable of withstanding a test level equivalent to an uplift loading of 1.7 kPa (35 pounds/ft^2)

(5) Twisted mounting surface of 20 mm/m (1/4 inch per foot) per the test procedure in Section V, Paragraph E.

(6) Hail impact per the test procedure in Section V, paragraph F. The module shall be capable of withstanding 20.0 mm (3/4 inch) diameter hailstone impact.

All of the above are tests which will be incorporated into the industry standards document (See IIB2 Commentary). It would be legitimate to in-

dicate here the requirement to meet, for example, UL Standard No.XX, any level of testing, and list any areas where the industry standards must be exceeded.

However, it must be noted that this document is meant to be a procurement specification. It cannot be emphasized ehough that an industry standard would not impose broad based minimum requirements. On the other hand, from a marketing standpoint, we may want a single module design that satisfied a significant percentage of the market. The 3/4 inch requirement does that for the U.S. In fact, to satisfy 90% of the U.S. hail requirements would require a 1¼ - 1½ inch hail requirement. Note, however, module designers and manufacturers should be given the opportunity to build modules under the above mentioned specifications if his desire is to penetrate the 10%-20% of the market which does not impose such strict requirements.

SECTION III

CHARACTERIZATION, QUALIFICATION AND ACCEPTANCE REQUIREMENTS

A. PERFORMANCE CHARACTERIZATION TEST REQUIREMENTS

The tests included in this section will be performed to characterize the module electrical and thermal performance. The characterization testing will be performed in the sequence shown in the flow diagram in Figure 3-1.

(1) Determination of Nominal Operating Cell Temperature - For purposes of providing a measurement of module performance that is representative of the anticipated terrestrial application, all module performance measurements shall be referenced to the Nominal Operating Cell Temperature (NOCT). NOCT is defined as the average cell temperature in the module under ambient conditions equivalent to the Standard Thermal Environment. (STE). The Standard Thermal Environment is characterized by 100 mW/cm^2 insolation, ambient air temperature of $20^{o}C$, average wind velocity of 1.0 m/s, with the module installed in an open-frame assembly. Electrical output terminations are open-circuited. Actual cell temperatures shall be taken at conditions approximating STE in order to obtain the solar cell NOCT. The approved techniques for performing the NOCT characterization test are included in Appendix A.

As previously stated, the determination of Nominal Operating Cell Temperature should be a STANDARD METHOD OF TEST FOR NOMINAL OPERATING CELL TEMPERATURE *and referenced as such. By using this procedure the above can be eliminated in an industry specification by referring to e.g., ASTM XXXX. Also necessary is a definition section including all terms requiring such in the specification document.*

(2) Initial Electrical Measurement - An appropriate size sample quantity of the prototype modules will be used to determine initial electrical performance per Section IV, paragraph A. Measurements shall be referenced to the NOCT determined per paragraph III.A.1, and at Nominal Operating Voltage (V_{no}). In addition to obtaining an initial I-V characteristic curve for each module at SOC, the average output

power (P_{avg}) at nominal operating voltage shall be calculated from measurements of all prototype samples tested. When these electrical measurements are to be made at conditions other than SOC, the temperature correction coefficients required to correct measurements to NOCT shall be previously determined in accordance with Appendix B.

B. DESIGN QUALIFICATION TEST REQUIREMENTS

This section specifies the minimum tests that shall be performed in order to verify that the modules will satisfy the design requirements of this specification and pt provide confidence that production modules will function within the specified performance requirements. Modules shall be mounted on rigid structural test frames simulating the selected mounting interface and configuration for all design qualification testing. The mounting arrangement shall be representative of the rooftop installation shown on the manufacturer's Interface Control Drawing. Modules shall be provided with suitable thermocouple or circuit monitoring instrumentation. As a minimum, the following qualification tests shall be performed in the order described below. For clarification, the test sequence is shown in the flow chart (Figure III-1).

(1) Ground Continuity Test - Each module having exposed external conductive surfaces (i.e., frame or structural members) shall be tested using a suitable continuity tester to verify that electrical continuity exists between all such surfaces and the module grounding point. The maximum resistance to ground shall be 50 milliohms.

As with other tests to be performed in PV modules this test will ultimately be part of the industry standard and there should be no need to specify it if compliance with the Standard for Photovoltaic Flat Plate Modules is specified.

(2) Electrical Isolation Test - Each module shall be subjected to a 'Hi-Pot' test conducted with the output terminations short-circuited. Test leads from a suitable dc voltage power supply shall be connected with the positive lead on the terminals and the negative lead on the module grounding stud.

In the case of modules not required to provide a grounding stud, the

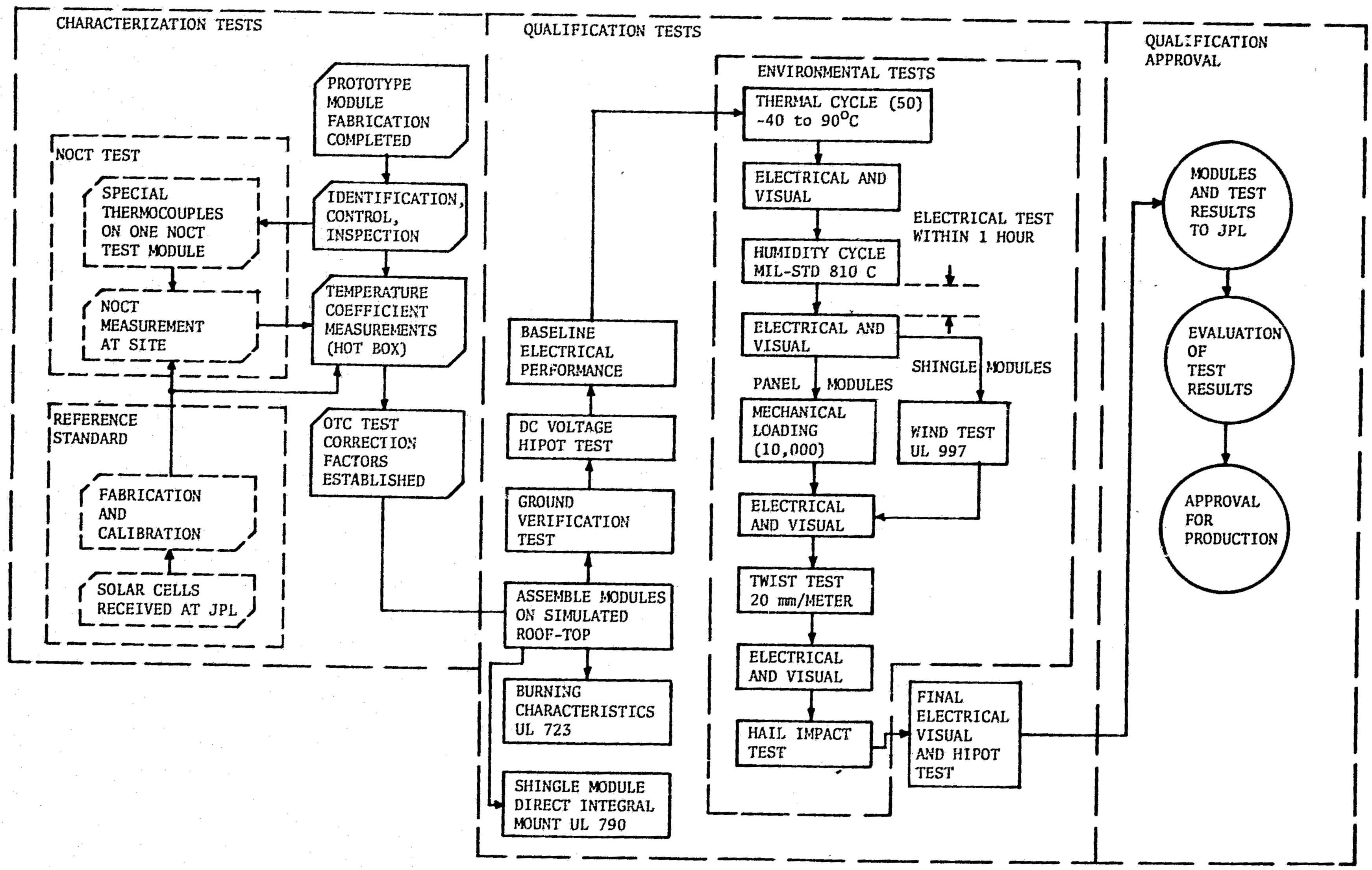
CHARACTERIZATION TESTS
QUALIFICATION TESTS
QUALIFICATION APPROVAL
NOCT TEST
SPECIAL THERMOCOUPLES ON ONE NOCT TEST MODULE
NOCT MEASUREMENT AT SITE
REFERENCE STANDARD
FABRICATION AND CALIBRATION
SOLAR CELLS RECEIVED AT JPL
PROTOTYPE MODULE FABRICATION COMPLETED
IDENTIFICATION, CONTROL, INSPECTION
TEMPERATURE COEFFICIENT MEASUREMENTS (HOT BOX)
OTC TEST CORRECTION FACTORS ESTABLISHED
BASELINE ELECTRICAL PERFORMANCE
DC VOLTAGE HIPOT TEST
GROUND VERIFICATION TEST
ASSEMBLE MODULES ON SIMULATED ROOF-TOP
BURNING CHARACTERISTICS UL 723
SHINGLE MODULE DIRECT INTEGRAL MOUNT UL 790
ENVIRONMENTAL TESTS
THERMAL CYCLE (50) -40 to 90°C
ELECTRICAL AND VISUAL
HUMIDITY CYCLE MIL-STD 810 C
ELECTRICAL TEST WITHIN 1 HOUR
ELECTRICAL AND VISUAL
PANEL MODULES
SHINGLE MODULES
MECHANICAL LOADING (10,000)
WIND TEST UL 997
ELECTRICAL AND VISUAL
TWIST TEST 20 mm/METER
ELECTRICAL AND VISUAL
HAIL IMPACT TEST
FINAL ELECTRICAL VISUAL AND HIPOT TEST
MODULES AND TEST RESULTS TO JPL
EVALUATION OF TEST RESULTS
APPROVAL FOR PRODUCTION

FIGURE III-1

mounting structure shall be used as the second test point. Voltage shall be applied at a rate not to exceed 500 V/sec up to the test voltage of 1500 Vdc, and then held at the required test voltage for 1 minute. The module shall be observed during the test and there shall be no signs of arcing or fhashover. Leakage current shall be monitored during the test and shall not exceed 50 microamps.

This test is similar to the ground continuity test in that it will also be included in an industry standard for PV modules.

(3) Baseline Electrical Measurement - Subsequent to assembly in the structural test frame, each module shall be remeasured to establish a baseline electrical output power which will serve as the comparison value for determination of the effects of qualification testing on electrical performance. The measurement shall be made per Section IV, Paragraph A.

This is not necessary in a future industry specification. The test may be performed and will be listed in the PV Module Standard Qualification Procedure.

(4) Visual Inspection - Each module shall be visually inspected to obtain a baseline identification of the presence or absence of any defects in the module for purposes of detecting any changes following environmental exposure. Pertinent sections of the applicable acceptance/rejection criteria or workmanship specification shall provide a guide for this inspection.

In a future industry specification, these inspection procedures will occur only on those modules sent to a qualified independent testing laboratory such as UL. This process will take place with the baseline electrical test prior to qualification testing for module compliance to established standards for PV Modules.

(5) Environmental Tests - Each module shall be subjected to the following exposures. Module electrical performance measurements and visual

inspection shall be conducted after each exposure. The tests shall be conducted in the order indicated:

(a) Thermal cycling test

(b) Humidity cycling test

(c) Mechanical cycling test, if applicable

(d) Wind resistance test, if applicable

(e) Twisted mounting surface test

(f) Hail impact test

These tests would only be specified if not previously specified in the PV Standards Document. In a specification values can be specified if they exceed minimum values as stated in the Standards Document.

(6) Qualification Pass/Fail Criteria - The output power degradation of each tested module determined after completion of all qualification tests, shall not exceed 5 percent of the baseline electrical performance determined per Section III, paragraph B.3. The module shall pass the electrical isolation test when retested at completion of qualification tests. There shall be no occurrence of open circuit or short circuit conditions during tests in which the module circuitry is instrumented. The allowable level of such observable cracks or other mechanical degradation (such as delamination of coatings) shall be determined by the JPL-approved manufacturer's module acceptance testing plan. Acceptable performance under the qualification testing requirements is a prerequisite for JPL approval of the module design.

In a future industry specification, degradation values can be specified in the event the degradation value is less than the maximum degradation allowed by a future industry standard for PV modules. The test procedure and sequence of tests will be established in the standards document. Should special sequencing of tests be desired it may be indicated.

C. MODULE PRODUCTION ACCEPTANCE REQUIREMENTS

Module acceptance shall be based on meeting the following requirements:

(1) Electrical Performance - Each module shall be measured to determine its current-voltage characteristics (I-V curve). Measurement shall be made in accordance with paragraph A of Section IV. No module shall be accepted for delivery which produces less than 90 percent of the average module output power (P_{avg}) under Standard Operating Conditions.

(2) Electrical Isolation - Each module shall be subjected to a 1500 Vdc Hi-Pot test, per Section III, Paragraph B.2, to assure adequate electrical isolation for safety of operating personnel at system operating voltages.

(3) Mechanical and Visual Inspection - Modules shall be mechanically and visually inspected, on the basis of criteria developed by the manufacturer, and approved by JPL, defining acceptable/rejectable levels of workmanship and quality.

The above three acceptance requirements are good examples of specification requirements.

SECTION IV

PERFORMANCE MEASUREMENT PROCEDURES

A. ELECTRICAL PERFORMANCE

Electrical performance measurements shall be referenced to Standard Operating Conditions (SOC) as defined as 100 mW/cm^2 AM1.5 irradiance, Nominal Operating cell Temperature (NOCT). All procedures, equipment, standards related to measurements shall conform to the latest revision of NASA TM 73702, Terrestrial Photovoltaic Measurement Procedures. A reference cell which has spectral response representative of the cells in the module shall be the only irradiance reference used. Secondary standards or transfer modules shall not be used.

To provide for efficient module testing, module electrical performance may be based on measurements made at either Standard Operating Conditions (SOC) or at Optional Test Conditions (OTC) defined as 100 mW/cm^2 irradiance, and a cell temperature other than NOCT.

1. <u>Module Output Power Measurements at SOC</u>

When module performance is measured at SOC, the output power of individual modules shall be calculated as the product of V_{no} (15.0 Vdc unless otherwise specified) and the module current taken from the I-V characteristic curve at V_{no}:

$$P = V_{no} \cdot I_{SOC} \tag{1}$$

where

V_{no} = Module nominal operating voltage at NOCT

I_{SOC} = Module current at NOCT and V_{no}

2. <u>Module Output Owner Measurements at OTC</u>

When module performance is measured at Optional Test Conditions (OTC) the individual module output power must be determined by application of appropriate temperature correction coefficients to the voltage and current data obtained from the OTC I-V characteristics curve. Under these conditions, the module output power is calculated directly from:

$$P = V_{no} \; (I_{OTC} + AI)$$

where

I_{OTC}	=	Current at T_{OTC} from OTC I-V curve
I	=	Current temperature correction, amps
	=	C_I $(T_{NOCT} - T_{OTC})$
C_I	=	Voltage point on OTC I-V curve
	=	$V_{no} - V$
V	=	Voltage temperature correction, volts
	=	C_V $(T_{NOCT} - T_{OTC})$
C_V	=	Voltage temperature coefficient, volts/^{o}C
T_{NOCT}	=	Predetermined value of NOCT
T_{OTC}	=	Selected optional test temperature

Determination of the temperature coefficients shall be accomplished by the method described in Appendix B.

Alternate temperature correction procedures such as that provided by computer controlled Large-Area Pulsed Solar Simulator (Xenon source) may be used if approved by JPL.

This test procedure, NASA TM 73702, Terrestrial Photovoltaic Measurement Procedures, should be adopted as a standard method of test. This will eliminate the need for duplication as a test number NASA TM 73702 can be specified.

SECTION V

TEST PROCEDURES

Two approaches can be taken to evaluate PV modules. First, a test method (procedure) can be developed to assure uniform testing of all PV modules. Evaluation can then be done with respect to the tests and the specific module application. Or secondly, specific and strict values can be specified which the module must adhere to when undergoing the established tests.

Typically, the first approach can be undertaken when standards have been established and an independent laboratory carries out the testing of the products. The second approach is used more often when a product is in its infancy and standards have not been developed. This approach, however, is limited to specification on a job by job or at most a region by region basis, not on a catch all basis where the most severe requirements throughout the country are included in the specification.

A. THERMAL CYCLING TEST PROCEDURE

The module shall be subjected to the thermal cycling procedure per Figure V-1, consisting of 50 cycles with the cell temperature varying between -40°C

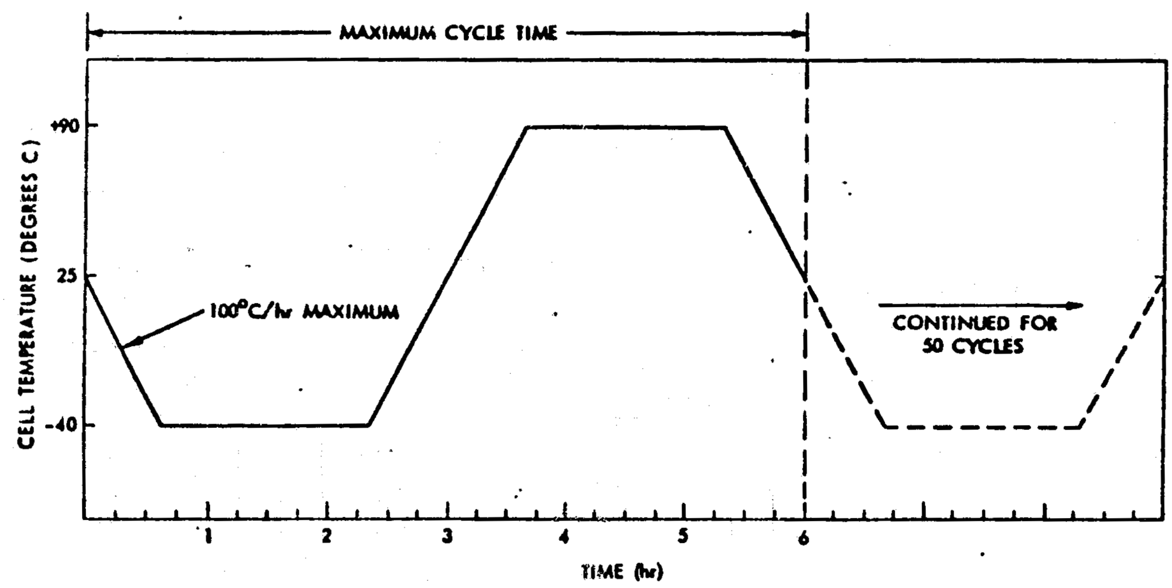

Figure V-1. Thermal Cycle Test (Shorter cycle time is acceptable if 100°C/hr maximum rate of temperature change is not exceeded. Chamber may be opened at 25 cycles for visual inspection.)

and 90°C. The temperature shall vary approximately linearly with time at a rate not exceeding 100°C per hour and with a period not greater than 6 hours per cycle (from ambient to -40°C to +90°C to ambient. The module circuitry shall be instrumented and monitored throughout the test to verify that no open circuits or short circuits occur during the exposure.

B. HUMIDITY TEST PROCEDURE

The module shall be subjected to the humidity cycling procedure per Figure V-2. The module shall be tested in the open circuit condition, but with terminations protected from water condensation. Electrical performance test, per paragraph IV.A, shall be performed within one hear after removal from the humidity chamber, or within another mutually agreed-upon time period if the testing is subcontracted.

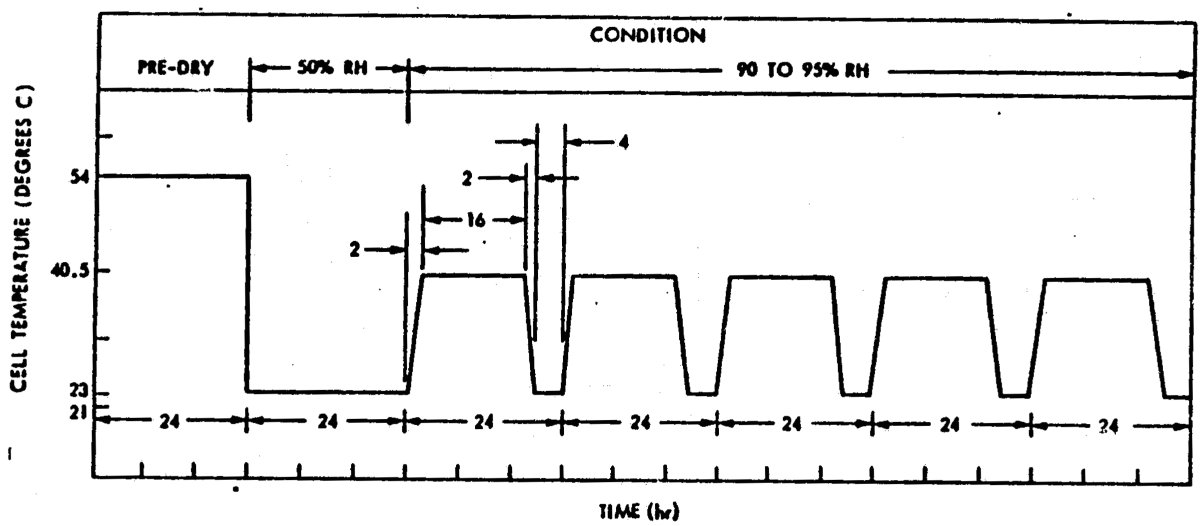

Figure V-2

Both the temperature cycling test and the humidity test will be included in the industry standards and will be used to evaluate designs of modules. These tests will establish infant mortality in modules and help eliminate designs which are prone to such degradation.

C. MECHANICAL CYCLING TEST PROCEDURE

Panel type modules shall be subjected to a cyclic load test in which the module is supported only at the design support points and a uniform load normal to the module surface is cycled 10,000 times in an alternating negative and positive direction. Cycle rate shall not exceed 20 cycles/minute. The module circuitry shall be instrumented to verify that no open circuitry or short circuits occur during the test. JPL Document 5101-19 "Cyclic Pressure Load Developmental Testing of Solar Panels", Febriary 1977, describes techniques suitable to the performance of this test.

This could be more simply stated by indicating standard method of test "Cyclic Pressure-Load Developmental Testing of Solar Panels" JPL Document 5101-19 is to be used for testing of mechanical cycling. This test should be established as a standaed upon verification of its validity as a degradation test.

D. WIND RESISTANCE TEST PROCEDURE

Shingle type modules shall be subjected to the wind resistance test described by Underwriters Laboratories, Standard UL 997, Latest Revision, "Standard for Wind Resistance Testing of Prepared Roof Covering Materials." The modules shall be subjected to air flow equivalent to laoding representative of uplift force 1.7 kPa (35 pounds/ft^2). The module circuitry shall be instrumented to verify that no open circuitry or short circuits occur during the test.

This is an example of an existing testing standard which can be directly applied to a specific PV module. Wind uplift test, however, should not be restricted to shingle type modules. The module itself is not of critical concern in a wind uplift test byt the support framing/module system is important. Similar test should be developed for all module mounting types.

E. TWISTED MOUNTING SURFACE TEST PROCEDURE.

The module shall be subjected to a twist test by deflection of the substrate to which it is mounted. The deviation from a true flat surface during the test shall be ± 20 mm/m (±1/4 inch per foot) measured along either mounting surface as shown in Figure V-3. The module circuitry shall be instrumented to verify that no open circuits or short circuits occur during the deflection test.

F. HAIL IMPACT TEST PROCEDURE

The module shall be subjected to normal impact loading with 20 mm (3/4

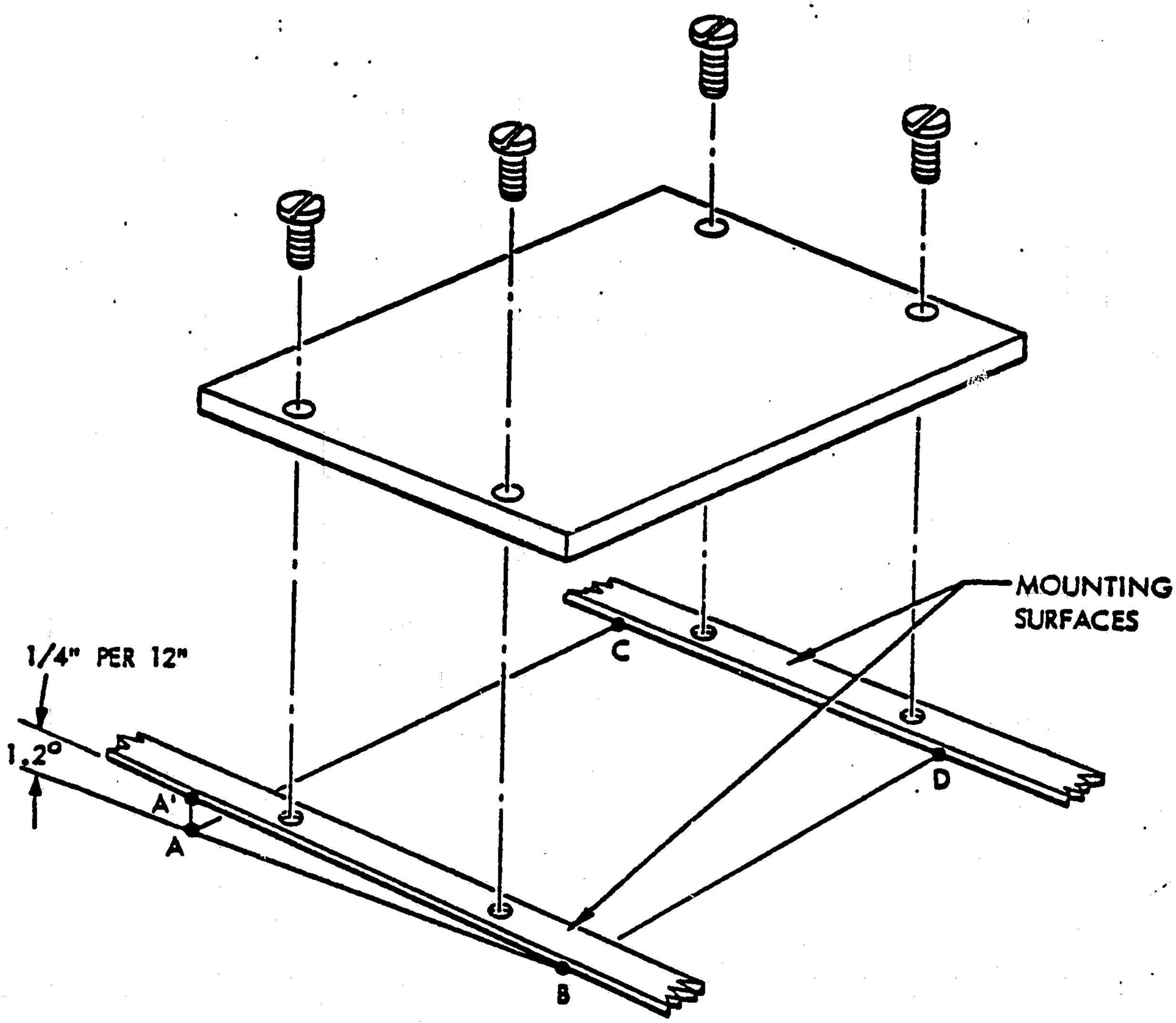

Figure V-3. Graphical Representation of "Twisted Mounting Surface" Requirement

- Points A, B, C, D are in a Plane
- Point A' is out of Plane the Amount Shown

inch) diameter iceballs traveling at terminal velocity of 20.1 m/sec (45 mph) specified size. At least three different points of impact shall be selected to include the test specimen's most sensitive exposed point, and each point will be struck at least three times (a minimum of 9 impacts). The most sensitive exposed point on a test specimen must be determined experimentally through destructive testing of a sample panel. Iceballs of 38 mm (1-1/2 in) diameter shall be fired at candidate sensitive points with increasing velocity until the panel is broken. Several different points on the panel should be broken, and the points broken at the lowest velocities should be used for subsequent testing.

The candidate points selected should include (where applicable) the following:

(1) Corners and edges of the module
(2) Edges of cells, especially around electrical contacts
(3) Points of minimum spacing between cells
(4) Points of support for any superstrate material
(5) Points of maximum distance from points of support in (4) above

Some scatter is expected in hitting a location on a module. Three repeated impacts are required to ensure that a sensitive point has been struck. Error of up to 13 mm (1/2 in) in the location hit is acceptable. Either pneumatic or spring-actuated guns for projecting the iceballs against the modules are acceptable. However, iceball velocity at impact must be controlled to within ± 5 percent of terminal velocity for the required hailstone size. Iceballs shall be generally spherical in shape with a maximum deviation in diameter of ±3 mm (±1/8 in.). The iceballs shall be colled to $-10^{\circ}C$ $\pm 2^{\circ}C$ as measured in the compartment where they are stored. The module shall be mounted in a manner representative of that used for actual installation of the module in the array. After each impact, the module shall be inspected for evidence of visible damage. Note that iceballs are the only acceptable hailstone simulation. Dropped steel balls, for example, shall not be used.

This test should also be adopted as a standard method of test used for testing of PV modules. Ratings can be assigned to each module tested as to the maximum size hailstones resisted during the test. In this way a designer/specifier can choose the module which best suits his application.

G. FIRE RESISTANCE TEST

1. Tests for Surface Burning Characteristics of Building Materials, UL 723 will be performed on all modules that, by their own structural quality or manner in which it is applied, is considered a building material.

2. Tests for Fire Resistance of Roof Covering Materials, UL 790 will be performed on all modules to be used as roof coverings.

These tests are examples of existing standard methods of test which should be applied to the testing of PV modules. Fire rating can be determined as can the amounts of and nature of any toxic fumes discharged during the burn process.

H. SALT FOG TEST

Standard Method of Salt Spray (Fog) Testing (ASTM B117) will be used and upon completion standard electrical tests shall be performed.

This standard test method can be used on all module designs and a rating procedure can be established to establish design prone to infant mortality, thus allowing the design specifier of PV systems to choose the module most suited for his application.

Included in Appendix C of this specification are other tests and standards which are applicable to PV modules in some applications, i.e., different mounting types have different requirements and therefore may require special tests.

APPENDIX A

DETERMINATION OF NOMINAL OPERATING CELL TEMPERATURE

1. PURPOSE

The purpose of this test is to acquire sufficient data to allow an accurate determination of the nominal operating temperatures of the solar cells of a terrestrial solar array module.

By definition, the Nominal Operating Cell Temperature (NOCT) is the module cell temperature under operating conditions in the Standard Thermal Environment (STE) which is defined as:

Insolation = 100 mW/cm^2
Air Temperature = 20°C
Wind average velocity = 1 m/s
Mounting = oriented normal to solar noon, open back
Electrical load - open circuit

The NOCT test procedure is based on bathering actual measured cell temperature data via thermocouples attached directly to the cells of interest, for a range of environmental conditions similar to the STE. The data are then presented in a way that allows accurate and repeatable extrapolation of the NOCT temperature.

2. DETERMINATION OF NOCT

The temperature of the solar cell (T_{cell}) is primarily a function of the air temperature (T_{air}), the average wind velocity ($\overline{V}$), and the total solar insolation (L) impinging on the active side of the solar array module. The approach for determining NOCT is based on the fact that the temperature difference ($T_{cell}-T_{air}$) is largely independent of air temperature and is essentially linearly proportional to the insolation level. Analyses indicate that the linear assumption is quite good for insolation levels greater than about 40 mW/cm^2. The procedure calls for plotting ($T_{cell}-T_{air}$) against the insolation level for a period when wind conditions are favorable. The NOCT is then determined by adding T_{air} = 20°C to the value of ($T_{cell}-T_{air}$) extrapolated for the STE insolation level of 100 mW/cm^2, i.e., NOCT = ($T_{cell}-T_{air}$) STE + 20°C.

The plot of ($T_{cell}-T_{air}$) vs L shall be determined by conducting a minimum of two field tests in which the module being characterized is tested under terrestrial environmental conditions approximateing the STE in accordance with the testing guidelines which follow. Each test shall consist of acquiring a semi-continuous record of $(T_{cell}-T_{air})$ over a one or two day period, together with other measurements as required to characterize the terrestrial environment during the testing period. Acceptable data shall consist of measurements made when the average wind velocity is 1 m/s ±0.75 m/s and with gusts less than 4 m/s for a period of 5 minutes prior to and up to the time of measurement. Local air temperature during the test period shall not siffer by more than 5°C and shall lie in the range of 20°C±15°C. Using only acceptable data as so defined, a plot shall be constructed which defines the relationship between $(T_{cell}-T_{air})$ and the insolation level (L) for L 40 mW/cm^2.*

When $(T_{cell}-T_{air})$ is plotted as a function of L for average wind velocities less than 1.75 m/s, results similar to those shown in Figure A 1 are obtained. For the data shown, the local air temperature was 15.6°C±4.5°C and the wind speed varied from zero to less than 4 m/s with an average of 1 m/s. Using the plot of $(T_{cell}-T_{air})$ at STE is determined by extrapolating the average value of $(T_{cell}-T_{air})$ for L = 100 mW/cm^2. Using the data in Figure A-1 as an example, $(T_{cell}-T_{air})$ at STE is determined to be 25.1°C. The preliminary value of NOCT is thus 25.1°C + 20°C = 45.1°C.

3. AIR TEMPERATURE AND WIND CORRECTION

A correction factor to the preliminary NOCT for average air temperature and wind velocity is determined from Figure A-1. This value is added to the preliminary NOCT and corrects the data to 20°C and 1 m/s. T_{air} and $\overline{V}$ are the average temperature and wind velocity for the test period.

For the test data shown in Figure A-1, $\overline{V}$ is 1 m/s and $\overline{T}_{air}$ is 15.6°C. From Figure A-2, the correction factor is 0°C. The NOCT is, therefore, 45.1°C.

4. TEST GEOMETRY

a. <u>Tilt Angle</u>. The plane of the module shall be positioned so that it

*If the air temperature varies by more than 5°C, the resulting effect appears as an increase in the scatter of the plotted data. As a result, the data will be more difficult to fit and a less accurate result is possible.

is normal to the sun (±5°) at solar noon.

b. Height. The bottom edge of the module shall be 0.6 m (2 ft) or more above the local horizontal plane or ground level.

c. Panel Configuration. The module shall be located in the interior of a 1.2 m x 1.2 m (4 ft x 4 ft) panel designed to simulate the thermal boundary conditions of the expected field installation. For modules designed for free-standing, open back installations, black aluminum plates or other modules of the same design shall be used to fill in any remaining open area of the panel surface. During testing, the panel should be supported in a manner which allows normal cooling of the rear surface. In the case of modules that are not self-supporting or have special mounting characteristics, such as shingle modules, the test module shall be centrally located in the panel and integrated with representative supporting structure and interfacing modules to simulate the thermal boundary conditions expected in field application.

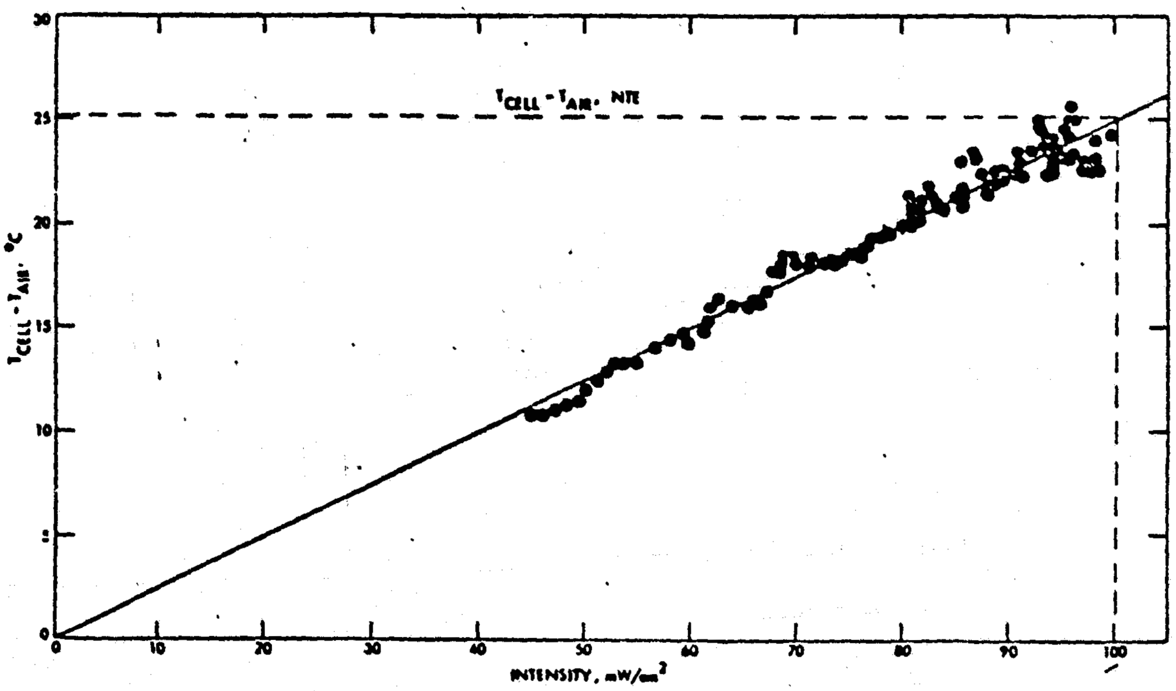

Figure A-1. Typical Cell Temperature Data

d. Surrounding Area. There shall be no obstructions to prevent full irradiance of the module beginning a minimum of four hours before solar noon and up to four hours after solar noon. The ground surrounding the module shall not

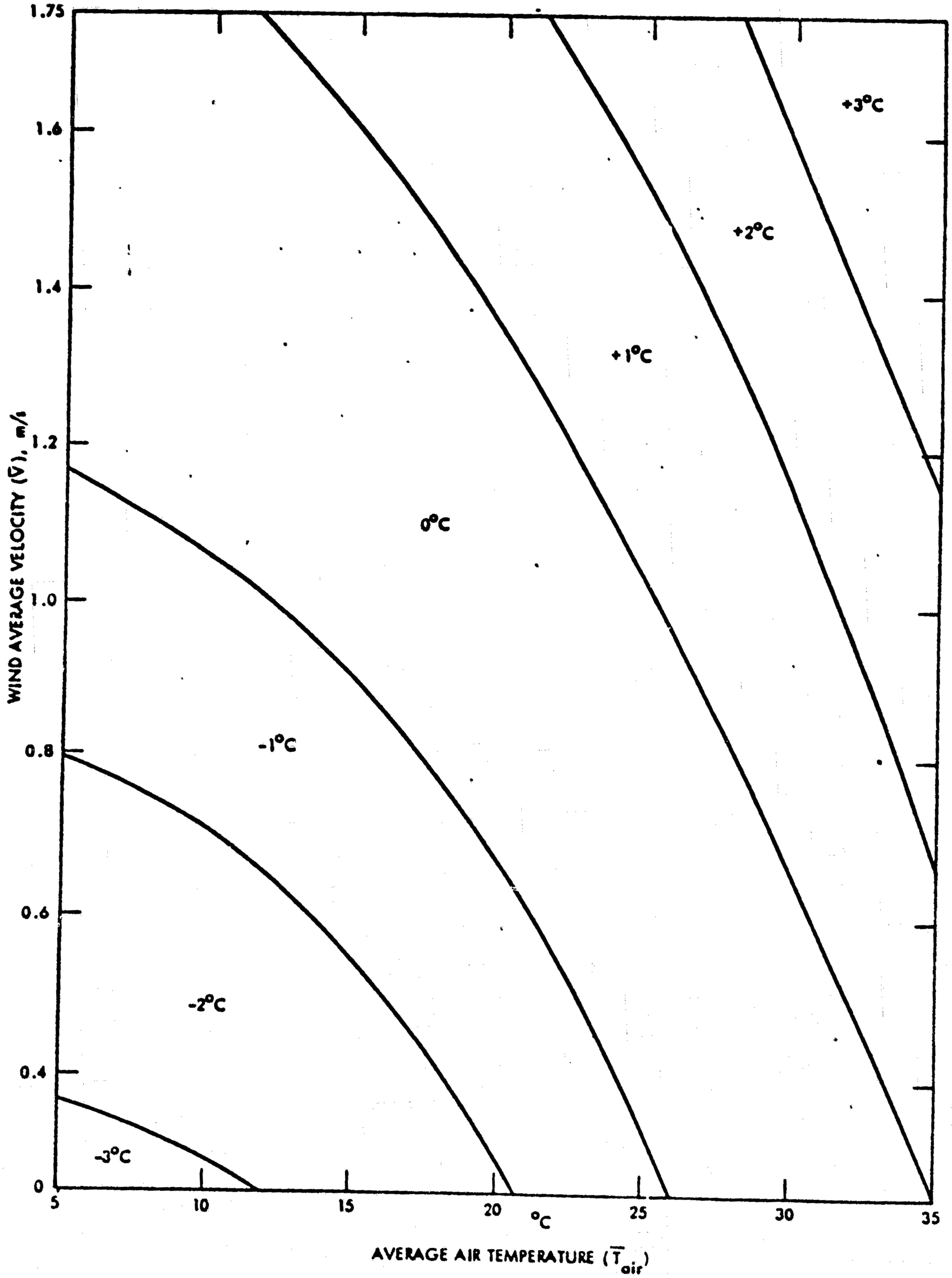

Figure A-2. NOCT Correction Factor

have a high solar reflectance and shall be flat and/or sloping away from the test fixture. Grass and various types of ground covers, blacktop, and dirt are recommended for the local surrounding area. Buildings having a large solar reflective finish shall not be present in the immediate vicinity. Good engineering judgement shall be exercised to ensure that the module is receiving a minimum of reflected solar energy from the surrounding area.

e. Wind Direction. The wind shall not be predominantly from due east or due west; flow parallel to the plane of the array is not acceptable and can result in a lower-than-typical operating cell temperature.

f. Module Electrical Load. In order to simplify testing, data shall be obtained for a module open-circuit condition responding to zero electrical power output.

5. TEST EQUIPMENT

a. Pyranometer. The total solar irradiance on the active side of the module shall be measured by a pyranometer mounted on the plane of the module and within .3 m (1 ft) of the array. The pyranometer used shall have a traceable annual calibration to a recognized standard instrument and shall be either (1) a temperature-compensated unit which has less than ± 1 percent deviation in sensitivity over the range $-20^{\circ}C$ to $+40^{\circ}C$, or (2) a unit which incorporates a temperature sensor and has a sensitivity-temperature correction supplied with its calibration.

b. Wind Measurement. Both the wind direction and wind speed shall be measured at the approximate height of the module and as near to the module as feasible.

c. Air Temperature. The local air temperature shall be measured at the approximate height of the module. The measurement shall be made in the shadow of the module and shall be accurate to $\pm 1^{\circ}C$. An average local air temperature is desired. This is obtained satisfactorily by increasing the thermal mass of the thermocouple by imbedding the thermocouple in a solder sphere of approximately 6 mm (1/4 in.) diameter. The thermocouple must be appropriately shielded and vented.

d. <u>Cell Temperature</u>. The temperature of at least two representative interior solar cells shall be measured to ±1°C. Thermocouples shall be 36 gauge, and shall be soft-soldered directly to the back of the cells.

e. <u>Substrate Surface Temperature</u>. The exterior temperature of the rear of the solar module shall be measured to ±1°C beneath a representative cell and when practical beneath a representative space between cells. Thermocouples shall be 26 gauge, and shall be bonded down with aluminized epoxy adhesive or the equivalent.

6. DATA RECORDING

All data shall be printed out approximately every 2 minutes. In addition, solar intensity, wind speed, wind direction, and air temperature shall be continuously recorded.

7. CLEANING

The active side of the solar cell module and the pyranometer bulb shall be cleaned before the start of each test. Dirt shall not be allowed to build up. Cleaning with a mild soap solution followed by a rinse with distilled water has been proven to be effective.

8. EQUIPMENT CALIBRATION

A calibration check shall be made of all the equipment prior to the start of the test.

This test should be adopted as a standard method of testing. One section of this test must be rewritten, however. Part 3C must be written in such a manner so as to allow for the testing and determination of NOCT for the four general mounting types. Further work must be done in this area to ensure the proper evaluation of NOCT so the designer/specifier can properly design the array.

APPENDIX B

DETERMINATION OF TEMPERATURE CORRECTION COEFFICIENTS

1. PURPOSE

The purpose of this test is to determine the temperature correction coefficients used in transforming module electrical performance measurements made at Optional Test Conditions to Standard Operating Conditions.

2. APPROACH

A photovoltaic I-V characteristic curve obtained at a given cell temperature and a fixed insolation level can be transformed by a point-by-point correction to an I-V curve at a different temperature. For purposes of translation from OTC toSOC the insolation is constant at 100 mW/cm^2. The region of the I-V curve of interest is near the maximum power point. The current and voltage points on the SOC I-V curve is near the maximum power point. The current and voltage points on the SOC I-V curve can be obtained from the coordinates of a point on the OTC I-V curve with the following equations:

$$I_{SOC} = I_{OTC} + C_I\ (T_N - T_0) \quad (1)$$

$$V_{SOC} = V_{OTC} + C_V\ (T_N - T_0) \quad (2)$$

where

V_{OTC}, I_{OTC}	are coordinates of a selected point on the curve obtained at OTC.
V_{SOC}, I_{SOC}	are coordinates of the corresponding point on the SOC curve
T_N	is actual cell temperature, usually NOCT, ±2°C, during the SOC curve measurement
T_0	is actual cell temperature, during the OTC curve measurement
C_I	the current temperature coefficient, expresses as amps/°C
C_V	the voltage temperature coefficient, expressed as negative volts/°C

The values of C_I ans C_V are to be determined empirically by a curve overlay procedure applied to I-V curve measurements of a minimum of 10 modules with cell temperatures approximating both OTC and SOC. The values of C_I and C_V for the 10 modules will be averaged to establish mean values to be used in calculating the power of production modules.

3. PROCEDURE

To determine C_I and C_V, the following procedure shall be used:

(1) Install the module to be tested in a temperature controlled environment. After stabilizing the module temperature at the cell temperature selected for OTC within ±2° obtain an I-V curve for OTC conditions. Record the actual temperature (T_0).

(2) Repeat step (1) for SOC with the module stabilized at NOCT ±2°C. Record the actual temperature (T_N).

(3) On the curve obtained at SOC, mark two points, near the maximum power point, and approximately equi-distant from it. For reference, these points should be approximately at 90% of I_{SC} and 60% of V_{OC}.

(4) Using a light box of similar equipment, superimpose the OTC curve and translate the curve rectalinearly until the curves match closely at the marked points. Mark the overlayed curve at the same points.

(5) Separate the curves and determine the voltage ($V_{SOC}-V_{OTC}$) shifts required to achieve the match.

(6) Calculate the C_I and C_V from the following:

$$C_I = \frac{I_{SOC} - I_{OTC}}{T_N - T_0}$$

$$C_V = \frac{V_{SOC} - V_{OTC}}{T_N - T_0}$$

C_V is negative

(7) Determine the average values of C_I and C_V for the 10 modules.

APPENDIX C
SPECIAL TESTS

LOAD REQUIREMENTS

Rack, standoff and integrally mounted modules will be required to conform to the "Building Code Requirement for Minimum Design Loads in Buildings and Other Structures" (ANSI A58.1-1972). These requirements are intended to govern assumptions for dead, live and other loads in the design of buildings and other structures which are subject to building code requirements. The loads specified are the minimum suitable for use with stresses and load factors recommended in current design specifications for comcrete, steel, wood and other structural materials used in buildings.

PLASTIC TESTS

Modules with plastic covers should use plastic tested using "Standard Recommended Practice for Outdoor Weathering of Plastics" (ASTM D1435-75). This recommended practice is intended to define conditions for the exposure of plastic materials to weather and is limited to the method by which the material is to be exposed and the general procedure to be followed. It is intended for use with finished articles of commerce. Means of evaluation of the effects of weathering will depend upon the intended usage of the test material. For plastic cover material the evaluation standards will include, but are not limited to:

D1003	Methods of Test for Haze and Luminous Transmittance of Transparent Plastics.
D1746	Method of Test for Transparency of Plastic Sheeting
D495	Method of Test for High-Voltage, Low-Current Arc Resistance of Solid Electrical Insulating Materials.

Modules which utilize plastic cover plates should be tested or the cover material should be tested for its resistance to marring. "Mar Resistance of Plastics" (ASTM D673) and "Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion" (ASTM D1044) are two test methods which cover the determination of resistance of plastics to surface marring caused by falling and surface abrasion, respectively. These tests should give indication of the plastic cover material's ability to perform over long periods of time in environments in which airborne particulates are high.

Modules which utilize an adhesive to bond modules to frames or modules to modules should use the "Recommended Practice for Atmospheric Exposure of Adhesive Bonded Joints and Structures" (ASTM D1828). This recommended practice defines the procedure for the direct exposure of adhesive-bonded joints and structures to natural atmospheric environments. This recommended practice is limited to the procedure by which samples are exposed and does not cover the tests that may be used to evaluate the effects of atmospheric exposure on these adhesive-bonded joints and structures.

Test methods include:

ASTM D 1002	Test for Strength Properties of Adhesive Bonds
D 905-49	Adhesive Bonds in Shear by Tension Loading
D 897	Method of Test for Tensile Properties of Adhesive Bonds

FIRE TESTS

Direct and integrally mounted modules will be required to undergo "Tests for Fire Resistance of Roof Covering Materials" (UL 790), "Standard Methods of Fire Tests of Roof Coverings (ASTM E108), or "Standard Methods of Fire Tests of Roof Coverings" (NFPA 256). The tests described in these standards are applicable to roof covering materials and are intended to measure the fire-resistance characteristics against fires originating from sources outside a building on which they may be installed. They are applicable to roof coverings intended for installation on either combustible or noncombustible decks when applied in the intended manner.

Integral mounted modules may be required to undergo "Fire Tests of Building Construction and Materials" (UL 263), "Standard Methods of Building Construction and Materials (ASTM E119), or "Standard Methods of Fire Tests of Building Construction and Materials" (NFPA 251). These tests are applicable to assemblies of masonry units and to composite assemblies of structural materials for buildings, including bearing and other walls and partitions, columns, girders, beams, slabs, and composite slab and beam assemblies for floors and roofs. They also apply to other assemblies and structural units that constitute permanent integral parts of a finished building.

ENVIRONMENTAL TEST (FUNGUS)

PV modules which will be mounted on or in close proximity to a roof surface should undergo fungus resistance tests. Tests which may be used, but not limited to, are MIL-STD-810C, Environmental Test Methods, Method 608.1, Fungus, "Standard Recommended Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi" (ASTM G21-70).

ENVIRONMENTAL TESTS (RAIN)

Rain tests have been incorporated in other tests including fire tests, weather exposure tests, and salt-fog tests. A rain test is described in MIL-STD-810C Method 506.1, Rain, which covers a test conducted to determine the effectiveness of protective covers or cases to shield equipment from rain. A rework of this MIL-STD must be undertaken for a specific rain test for PV modules. This test will be most critical for direct mounted shingle type modules.

WIND RESISTANCE

Modules which will be used as roof coverings will need to be tested for their ability to withstand wind uplift. This test is covered under UL 997 "Standard for Safety Wind Resistance of Prepared Roof Covering Materials." This test describes procedures for testing prepared roof coverings which comply with the requirements for construction, material specifications, and performance, including fire resistance, which when properly installed, to resist damage when subjected to normal high winds. Also related is ASTM D3161 "Standard Test Method for Wind Resistance of Asphalt Shingles.'

SHOCK TESTS

As modules will be shipped around the country, attention should be given to the ability of the module to withstand typical shock experienced during shipping. Portions of MIL-STD-810C Method 516.2, Shock, those dealing with transit drop test and edgewise drop tests, may be applied to the module directly. "Standard Method of Drop Test for Shipping Containers (ASTM D775) can be used to test the packing crate and module for its ability to withstand shocks during shipping.

CONSTRUCTION TEST

Modules construction of materials in a sandwich type construction can be tested for their flexure properties using "Standard Methods of Flexure Test of Flat Sandwich Constructions" (ASTM C393). This method covers a procedure for determining properties of flat sandwich constructions subjected to flatwise flexure in such a manner that the applied movements produce curvature of the plane of a sheet of the sandwich construction.

APPENDIX 21. CSI FORMAT SPECIFICATION

PURPOSE: A specification was written both in general format and as an example showing the format of a document that is typically used by the architect/engineer to specify equipment typical to the building industry.

CONCLUSIONS: This type specification can be used by the PV industry and the building industry to specify photovoltaic modules as well as photovoltaic systems. It is important to use a document that is familiar to the personnel found on a building job site. The CSI specification can be found on many building job sites and, therefore, is an appropriate document for the specification of photovoltaic equipment.

RECOMMENDATIONS: The photovoltaic industry in general should familiarize itself with documents such as the CSI specification to ensure its easy use by architects, engineers and builders in not only the residential market, but also all building specific applications.

INTRODUCTION

Every product or device incorporated into a building project, regardless of the project's scale will be specified by the designer to insure that the Owner gets what he has paid for, that the device is properly treated during shipping, and that it is installed according to the manufacturer's or designer's recommendations. Throughout history, the building industry has been factured into regional areas of material and product use. Designer's and builders were familiar with products and services available only in their local area. Specification of a product was related more toward experience than expertise. However, with the advent of expanding regionalism, and industrialization/specialization in manufacture of products, a particular product specified on a job in a state were made in another. The intimate contacts between manufacturer and specifier were lost; and so was the ability to assure the owner he was getting what he paid for. Manufacturers specialization and centralization required that he develop an acceptable way to assure the specifier, and ultimately the owner, of his product's quality. To do this, the industry developed consensus standards. Consensus standards simply aid in the definition of acceptable quality for any product or service. These standards have, for the most part, solved the problem of quality assurance. However, they have created another unique problem for the building designer or specifier. In order to insure a particular level of quality in a building, the specifier is obligated to know for every product he specifies, all of the standards which must be referenced in the specification. For each building project, there might be thousands of products and materials used. Each product may have ten or more standards to which it must comply before it becomes acceptable to the designer. The specifier's plight becomes obvious. He is overwhelmed with standards and qualifications that must be referenced to obtain the desired end building product. To alleviate this problem, the Construction Specifications Institute developed a Uniform Construction Index. "In 1966, major elements of the United States construction industry jointly published the first edition of the Uniform System for Construction Specification, data filing and cost accounting; Title I Buildings. For several years prior to publication, the conference on uniform indexing systems explored many avenues in search for simple, logical and flexible system for rapid classification and retrieval of technical data in the construction industry. Among others, the following unrelated documents generallt used in the construction industry were examined as a possible basis for inter-related uniform systems: CSI Format for Building Specifications, known as theCSI Format for Construction Specifications, originally published by the Construction Specifications Institute, 1963; Standard Filing System and Alphabetical Index, originally published by the American Institute of Architects, 1920; and Suggested Guide for Field Cost Accounting, originally published by the Associated General Contractors of American, 1961. Because of the research/storage/retrieval application relationship existing between technologies and specifications, it was determined that a uniform system based on specifications would best meet the needs of the construction industry. The inter-relationship of place, trade, function or material inherent in the 16 division grouping of the CSI format for building specifications was determined to be the most appropriate arrangement for a system which would become a statement of both principal and mechanics. This sytem would encourage closer communications and understanding among three of the dominent forces in the construction industry: manufacturer, designer/specifier, and builder. This uniform system has gained wide recognition and ultimate utilization by all facets of the construction industry and is recognized as an industry standard. This document is inherently flexible and was used to meet changing needs in both technology and methodology. Experience and use as a result of feedback has indicated that even more responsive to construction needs. In 1970 a joint industry conference comprised of representatives and major elements of the construction industry in the U.S. convened to start work on a revised edition of the Uniform System.."[1]

Although the CSI Format presents the specification organization, it does not include any model or representative specifications to the designer or specifier to draw upon. An additional manual has been required, companion volume to the CSI Format. This has been traditionally represented in the construction industry by MasterSpec.[r] MasterSpec[r] has a system that not only pulls all the required standards into one unified format, it also standardizes specifications to alleviate the regional characteristics that have also existed in this aspect of the building industry. All products, materials, or processes have been broken down into the same 16 division format as CSI uses. They are as follows:

0. Conditions of the Contract
1. General Requirements
2. Site Work
3. Concrete
4. Masonry
5. Metals
6. Wood and Plastics
7. Thermal and Moisture Protection
8. Doors and Windows
9. Finishes
10. Specialties
11. Equipment
12. Furnishings
13. Special Construction
14. Conveyance Systems

1. Uniform Construction Index, The Construction Specifications Institute, 1150 17th Street, N.W., Washington, D.C. 10036, page 3.

15. Mechanical
16. Electrical

Each of these 16 Divisions is then broken into broad scope and narrow scope categories. For instance, under the major category "Electrical" the broad scope designation where residential flat plate modules would fall is referred to as Power Generation - 16200. The specific narrow scope area, yet unassigned, might be called Photovoltaic Generating Devices and be assigned the number 16270. Within this numerical format would be a generalized specification on Photovoltaic generating devices that describes the general characteristics of the job, characteristics of the product specified and finally the proper execution of the product on the job site. The use of this type of specification procedure in the building industry is beneficial for a number of reasons. First, it serves as a very good checklist for the specification writer to maintain a comprehensive, high-quality specification. Second, liability and insurance companies view the use of a standardized specification as beneficial and give rate reductions to professional corporations for their liability insurance. Third, the resistance generally displayed toward new product usage in the building industry would be practically overcome by developing this type of standardizing specification which allows immediate incorporation and understanding of a particular product's needs and requirements into a specification writer's vocabulary. Finally, the builder, who is being asked to provide a bid price on an unknown quantity will now exactly what will be required. The following is an example of the proper categorical breakdown and commentary for a typical residential application. It is done under Division 16 of the CSI Format, subdivision 16270, Flat Plate Photovoltaic Modules. It is simply a listing with commentary.

CSI FORMAT EXAMPLE

In order to fully illustrate the use of a CSI specification, a typical specification for a photovoltaic module follows. This was prepared for a PV array on a residence located in Western Pennsylvania. The photovoltaic array will form a south slope of the roof, i.e., an integrally mounted array and will consist of 1,000 $ft.^2$ of photovoltaic modules. The entire specification is presented here, with notes concerning the rationale behind each requirement.

DIVISION 16 - ELECTRICAL
SECTION 201 - FLAT PLATE PHOTOVOLTAIC MODULES

Part 1 - General

1.01 Description

A. Related Work Specified Elsewhere

1. Electrical Distribution System	- Sec. 16480	
2. Power System Storage	- Sec. 16280	
3. Controls & Instrumentation	- Sec. 16900	
4. Grounding	- Sec. 16450	
5. Roofing	- Sec. 07300	
6. Flashing	- Sec. 07700	
7. Sealants		
8. Gasketing		
9. Other		

Specifier Note

Add or delete items as applicable, to set limits of work under this section.

Commentary:

This particular sectic deals with work that is related to the photovoltaic module as part of the total electrical generation system that will be installed in the building or related to the direct installation of the module. Because this work may not be electrical, or not properly placed in Section 16270, Flat Plate Photovoltaic Modules, it will appear elsewhere in a complete CSI format specification. It is shown here for three reasons: First, the manufacturer who will be responsible for the supply of the PV module wants to know that everything which concerns the installation of this particular module is correctly specified. The installation subcontractor, also, wants to know what type of building to module interface is being requested by the drawings and specifications so he can be sure his bid price will reflect all the work he will be required to perform. Third, the specification writer can use this format to divide the work into the proper building trades and to take the best advantage of available labor and reduced conflicts over job responsibilities. For instance, the module manufacturer may give a price for a "turnkey" operation, not only providing the module but the installation of the module onto the building only to find the flashing and wiring which he has priced out must be performed by on-site union labor. At this time, he must negotiate with the union at a possibly higher rate than originally anticipated. This could be avoided by using the CSI format.

B. Work Installed but Furnished by Others

1. Control points and wiring	-	Sec. 16470	Add or delete items as applicable
2. Flashing	-	Sec. 07700	
3. Other			

Commentary:

This area deals with all work that would be done by the installation subcontractor, although the materials or products may be supplied by someone other than the module supplier. This area clarifies what the module manufacturer will be required to supply with the module and what the installer is expected to do. In addition, this allows the specifier the opportunity to very carefully determine what will be included in any bid price for the modules by defining the limits of responsibility of the module manufacturer. An example of this would be if the module manufacturer, supplier or installer would be asked to bid the installation of perimeter array flashing along with the module cost, but that the flashing itself would be provided by a local sheet metal supplier.

C. Work Furnished but Installed by Others

1. Anchorage System	-	Sec. 05100
2. Panels	-	Sec. 16270
3. Other		

Commentary:

This area of the specification is in many respects the reverse of Section B since it outlines work or products that will be supplied by the module manufacturer but will be installed on the job site by another trade. For instance, the module manufacturer or installer or supplier would be asked to supply wiring to interconnect the modules into branch circuits, but the actual work on the site would be done by a particular electrical subcontractor.

D. Description of Array

1. When complete, the array shall be capable of producing Vdc electrical energy. Its output capacity shall be based on ___ mW/cm^2 solar insolation and a NOCT rating appropriate for the particular installation (See 3.04a Testing).

   Modify as necessary to define broad-scope requirements of system.

2. It shall be an array made of discrete modules interconnected to assure a system performance under normal circumstances as stated in Section D1 above for __ year life.

Commentary:

This area includes these and other specific descriptions related to each particular installation, such as the number of modules and their size and the location of the array on the building. This also would include any particular buildings done by the building designer which detail the array. They should be referenced here to provide project coordination.

E. Definitions

List definitions related specifically to this job, as necessary. These particular definitions are shown only as examples.

1. Solar Cell - The basic photovoltaic device which generates electricity when exposed to sunlight
2. 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.
3. 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.
4. Branch Circuit - A number of modules or paralleled modules connected in series to provide DC power at the system voltage level required.
5. Residential Photovoltaic Power System - the aggregate of all branch circuits, arrays, together with the auxiliary systems, power conditioning wiring, protection, control and utility interface and facilities required to convert terrestrial sunlight into electrical energy suitable for connection to a residential electric distribution system or a utility power grid.

1.02 Quality Assurance

A. Acceptable Manufacturers

1.
2.

Provide list of acceptable manufacturers.

A. Acceptable Manufacturers

1. Manufacturers desiring to submit proposals for the work shall obtain pre-bid approval from the owner.

Use this method if desirable to limit bidding to manufacturers with es-

No other proposals will be accepted. — tablished records.

2. Pre-bid approval will be based upon the following:
   a. Financial capability
   b. Delivery schedule
   c. Mounting details
   d. Electrical connections
   e. Safety methods
   f. Compliance to the Requirements
   g. ______________________________

3. Submit data to

____

____

Commentary:

Where a new product or technology is introduced into the building industry, there is always a trial period when there are only a few manufacturers who produce products which will meet the requirements set by the designer or project specifier. In this case, they will simply be named in the specification. This will be more likely a near term condition. It should be noted that when a project uses public funds, many times a competitive bid is required to determine which product is to be used. This particular technique is not sufficient for competitive bid situations. As the photovoltaic technology matures and the number of competent manufacturers increases, the specifier might simply write a performance specification to accept proposals from numerous manufacturers on how their product qualifies for the job. Since this may create interest from a diverse group of manufacturers, the designer or specifier may wish to pre-qualify the manufacturer to eliminate ones that ultimately will not comply. For instance, if a project is being designed for construction in Kansas, the designer may require a glass superstrate be used to achieve the proper hail resistance. Therefore, although manufacturers who make modules with superstrates other than glass may want to prepare a price, the designer in this case, would inform the manufacturer that he would not comply, and therefore, save him the time and preparation of a quote.

B. Design Criteria

1. Manufacturers proposals shall include the following: — Modify list to suit subject.
   a. System performance data meeting test requirements of PV industry.

Specifications for Residential PV Modules.

b. Module model number.
c. Gross dimensions
d. Module weight
e. Wiring details
f. Nominal operating cell temperature
g. Instruction details on the module and roofing details
h. structural and mounting details including waterproofing where needed.
i. PV array layout showing orientation and number of PV panels.
j. All warranty and guarantee formalities.

This is to be omitted if the structure is not a component supplied by the module manufacturer, and added to the work specified elsehwere.

2. Submit data to:

____

____

Commentary:

The intention of this portion of the specification is to assure, during the submission and bidding phase of the project, the manufacturer's eventual compliance with all the requirements outlined in Part 2 of the specification - Products. Part 2 would originally be written to reflect the designer's requirement and would not necessarily be a description of the manufacturer's specific product. In fact, this particular part of the specification may be written and released to assist the specifier in a product selection before a full specification is needed. Part 2 "Products" and Part 3 "Execution" could then be written around a particular product.

C. Erector Qualifications:
1. Acceptable Erectors:
   a.________________
   b.________________
   c.________________

OR

C. Erector Qualifications:
1. Erectors desiring to submit proposals for the work shall obtain the bid approval from the Owner.
2. Pre-bid approval will be based on the following:
   a. Manufacturers approval
   b. Financial capability

c. Delivery Schedules
d. Past Experience
e. Other

Commentary:

Many times in the building industry, new products are introduced with no precedence requiring installation skills not found generally among traditional building trades. In this case, the specifier may look for recommendations from the manufacturer or his own experience and knowledge of local contractors who are capable of proper installation. The installer would be named and the general contractor would be required to use him. This may be the near term condition in the PV industry. If the product is introduced into the market place successfully, the number of installers desiring employment through the installation of residential PV modules will increase. At some point, the number of qualified installers will be beyond the specifiers own knowledge, therefore, a standard technique - the pre-bid approval, is used. The pre-bid approval is simply a screening that the specifier and designer will do of all potential applicants indicating which ones will in fact, comply with specification before seeking a price.

D. Requirements of Regulatory Agencies	
1. System when installed shall conform to requirements of all local, state and national ordinances and applicable building codes. Secure permits as required	To date current codes do not address solar applications. Specific areas should be investigated.
2. Comply with National Code as follows:	
a. National Electric Code	Modify as applicable.
b. National Fire Protection Assoc.	List specific area as known.
c. Other	

Commentary:

This section of the Specification relates to two areas of concern - one for the system designer and one for the module installer. Each individual must become familiar with all of these regulating agencies and make sure the job is in compliance with the requirements. The module manufacturer must, as part of his responsibility, provide sufficient information to the specifier to allow him to determine compliance with the above regulations. This may be in the form of a

UL stamp (See UL approvals section). Manufacturers whose equipment has been designed in ignorance of this information or cannot supply substantiation of compliance may not be considered further. In fact, they most probably will not go beyond the pre-bid meeting with the specification writer and designer.

E. Allowable Tolerances

Commentary:

In many projects the manufacturer may only supply the module a frame. In order to assure assembly, different tolerances can be maintained at the job site. Each component must be manufactured within set tolerance limits. Manufacturer will design his module to be within certain dimensional characteristics during installation and during the use of the module throughout its life. (This accounts for expansion and contraction). The designer and installer must be aware of these to assure that the support system can be designed to accommodate the module. Therefore, they will be stated in this section.

F. Job Mock-Up

Commentary:
In some cases, the manufacturer may be asked to and will supply items and materials not normally supplied by his company. This might relate to special perimeter gasketing, special cover plates or special terminals. In this instance, the designer may ask for a sample of the potential product. (See 1.03 Submittals) In this case the manufacturer will be supplying the installation equipment more than likely and will be providing an example of the on-site installation system for review of the designer.

1.03 Submittals
A. Samples
1. Submit samples of all components to be used in the Work.

Commentary:

In the event that a sample is asked for, this sample shall be submitted to the designer at the address specified.

2. Samples to be approved by Owner and kept at the designer's office.

B. Shop Drawings
   1. Submit shop drawings showing methods and details of construction.
   2. Obtain owners approval.

Commentary:

All items to be supplied and integrated on a particular job must be carefully coordinated. To do this well and to check dimensions and specified changes in stock items, the manufacturer must provide the system designer with measured scale drawings of all equipment supplied. No shipment of equipment should begin until dimension drawings have been submitted, approved and returned.

C. Tests
   1. Module electrical test prior to shipment
   2. Test final array for compliance with specifications and submit results for approval.

Commentary

The tests to be performed by the manufacturer on each module shall be limited to those which determine compliance with the CSI format and specifications, and insure proper performance of the module after installation at the job site. They are not intended to include areas more appropriately handled by the industry certification. (See Appendix 20, Figure III). The certification might require rigerous testing of prototype production modules to assure a working concept and good execution that would be in compliance with industry standards. These might be performed on a random selection of production modules, but are too time consuming with industry standards. For further clarification of this particular topic, see Appendix 20.

   3. Schedule of Tests
      a. Ground Continuity Test. Each module shall be provided with a grouding stud which shall be tested using suitable continuity test to verify that all electrical continuity exists between the grounding stud and all exposed external conductive surfaces. Also, if grounding studs are not required, test for

zero continuity must be performed between either the positive and negative terminal and any exposed conductive surface.

b. Module Electrical Output. The electrical output of each module shall be measured on the following conditions:
   1) ___ mW/cm^2 insolation; normal, instantaneous
   2) ambient air - _____
   3) wind velocity - ______
   4) open back and
   5) electrical load - open circuit

Commentary:

These tests for module electrical output are peak val[illegible] only, and are not intended to represent the module under field conditions. Because there have been four basic mounting types illustrated in this report and each of these mounting types will provide different module operation characteristics, each module design must have its performance certified under each of these mounting conditions. Manufacturers shall provide the rating curve to the design for the purpose of module and array output estimations contingent upon the particular installation of the module. The required design output will appear in 2.01-B, Module Electrical Performance Criteria.

c. Module Mounting. All modules to be series wired must be tested and matched within ___ output under instantaneous conditions outlined in 1.03C Tests.

D. Maintenance Data and Operating Instructions:
   1. Submit complete instructions to the system designer showing methods and criteria for maintaining and operating system.
   2. Upon complete installation of the array and final inspection of the building project, the installer or building contractor shall provide the Owner a complete set of instructions showing proper maintenance techniques.

E. Maintenance Materials
   1. Provide owner with________ spares for future use.

   If applicable provide detailed list of spares.

1.04 Product Delivery, Handling and Storage

A. Delivery of Materials

1. All materials shall be delivered to site in protective packaging, as per specified shipping method.

2. All damaged materials shall be returned to manufacturer and replaced with undamaged materials meeting specifications.

B. Storage of Materials

1. All materials shall be stored at the site and protected from damage.

2. Replace all damaged materials

1.05 Job Conditions

A. Existing Conditions

1. Review project to assure proper conditions exist to allow first class installation and operation of system.

Note specific problems which may cause difficulties.

Commentary:

This review will most probably be made by the installer to assure that all dimensions are correct and that all materials and fasteners specified elsewhere are in places requested by the designer and the manufacturer.

B. Environmental Conditions

1. Install system under acceptable temperature and weather conditions to assure proper operation of system

Note specific conditions which must be met.

2. ______________________________

Commentary:

These conditions are to be provided by the manufacturer; in this case, manufacturers of both the module and supporting components (See Section 1.01-A, Related Work Specified Elsewhere). The designer or the member of the designing team supervising the construction project will determine compliance under 3.01-F, Installation.

C. Sequencing

1. Schedule work in proper sequence with other trades to assure proper installation and operation of system.

Note possible conflicts if known.

2. ______________________________

1.06 Guarantee

A. Manufacturers Guarantee

1. Provide manufacturers guarantee covering replacement of all defective parts for a period of one year from date of acceptance on job site.

Note details of specific components if needed.

B. Installers Guarantee

1. Provide written guarantee of installer covering replacement of materials damaged by faulty installation.

Commentary:

In the near term market or perhaps through the demonstration phases of residential photovoltaic applications, these will not be required, but as the industry grows, they will undoubtedly become extremely important. Currently, solar thermal collectors are being guaranteed for five years.

C. Installers Performance Bond

1. The installer's performance bond may be supplied in lieu of an installation guarantee.

1.07 Certiciation

A. Manufacturer shall provide evidence in writing to the designer that his module passes all industry certifications required for the particular installation specified.

B. Manufacturer shall display on each module the official seal of certification and approval by the industry.

Commentary:

This "industry certification" is not yet available, but is currently exemplified by the Block 4 Solar Cell and Module Design Test Specifications for Residential Applications.[1] *It would be hoped that through the consensus standards writing group such as ANSI and government support through organizations such as SERI,*

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1. Block IV Solar Cell Module Design Test Specification for Residential Applications, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, November 1, 1978, Report No. 5101-83.

standards and required tests would be identified. At that point, special testing laboratories would be designated for PV modules and systems such as UL, to undertake certification. In any case, the certification is mandatory. (See Appendix 20).

PART 2 - PRODUCTS

2.01 - General

A. The Flat Plate Photovoltaic Module shall be the product of a single manufacturer or an assembly of parts as approved by the prime manufacturer of the module.

Commentary:

This section of the specification deals with the particulars of the module to be supplied to the job site for inclusion into the building project. Part 2.01-A begins with the above description.

B. Module Electrical Performance Criteria

Add details of performance requirements as pertains to project.

1. Module efficiency shall be defined as the ratio of the module power to the product of the gross module area and insolation of ___ mW/cm^2; for a shingle module, the gross exposed module is utilized.
2. Module power shall be identified as the maximum power measured at the module terminals using the test procedures described in 1.03-C Tests, with the NOCT being defined as the average cell temperatre within a photovoltaic module operating at ambient conditions listed in 1.03-b Module Electrical Output.
3. Listing of the Module Performance
   a. Module Voltage
   b. Module Amperage
   c. Module Wattage

Commentary:

All ratings in Section 3 above shall be based on definitions in 2.01-B as well as the tests listed in 1.03-C. They shall be provided for the anticipated installation, taking into account all the installation conditions. This particular section of the Module Performance Criteria is intended to assure *that the general items that will determine module performance will be agreed upon. These could be called the "Standards of the Industry". Eventually, either when the modules reach the building site or when the array is completed, they will be tested to meet these requirements in accordance with the particular installation.*

C. System Mechanical Performance Criteria
   1. Life span -___ years
   2. Degradation - ___ electrical performance
   3. Impact Loading -____ hailstones
   4. Wind Loading - ___mph
   5. Module Weight
   6. Other

Add details of mechanical criteria as pertains to project.

Commentary:

This area of the performance criteria will deal with all areas outside of electrical performance that will effect how the module interfaces with the building environment.

A. Edge Handling - Specify for Special
   1.
   2.
   3.

Specify for special edge details

B. Structural System
   1. Steel
   2. Wood
   3. Concrete
   4. Other

Complete if a part of manufacturer responsibility or if shown elsewhere in the specification. Indicate in 1.01-A.

C. Terminations
   1. J Box
   2. Terminals
   3. Pigtail
   4. Other

D. Diodes
   1. Integral
   2. Separate

E. Other

Commentary:

This section of the specification deals with all of the specific characteristics of the module and is job specific. The manufacturer will supply a product *based directly on the information shown above. The individual supervising the installation will check the modules at the job site for compliance.*

2.03 Fabrication

A. General

1. The prime manufacturer shall be responsible for the proper performance of the panel assemblies.

Commentary:

This section will include any construction requirements not specifically mentioned in 2.02 - Materials.

B. Panel Electrical Construction

1.

2.

Special construction requirements may be specified here.

Commentary:

In this section special requirements such as panel shorting may be designated for installation safety. For instance, this particular safeguard may not be required by code, depending on the type of terminals and module frame, due to an installer's or an OSHA requirement, it might be added. Special types of terminals would be included here.

C. Panel Mechanical Construction

Commentary:

In this section, the specifier can outline any particular changes or options he would like to have placed on the modules other than the standard ones supplied whioh he needs for his particular job. A common item might be an aluminum frame cross section that would match with a particular panel framing system used in a sloped skylight or on a vertical wall panel system already selected to be used on the job. This might allow easy integration of the PV module. This requirement should also appear on the design drawings and on the shop drawings supplied by the manufacturer.

Part 3 - EXECUTION

3.01 Inspection

A. The installer shall review the work completed by others prior to the commencement of work under this section. If previous work is unacceptable, he will notify the owner in writing of the discrepancies and will not start work until an acceptable solution is found.

Commentary:

The installer in this case is the module or array installer. He may be responsible for all or only part of the work. If the array is to be standoff, for instance, the module installer would arrive on the job site after the roof has been installed. The devices that attach to the roof and standoffs could be attached and already flashed to prevent water leakage. In addition to this, if the module required a subframe for attachment, this, too, might also be in place. The installer would check for proper tilt, level and dimensional tolerance. If any of the above items did not conform to either the drawings or specifications, he should notify the general contractor immediately.

B. Items to be Reviewed Include the following:
   1. Dimensional Tolerances
   2. Materials
   3. Treatments
   4. Installation
   5. Damaged Work
   6. Tilt
   7. Completeness
   8. Other

List possible problem areas if known.

C. The installer shall perform visual checks on all modules to identify and report any damages wich occurred during shipping.

3.02 Preparation

A. The installer shall prepare the area to receive the array in accordance with the details shown on the approved shop drawings.

B. Areas of particular concern are
   1. Damaged work already in place
   2. Other

List areas if known.

3.03 Installation

A. The installer shall assemble the array in strict accordance with the approved manufacturers shop drawings and installation requirements.

B. The installer shall assemble the array in strict accordance with the designer's drawings and specifications.

C. ALl panels which are not ultimately shorted or have protected terminals shall be covered during daytime installation or shall be installed at night.

D. Only that work which has been speficially outlined as his responsibility shall be done by the module installer.

E. No installation by either the module manufacturer or associated material suppliers shall proceed during weather conditions that are adverse as defined in the sections specified in 1.10A (For references see Part I - General 1.01, Description). These weather conditions would include, but not be limited to, heavy rain, snowstorms, wind in excess of ______, extreme cold, below freezing, extreme heat _______ or above, sandstorms, hailstorms, etc.

F. All work shall be performed in a neat and workmanlike manner.

Commentary

On all building projects the basic "laws" for what will be considered neat and workmanlike will be shown on the drawings and described. All laws need enforcers and juries to evaluate compliance and settle disputes. On building projects, the role of judge and jury is filled by the architect. Under him, Contract A-201, General Conditions of the Contract for Construction - Sec. 2.2.7 states "The Architect will be the interpreter of the requirements of the contract documents and the judge of the performance thereunder by both the Owner and the Contractor"

Some areas of concern to the architect in reference to the PV module would be: straightness and plumbness within the frame enclosure, mating to adjoining modules, maintenance of common surface planes, damage of modules during installation, and haywiring where not specified.

G. Others

3,04 Field Quality Control

A. Testing

1. Each module shall be tested prior to installation for electrical isolation to assure protection against electrical shock during installation. This test shall be performed by connecting a continuity tester to the positive terminal and then to any exposed module conductive surface. No continuity shall exist.

2. Each module shall be tested for electrical performance prior to installation. This test shall take place under a minimum of ____ mW/cm^2 insolation normal to the module, instantaneous, measured by a standard cell provided by the manufacturer. The average outout of all the module tests shall be equal to the stated in 2.01-B module electrical performance. The manufacturer shall supply sufficient performance curves to de-rate the module for both temperature and insulation conditions.

3. The minimum outout allowable for the entire array after installation shall be 90% of the average module output measured in 3.04-A3, Testing.

B. Cleaning

1. Upon completion of installation of the array, all cover and frame surfaces shall be cleaned in accordance with instructions by the manufacturer.

CONCLUSION

Although the CSI Format is a nationally recognized specification format, and is very inclusive, it should be noted that certain cautions need be addressed. This format was designed to be used for any size building project. Its complexity and level of detail must be modified to adjust itself to the cost and concerns of the particular project. The only drawback in its use occurs in the residential marketplace. There are two distinct groups of contractors currently operating in the residential housing market. First is the large scale speculator. This contractor usually builds perhaps 50 or more houses a year. He is experienced, organized and frequently works with subcontractors whose work must be interfaced with performance of others on the job. His ability to deal with specifications and contract writing is refined, allowing him to work efficiently and at a profit. The other group of contractors are usually small and build three to ten homes a year and run a very informal business. Contracts may be as simple as a handshake or, at most, a brief list of materials along with a very simple set of drawings. His experience with specifications may be limited; when faced with a fully formatted CSI specification for the installation of the residential PV modules, he may simply "throw up his hands" in confusion. If he prepares a price on a residential project described by such a specification, his price will be elevated to take care of the grey areas he perceives. The unfortunate fact is the majority of residential contractors fall under the second category. Therefore, this specification will probably be most useful in the non-residential work. This does not indicate that in the abbreviated form of the uniform construction index, CSI format cannot be used in the residential work or should not. It should serve to educate as well as inform the contractor what he is expected to do. It is anticipated that much higher quality and a more identifiable product could be achieved in the residential market if the clients would only use this type of specification. We have decided, therefore, to complete a specification based on an example to illustrate how it might appear.

EXAMPLE - FINISHED SPECIFICATION

SECTION 201 - FLAT PLATE PHOTOVOLTAIC MODULES

PART I - General

1.01 Description

A. Related Work Specified Elsewhere

1. Electrical Distribution System - Sec. 16480
2. Power Systems Storage - Sec. 16280
3. Controls and Instrumentation - Sec. 16900
4. Grounding - Sec. 16450
5. Roofing - Sec. 07300
6. Flashing - Sec. 07700
7. Sealants - Sec. 07900
8. Gasketing - Sec. 07950

These items have specifications written elsewhere in the CSI Document. Items 5-8 are included as this installation is in fact the roof and a water-tight membrane.

B. Work Installed but Furnished by Others

1. Control Points and Wiring - Sec. 16470
2. Flashing - Sec. 07700

Due to special requirements imposed by the PV panel these installation areas will be included in the panel installers responsibility.

C. Work Furnished but Installed by Others

1. Anchorage System - Sec. 05100
2. Panels - Sec. 16270

The framing system will be several parts of on-site components and factory assembled components. Those requirements and specifications for on-site framing component installation are found in Sec. 05100.

D. Description of Array

1. When complete, the array shall be capable of producing 220 V DC electrical energy. Its output capacity shall be based on 100 mW/cm^2 solar insolation and a NOCT rating appropriate for the particular installation (See 3.04a Testing)

2. It shall be an array made of discrete modules interconnected to assure a system performance under normal circumstances as stated in Section D1 above for 20 year life.

3. The array shall, also, deliver a minimum of 10 kW_p @ 100 mW/cm^2 solar insolation.

4. The array shall be 24'x45'-4" nominally and consist of 32"x96" (nominal) panels.

E. Definitions

1. Solar Cell - The basic photovoltaic device which generates electricity when exposed to sunlight.

2. 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.

3. Panel - A factory assembly or one or more modules.

4. 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.

5. Branch Circuit - A number of modules or paralleled modules connected in series provide DC power at the system voltage level required.

6. Residentoal Photovoltaic Power System - the aggregate of all branch circuit arrays, together with the auxiliary systems, power conditioning wiring, protection, control and utility interface and facilities required to convert terrestrial sunlight into electrical energy suitable for connection to a residential electrical distribution system or a utility power grid.

1.02 Quality Assurance

A. Acceptable Manufacturers.

1. Manufacturers desiring to submit proposals for the work shall obtain pre-bid approval from the owner. No other proposals will be accepted.

2. Pre-bid approval will be based upon the following:
   a. Financial capability
   b. Delivery schedule
   c. Mounting details
   d. Electrical connections
   e. Safety Methods
   f. Compliance to the Requirements

A decision was made not to specify manufacturers by name but rather to limit them by the items stated here as well as those mentioned later in this specification.

B. Design Criteria

1. Manufacturers proposal shall include the following:
   a. System performance data meeting test requirements of Specifications for Residential PV Modules.
   b. Module model number
   c. Gross dimensions
   d. Module weight
   e. Wiring details
   f. Nominal operating cell temperature
   g. Instruction details on the module and roofing details
   h. PV array layout showing orientation and quantity of PV panels.
   i. All warranty and guarantee formalities.

2. Submit data to:
   Samual Frank
   ABC Construction Co.
   1234 W. Battery
   Charleston, S.C. 29802

C. Erector Qualifications:

1. Erectors desiring to submit proposals for the work shall obtain the bid approval from the Owner.

2. Pre-bid approval will be based on the following:
   a. Manufacturers approval
   b. Financial capability
   c. Delivery schedules
   d. Past experience

As with the P.V. panel manufacturer, erectors have not been named but will be chosen on the listed qualifications

D. Requirements of Regulator Agencies

1. System when installed shall conform to requirements of all local, state, and national ordinances and applicable building codes. Secure permits as required.

To date, current codes do not address solar applications.

2. Comply with National Codes as follows:
   a. National Electric Code __________
   b. National Fire Protection Association __________
   c. BOCA __________

E. Allowable Tolerances

1. Size: Width 32± .09375"
   Length 96± .1672"

2. Square: ± .09375"

In order to ensure interfacing with the roof framing structure tight tolerances must be met on all panels.

1.03 Submittals

A. Samples

1. Submit samples of all components to be used in the work.

2. Samples to be approved by Owner and kept at site or at the designer's office.

B. Shop Drawings

1. Submit shop drawings showing methods and details of construction

2. Obtain owners manual

This is extremely important to ensure proper installation of the array into the roof.

C. Tests

1. Module electrical test prior to shipment

2. Test final array for compliance with specifications and submit results for approval.

3. Schedule of Tests

a. Ground continuity test. Each module shall be provided with a grounding study which shall be tested using suitable continuity test to verify that all electrical continuity exists between the grounding stud and all exposed external conductive surfaces.

b. Module Electrical Output. The electrical output of each module shall be measured on the following conditions:

1) 100 mW/cm^2 insolation, normal, instantaneous
2) ambient air - 20^{o} C
3) wind velocity - 1 m/s
4) open back
5) electrical load - open circuit

c. Module Mounting: All modules to be series wired must be tested and matched within ±5% of I_{sc} output under instantaneous conditions outlined in 1.03C - Tests. It shall stay in place untul the final array inspection. Module manufacturer shall provide instructions for its removal.

D. Maintenance Data and Operating Instructions:

1. Submit complete instructions to the system designer showing methods and

criteria for maintaining and operating system.

2. Upon complete installation of the array and final inspection of the building project, the installer or building contractor shall provide the owner a complete set of instructions showing proper maintenance techniques.

E. Maintenance Materials
   1. Provide owner with five (5) spares for future use.

1.04 Product Delivery, Handling and Storage

A. Delivery of Materials
   1. All materials shall be delivered to site in protective packaging for shipment by rail.
   2. All damaged materials shall be returned to manufacturer and replaced with undamaged materials meeting specifications.

B. Storage of Materials
   1. All materials shall be stored at the site and protected from damage.
   2. Replace all damaged materials.

1.05 Job Conditions

A. Existing Conditions
   1. Review project to assure proper conditions exist to allow first class installation and operation of system.

B. Environmental Conditions
   1. Install system under acceptable temperature and weather conditions to assure proper operation of system.

C. Sequencing
   1. Schedule work in proper sequence with other trades to assure proper installation and operation of system.

1.06 Guarantee

A. Manufacturers Guarantee
   1. Provide manufacturers guarantee covering replacement of all defective parts for a period of one year from date of acceptance.

B. Installers Performance Bond
   1. The installer's performance bond may be supplied in lieu of an instal-

Performance Bonds are often required when contractors lation guarantee.

are not well known by the designer. This will insure completion of the installation in the event of default.

1.07 Certification

A. Manufacturer shall prpvide evidence in writing to the designer that his module passes all industry certifications required for the particular installation specified.

B. Manufacturer shall display on each module the official seal of certification and approval by the industry.

This certification will come from a recognized testing laboratory who will perform the standard tests as deemed necessary by the industry.

PART 2 - PRODUCTS

2.01 General

A. The Flat Plate Photovoltaic Module shall be the product of a single manufacturer or an assembly of parts as approved by the prime manufacturer of the module.

B. Module Electrical Performance Criteria
   1. Module efficiency shall be defined as the ratio of the module power to the product of the gross module area, and insolation of 100 mW/cm^2; for a shingle module, the gross exposed module is utilized.

   2. Module power shall be identified as the maximum power measured at the module terminals using the test procedures described in 1.03-C Tests, with the NOCT being defined as the average cell temperature within a photovoltaic module operating at ambient conditions listed in 1.03-Cb, Module Electrical Output.

   3. Listing of the Panel Performance:
      a. Voltage - 100 ± 10% @Peak
      b. Amperage - 1.75A ± 10% @Peak
      c. Wattage - 200 W_p Min.

C. System Mechanical Performance Criteria
   1. Life span - 20 years
   2. Degradation - 10% electrical performance over life
   3. Impact loading - 1¼" hailstones
   4. Wind Loading - 30 mph

5. Module weight

2.02 Materials

A. Edge Detail

1. As per enclosed drawing

B. Termination

1. Mail/Female Plug Terminals

C. Diodes

1. Rated Blocking & Bypass Diodes mounted on each panel.

2.03 Fabrication

A. General

1. The prime manufacturer shall be responsible for the proper performance of the panel assemblies.

B. Panel Electrical Construction

1. Blocking diodes integral to interconnect system.
2. Shorted for installation.

C. Panel Mechanical Construction

1. Special edge mounting details as per enclosed drawing.

PART 3 - EXECUTION

3.01 Inspection

A. The installer shall review the work completed by others prior to commencement of work under this section. If previous work is unacceptable he will notify the Owner in writing of the discrepancies and will not start work until an acceptable solution is found.

B. Items to be reviewed include the following:

1. Dimensional Tolerances
2. Materials
3. Treatments
4. Installation
5. Damaged Work
6. Tilt
7. Completeness

C. The installer shall perform visual checks on all modules to identify and report any damages which occurred during shipping.

3.02 Preparation

A. The installer shall prepare the area to receive the array in accordance with the details shown on the approved shop drawings.

B. Areas of particular concern are:
   1. Damaged work already in place
   2. Tolerances

3.03 Installation

A. The installer shall assemble the array in strict accordance with the approved manufacturers shop drawings and installation requirements.

B. The installer shall assemble the array in strict accordance with the designer's drawings and specifications.

C. All panels which are not ultimately shorted or have protected terminals shall be covered during daytime installation or shall be installed at night.

D. Only that work which has ben specifically outlined as his responsibility shall be done by the module installer.

E. No installation (by either the module manufacturer or associated material and supplier's) shall proceed during weather conditions that are adverse as defined in the Sections specified in 1.01A. (For references see Part I - General 1.01, Description) These weather conditions would include but not be limited to heavy rain, snowstorms, wind in excess of 15 mph, extreme cold, below freezing, extreme heat 100^{o}F or above, sandstorms, hailstorms, etc.

F. All work shall be performed in a neat and workmanlike manner.

)4 Field Quality Control

Testing

1. Each module shall be tested prior to installation for electrical isolation to assure protection against electrical shock during installation. This test shall be performed by connecting a continuity tester to the positive terminal and then to any exposed module conductive surface. No continuity shall exist.

2. Each module shall be tested for electrical performance prior to installation. This

test shall take place under a minimum of 50 mW/cm^2 insolation normal to the module instantaneous measured by a standard cell, also normal, and to be provided by the manufacturer. The average output of all the module tests shall be equal to that stated in 2.01-B Module Electrical Performance. The manufacturer shall supply sufficient performance curves to de-rate the module for both temperature and insolation conditions.

3. The minimum output allowable for the entire array after installation shall be 90% of the average module output measured in 3.04-A3, Testing.

B. Cleaning

1. Upon completion of installation of the array, all cover and frame surfaces shall be cleaned in accordance with instructions by the manufacturer.