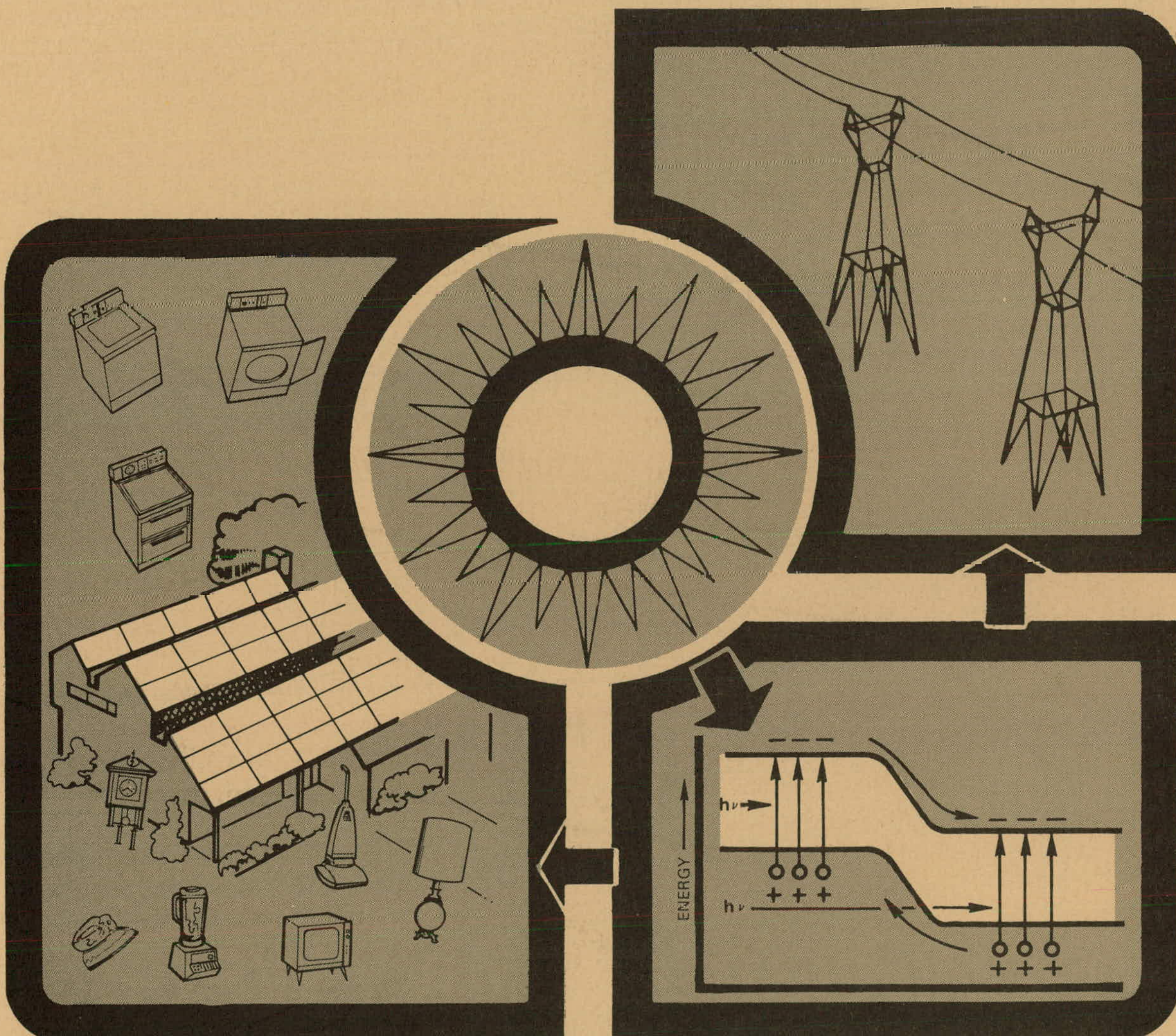
cy in M+R

MASTER

AEROSPACE REPORT NO.
ATR-78(7694-02)-2

SURVEY AND SCREENING OF INTERMEDIATE-SIZE PHOTOVOLTAIC TOTAL ENERGY AND ELECTRIC APPLICATIONS



FOR THE UNITED STATES DEPARTMENT OF ENERGY
DIVISION OF DISTRIBUTED SOLAR TECHNOLOGY

UNDER CONTRACT NO. EY77-C-03-1101
PROJECT AGREEMENT 8

THE AEROSPACE CORPORATION

Aerospace Report No.
ATR-78(7694-02)-2

MASTER

SURVEY AND SCREENING OF INTERMEDIATE-SIZE PHOTOVOLTAIC TOTAL ENERGY AND ELECTRIC APPLICATIONS

Date Published -- August 1978

Prepared by

E. J. Rattin
Energy and Resources Division
THE AEROSPACE CORPORATION
El Segundo, California

Prepared for

Division of Distributed Solar Technology
THE UNITED STATES DEPARTMENT OF ENERGY
Contract No. EY77-C-03-1101
Project Agreement 8

FOREWORD

This report documents the results of one of several analytical investigations conducted under Contract No. EY77-C-03-1101, Project Agreement 8, "Photovoltaic Mission Analysis", for the U.S. Department of Energy, Division of Distributed Solar Technology. The studies described here were carried out as part of Task 1: Photovoltaic Total Energy Systems, and Task 2: Intermediate-to-Large Load Center Missions for Photovoltaic Electricity.

The work was accomplished by the Energy Systems Directorate of the Energy and Resources Division of The Aerospace Corporation. Dr. Harold Macomber of the Silicon Technology Programs Branch is the DOE Program Manager for this contract, and Dr. M. B. Watson, Principal Director of the Energy Systems Directorate, is the Principal Investigator. Dr. S. L. Leonard, Director, Photovoltaic Systems Office, has provided the program management.

This document was prepared by E. J. Rattin.

The author wishes to express appreciation for technical contributions to this study by several other Aerospace Corporation personnel. These include S. Cheung, F. J. Collins, D. J. Johnson, Dr. S. L. Leonard, P. L. Merryman, and E. K. Weinberg. Special appreciation is due Dr. H. M. White for his extensive contributions to several phases of this study. The extensive literature search and document acquisition effort supporting this study would have been impossible without the valuable assistance of Aerospace library personnel, especially that of R. C. Anthony, S. L. Larson, and M. J. Tomlinson. Appreciation is also expressed to Kathy Morris, Janet Rausch, and Fred C. Eggers, whose combined efforts resulted in the production of this document.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

One of the principal objectives of The Aerospace Corporation photovoltaic mission analysis effort has been to identify and evaluate applications for photovoltaic solar energy conversion that could lead to significant contributions to the national energy supply and that would provide attractive opportunities for application experiments aimed at stimulating the adoption of photovoltaic technology. The scope of the study has included applications both for electric-only photovoltaic (PV) systems and for photovoltaic total energy systems (PTES), i.e., systems that provide both photovoltaic electricity and solar thermal energy to meet all or part of the energy demand at a single load point or a group of related load points. In either case, both flat-plate and concentrating systems have been considered and it has been assumed that the thermal energy is collected in and transported by the fluid used in an active cooling system for the photovoltaic cells. Because the efficiency of photovoltaic devices decreases rapidly with increasing temperature and because the operational lifetime of such devices is reduced by prolonged operation at elevated temperatures, a practical upper limit of about 200°C (400°F) was assumed for the temperature at which arrays can be allowed to be operated. This limitation, in turn, places an upper bound on the temperature at which solar thermal energy is available in PTES applications.

Since the number of potential PV and PTES applications is extremely large and since detailed evaluation of a candidate application is a lengthy process, it is clearly unreasonable to attempt a full-scale investigation of every candidate. An initial screening aimed at identifying the most promising applications has therefore been required, with the expectation that detailed evaluation will be made of only the higher-ranking candidates. This report contains a description of the screening procedure that was adopted and a discussion of the results.

The process of selecting promising photovoltaic applications began with the identification of the sectors of the U.S. economy in which such applications are most likely to occur. An important indicator in this connection is the pattern of energy consumption in the various economic sectors, as presented in Table S-1 (for 1974, the most recent year for which the data were available). On the basis of these data, the manufacturing, residential, commercial, and agricultural sectors were chosen for emphasis because of the significant percentages of both electric and low-temperature thermal energy that are used. A limited amount of attention was also given to the mining sector, but a thorough exploration of this sector was not possible within the constraints (of time and resources) of the study. The utility sector was not considered because it has been investigated rather thoroughly in earlier work (Refs. 1-5). The remaining sectors (transportation and construction) are not expected to provide many photovoltaic possibilities until, perhaps, the advent of large-scale use of electric vehicles which must await the development of advanced batteries. These economic sectors were therefore not further considered in this study.

The next step in the screening process was the selection of criteria to be used in ranking potential applications in each of the economic sectors that were studied. Criteria were desired that provide measures of either (a) the degree to which important requirements of the application could be met by a (flat plate or concentrating) photovoltaic system, or (b) the size of the potential photovoltaic market associated with the application. Another consideration was the availability of sufficient data to permit utilization of a criterion with most of the applications under investigation. Because of the very large number of the applications to be screened, it was not feasible to use criteria that would require significant amounts of analysis or modeling. For this reason, such criteria as life-cycle cost or breakeven cost (versus competing energy sources) were not used.

Table S-1. 1974 Energy Consumption

Major Economic Sectors	Total Energy Consumption, Quads (10^{15} Btu)	Electric Energy, in % of Total	Potential Thermal Fraction, % of Total*** *
Manufacturing	20.11	10.4	10
Transportation	16.77	0.08	
Utilities (Electric)	11.2	(-36.3**)	
Household (Residential)	11.11	18.0	63
Commercial	5.41	33.5	49
Mining	1.93	7.4	
Construction	1.86	0.8	
Agriculture	1.41	7.8	8

* Includes refrigeration and airconditioning (potential absorption chiller application)

* Generation of electricity, not consumption

*** Percentage of total energy consumption that is used in the form of thermal energy at temperatures below 200°C (400°F)

The criteria that were adopted for use in the screening process are listed in Table S-2, which also provides an indication of which criteria were used in ranking which classes of applications. In the table, the "buildings" heading represents both residential and commercial (including institutional) applications and the "industrial" heading refers to the manufacturing sector. No mention is made in the table of the agricultural sector because it was found, as the work progressed, that the diversity of farming practices and the lack of appropriately organized basic data made application of the formal screening criteria to this sector impossible within the constraints of the study.

As is indicated in Table S-2, the first of the listed criteria was used only in evaluating PTES applications, while the remainder were applied to both PV and PTES candidates. The thermal-to-electric ratio is the ratio of the characteristic thermal demand of the application to the electric demand; a good fit is provided if the ratio is between 0 and 6 for flat panel systems or between 3 and 8 for concentrating systems. The phasing criterion is simply a measure of the degree of coincidence between the diurnal demand profile and the insolation profile. The energy density ratio criterion is a measure of the fraction of the energy demand of a structure (residential or commercial) that can be supplied by photovoltaic collectors mounted on its roof. (This criterion was used primarly in evaluating applications in which the energy demand of a building is to be met. It was not used in screening industrial or agricultural applications.) In applying the market size/growth criterion, preference was given to applications representing large potential markets (in aggregate kW of demand) and markets that are growing rapidly. Use of the market location criterion was designed to select applications in which the geographic location of the associated market is favorable because of, for example, high insolation or high fossil fuel prices. The demand level criterion was used to give preference to applications with small unit demand. (Competitive power sources are, in general, less well adapted to serving small loads than are photovoltaic systems.) The reliability criterion permits ranking of applications on the basis of their tolerance of power outages.

Table S-2. Applicability of Screening Criteria

	PV Total Energy		PV Electric	
	Buildings	Industrial	Buildings	Industrial
Thermal-to-Electric Ratio	X	X	–	–
Phasing of Demand-to-Insolation Profiles	X	X	X	X
Energy Density Ratio	X	–	X	
Market Size/Growth	X	X	X	X
Market Location	X	X	X	X
Demand Level	X	X	X	X
Reliability Requirement	X	X	X	X
Percent of Value Added by Energy Used In Manufacture	–	X	–	X
Percent of Power Generated In-house	–	X	–	X

The final two criteria were used only in screening industrial applications. The value added criterion gives preference to applications in which a large fraction of the total value added during manufacture is traceable to the cost of energy. In applying the in-house power generation criterion, higher ratings were assigned to applications in industries that generate much of their own energy because such industries are judged to be more hospitable to (and better equipped to handle) in-house photovoltaic generation.

In applying the criteria of Table S-2, an initial screening was first carried out against the thermal-to-electric ratio and market size/ growth criteria, for PTES applications, and against the market size/growth criterion alone for PV (all-electric) applications. Application classes surviving this initial screening were then subjected to evaluation against the other criteria. This two-step screening process was made necessary by the large number of candidate applications which had to be evaluated; the task of providing a full data base supporting all of the screening criteria for all applications would have been impossibly large.

Buildings

Table S-3 lists in the left column the building categories which were evaluated against the market size, market growth, and thermal-to-electric ratio criteria in the preliminary screening activity. The right column shows the building types which remained for the final screening effort. The national energy consumption of high-rise apartments, defined as over 3 stories in height, was found to be too low to warrant inclusion in the study.

Of interest was the finding that thermal-to-electric ratios for residential structures, as well as temperature levels of the required thermal energy, were such as to favor flat plate collectors during the cooling season, although concentrating collectors were suitable in some climatic regions during the heating season, when thermal energy demand was highest. In contrast to this, flat plate collectors were preferable in both heating and cooling seasons for most of the commercial and institutional

Table S-3. Building Categories

	After Preliminary Screening
Single-Family Houses	
Low-Rise Apartments	
Office Buildings	
Stores	
Shopping Centers	
Restaurants	Single-Family Houses
Motels	Low-Rise Apartments
Warehouses	Office Buildings
Supermarkets	Misc. Retail Stores
Hotels	Shopping Centers
Schools	Supermarkets
Hospitals	Schools
Churches	
Nursing Homes	
Social	
Libraries/Museums	

Note: Rank-ordered by growth rate and energy consumption building types. All types of buildings tended to require absorption cooling to make photovoltaic total energy systems attractive.

The energy density ratios determined for the residential building sector indicated that heating season demand could not be satisfied in most regions by roof-mounted collectors, because of limits on the available roof area. On the other hand, cooling season demand could be met by such roof-mounted systems in all regions for single family houses but not for two-story or taller apartment buildings. None of the five commercial and institutional buildings remaining for final screening allow all of their energy demand to be met from roof-mounted collectors in either season. On the basis of the energy density criterion alone, the shopping center category appears most suitable for total energy systems out of the commercial/institutional sector, particularly in the heating season. Office buildings rank second from the point of view of this criterion. None of the non-residential building types can meet their energy requirement without utility supplement or backup, if it is assumed that only roofs are available for collectors.

The fastest growing segment of the buildings market is the mobile home sector. Although mobile homes still constitute a small market relative to the other building types, mobile homes offer the prospect of lower system installation cost because of factory construction, and might, therefore, have earlier penetration potential.

A regionalization scheme involving 12 climatic zones was used in evaluating location factors. When only insolation and competitive energy prices were considered, it was found that, on a national basis, low-rise apartments made slightly better candidates for photovoltaic total energy power than single-family homes, because of their concentration in regions with higher energy cost and other factors, and that the Southwest, the Far West, and the Southern Plains regions were the favored locations for both types of residential applications. In the case of low-rise apartments, an additional region, the Midwest, was found to be favorable. This was also true in the instance of the commercial and institutional building sector, where the Midwest ranked next to the Far West in preference in most cases.

Industrial

This study considered the 451 industries defined at the four-digit level of the Standard Industrial Classification (SIC) code that are contained in the 20 industry groups designated by the Census as SIC 20 through 39, under the heading of Manufactures. Only those industries utilizing important quantities of process heat were, however, given consideration for total energy system application. As in the instance of building applications, a preliminary screening process was essential to reducing this large set of candidate application classes to a number small enough to permit accumulation of the extensive data base required for the use of all of the screening criteria described earlier. In the instance of total energy candidates, this preliminary screening initially reduced all the process-heat-consuming industries to the top 50, when ranked on the basis of yearly consumption of process heat at temperatures less than 200°C (400°F). A further ranking on the basis of growth in process heat requirements projected to the year 2000 reduced this set of candidates to 30. This candidate set was then reduced to 16, with the thermal-to-electric ratio criterion being used as a ranking factor. A final reduction was accomplished by ranking against the percent-of-value-added-by-energy and the demand level (energy consumption of a typical establishment) criteria. This resulted in the designation of the industries shown on Table S-4 as the final set of potential photovoltaic application candidates to be evaluated by using the full set of screening criteria.

For the all-electric photovoltaic applications, the preliminary screening was based on total electric energy consumed, the quantity of electric energy generated in-house, the percent of value added by the energy used during manufacture, and the size of a typical establishment. An interesting result of this screening process was the similarity of the outcome to that of the total energy systems screening, with four of the five all-electric candidates also having been earlier selected for the final set of total energy candidates.

Table S-4. Characteristics of Industrial Candidates

<table>
<tr><th></th><th>Pulp</th><th>Paper</th><th>Paperboard</th><th>Gypsum</th><th>Wet Corn Milling</th></tr>
<tr><td>Thermal-to-Electric Ratio</td><td>5-6</td><td>5-6</td><td>5-6</td><td>4-6</td><td>2-10</td></tr>
<tr><td>Total Electric Power Consumption in 1974, kWh x 10^9</td><td>4.6</td><td>31.6</td><td>21.8</td><td>0.9</td><td>1.9</td></tr>
<tr><td>Total Process Heat Consumption at less than 400°F in 1976, in kWh x 10^9</td><td colspan="3">340</td><td>5.1</td><td>4.5</td></tr>
<tr><td>Energy Consumed by Typical Establishment, 1971, kWh x 10^9</td><td>0.85</td><td>0.21</td><td>0.31</td><td>0.19</td><td>1.0</td></tr>
<tr><td>% of Energy Value in Total Value Added, 1971</td><td>13.6</td><td>14.5</td><td>15.4</td><td>10.1</td><td>11.4</td></tr>
<tr><td>Ratio of Generated Electric to Purchased Electric Power</td><td>0.78</td><td>0.72</td><td>1.2</td><td>(no data)</td><td>0.74</td></tr>
<tr><td>Location Factor Ranking</td><td>3</td><td>4</td><td>2</td><td>1</td><td>5</td></tr>
</table>

Table S-4 shows some salient characteristics of the selected industrial application candidates. It also provides a location-criterion ranking which was obtained in a manner similar to that used in the case of buildings, but for a different regionalization scheme involving only six solar performance regions rather than the 12 climate regions used in the building evaluation.

Agricultural

Formal applications screening was not performed for the agricultural sector since the complexity of this sector made it impossible, except in a very gross sense, to group together potential applications into classes of sufficiently similar characteristics to apply the screening criteria discussed earlier. An extensive literature search, evaluation of published data, and consultation with agricultural specialists disclosed that agricultural energy demand is quite diverse and that it is strongly dependent on such variables as location, season, weather in any given year, traditional farm practices, and market conditions.

Instead of screening all possible combinations of applications which might occur on farms, and whose energy demand level would vary with factors such as those listed above, an examination was made of farms typical of sections of two selected states. The selection of states was based on irrigation energy demand. On a national basis irrigation accounts for the third highest energy-consuming segment of this sector (1974 consumption = 260×10^{12} Btu). The highest consuming sector was the manufacture of fertilizer (off farms) at 621×10^{12} Btu, followed by mobile farm operations with a consumption of 518×10^{12} Btu, both also in 1974. When states were ranked on the basis of irrigation energy consumption, it was found that the top 15 states accounted for 95% of the national consumption, and that 14 of these states were in the Western U.S. From the six top ranking states, Arizona and Kansas were selected for more detailed analysis. Arizona was chosen because it has the highest seasonal water demand per acre and irrigates practically all of its harvested land with pumped groundwater, the most energy-intensive form of irrigation. Kansas was chosen because it has the lowest percent of groundwater-irrigated land among the top six states.

On the basis of consultation with local agricultural experts, the characteristics of farms typical of the areas were determined. Values for the average monthly energy consumption for the various crops and livestock operations in these states were used to construct yearly energy demand profiles for representative farms. These farms were typical of actual farms in the states in question, except that livestock were added in proportions larger than typical for field crop farms in these areas in order to increase winter energy demand. Figure S-1 shows such an energy demand profile as constructed for such a "typical" west Kansas farm. This profile excludes auto and truck energy consumption but includes tractor, harvester, and combine consumption. The figure illustrates the relatively short fraction of the year in which the full output of a photovoltaic irrigation system could be utilized. The energy values represented by the curves labelled "crop energy" and "total energy" contain the irrigation energy demand that is also shown separately, as well as drying energy. It is stressed that the farm whose hypothetical profile is shown on this figure already has been assigned more livestock than is common in this geographic region. It is obvious that very much more livestock would have to be added to have a major effect in flattening the energy demand curve to the extent believed to be required to permit cost-effective utilization of a photovoltaic system.

This study did not evaluate other combinations of energy demands outside the farm unit which might permit more desirable demand profiles and thus enhance the economic competitiveness of photovoltaic power. Such combinations should be investigated and should include (a) winter season pumping of water to be stored against summer use and then distributed as surface water (with a corresponding lower energy demand for pumping in the growing season), (b) the formation of cooperatives among users with chronologically successive rather than coincident demand profiles, (c) the inclusion of food packing industries among such cooperatives, and (d) the use of fertilizer manufacturing cooperatives.

Results and Recommendations

Applications which survived the preliminary screening described earlier were evaluated to greater depth in the final study phase on the basis of the full set of screening criteria and a formalized scoring

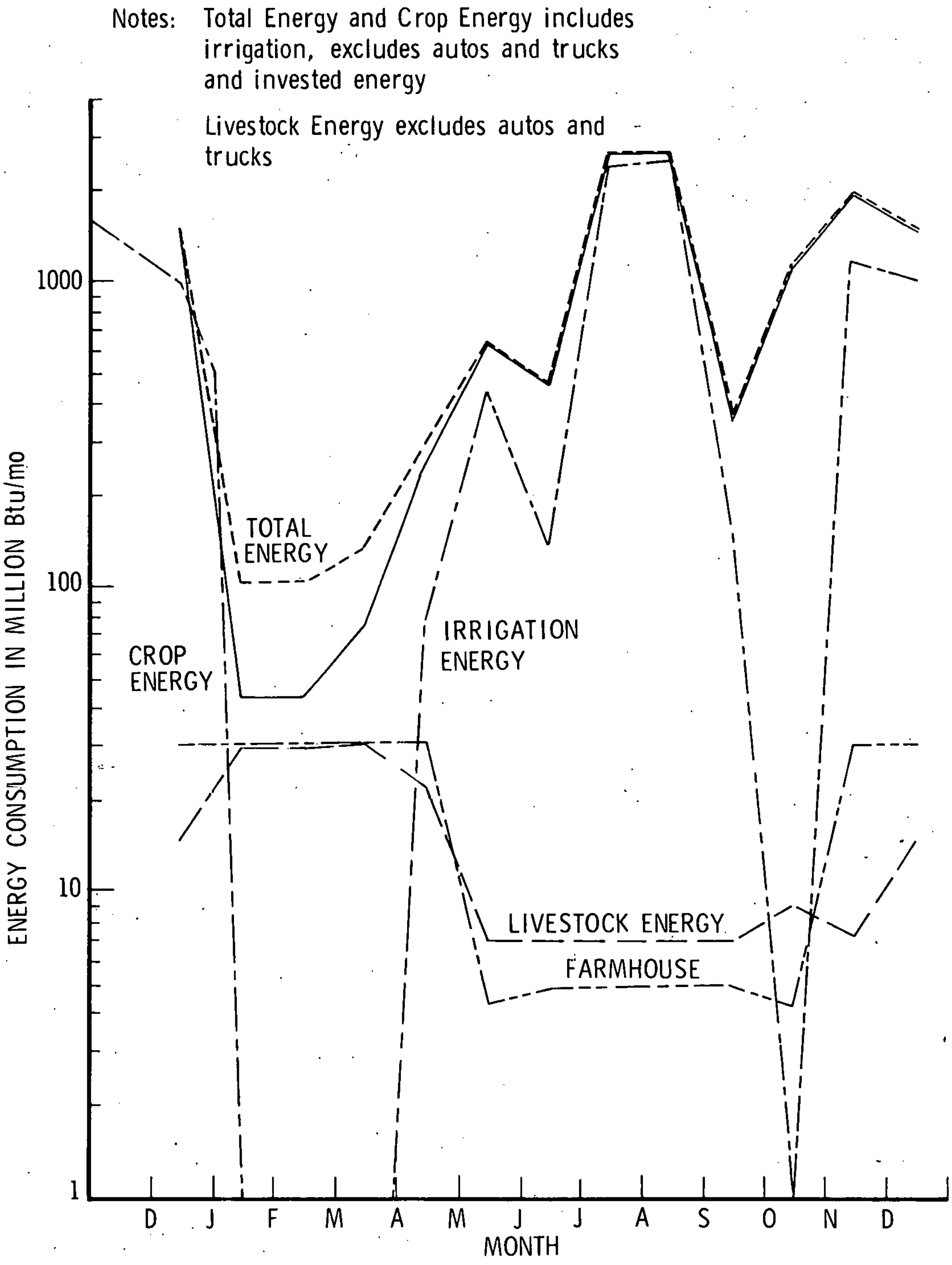


Figure S-1. 1974 Energy Consumption of Typical West Kansas Farm (Livestock Added) procedure carried out by a number of personnel familiar with solar energy systems and their application. Criteria were weighted by voting on ballots and the applications were subsequently also rated by ballot. Tables S-5 and S-6 show the results of this evaluation process by translating the individual application scores into a preferential ranking. Low-rise apartments scored highest for both forms of PTES as well as in the all-electric system category. Of special interest was the fact that single-family houses, when all criteria were evaluated concurrently, scored second in the instance of all-electric systems and ranked below office buildings in the total energy system categories.

The pulp and paper group scored highest in the industrial applications sector. Of that group, the pulp mill industry would appear to make the most interesting candidate for further evaluation of photovoltaic power because (a) its geographic concentration is greatest in regions with relatively good insolation, (b) the rural location of its establishments should allow adequate area for collector installation, and (c) this industry appears accustomed to generating a large fraction of its electric and thermal energy demand in-house.

The results of the agricultural sector evaluation do not lead to identification of specific applications to be studied in more detail. Instead, combinations of applications need to be studied, involving perhaps a variety of farm units, or farm units associated with food processing industries, or farm units associated with water transmission systems, etc., to produce conditions under which photovoltaic power might be able to compete with conventional power sources. It is considered unlikely that individual farm units, except in special cases, will be able to develop energy demand profiles that match the yearly insolation profile well enough to favor the use of photovoltaic power. The development of short-range, electrically-powered mobile farm machinery (using advanced batteries) would assist in making demand profiles of farms more suitable for photovoltaics.

These results lead to the recommendation that low-rise apartment buildings and office buildings, which have not been studied to date, receive more detailed analysis to determine the conditions under which photovoltaic power would be cost-competitive against utility power and to determine the potential size of this building market. Pulp mills should be studied as the most interesting potential industrial application.

Table S-5. Application Rankings Resulting from Screening

Buildings

	PTES		PV
	Absorption Cooling	Vapor Compression Cooling	Vapor Compression Cooling
Low Rise Apartments	1	1	1
Offices	2	2	4
Stores, Misc. Retail	3	4	3
Single-Family Houses	4	3	2
Schools	5	5	5
Shopping Centers	6	6	6
Supermarkets	7	7	7

PTES = Photovoltaic Total Energy Systems

PV = Photovoltaic All-Electric Systems

Table S-6

Application Rankings Resulting From Screening Industrial

	PTES	PV
Pulp/Paper Group	1	1
Gypsum Products	2	3
Wet Corn Milling	3	2

Another important recommendation is based on the considerable difficulty experienced in this study in finding the statistical information needed for estimating the solar equipment market potential. It would be helpful to future assessments of photovoltaic or solar thermal markets if the various Censuses were expanded to provide data on such parameters as sizes of buildings, numbers of stories of buildings, characteristics of roof construction and roof orientation, numbers of units per apartment building, roof areas, exterior parking areas adjacent to buildings, and variations in these parameters as a function of geographic location. Institutional buildings should be included in the Commercial Census, and all of the data should be segregated geographically down to the county level. The Census of Manufacturers should be expanded to provide more energy consumption data at the county level of aggregation, and at the individual plant level instead of merely by industry. Similarly, the Census of Agriculture should be expanded to include more data on energy consumption by farm operation as a function of time of year and of location. It should include more information on the energy consuming activities of cooperatives and on the composition of farms as a function of location.

The Department of Housing and Urban Affairs has been able to arrange with the Bureau of the Census for collection of supplemental data of special interest to that Department. It may therefore be feasible for the Department of Energy to make similar arrangements to obtain data of special interest to solar energy development and commercialization programs.

1. INTRODUCTION

1.1 GENERAL

The objectives of The Aerospace Corporation photovoltaic mission analysis effort include the support of the planning, development and guidance of the DOE National Photovoltaic Program on a continuing basis by: (1) identifying and evaluating those photovoltaic applications (including total energy applications) that are most likely to lead to significant contributions to the national energy supply, and (2) identifying and evaluating attractive opportunities for demonstration programs and other strategies that will stimulate the growth of photovoltaic markets. Among the several tasks of this mission analysis activity is that of identifying the most promising photovoltaic total energy or electric-only applications for more detailed analysis effort. This report primarily describes activities carried out during 1977 and part of 1978 in addressing this identification task.

1.2 BACKGROUND

Since 1974, only a few potential photovoltaic (PV) application classes have received study in the form of mission analysis, conceptual design, and market forecasting. Utility and residential housing analyses were reported by Aerospace Corporation, General Electric, Westinghouse, and Spectrolab (Refs. 1-5). Shopping centers studies were also reported by Spectrolab (Ref. 5) and Ref. 3 also describes a study of an application to a school. Aerospace Corporation (Ref. 6) reviewed a number of near-term applications primarily from a market forecasting point of view, as did Intertechnology Corporation (Ref. 7) and BDM Corporation (Ref. 8). No important discussion of industrial photovoltaic (PV) applications has been found in the recent literature and agricultural applications have also received limited treatment with emphasis on irrigation (Ref. 9).

In the context of mission analysis, it thus appeared desirable to expand the scope of investigations of potential PV power generation utilization to other applications encompassing the commercial and institutional building, industrial, and agricultural sectors. The number of application classes within these sectors is large, with, for example, 451 industries listed in the Census of Manufactures alone, and literally dozens of distinct building types with distinct demand characteristics contained within the commercial and institutional building sectors. The extent of the study effort required to cover all of these potential applications with equal emphasis is impossibly large, particularly in reference to the resources available to the Aerospace Mission Analysis task. It became necessary, therefore, to select for detailed analysis only those application classes which exhibit a common set of the most desirable characteristics. Since a major goal of the effort devoted to solar power is the displacement of fossil fuel energy, particularly that in the form of oil and natural gas because of anticipated shortages, applications with large potential markets are desired. In addition, photovoltaics should show potential for early and rapid penetration of such markets. Finally, application classes selected for detailed study should be representative of other application classes so that their analysis will, by inference, also provide useful information for such other classes.

A realistic appraisal of the near-term applications discussed by Aerospace Corporation (Ref. 6) and others yields the conclusion that none of these offer the potential for large fossil fuel displacement. Consequently, midterm and far-term applications, those whose economic breakeven costs demand PV array prices probably not reachable by 1985, are believed to be the prime candidates for further consideration. The residential, commercial, and institutional building, industrial, and agricultural sectors contain such applications. Because of the considerable expenditure of energy in these sectors for space and water heating and for space cooling, the search for desirable applications must also consider those for photovoltaic total energy (PTES) systems. Total energy systems are those in which thermal energy from actively cooled arrays can satisfy thermal energy needs of an application. The economic use of this waste energy can, at the same time, assist in reducing the cost of electric energy generated by the photovoltaic system. The total energy (PTES) concept is also applicable to those industrial processes requiring low temperature process heat, and may be applicable to the agricultural sector where some need exists for low temperature heat for crop drying, for space heating, and for process hot water.

Because of already extensive study of utility applications by several organizations, it was not believed necessary to include this sector in the activity reported herein.

1.3 SPECIFIC OBJECTIVES

The primary objective of this screening study was the rational reduction of the large number of candidate PV and PTES application classes within three generic groups (buildings, industrial processes, and agricultural operations) to a small set of representative applications with the greatest overall market potential. These applications were then to be analyzed and evaluated in greater detail in subsequent studies. This reduction in number of application classes was to be accomplished by use of carefully selected screening criteria operating on data bases which are appropriate to the objective of achieving a relative ranking of the applications. Although information accurate on an absolute basis is desirable for this purpose, it is not essential as long as errors in the data base affect all selection candidates equally. Every effort was made to obtain accurate data but limited resources did not always allow this. This screening study could not engage in primary data research but had to rely on secondary data sources which were often of questionable accuracy. In many cases, also, the desired data were simply not available from secondary sources.

A secondary objective of this study was to identify suitable photovoltaic test and demonstration subjects. The acceptance of this objective was based on the presumption that the same characteristics that make an application class a desirable subject for detailed mission analysis and conceptual design study also make it desirable for consideration as a test and demonstration subject.

The screening activity was originally intended to satisfy internal needs of the Aerospace Mission Analysis project for identification of suitable applications for study. The potential interest which at least some of the data collected and interpreted by this study might have for a larger audience led to the decision to document the data base and the screening results more extensively. At a minimum, it was believed that the identification by this study of shortcomings in the available data base could serve to stimulate further effort by appropriate government agencies to gather (or improve) the data necessary for good market forecasting. Market research appears important in guiding Department of Energy research and development activities. Steps need therefore to be taken to provide better statistical information than is currently available. In this context it is important to reiterate that the data base collected for screening was not intended to serve the purpose of market research, in the sense of predicting a photovoltaic market share. Market-related criteria were used only in comparisons between applications in order to establish relative preferences based on potential market size.

1.4 STUDY FLOW

The applications screening activity consisted of three main phases as shown in Fig. I-1. In the first phase, both the objectives of the study and the selection (screening) criteria were defined. The criteria definition process involved the participation of personnel acquainted with photovoltaic technology as well as with marketing-related subjects and methodologies. These personnel assisted in deriving as compact a set of criteria (also listed on Fig. I-1) as was consistent with addressing all of the critical characteristics of the applications classes under consideration. Completion of definition of the criteria, described in Section 2 of this report, allowed the accumulation of the data bases that support the application of these criteria, both during the preliminary screening activity and in the final application selection. As described in Section 3, preliminary screening was made necessary because the number of potential application classes was too large to permit acquisition of

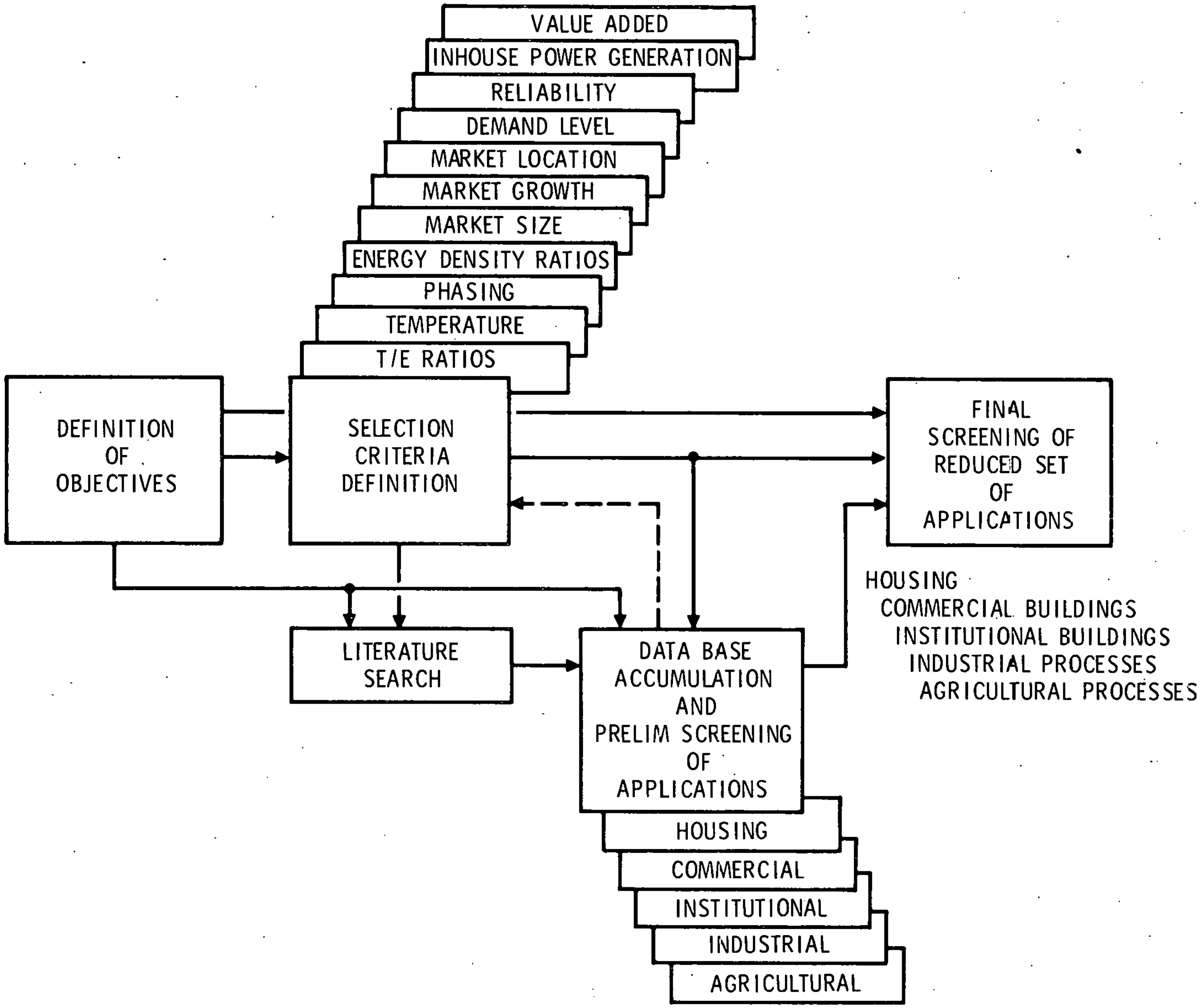


Figure I-1. Program Flow

equivalent data bases for all of them. When sufficient data became available, one or more of the higher-rated criteria were applied to rank-order applications classes within an economic sector and to retain only the top-ranking applications for further consideration. Also, the availability of data and its quality were allowed to act in a feedback mode to alter both the content of the final set of selection criteria as well as the scoring weight to be assigned to each. Lack of reliable data concerning a criterion tended to reduce its value in the screening process and therefore its weight.

The final screening, discussed in Section 4 of this report, addressed a considerably smaller set of application classes than were in the candidate list at the start of the data accumulation phase. However, candidate applications not retained through the final step are not necessarily poor prospects for PV or PTES systems; they are only perceived to have less overall potential in terms of displacement of conventional energy.

2. SCOPE

2.1 ENERGY USE SECTORS INCLUDED IN THE STUDY

2.1.1 Overview

FEA statistics on energy consumption, in quads (one quad = 10^{15} Btu), by economic activity sector for the year 1974 are summarized on Table II-1. Manufacturing consumed the largest amount of energy of all of the sectors but was only third in the consumption of electricity. Although transportation was the second largest energy consuming sector, it is an unlikely prospect for photovoltaic energy in the near term, and probably also in the mid-term, both because of the need for improved battery characteristics for mobile applications and because of the large capital cost of the extensive road-side servicing infra-structure that intercity transportation would require. This sector has, therefore, been excluded from the application screening activity. Although utilities are third in consumption of energy, this sector has also been excluded from this screening since it has already been, and is currently, receiving considerable study and evaluation by a variety of organizations, including The Aerospace Corporation.

Although the household sector was fourth in total energy consumption, it was almost equal to manufacturing in electricity use and is, for other reasons as well, an excellent prospect for photovoltaic application. This sector has already received considerable attention in previous studies, but it was included in the screening effort because of the desirability of exploring market-related statistics in more detail than was done in previous work.

The commercial sector was only fifth in total energy use, but it consumed proportionally more electric energy than any other sector and should therefore be of special interest for photovoltaic application evaluation. Again, consideration has already been given to this sector by previous and concurrent studies but, as in the instance of residences, market statistics and their influence on the selection of preferred market segments within this sector seemed worthy of further investigation.

Table II-1. 1974 Energy Consumption By Sector*

Sector	Total Consumption, Fuels and Electricity, In Quads	Electricity Consumption Only: In Quads	Electricity Consumption Only: In %
Agriculture	1.407	0.109	7.75
Mining	1.930	0.142	7.36
Construction	1.855	0.015	0.81
Manufacturing	20.105	2.091	10.40
Transportation	16.773	0.013	0.08
Commercial	5.411	1.810	33.45
Household	11.108	1.996	17.97
Electric Utilities	11.187	(Electricity Generated: -6.363)	(-36.3)
	69.775		

*FEA Data (Ref. 10)

Mining ranked sixth in consumption of energy in 1974 but only some process heat requirements of this sector were included in the review of industrial total energy (PTES) applications. This sector should receive additional attention when feasible because it appears to offer at least one major advantage for solar energy usage: there are commonly large tracts of nearby land available for collector installation. Electro-winning segments of this sector should be especially attractive for further evaluation.

Construction was not included in this screening study because of the largely mobile nature of its equipment and the relatively small electricity consumption of this sector.

Agriculture as an energy consuming sector was briefly investigated, but the results obtained were severely constrained by the sector's complexity, by the great diversity of its energy needs, its energy sources, its traditional practices as a function of geographic location, and its engineering data base. As a result, the product of the investigation was limited, very largely, to an evaluation of the scope of studies required to properly explore this sector.

2.1.2 Household (Residential) Sector

Residential applications were screened first because of the presumption that prior interest in solar thermal applications in this sector, and extensive Census data related to housing, would have created a good screening data base for this sector. It was indeed found that much useful information had been generated by prior studies concerning energy needs as well as market statistics of this sector. Residential housing statistics were, however, as was the case with the other energy use sectors, often incomplete with respect to data items of specific interest for evaluating solar applications. It was also found that many parts of the existing secondary-source data base were mutually inconsistent and thus not reliable, as discussed in Section 3 of this report.

Table II-2 shows the functional end-uses for energy in the residential sector. It is apparent that, on a national average basis, only about 18% of the energy needs of this sector were met by electricity, that its major energy needs were for low temperature thermal energy, and that the objective of reduced national fossil fuel consumption could thus be best met by photovoltaic total energy systems (PTES) if these were technically and economically feasible. The data in this table also emphasize that single family homes constitute, by far, the largest market segment of this sector. This segment is, coincidentally, also a particularly good potential application for PV or PTES because of the adaptability of these modular systems to the low energy demand levels typical of single family residences.

2.1.3 Commercial Sector

Table II-3 shows the functional uses of energy in the commercial sector in 1974. Electrical usage, as a percentage of total energy consumption, is higher in this sector than in the residential sector, but ranks somewhat below that of the residential sector in terms of total energy consumption. As in the instance of the residential sector, photovoltaics could contribute more to reduction in fossil energy consumption by its utilization in a total energy mode, if feasible. The data base for evaluating the commercial sector for application screening purposes is less extensive than for the residential sector, primarily because the Commercial Census is smaller in scope than the Housing Census. Some of the solar thermal studies performed since 1973, and addressing this sector, have produced information of use to this study. However, problems with data reliability appear to exist as they do with residential data.

2.1.4 Manufacturing (Industrial) Sector

Table II-4 shows the major consumption of energy in the industrial sector to be in the form of direct heat, process heat, and in raw materials production. Of these, the process heat fraction is the most amenable to PTES application because of temperature limitations on photovoltaic cells (discussed in Sections 3 and 4). Also of interest is, of course, the fraction of energy consumed in the form of electricity for functions such as

Table II-2. 1974 Functional Uses of Energy in Residential Sector*

Use	Energy Consumed In Quads	Energy Consumed % of Total
Space Heating	7.06	63.6
Water Heating	2.05	18.5
Cooking	0.66	5.9
Refrigeration	0.36	3.2
Air Conditioning	0.30	2.7
Lighting	0.24	2.2
Clothes	0.16	1.5
Other	0.27	2.4
Total	11.11	100.00

Distribution By Fuel Type, In %		Distribution By Residence, In %	
Electricity	18.0		
Natural Gas	47.7	Single Family Detached	67.3
LPG	6.4	Single Family Attached	12.0
Fuel Oil	24.6	Low Rise Apartments	11.0
Kerosine	3.3	Others	9.7
	100.0		100.0

*FEA Data (Ref. 10)

Table II-3. 1974 Functional Uses of Energy in Commercial Sector*

Use	Energy Consumed In Quads	Energy Consumed % of Total
Space Heating and Cooling	3.535	65.3
Lighting	0.797	14.7
Water Heating	0.331	6.1
Cooking	0.208	3.9
Refrigeration	0.122	2.3
Other	0.419	7.7
Total	5.412	100.0

Distribution By Fuel Type, In %

Natural Gas	41.6
Electricity	33.6
Residual Oil	12.6
Distillates	5.3
Coal	2.6
LPG	1.9
Other	2.4
	100.0

*FEA Data (Ref. 10)

[redacted]

Table II-4. Functional Uses of Energy in Manufacturing Sector, 1974*

Use	Energy Consumed In Quads	Energy Consumed % of Total
Direct Heat	5.3	26.0
Process Steam	4.2	21.0
Raw Materials	3.9	19.0
Machine Drive	1.0	5.0
Electricity Generation (Net)	0.5	3.0
Electrolytic Processes	0.4	2.0
Coke Production (Net)	0.4	2.0
Space Conditioning, Lighting	0.1	1.0
Other	4.3	21.0
Total	20.1	100.0

*FEA Data (Ref. 10)

machine drive, lighting, and electrolytic processes. It was not possible during this study to investigate industrial applications specifically involving electrolytic processes. Such detailed analyses are recommended, especially of electrowinning and refining rather than plating processes, since a high percentage of the former industries are located in rural areas with increased availability of land area for collector fields. Table II-5 shows the largest users of energy within the industrial sector aggregated into industry groups as defined by the Standard Industrial Classification (SIC) Code used by the U.S. Census. The selection of the best prospects for total energy or all-electric systems required consideration of factors such as process heat temperature levels, in-house power generation traditions and practices, and plant site location. Evaluations of these factors were performed for industries at the four-digit SIC code level, as fine a detail as was permitted by the available data base.

2.1.5 Agricultural Sector

Functional uses of energy in the agricultural sector are shown in Table II-6. Candidate applications for PV or PTES can be found among all of these functions, even that fraction under "farm vehicles" which contains short range, on-farm-only mobile applications such as tractors, harvesters, and combines. The "machine drive" category includes crop irrigation, which has already received extensive evaluation for solar thermal electric application as well as some consideration for PV application. The seasonal nature of agricultural operations makes it desirable to evaluate PV application to energy consuming operations which succeed each other rather than those that are coincident in time in order to maximize the utilization period of farm PV installations.

2.2 APPLICATION CHARACTERISTICS TO BE EVALUATED FOR SCREENING PURPOSES

The objective of the screening analysis is to utilize screening criteria appropriate for selecting a few of the most promising application classes for subsequent detailed analysis for either PTES or PV system application. The approach used for this selection process emphasizes criteria based on (a) those application characteristics which would allow PV

[redacted]

Table II-5. 1974 Energy Use By Manufacturing Sector*

SIC	Total Use, In Quads	NG,** %	Electr., %	Coal, %	Fuel Oil, %	Other, %
20 - Food	0.9	51	14	8	14	13
26 - Paper	2.2	19	6	9	23	43
28 - Chemicals	5.2	40	8	6	5	40
29 - Petroleum	3.1	36	3	-	11	50
32 - Stone, Clay, Glass	1.3	53	8	18	10	11
33 - Steel	3.4	20	5	74	8	(7)
- Aluminum	0.6	36	34	10	2	18
- Other Primary Metals	0.8	53	19	5	6	17
All Others	2.6	3.9	26	6	13	16
Total	20.1	35	10	18		26

*FEA Data (Ref. 10)

**Natural Gas

Table II-6. 1974 Functional Use of Energy in Agricultural Sector*

Use	Total Energy Consumed, In Quads	Electric Only	
		In Quads	In %
Drying/Heating	0.111	0.004	3.6
Water Heating	0.010	0.003	30.0
Lighting	0.011	0.011	100.0
Refrigeration	0.005	0.005	100.0
Machine Drive	0.354	0.086	24.0
Farm Vehicles	0.728	-	0.0
Other	0.189	0.001	0.5
Total	1.408	0.110	7.8

Distribution By Agricultural Sector, In %	
Crops	77
Livestock	17
Others	6

Distribution By Fuel Type, In %	
Electricity	8
Natural Gas	12
LPG	10
Distillates	35
Gasoline	33

*FEA Data (Ref. 10)

or PTES systems to maximize fossil fuel displacement on a national basis, and (b) those characteristics which would enhance rapid commercialization of the photovoltaic technology. These latter characteristics are those which improve the competitive status of PV against conventional energy sources. Although somewhat different sets of characteristics are required to serve as criteria for the different energy use sectors, most of the characteristics were common to all sets. The criteria sets for PV evaluation differed, in a few respects, from those intended for PTES evaluation. The selection of these screening criteria preceded and guided the data base search. Some natural feedback took place since absence of a sufficient data base required alteration of the set of screening criteria, at least to the extent of changing the weight allocated to a criterion insufficiently supported by data. The criteria used in the application selection process are described briefly below, with more detail provided in Section 4.

Thermal-to-Electric Ratio (T/E)

This criterion applies to evaluations of PTES applications in buildings, industrial processes, and agricultural operations where by-product thermal energy produced from an actively cooled array can be utilized. It measures the ratio of the average thermal energy demand (in the form of hot water, steam, or hot air) of a specific application class to the average electric demand over the same time period. The time periods involved are either monthly or seasonal, such as the heating and cooling seasons. The criterion does not take into account hourly or daily variations in this ratio as a result of non-coincidence of the daily demand profiles of the thermal and electrical loads. It requires collection of energy demand data.

Temperature

This criterion applies to the evaluation of PTES applications only. Its utility is based on the fact that the temperature-efficiency relationship governing energy production by photovoltaic devices will place an upper limit on the temperature level of thermal loads served by PTES. The temperature limit will determine the proportion of the thermal demand of specific application classes which PTES can supply and will guide the selection of either flat-plate collector or concentrator-collector systems for specific application classes. The primary data needed in applying this criterion are the temperature levels of the process heat utilized by various industrial application candidates.

Phasing of Demand and Insolation Profiles

This criterion provides only a qualitative indication of the need for storage on the basis of whether the demand leads or lags the daily insolation. Leading demand implies storage of energy over a longer period of time than would be required for lagging demand. The application of the criterion requires the determination of demand profiles typical of a particular application class. For some applications, consideration was given in a qualitative sense to the match between seasonal demand and seasonal insolation profiles.

Energy Density Ratio

The energy density ratio is the ratio of the amount of energy (electric and thermal) that can be produced by PTES or PV systems on a unit area of roof to the amount of energy required by the application per unit roof area. The criterion is therefore applicable only to buildings and is of importance in evaluating applications with urban locations where room for collector deployment in addition to that on the building roof may not be available. In effect, it measures the proportion of the total energy demand of a particular application class that solar photovoltaic systems could supply under conditions limiting collector area, and gives a measure of the backup utility service which must be provided. This criterion is applicable to both PV and PTES system screening. Its use requires availability not only of demand data but also of typical roof areas for various structures.

Market Size

This criterion provides a measure of the amount of potentially displaceable fossil fuel energy consumption in an application class and gives an indication of the potential ease of commercialization. The larger the market, presumably, the more interested private industry will be in addressing it. Application of the criterion requires acquisition of data on the number of unit applications, and the average energy demand per unit application.

Market Growth

In addition to the total sizes of specific markets at a given date, it is desirable to determine the annual growth rate experienced by these markets. Such data provide information not only on the amount of fossil fuel which could be displaced in the future but also on commercialization prospects, since the new construction market, for example, might be easier to penetrate than a retrofit market. Penetration of the latter may involve technical difficulties as well as higher costs. Further, remaining useful lifetime of existing structures may not permit amortization of investment costs at affordable or competitive annual rates. Application of this criterion requires availability of predictions of new construction or new installation rates, preferably to the year 1990, or, in the instance of industrial applications, the prediction in growth of production capacity.

Market Location

This criterion encompasses several application class attributes all of which are related to geographic location. It is important to know the distribution of units within an applications class over the U.S. so as to determine the proportion of the total energy demand that is found in solar-favored regions. In the instance of building applications, information on the geographic distribution of the application is desired in order to determine climate-related space heating and cooling demand. It is also useful to have data on the distribution of the unit applications between central city, suburban, and rural locations, in order to gain a qualitative understanding of the possibility (on a class-wide basis) of supplementing roof-mounted collectors with additional collectors located external to the structure. Finally, information on the geographic distribution is needed in order to allow the cost of conventional energy, which varies with location, to enter the evaluation of an application for economic competitiveness.

Demand Level

Data on the typical size of unit applications within a class are needed in order to allow a qualitative judgement concerning potential for economic competitiveness. Lower initial costs of smaller PV systems tend to permit easier financing through means such as short-term bank loans. Higher unit demand may require longer term debt arrangements, or, in the instance of large commercial or industrial applications, equity financing. The modularity of PV permits greater competitiveness against other alternative energy sources, such as solar thermal electric systems, in applications with low demand level, e.g., private residences, small apartment buildings, and small commercial structures; in contrast to such competing energy sources, PV energy costs do not scale-up rapidly with diminishing size.

Large unit demand may, however, be an advantage in application classes where high prospective energy costs would cause greater receptivity toward means of cost savings through use of alternative energy sources. The large size of an individual industrial establishment may, in addition, imply greater ability to raise the financing required for the high initial cost of a PV system as well as greater willingness to accept life cycle costing as a basis for economic comparison with conventional energy sources.

In balance, it was believed that small unit demand is of advantage in those applications where mortgage financing is conventionally available, whereas larger energy demand levels would be favored in the case of industrial applications where other financing means are predominant.

Reliability

This criterion measures the ability of an applications class to tolerate power outage in terms of number of occurrences over a given period as well as in duration of each individual event. This ability affects the cost of utility back-up, or the cost of on-site energy storage associated with the installation. The use of this criterion in this study is qualitative only.

Percent Value Added by Energy Used in Manufacture

This criterion applies to industrial sector applications; its application requires data on the cost of the energy and the cost of the other materials and operations required in the manufacture of a product.

Percent of Power Generated In-house

This characteristic is associated with both industrial and commercial applications, since some large building complexes have privately-owned power generation facilities and perhaps as many as 600 privately-owned building total-energy systems may currently be in operation. It measures the ability of an applications class to cope with a distributed power installation and its receptivity to substitution of utility power by an on-site installation. In this screening analysis, it has only been applied to industrial applications.

2.3 DATA BASE

In order to apply the screening criteria discussed in the previous section, it was obviously necessary to obtain a wide variety of quantitative information. A major part of the effort accordingly had to be devoted to the acquisition of the large amounts of data that were required. The scope of activities connected with development of this data base encompassed acquisition of bibliographic searches from a variety of organizations, search of the Aerospace library data base, and direct contacts with potential data sources. Computer data searches were obtained from the following sources:

NASA Scientific and Technical Information Facility
Smithsonian Science Information Exchange
DOE Technical Information Center (TIC)
National Technical Information Service (NTIS)
Battelle Memorial Institute (BEIC Data Base)
Defense Documentation Center
U.S. Department of Agriculture Research Library
Economic Research Service of the U.S. Department of Commerce

Council for Agricultural Science and Technology
American Society of Agricultural Engineers

Hand searches were conducted of various engineering indices and of U.S. Census publications. Direct personal contacts were made with authors of pertinent publications to ask for additional data and/or for referrals to other potential data sources. Government agencies contacted directly for information included the Agricultural Research Service, the Economic Research Service of the Department of Commerce, the FEA, and offices within the DOE.

The general topics about which data were sought included:

Total energy concepts, designs, applications and markets, including solar energy total energy concepts

Modular integrated utility system (MIUS) designs, applications, and markets

Energy requirements of buildings, industrial processes and agricultural operations. Projected changes in their future requirements.

Statistics on inventories of unit applications, and projected changes in such inventories

Solar energy applications to buildings, industrial processes, and agricultural operations

A large number of report listings were received as a result of these searches, requiring considerable effort for their review and for selection of potentially useful data. The number of data sources that was finally used was relatively small because of perceived unreliability of much of the reported data and the lack of data in a format permitting its expeditious use for the screening activity without extensive rework. Section 3 discusses the quality of the data base in more detail.

Bibliographies of all of the data sources containing information pertinent to the study subjects are provided as an appendix to this report. Sources used directly in assembling the screening data base are referenced in the text.

2.4 SCREENING

The scope of the screening activity encompassed three residential building classes, 15 commercial and institutional building types, 451 industries (at the four-digit SIC code level), and combinations of crop and livestock operations (to synthesize hypothetical agricultural operation modes leading to nearly full utilization of PV system power output over the entire year). The difficulty of providing a data base to permit screening of all of these potential applications against the full set of screening criteria required some preliminary screening against a few of the criteria, such as market size and market growth rate, during the data base development phase of the study. This was done in order to reduce the set of potential applications to a manageable size. The rationale for, and the results of, this preliminary screening are described in Section 3.

The final screening activity to select a small set of applications for more detailed analysis used all of the selection criteria discussed in Section 2.2 above in a weighted scoring approach described in detail in Section 4. The determination of the weights to be assigned to each criterion, and the assignment of criteria ratings, was accomplished through ballotting by a group of individuals at Aerospace Corporation with specific background in photovoltaic and solar thermal electric systems analysis and application in either total energy or all-electric configurations.

3. DATA BASE DEVELOPMENT

3.1 RESIDENTIAL BUILDING SECTOR

3.1.1 Quality of Data

A number of organizations have published data on residential energy consumption, ranging from U.S. totals to regional totals, and covering both measured and calculated energy demand by individual housing units on a U.S. average and a regional average basis, as well as demand typical for some cities. In addition, this residential unit energy demand has been disaggregated into end-use demand, again for a variety of regionalization schemes. Both the bibliography associated with this report section and the specific references cited in this section provide an overview of the quantity and variety of these data. Only a brief comparative analysis of such published data was feasible under this study. However, discrepancies in the available data were found to be quite apparent, making the selection of data sources on the basis of accuracy quite difficult. Discrepancies are present not only in the summaries of total regional energy consumption in this sector, but also in the distribution of end-use demand. Table III-1 shows values of total U.S. residential energy demand for 1970, as estimated in six different studies, and exemplifies the spread in the data. Because of extensive secondary referencing, review of the respective reports will not, in most instances, permit identification of the causes of the spread in data values. In some cases measured values are being reported. In other instances, energy consumption values are calculated for building designs prepared by architectural firms for a standard unit size and then applied to the entire housing inventory in place in 1970, disregarding the actual unit size distribution.

Figures for end-use energy demand from various sources also exhibit considerable differences, as exemplified on Table III-2, which compares such figures for three of the four Census regions for which the referenced sources presented data. Space heating and cooling demand is, of course, not

Table III-1. Total U.S. Energy Demand, Residential

Source	Demand in 10^{12} BTU/Yr
Rand (Ref. 11)	14,000
Westinghouse (Ref. 12)	9,466
FEA (Ref. 13)	11,403
SRI (Ref. 14)	9,941
Mathematica (Ref. 15)	9,588
BNL (Ref. 16)	9,764

only a function of the climatic conditions existing over a geographic area, but also of building characteristics and of local usage patterns. Many different combinations of such characteristics appear possible in calculating energy consumption, and the sources reviewed to date seem to have utilized a variety of such combinatorial possibilities. In terms of total U.S. residential consumption, it is probable, however, that demand in 1970 was between 9 and 10 quads.

Although Census sources provide relatively more detailed demographic data in the residential housing category than in any other Census data category, multifamily housing appears to have a poorer data base than single-family housing. Some data of particular importance to assessing the feasibility of solar energy application to apartment buildings are

Table III-2

DATA BASE: INCONSISTENCES IN AVAILABLE DATA

EXAMPLES

Demand in 10^6 BTU/Unit-Year (1970)

Load/Source	Northeast (Boston)	North Central (Madison)	South (Nashville)
• Residential Space Heating:			
TRW (Ref. 17)	47	60	99
Rand (Ref. 11)	130	150	91
FEA (A. D. Little) Ref. (13)	160	168	71
• Residential Cooling:			
TRW	3.4	6.0	17.4
Rand	4.4	6.7	21.0
FEA (A. D. Little)	0.3	1.1	4.9
• Residential Hot Water:			
TRW	24	29	26
Rand	31	32	29
FEA (A. D. Little)	29	27	23

unavailable from the Census on a regional basis. No information is available, for example, on the distribution of numbers of floors in apartment buildings as a function either of the number of units within a building or of the total area contained within the building. Such data are required in order to determine the ratio of available energy from solar radiation received on the building roof to the energy demand of a building. Also lacking are data on the amount and type of parking associated with multifamily buildings; availability of such information might permit estimates of available area for deploying collectors in addition to that available on roofs. Further, statistics concerning type and orientation of roof structure, and projections of construction trends with respect to this design feature, are also absent, as they are for single-family residences.

Much of the available information of interest to solar application studies with reference to both single and multifamily residential housing is poorly regionalized. In general, housing data by state or county are only contained in the Decennial Census. Annual census reports concerning housing appear to be based on limited sampling and consequently offer statistics only for either the four Census regions or the nine Census divisions, making accurate apportionment of the data into suitable climatic regions impossible. Information on such topics as average floor area per unit, for example, is only available in annual census publications such as the Construction Reports, and then only for new construction in each year covered, making its extension to the entire residential inventory difficult.

Attempts to segregate residential building inventory and energy demand data into climatologically meaningful geographic regions appear to have been made only by GE (Ref. 18). An IGT study currently in progress, (Ref. 19) uses a similar regionalization scheme for which inventory and demand data are being assembled. These data were not available at the time of the applications screening effort described herein. In both instances, the climatic regions selected, 12 in Ref. 18 and 11 in Ref. 19, are quite large and contain subregions varying considerably in those weather characteristics which determine heating and cooling loads. For example, although the California coastal climate differs considerably from that of the interior of the state, the total heating and cooling loads for the entire state are computed from models of buildings located in Los Angeles. Climatic regionalization to smaller geographic areas with more homogeneous climates appears to be handicapped primarily by the absence of detailed hourly insolation data.

3.1.2 Baseline Data and Sources

The bibliography associated with this report section lists the publications which were reviewed for data sources. As indicated earlier, considerable disparity was found to exist in estimates of building inventory, thermal and electric loads of buildings, regional energy demand totals, and so forth. Only one of the data sources available to this study, GE (Ref. 18), provides data on heating and cooling loads for both single and multifamily housing in accordance with a climatic regionalization scheme. Even though imperfect by a number of measures, this source was selected as the basis for the applications screening activity. In addition to regional heating and cooling loads for single-family houses and low-rise and high-rise apartments, Ref. 18 also provided figures on domestic hot water loads. Values for baseline electric loads were obtained from Ref. 16 which indicated little regional variation in this load. (The baseline electric load includes lighting and small appliances such as refrigeration, television, etc.)

GE (Ref. 18) used BEA (Bureau of Economic Analysis) economic areas, of which there are 171 in the 48 contiguous states, as the basic geographic units to aggregate into climatic regions. This choice was based on recognition of the need for forecasting economic parameters of such climatic regions in order to estimate future market potential for solar applications. The Department of Commerce provides forecasts of important economic parameters by BEA region. These forecasts include data on projected population and on projected employment and earnings by industry group. Twelve locations, each representative of a distinct climatic type, were then selected on the basis of availability of hourly solar and weather observation data by NOAA. An attempt was also made to include major population centers among these locations. Because primary building loads are heating and cooling loads, the climatic parameters used to define the twelve locations and to associate BEA areas with these locations included heating and cooling degree-days, dry-bulb and wet-bulb temperatures, and average total horizontal insolation. BEA areas with similar climates were then aggregated with each of these twelve locations to permit association of regional building inventory with climatic factors. The 171 BEA areas were thus aggregated into 12 regions. This approach permits forecasts of the changes in the building inventory caused by changes in the demographics and economics of each region. Figure III-1 shows these climatic regions superimposed on a map of BEA areas provided by the Department of Commerce. This figure makes it readily apparent that some of the 12 regions must have considerable variation in climate internal to regional boundaries. The effect of these variations on the accuracy of estimates of total regional energy demand is mitigated somewhat by the selection of major population centers for most of the twelve climatologically representative cities. The calculated unit heating and cooling demand is thus directly applicable to a large fraction of the building inventory within each region. Nevertheless, definitive market estimates should probably be based in the future on a regionalization scheme designed to be more representative of the various micro-climates found within the regions shown in Figure III-1.

Ref. 18 contains forecasts to the year 2000. However, this study used only the data furnished for 1970 based on the Census of Housing, and the forecasts for 1980 and 1990 by Ref. 18 in preparing the data base for the applications screening.

Ref. 18 provides forecasts of the numbers of one- and two-family houses and of low-rise and high-rise multiple unit housing. These forecasts are primarily based on relationships between population and housing inventory, and on the assumptions that there will be a decline in the numbers of persons per household, a decline in the number of one- and

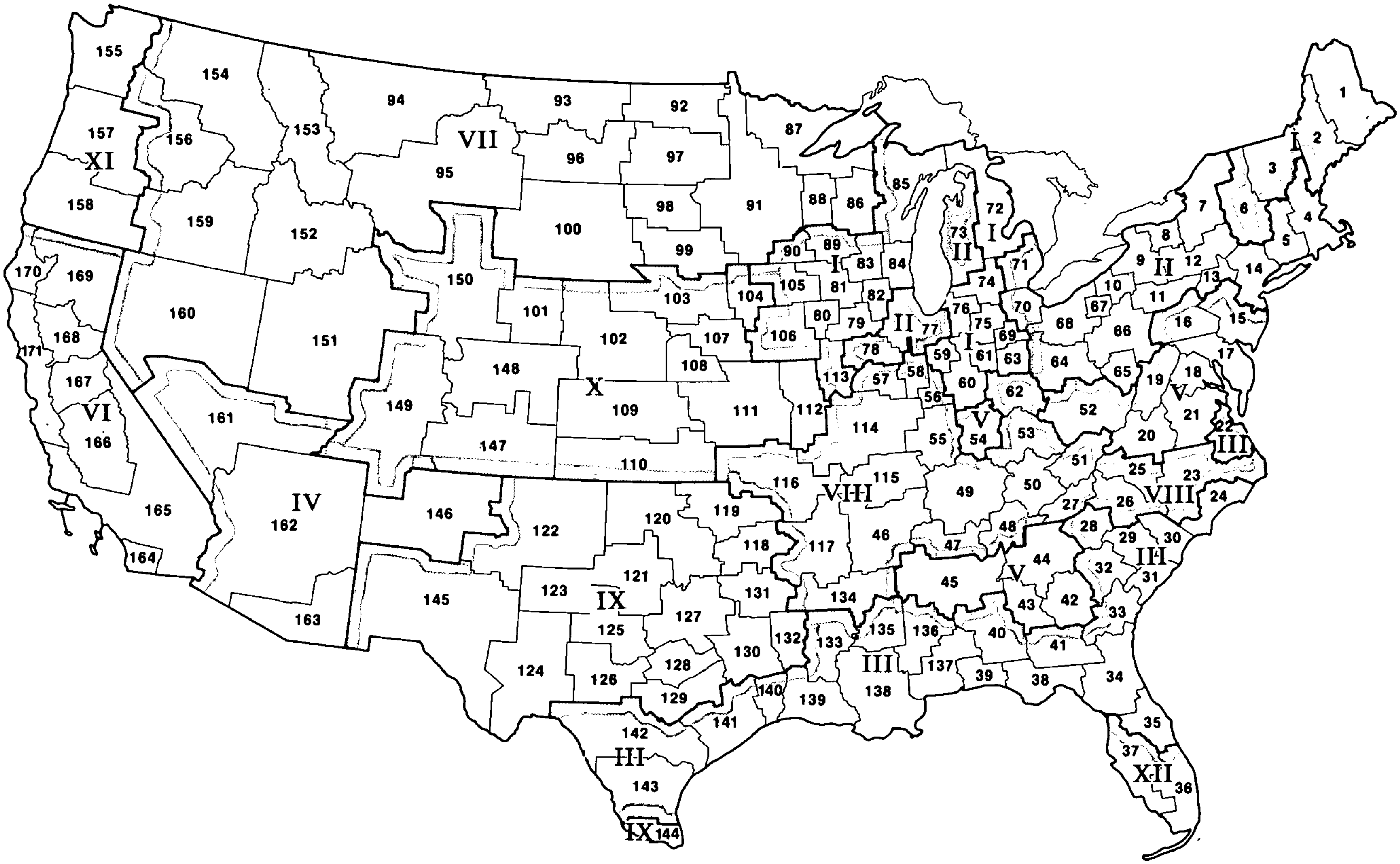


Figure III-1. Climatic Regions Defined by BEA Areas

Ref. 18

two-family homes in proportion to the total number of housing units, and an increase in the number of mobile homes and apartment units, as a percentage of the total housing inventory.

The building models for which heating, cooling, and domestic hot water loads were computed by GE (Ref. 18) included a single-family home of two stories with a total floor area of 1800 ft^2, a 14-story multiple unit high-rise building containing a total floor area of 145,000 ft^2, with the number of units contained within not defined, and a multiple unit low-rise building of 3 stories and total floor area of 21,600 ft^2, again without a definition of the number of units within. Applying the loads computed for these building models to the entire residential building inventory, with its extensive range of building size and types, to derive the national demand produces considerable deviation between the data in Ref. 18 and other estimates. As indicated earlier, most other sources estimate the total residential sector demand as between 9 and 14 quads for 1970. Using the GE (Ref. 18) model results in a total demand of about 18 quads for the same year. Part of that discrepancy is due to the greater than average floor area assumed for single-family residences. Table III-3 shows average floor areas for new single-family homes constructed over a range of years, since averages covering the entire inventory-in-place in 1970 are not available from the Census. At least for homes built between the years of 1966 and 1974, average floor areas of single-family homes were between 10% and 15% smaller than the values assumed in Ref. 18. Table III-4 shows the distribution of the numbers of floors of multiple unit buildings as a function of residential units contained within. On the basis of about 1000 ft^2 of floor area per unit, as indicated by the admittedly limited information of Table III-5, the low-rise building modeled in Ref. 18 would contain about 21 units. Table III-4, which shows 80% of all units to be contained in buildings of less than 19 units each, would indicate that this model is not typical of the building inventory in 1970. It is probably not typical of the current inventory either nor of that in the foreseeable future. Additional errors may thus have been introduced by these atypical

Table III-3

Average Square Feet of Floor Area of New Homes*
(Number Built, in Thousands, in Parenthesis)

Year Built		US Total	Location by Census Region NE	NC	S	W
1966	ft^2	1535	1590	1530	1465	1650
	(No.)	(792)	(129	191	334	137)
1968	ft^2	1580	1645	1560	1515	1690
	(No.)	(840)	(128	210	342	160)
1970	ft^2	1500	1570	1530	1440	1555
	(No.)	(793)	(111	170	356	156)
1972	ft^2	1555	1555	1555	1520	1625
	(No.)	(1143)	(149	231	524	239)
1974	ft^2	1695	1600	1660	1760	1660
	(No.)	(932)	(131	217	394	190)

*Census Data (Ref. 20)

Table III-4. Distribution of Units by Apartment Building Height from 1970 Census of Housing, U.S. Totals

Building Size	Total	Number of Units in 1000's in Buildings with number of stories of 1 - 3	4 - 6	7 - 12	≥ 13
less than 10 Units/Building	17,773	17,589	184	---	---
10 - 19 Units/Building	2,303	1,894	373	28	9
20 - 49 Units/Building	1,960	1,124	720	95	21
50 or more Units/Building	2,259	579	611	562	507
		% of Units in Buildings with Numbers of Stories of			
less than 10 Units/Building	73	72.4	0.8	---	---
10 - 19 Units/Building	9.5	7.8	1.5	0.12	0.04
20 - 49 Units/Building	8.1	4.6	3.0	0.4	0.09
50 or more Units/Building	9.3	2.4	2.5	2.3	2.1

*Census Data (Ref. 21)

Table III-5. Average Square Feet of Floor Area in New Apartments (Numbers of Units, in Thousands, in Parentheses)

Average Square Feet of Floor Area in New Apartments
(Numbers of Units, in Thousands, in Parenthesis)*

Year Built		U.S. Total	Location by Census Region NE	NC	S	W
1972	Ft^2	1035	1102	1003	1098	966
	(No.)	(828)	(132	174	304	218)
1974	Ft^2	1021	1000	951	1043	1062
	(No.)	(760)	(95	152	344	170)

*Census Data (Ref. 22)

low-rise and high-rise building models. Finally, many possible additional error sources are associated with the choice of detailed building characteristics since the chosen approach was intended to represent not only the inventory-in-place but also buildings likely to be constructed over the next 30 years. In summary, although the many inaccuracies of the data abstracted from Ref. 18 were recognized, it was necessary to use these data in the screening activity because they are the best available and because resources for a completely new housing statistical survey and design and analysis effort were not available.

3.1.3 Derivation of Specific Data Required for Screening

As previously discussed, the criteria selected for applications screening required availability of information about average thermal and electric loads for each application class as a function of geographic region, estimates of the total number of potential applications in each class and in each region, data on the anticipated growth in these classes of applications, estimates of available collector area associated with each class of application, typical load profiles, and data on other parameters associated with location, such as insolation, competing energy prices, and distribution of applications among central city, urban, suburban and rural locations. Ref. 18 was used as the primary source of data on space heating and cooling loads as well as for estimates of domestic hot water loads, and, as stated earlier, for inventory forecasts to the year 1990. On the basis of this information, average daily loads for heating and cooling seasons were determined. The cooling loads were assumed to be met either by vapor compression refrigeration systems with a coefficient-of-performance (COP) of 3, so that the electric demand caused by the cooling load would amount to one-third of the cooling load, or by absorption cooling systems with a COP of 0.7, proportionately increasing the thermal demand in the cooling season. Figures for the domestic hot water demand from Ref. 18, treated as a thermal demand only, and for the baseload electric demand from Ref. 16 were added to the heating and cooling seasonal demands. These hot water and baseload electric loads represented total demand in the interim periods between heating and cooling seasons. It thus became possible to estimate total electric and thermal demand per unit area for each of the application classes, the total demand per climatic region (on the basis of the total floor areas in the regional inventory), and the thermal-to-electric demand ratio for each applications class and for each season.

Because the definition of high-rise buildings used by GE (Ref. 18) excluded all multi-unit buildings of 13 stories or less, the total energy consumption represented by this class of application was very small in most regions and zero in the remainder. This class was therefore dropped from further consideration in the screening activity and no additional data were derived for it.

3.1.3.1 Thermal-to-Electric Ratios

Table III-6 shows the thermal-to-electric ratios (ratio of average thermal demand to average electric demand) developed for single-family homes and for low-rise apartments, for both heating and cooling seasons, and for absorption or vapor compression cooling during the cooling season. This table also provides the key for relating the designator cities used in

Table III-6. Data Base: Thermal/Electric Ratios - Residential Buildings

Region	Cooling System	T/E Single Family H	T/E Single Family C	T/E Low Rise Apts H	T/E Low Rise Apts C
Eastern Great Lakes (Boston)	CA	8.3	1.0	3.9	1.3
	CV	8.3	0.30	3.9	0.35
Midwest (Madison)	CA	9.5	2.2	4.7	3.5
	CV	9.5	0.24	4.7	0.24
South East (Charleston)	CA	6.8	1.7	2.4	3.1
	CV	6.8	0.26	2.4	0.26
South West (Phoenix)	CA	4.2	2.5	1.4	3.0
	CV	4.2	0.23	1.4	0.26
Mid Atlantic (Washington, D.C.)	CA	7.7	1.1	3.7	1.5
	CV	7.7	0.29	3.7	0.34
Far West (L.A.)	CA	5.9	0.5	1.7	1.0
	CV	5.9	0.33	1.7	0.37
Northern Plain (Bismarck)	CA	10.2	1.1	4.2	1.4
	CV	10.2	0.29	4.2	0.34
Central Humid (Nashville)	CA	8.2	2.3	3.1	1.6
	CV	8.2	0.24	3.1	0.33
Southern Plain (Ft. Worth)	CA	7.3	2.7	2.7	3.7
	CV	7.3	0.22	2.7	0.24
Central Plain (Omaha)	CA	8.8	1.2	3.9	2.3
	CV	8.8	0.29	3.9	0.29
Pacific Northwest (Seattle)	CA	6.4	0.8	2.9	1.5
	CV	6.4	0.31	2.9	0.34
South Florida (Miami)	CA	2.4	2.4	2.4	3.9
	CV	2.4	0.23	2.4	0.23

H = Heating Season; C = Cooling Season

CA = Absorption Cooling; CV = Vapor Compression Cooling

Ref. 18 to regional designators, understood from Ref. 23 to be preferred, at least in 1976, by ERDA. The discussion of screening criteria ratings in Section 4 of this report explains that lower rankings are assigned to applications requiring thermal-to-electric ratios of less than 3 for concentrating collectors because of the likelihood that, in such cases, thermal energy would be dumped in substantial quantities at certain times of the day. On this basis, the data of Table III-6 indicate that either concentrating or flat plate collectors appear to be applicable to most of the single-family housing inventory during the heating season. During the cooling season, however, the ratios computed either for vapor compression systems or for absorption cooling indicate that concentrator systems might be less desirable than flat plate collectors for this applications class. Review of the ratios developed for low-rise multiple unit structures shows a number of regions in which concentrating collectors would receive low ratings even in the heating season, although several regions appear to be able to utilize them for absorption cooling during the cooling season. In all of the regions, non-concentrating systems would tend to rank high for this application class, as they do for single-family homes.

3.1.3.2 Market Size

Tables III-7 and III-8 provide data, segregated by climatic region, on the number of buildings and their collective floor area, the total regional energy demand, and the growth in inventory for the two residential applications classes of interest to the screening activity. The 1975 inventory values were derived from Ref. 18 as the mean between th 1970 existing inventory and the forecast 1980 inventory. 1975 was selected as the preferred base year over 1970, since commercial building baseline inventory data, described in another section of this report, were only available for 1975. Values of saturation of residential housing by heating and cooling systems were projected by Ref. 18 and were used in the computation of total regional energy demand. Because potential improvements in building energy conservation were not taken into account in projecting

Table III-7. Data Base: Market Size - Residential Buildings
Single-Family Homes

Region	# of Homes x 10^3 1975	1990	Floor Area $ft^2 \times 10^6$ 1975	1990	Energy Demand BTU/yr x 10^{12} 1975	1990	Average Annual Growth %
Eastern Great Lakes	12,631	14,273	22,736	25,692	3,197	3,613	0.8
Midwest	4,462	5,131	8,032	9,237	1,281	1,473	0.9
South East	4,773	5,441	8,591	9,794	714	814	0.9
South West	659	830	1,186	1,494	75	95	1.5
Mid-Atlantic	6,150	7,011	11,070	1,262	1,291	1,472	0.9
Far West	4,830	5,699	8,694	10,259	582	687	1.1
Northern Plain	2,306	2,514	4,151	4,525	764	833	0.6
Central Humid	5,754	6,329	10,357	11,393	960	1,056	0.6
Southern Plain	2,915	3,207	5,247	5,772	482	530	0.6
Central Plain	2,245	2,402	4,041	4,324	600	642	0.5
Pacific Northwest	1,208	1,365	2,174	2,457	244	276	0.8
South Florida	1,053	1,221	1,895	2,198	72	84	1.0
U.S. Total	48,986	55,423	88,174	99,760	10,262	11,596	0.8

Table III-8. Data Base: Market Size - Residential Buildings Low-Rise Apartments

Region	# of Bldgs. x 10^3 1975	# of Bldgs. x 10^3 1990	Floor Area $ft^2 \times 10^6$ 1975	Floor Area $ft^2 \times 10^6$ 1990	Energy Demand BTU/yr x 10^{12} 1975	Energy Demand BTU/yr x 10^{12} 1990	Average Annual Growth %
Eastern Great Lakes	791	1,163	17,086	25,116	1,849	2,718	2.6
Midwest	135	227	2,916	4,899	360	605	3.5
South East	97.7	175	2,110	3,777	145	260	4.0
South West	19.4	32	419	691	25	41	3.4
Mid-Atlantic	207	339	4,471	7,332	427	700	3.4
Far West	235	371	5,076	8,020	275	435	3.1
Northern Plain	59.2	97	1,279	2,098	159	261	3.4
Central Humid	134	226	2,894	4,891	206	348	3.6
Southern Plain	52.3	100	1,130	2,158	86	164	4.4
Central Plain	59.8	97	1,292	2,106	141	230	3.3
Pacific Northwest	29.1	49	629	1,069	53	90	3.6
South Florida	34.1	53	737	1,150	42	66	3.0
U.S. Total	1,854	2,929	40,039	63,254	3,768	5,953	3.1

energy demand to 1990, the energy values shown on Tables III-7 and III-8 have usefulness for internal comparison only.

3.1.3.3 Energy Density Match

Energy density ratios can be computed on the basis of the data in Tables III-9 and III-10, in which the previously computed average daily energy demands for the two seasons and the two cooling systems are compared to the average daily amounts of energy available from horizontal PTES panels in the 12 regions of interest. The baseline insolation data presented in the first two columns of these tables represent seasonal averages of total horizontal insolation, computed as shown on Table III-11. The energy generated in horizontal panels is used as a common denominator since local conditions in various regions will determine preference for either tracking collectors or stationary collectors placed at an angle determined by the local latitude. However, to show the improvement possible due to the tracking, Table III-12 provides ratios of direct normal to total horizontal insolation for the 12 regions. This table also shows the increased insolation available from stationary collectors placed at an angle of 45°, and thus permits rapid estimation of energy ratios based on inclined, stationary collectors, in comparison with tracking collectors. Table III-11 is based on the latest revision of previously published (Ref. 24) insolation data, which has recently been documented by a formal report (Ref. 25). However, at the time Table III-11 was prepared, the revisions did not include Los Angeles and Seattle data. Insolation values for these cities, and the climatic regions associated with them, are those reported in Ref. 24. Energy densities in Tables III-9 and III-10 are presented on a unit area basis, with allowance for reduction of roof area available for collectors due to the necessity of collector spacing to minimize collector shadowing. The baseline assumption is that of a flat roof. Further reduction in available energy must be made for other roof designs if these increase the need for collector spacing. If Table III-12 is to be used to estimate with accuracy the increases in energy availability made feasible by using either inclined flat plate collectors or tracking collectors,

Table III-9. Data Base: Energy Density Match Low-Rise Apartments

Region	Average Insolation		Energy in BTU/FT² - Day									
			Heating Season (H.S.)				Cooling Season (C.S.)					
			Demand		Avail. Energy		Demand, V.C.		Demand, Absorption		Avail. Energy	
	H.S.	C.S.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.
Eastern/Gr. Lakes (Boston)	739	1684	314*	80*	222	44	34	96	102	80	505	101
Midwest (Madison)	923	1865	374*	80*	277	55	34	138*	281	80	560	112
South East (Charleston)	945	1611	192	80*	284	57	34	131*	251	80	483	97
Southwest (Phoenix)	1256	2442	114	80*	377	75	34	128	238	80	733	147
Mid Atlantic (Wash. DC)	730	1662	300*	80*	219	44	34	99	117	80	499	100
Far West (L. A.)	1404	2033	139	80	421	84	34	90	78	80	610	122
Northern Plain (Bismarck)	806	2040	340*	80*	242	48	34	98	110	80	612	122
Central Humid (Nashville)	752	1745	246*	80*	226	45	34	103	130	80	524	105
Southern Plain (Fort Worth)	996	1964	220	80*	299	60	34	142*	298	80	589	118
Central Plain (Omaha)	910	1862	312*	80*	273	55	34	115*	182	80	559	112
Pac. North-west (Seattle)	704	1945	231*	80*	211	42	34	99	116	80	584	117
South Florida (Miami)	1129	1586	190	80*	339	68	34	145*	311	80	476	95

* = Indicates Inadequate Available Energy to Meet Demand on Basis of 1 ft² of Roof Area to 1 ft² of Consuming Area. Assumes Flat Roof.

Notes: Available Thermal Energy is Assumed at 50% of Insolation, with Collector Packing Fraction of 0.6

Available Electrical Energy is Assumed at 10% of Insolation, with Collector Packing Fraction of 0.6

V. C. = Vapor Compression Cooling System, COP of 3

Absorpt. = Absorption Cooling System, COP of 0.7

Average Insolation is Daily Total Horizontal Insolation Averaged Over the Months in Season

Table III-10. Data Base: Energy Density Match Single-Family Residences

Region	Average Insolation		Energy in BTU/FT² - Day									
			Heating Season (H.S.)				Cooling Season (C.S.)					
			Demand		Avail. Energy		Demand, V.C.		Demand, Absorption		Avail. Energy	
	H.S.	C.S.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.
Eastern/Gr. Lakes (Boston)	739	1684	489*	59*	222	44	20	68	57	59	505	101
Midwest (Madison)	923	1865	562*	59*	277	55	20	85	130	59	560	112
South East (Charleston)	945	1611	400*	59*	284	57	20	78	102	59	483	97
Southwest (Phoenix)	1256	2442	247	59	377	75	20	89	147	59	733	147
Mid Atlantic (Wash. DC)	730	1662	453*	59*	219	44	20	70	67	59	499	100
Far West (L.A.)	1404	2033	347	59	421	84	20	61	30	59	610	122
Northern Plain (Bismarck)	806	2040	599*	59*	242	48	20	69	63	59	612	122
Central Humid (Nashville)	752	1745	481*	59*	226	45	20	85	133	59	524	105
Southern Plain (Fort Worth)	996	1964	432*	59	299	60	20	92	159	59	589	118
Central Plain (Omaha)	910	1862	519*	59*	273	55	20	71	70	59	559	112
Pac. North-west (Seattle)	704	1945	376*	59*	211	42	20	65	45	59	584	117
South Florida (Miami)	1129	1586	139	59	339	68	20	87	141	59	476	95

* = Indicates Inadequate Available Energy to Meet Demand on Basis of 1 ft² of Roof Area to 1 ft² of Consuming Area. Assumes Flat Roof.

Notes:
Available Thermal Energy is Assumed at 50% of Insolation, with Collector Packing Fraction of 0.6
Available Electrical Energy is Assumed at 10% of Insolation, with Collector Packing Fraction of 0.6
V.C. = Vapor Compression Cooling System, COP of 3
Absorpt. = Absorption Cooling System, COP of 0.7
Average Insolation is Daily Total Horizontal Insolation Averaged Over the Months in Season

Table III-11. Mean Daily Total Hemispheric Insolation in kWh/m^2

	Bismarck	Boston	Charleston	Ft. Worth	Madison	Miami	Nashville	Omaha	Phoenix	Los Angeles (1)	Wash. D.C.	Seattle (1)
January	(H) 1.46	(H) 1.50	(H) 2.35	(H) 2.53	(H) 1.62	(H) 3.32	(H) 1.83	(H) 2.00	(H) 3.22	(H) 2.69	(H) 1.81	(H) 1.18
February	(H) 2.44	(H) 2.23	(H) 3.13	(H) 3.35	(H) 2.53	(H) 4.14	(H) 2.59	(H) 2.80	(H) 4.32	(H) 3.59	(H) 2.56	(H) 2.08
March	(H) 3.68	(H) 3.20	(H) 4.22	(H) 4.46	(H) 3.58	(C) 5.05	(H) 3.56	(H) 3.85	(H) 5.72	(H) 4.99	(H) 3.55	(H) 3.30
April	(H) 4.60	(H) 4.18	5.46	5.09	(H) 4.40	(C) 5.85	4.86	(H) 4.91	7.42	(H) 5.05	4.60	(H) 4.60
May	5.82	5.26	(C) 5.86	5.99	(H) 5.49	(C) 5.81	5.75	5.87	(C) 8.44	6.75	5.43	5.23
June	(C) 6.49	(C) 5.73	(C) 5.81	(C) 6.80	(C) 6.14	(C) 5.38	(C) 6.19	(C) 6.68	(C) 8.63	(C) 7.40	(C) 5.99	(C) 6.61
July	(C) 6.88	(C) 5.51	(C) 5.67	(C) 6.81	(C) 6.10	(C) 5.56	(C) 5.96	(C) 6.63	(C) 7.84	(C) 7.38	(C) 5.64	(C) 6.69
August	(C) 5.91	(C) 4.69	(C) 5.00	(C) 6.26	(C) 5.39	(C) 5.14	(C) 5.47	(C) 5.86	(C) 7.22	(C) 6.64	(C) 5.11	(C) 5.08
September	4.26	3.97	(C) 4.39	(C) 5.10	4.09	(C) 4.59	(C) 4.40	(C) 4.32	(C) 6.35	(C) 5.45	(C) 4.20	4.07
October	(H) 2.86	2.80	(C) 3.76	4.05	(H) 2.87	(C) 4.11	3.51	3.30	4.97	4.26	3.13	(H) 2.27
November	(H) 1.59	(H) 1.58	(H) 2.94	(H) 2.94	(H) 1.59	(C) 3.51	(H) 2.24	(H) 2.03	(H) 3.62	(H) 3.07	(H) 2.05	(H) 1.12
December	(H) 1.17	(H) 1.27	(H) 2.27	(H) 2.40	(H) 1.22	(H) 3.21	(H) 1.64	(H) 1.61	(H) 2.94	(H) 2.53	(H) 1.52	(H) 0.96
<u>Mean Daily Insolation averaged for:</u>												
Cooling Season												
kWh/m^2	6.43	5.31	5.08	6.19	5.88	5.00	5.50	5.87	7.70	6.72	5.24	6.13
Btu/Ft^2	2040	1684	1611	1964	1865	1586	1745	1862	2442	2132	1662	1994
Heating Season												
kWh/m^2	2.54	2.33	2.98	3.14	2.91	3.56	2.37	2.87	3.96	3.92	2.30	2.22
Btu/Ft^2	806	739	945	996	923	1129	752	910	1256	1212	730	704

H = Heating Season
C = Cooling Season

Source: Ref. 25

(1) Ref. (24)

Table III-12. Insolation Conversion Factors

	Latitude Degrees	Direct Normal Radiation / Total Horizontal Radiation: Spring	Summer	Fall	Winter	Total Radiation on 45°, South-Facing Flat Collector / Total Horizontal Radiation: Spring	Summer	Fall	Winter	Annual	Comments
Eastern/Gt Lakes (Boston)	42.4	1.1	1.0	1.3	1.6	1.04	.89	1.34	1.74	1.13	
Midwest (Madison)	43.1	1.2	1.1	1.5	1.8	1.06	.91	1.39	1.82	1.14	
South East (Charleston)	32.9	1.0	0.9	1.2	1.4	0.95	.83	1.22	1.48	1.07	
Southwest (Phoenix)	35.8	1.2	1.1	1.4	1.6	.95	.80	1.24	1.51	1.05	
Mid-Atlantic (Wash., D.C.)	39.0	1.1	1.0	1.3	1.6	1.02	.88	1.29	1.58	1.12	
Far West (L.A.)	33.9	1.2	1.1	1.4	1.6	.97	.83	1.29	1.55	1.07	Used Santa Maria Values
Northern Plain (Bismarck)	46.8	1.3	1.3	1.7	2.1	1.12	.94	1.50	2.00	1.23	
Central Humid (Nashville)	36.1	1.0	1.0	1.2	1.4	.96	.85	1.25	1.48	1.07	
Southern Plain (Ft. Worth)	32.8	1.1	1.1	1.3	1.5	.95	.82	1.24	1.48	1.06	
Central Plain (Omaha)	41.4	1.2	1.1	1.5	1.8	1.02	.89	1.37	1.72	1.14	
Pac. Northwest (Seattle)	47.5	1.1	1.2	1.3	1.3	1.07	.94	1.38	1.64	1.08	
South Florida (Miami)	25.8	1.0	1.0	1.2	1.3	.88	.77	1.15	1.34	1.00	

Source: Ref. 26

CONVERSION FACTORS FROM TOTAL HORIZONTAL RADIATION VALUES TO INDICATED VALUES

Spring: March, April, May
Summer: June, July, August
Fall: September, October, November
Winter: December, January, February

Note: Rounding of the data for Direct Normal as provided by the reference.

statistics on roof type and orientation for the 12 climatic regions would be required. Such data are not now available. All of the conclusions presented herein are therefore based on data subject to rather large error. However, it is probably true that the energy densities for the climatic regions in the South contain the least error because the incidence of flat roofs appears to be highest in those regions. For the same reason, the data for the Northern regions should exhibit the largest error because climatic conditions would make flat roofs almost infeasible there.

Tables III-13 through III-16 present the energy density ratios computed from the densities shown earlier. For single-story, single-family residences, only two climatic regions, the Southwest and the Far West, appear to allow heating season demand to be filled entirely by photovoltaics, either by providing electric energy only, or from the point of view of total energy utilization. Only the South Florida region permits heating of a two-story residence with a total energy system, but even there the residence would require utility backup for the electrical load. Cooling season ratios are much more favorable, with single-story home demand capable of being met by photovoltaic electric or total energy systems in all regions and two-story residence demand being filled by photovoltaics in 4 of the 12 regions, if absorption cooling is used. This conclusion is based on energy availability computed for total horizontal insolation only. If south-facing inclined collectors were used, heating season performance would improve in most of the regions, as inspection of Table III-14 indicates.

Tables III-15 and III-16, dealing with low-rise apartments, show a less favorable energy ratio relationship. Even the assumption of tracking collectors does not increase the number of regions in which available energy would be sufficient for two-story apartments except for Southern Florida in the heating season and for the Northern Plains region in the cooling season. Of course, the use of tracking systems would increase the fraction of the building energy need which could be supplied by photovoltaics and might therefore prove optimum upon economic analysis. It is of particular interest to note that total energy systems using absorption cooling can

Table III-13

Data Base: Energy Density Ratios

Single Family Residences
Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on: Total Horizontal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.45	.75	25.3	1.49	8.86	1.71
Midwest	.49	.93	28.0	1.32	4.31	1.90
Southeast	.71	.97	24.2	1.24	4.74	1.64
Southwest	1.53	1.27	36.7	1.65	4.99	2.49
Mid-Atlantic	.48	.75	25.0	1.43	7.45	1.69
Far West	1.21	1.42	30.5	2.0	20.3	2.07
Northern Plain	.40	.81	30.6	1.77	9.71	2.07
Central Humid	.47	.76	26.2	1.24	3.94	1.78
Southern Plain	.69	1.02	29.5	1.28	3.70	2.0
Central Plain	.53	.93	28.0	1.58	7.99	1.90
Pacific Northwest	.56	.71	29.2	1.80	12.98	1.98
South Florida	2.44	1.15	23.8	1.09	3.78	1.61

V.C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once when available energy is sufficient for a 1 story home and twice for a 2 story home.

Table III-14

Data Base: Energy Density Ratios
Single Family Residences

Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on: 45° South Facing Collector

	Heating Season		Cooling Season			
			V. C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.60	.99	22.52	1.33	7.89	1.52
Midwest	.64	1.21	25.45	1.20	3.92	1.73
Southeast	.91	1.24	23.23	1.19	4.55	1.57
Southwest	1.99	1.65	33.03	1.49	4.49	2.24
Mid-Atlantic	.63	.99	22.25	1.27	6.63	1.50
Far West	1.50	1.76	28.06	1.84	18.68	1.90
Northern Plain	.59	1.19	28.76	1.66	9.13	1.96
Central Humid	.60	.97	24.37	1.15	3.66	1.66
Southern Plain	.88	1.31	26.85	1.16	3.37	1.82
Central Plain	.70	1.23	27.44	1.55	7.83	1.86
Pacific Northwest	.72	.92	26.86	1.66	11.94	1.82
South Florida	3.27	1.54	21.66	.99	3.44	1.47

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once when available energy is sufficient for a one story home and twice for a two story home.

Table III-15

Data Base: Energy Density Ratios

Low Rise Apartments

Available Energy/Demand Based on Floor
Area Equal to Roof Area

Available Energy Based on: Total Horizontal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.77	.55	14.8	1.05	4.95	1.26
Midwest	.74	.69	16.5	.81	1.99	1.4
Southeast	1.48	.71	14.2	.74	1.92	1.21
Southwest	3.31	.94	21.6	1.15	3.08	1.84
Mid-Atlantic	0.73	.55	14.7	1.01	4.27	1.25
Far West	3.03	1.05	17.9	1.36	7.82	1.53
Northern Plain	.71	.6	18.0	1.24	5.56	1.53
Central Humid	.92	.56	15.4	.99	4.03	1.31
Southern Plain	1.36	.75	17.3	.83	1.98	1.48
Central Plain	.88	.69	16.4	.97	3.07	1.40
Pacific Northwest	.91	.53	17.2	1.18	5.03	1.46
South Florida	1.78	.85	14.0	.66	1.53	1.19

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once when available energy is sufficient for at least 1 story, and twice when for at least 2 stories.

Table III-16

Data Base: Energy Density Ratios

Low Rise Apartments

Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on: Direct Normal Insolation

	Heating Season		Cooling Season			
			V. C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.92	.73	14.9	1.05	4.95	1.26
Midwest	1.03	.98	18.1	.89	2.19	1.54
Southeast	1.84	.89	13.4	.71	1.86	1.16
Southwest	4.13	1.18	22.3	1.18	3.18	1.89
Mid-Atlantic	1.02	.76	15.5	1.07	4.50	1.33
Far West	3.61	1.25	21.8	1.64	9.50	1.85
Northern Plain	1.16	.99	23.4	1.62	7.23	1.99
Central Humid	1.14	0.70	16.0	1.06	4.19	1.36
Southern Plain	1.92	1.05	19.9	.96	2.27	1.70
Central Plain	1.28	1.0	19.3	1.14	3.60	1.64
Pacific Northwest	1.09	.64	20.6	1.41	6.03	1.75
South Florida	2.32	1.1	14.8	.69	1.61	1.25

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once when available energy is sufficient for at least 1 story, and twice when for at least 2 stories.

supply the cooling needs of building as high as seven stories (in the Far West region) but are inadequate in two of the twelve regions to cool even a two-story building. Electric utility backup appears to be required in all 12 regions.

3.1.3.4 Market Location

Some of the other location factors important to screening of application classes were more difficult to define quantitatively. For example, it would be of interest to determine the distribution of residential units between core cities, urbanized regions, suburban regions, and others. Further, it is important to the assessment of potential markets to obtain estimates of the distribution of multiple-unit buildings as a function of number of stories in each of the above regions. A more detailed count of residential units in cities of various sizes and in urban core areas versus suburban areas can be obtained from the Census tract data contained on Census summary tapes, but the cost, both in money and time, was considered to be too great to justify acquiring these data for the study reported here. However, the distribution of numbers of floors was unavailable from any of the sources contacted during this study.

Table III-17 (excerpted from Ref. 27) provides statistics which can be used for the qualitative judgments permitted for the screening activity but which are less useful for market penetration analysis. The data on this table confirm the trend assumed for the Ref. 18 projections, namely that multi-unit residential structures will show a greater growth rate than will single-family homes. It also shows a surprisingly large growth rate for multi-unit structures in rural areas and for mobile home units outside of urban areas. Urban areas are defined generally by the Census as all locations of 2500 inhabitants or more, excluding the rural portions of extended cities. Under this classification scheme, a suburban region would be counted under the urban designation. It appears that single-family residences outnumber multiple units about 2 to 1 in urban regions and about 13 to 1 in rural areas. Attached single-family units, most likely the two-story townhouse type, seem to be gaining rapidly in preference, not only

Table III-17. U.S. Year Around Housing Units - Occupied*

	In Millions			1975 in %			%, Air-Conditioned in 1975	Type of Heating Energy Used in 1975 in %					
	1970	1975	Annual % Growth	% of Total Housing	% of Urban	% of Rural		Utility Gas	Bottled Gas	Oil	Electric	Coal	Other
1. U. S. Total Housing	67.7	77.6	2.7	100.0			49.4	56	5.7	22.5	12.6	0.8	3.2
Single, Detached	44.8	49.5	2.0	64.0									
Single, Attached	1.99	3.13	9.5	4.0									
2-4 Units	9.01	9.80	1.7	13.0									
5 or More Units	9.83	11.79	3.7	15.0									
Mobile Units	2.07	3.34	10.0	4.0									
2. Urban, Total Housing	50.0	55.46	2.1	72.0	100		52	67	1	20	10.8	0.4	-
Single Detached	29.45	31.65	1.5	41.0	57								
Single Attached	1.90	2.75	7.7	3.6	5								
2-4 Units	8.28	8.93	1.5	11.5	16								
5 or More Units	9.56	11.24	3.3	15.5	20								
Mobile Units	0.81	0.91	2.4	1.2	1.6								
Inside SMSA	-	45.71	-	59.0	82.4								
Outside SMSA	-	9.75	-	12.6	17.6								
3. Rural, Total Housing	17.70	22.09	4.5	28.0		100							
a. Non-Farm, Total	15.30	19.45	4.9	25.0		88	43	33	15.6	28.1	18	1.6	
Single, Detached	13.04	15.36	3.3	20.0		70.0							
Single, Attached	0.09	0.37	33.0	0.5		1.7							
2-4 Units	0.69	0.85	4.3	1.1		3.9							
5 or More Units	0.27	0.56	16.0	0.7		2.5							
Mobile Units	1.21	2.31	13.8	3.0		10.5							
b. Farm, Total	2.40	2.64	1.9	3.4		12	40	12.4	33.5	30.5	12.8	3	
Single, Detached	2.31	2.48	1.4	3.2		11							
2-4 Units	0.03	0.03	0	-		-							
c. Inside SMSA	-	6.98	-	9.0	32	-							
Outside SMSA	-	15.11	-	19.5	68	-							

*Census Data (Ref. 27)

in the urban areas where land costs would tend to favor their development, but also in rural areas. Larger apartment structures, those containing five or more units, also exhibit interesting growth rates. Although rural housing represents only 25% of the total housing in the U.S., it represents a large market in itself, constituting about 15 million units in 1975, and it is the fastest growth market among the residential structures measured by the Annual Housing Survey. Another item of interest in this table is the higher percentage of heating by electricity for rural non-farm units than for urban units, as is that for heating by bottled gas. Both of these energy sources are expensive and should permit earlier competition from alternate energy sources.

Similar data, but excluding mobile units, are summarized on Table III-18 for the four Census regions. The data on this table confirm the regional shift of housing to the South and the West and also show marked increases in the multiple unit growth rate in those regions where insolation characteristics should make solar energy conversion more efficient. Other data, shown on Table III-19, reinforce the judgment that the South and the West are the major growth markets for new residential units. Since penetration by photovoltaic energy conversion systems of the new housing market rather than the retrofit market should be easier as a result of technical and economic factors, demographic trends thus appear to favor solar energy utilization. Although the regional distribution of numbers of stories in multiple-unit housing inventories is not available, some indication of construction trends can be derived from Table III-20, which shows new construction in the nine Census divisions in 1972. However, it represents only a sample of 44 Standard Metropolitan Statistical areas (SMSAs) out of the 243 SMSAs defined by the 1970 Census of Housing and Population. These areas were selected by Decision Sciences Corp., (Ref. 29) because they exhibited increases in construction activity between 1970 and 1972. As already shown previously in Table III-4 for the national apartment inventory in 1970, the total units-in-place in 1970 were also concentrated in two- and three-story, multiple-unit structures and in relatively small

Table III-18. Residential Buildings in 1975, in Thousands*

	North-East		North Central		South		West		
		% of U.S.		% of U.S.		% of U.S.		% of U.S.	U.S. Totals
Inventory, Total									
Single Residences,	9,696	18.4	14,702	28	18,570	35.3	9,650	18.3	52,600
Growth Rate (1970-75) %	2		1.8		2.7		3		2.4
Apartments, Units,	7,440	34	5,188	24	4,971	23	3,996	18.5	21,600
Units Growth Rate	0.7		1.8		5.6		5		2.8
Urban Inventory									
Single Residences,	6,715	19.5	9,448	27.5	10,743	31.2	7,490	21.8	34,400
Growth Rate (1970-75)%	1.4		1.7		1.9		2.4		1.9
Apartments, Units,	6,990	34.7	4,802	23.8	4,552	22.5	3,816	19	20,170
Units Growth Rate (1970-75)%	0.5		1.3		5.3		4.9		2.5
Rural Non Farm Inventory									
Single Residences,	2,830	18	4,166	26.5	6,827	43.4	1,911	12.1	15,730
Growth Rate (1970-75)%	3.5		2.6		4		5.1		3.7
Apartments, Units,	434	31	378	27	413	29.3	179	12.7	1,407
Units Growth Rate (1970-75)%	5		9.9		9.8		7.1		8
Rural Farm Inventory									
Single Residences,	152	6	1,088	44	1,001	40.	249	10	2,480
Growth Rate, (1970-75)%	2.9		0		3		3.1		1.4
Apartments, Units,	11	41	8	30	6	22	2	7	27
Units Growth Rate (1970-75)%	1.9		0		0		0		0

*Census Data (Ref. 27)

Table III-19

Projections of Numbers of Households by Census Regions and by Area Characteristics*
(in 1000's)

	Census Regions				
	NE	NC	S	W	
Metropolitan Areas					
Large					
1975	12,941	9,572	6,377	8,403	
1985	13,591	10,204	8,352	9,768	
% Change	5	6.6	31	16.3	
Medium					
1975	1,776	3,512	6,757	2,392	
1985	1,955	3,932	8,695	3,293	
% Change	10	12	28.7	37.7	
Small					
1975	87	1,169	1,417	615	
1985	90	1,320	1,727	809	
% Change	3.3	12.9	22	31.6	
Non-Metropolitan					
1975	1,422	4,809	8,029	1,843	
1985	1,655	5,599	9,589	2,417	
% Change	16.4	16.4	20	31.2	Total U.S.
Totals: 1975	16,226	19,062	22,580	13,253	71,121
1985	17,291	21,055	28,363	16,287	82,996

Note: Area Definitions based on 1970 Population:

Large Metropolitan Areas ≥ 1 Million

Medium Metropolitan Areas > 250,000 < 1 Million

Small Metropolitan Areas < 250,000

*Ref. 28

Table III-20. Apartment Building Size Distribution, 1972*

% of Projects in Census Division

	NE	MA	SA	ENC	WNC	ESC	WSC	M	P
# of Stories per Building									
1	1.6	2.2	12.8	4.5	10.8	4.0	6.9	2.7	9.9
2	39.6	53.7	55.4	57.9	62.6	74.5	77.5	45.4	64.9
3	36.9	13.4	13.7	29.2	21.6	18.3	14.6	41.7	19.5
4 and more	21.9	30.7	18.1	8.4	5.0	3.2	1.0	6.5	5.7
# of Buildings per Project									
1	57.2	55.0	51.2	50.0	68.4	36.4	31.6	58.3	61.1
2	10.2	13.7	9.6	12.4	4.3	9.7	9.8	10.6	7.3
3	2.1	5.8	4.5	6.6	3.6	6.6	5.8	5.8	3.8
4	10.7	3.2	5.0	5.3	2.2	4.9	4.0	4.0	4.0
5 and more	19.8	22.3	29.7	25.7	21.5	42.4	48.8	21.3	23.8
# of Units per Building									
1-10	38.0	46.0	55.0	55.0	53.0	50.0	58.0	32.0	58.0
11-20	28.0	15.0	18.0	21.0	30.0	31.0	30.0	27.0	22.0
21-30	14.0	3.0	7.0	8.0	9.0	10.0	7.0	17.0	7.0
31 and more	20.0	36.0	20.0	16.0	8.0	9.0	5.0	24.0	13.0

Census Divisions			Climatic Region with Closest Correspondence
NE	=	Northeast	Eastern/Great Lakes
MA	=	Middle Atlantic	Mid Atlantic
SA	=	South Atlantic	South East
ENC	=	East North Central	Midwest
WNC	=	West North Central	Northern/Central Plain
ESC	=	East South Central	Central Humid
WSC	=	West South Central	Southern Plain
M	=	Mountain	Southwest
P	=	Pacific	Pacific Northwest/Far West

*Ref. 29

numbers of units per building. In addition, Table III-20 indicates the great preponderance of two- and three-story structures in the southern and western states in contrast to the states along the northeastern seaboard. Both trends, that of concentrating construction in buildings of three stories or less, and that of including mostly small numbers of units per building, tend to favor solar energy application because of a closer match between energy available from roof-mounted collectors and the energy demand.

Among the market location criteria to be used in the application selection process is that of the competing electric energy and fuel energy costs associated with different regions of the country. The competitiveness of PV systems will be enhanced in those regions in which both insolation and competing energy prices are high. As a consequence, applications which predominantly occur in such regions will be preferred as candidates for more detailed examination, if they also possess the desirable characteristics associated with the other selection criteria.

Ideally, the effect of competing energy costs and the insolation level at a particular location on the viability of a PV system should be evaluated by computing the present discounted worth of the two competing energy systems assuming reasonable lifetimes, investment costs, and operational and maintenance costs. In addition, the usable energy produced by the PV system should be estimated through use of an adequate simulation model. However, the large number of data points in the screening activity, represented by combinations of applications, climatic regions, seasons and competing energy types, makes such a complete evaluation for each data point impossible. Consequently, a simpler approach was selected which allows value ranking of applications. This approach is based on the use of a figure of merit, K, which is roughly proportional to the value of the energy (thermal and electric) produced by a photovoltaic total energy system and therefore, also, proportional to the affordable price of such a system. The expression for this figure of merit takes two different forms, depending on whether the thermal-to-electric demand ratio of the application, T/E, is greater than or less than the ratio, $(T/E)_o$, of the thermal energy produced by the panel to the electric energy produced. (Clearly, $(T/E)_o$ is equal to the ratio of the average conversion efficiencies, η_T/η_e). The equations defining K are

$$K = k_t + k_e \left[\frac{(T/E)_o}{(T/E)}\right] \quad \text{for } T/E > (T/E)_o$$

and

$$K = k_t \left[\frac{T/E}{(T/E)_o}\right] + k_e \quad \text{for } T/E < (T/E)_o$$

where

k_t = the value of the thermal energy produced by unit area* of collector

k_e = the value of the electricity produced by unit area* of collector

The derivation of these equations is straightforward. If $T/E > (T/E)_o$, the collector is assumed to be sized to meet the thermal demand, i.e., to provide T units of thermal energy. In this case, it will also provide $T/(T/E)_o$ units of electric energy. Since only $T/(T/E) <$ units of electricity are needed, however, the amount of usable electricity produced is proportional to the ratio $(T/E)_o/(T/E)$. If $T/E < (T/E)_o$, the collector is sized to meet the electric demand, and similar arguments apply. For the purposes of this screening analysis, the thermal efficiency of the collectors, η_t, was assumed equal to 0.50, and that of the electrical efficiency, η_e, to 0.10. This produces a $(T/E)_o$ of 5.

---

* reduced by a 60% collector packing fraction

It should be emphasized that the parameter K is proportional only to the affordable price of the collector area of a photovoltaic total energy system. Other considerations affecting a decision to replace conventional energy systems with solar, such as the degree of storage required, are not reflected in this simplified ranking approach.

In order to develop K values for the various regions, information on forecast costs of conventional energy is required. Table III-21 shows prices forecast in 1977 for 1990 by the DOE, then the Federal Energy Administration (Ref. 30), for the 10 FEA regions. These prices have been adjusted for the 12 climatic regions used here. The fractions of each fuel used for residential heating and cooling applications are shown in Table III-22, but for the year 1985, the latest for which such a forecast could be obtained (Ref. 31). The assumption is made in the calculation of the K values that these fractions will not materially change between 1985 and 1990. The results of the calculations of energy costs in the 12 climatic regions are shown in Table III-23. The K values derived for the two building types are shown in Table III-24. The differences in relative value of the K factors in some of the climatic regions between single and multiple residences is due to their different thermal/electric ratios, as exemplified in Table III-6. Higher thermal demand in a region in which thermal energy is more expensive can enhance the value of a photovoltaic total energy system for that region when compared to other regions. Of course, higher insolation and higher conventional energy costs also increase the value of K relative to other regions. Thus, the higher K values for the cooling season are due to higher energy collected per unit area of collector.

When regional K factors are weighted by the energy demand in each region and are used to compute an average national value, low-rise apartments appear to allow higher collector costs than single residences, as is also shown on Table III-24. This is apparently due to the higher proportion of apartments in regions which have highest demand and high conventional energy costs, such as the northeastern United States.

Table III-21. 1990 Energy Prices* in 1977 Dollars (FEA PIES Projections)

Climatic Regions	FEA Regions	Electric Power, ¢/kWh Res.	Electric Power, ¢/kWh Comm.	Electric Power, ¢/kWh Ind.	Natural Gas, $/MCFT Res.	Natural Gas, $/MCFT Comm.	Natural Gas, $/MCFT Ind.	Distillate Oil, $/BBL Res.	Distillate Oil, $/BBL Comm.	Distillate Oil, $/BBL Ind.	Residual Oil, $/BBL Comm.	Residual Oil, $/BBL Ind.
Eastern Gt. Lakes	I, II, V	5.1	5.1	4.7	5.2	4.5	4.0	22.2	21.2	21.1	19.6	20.0
(Boston)		(14.8	14.9	13.7)	(5.0	4.4	3.9)	(3.9	3.6	3.6)	(3.1)	(3.2)
Midwest	V	4.1	4.1	3.5	3.7	3.4	3.1	21.9	20.8	20.8	20.5	20.3
(Madison)		(11.9	12.0	10.4)	(3.6	3.3	3.0)	(3.8	3.6	3.3)	(3.3	(3.2)
South East	IV	3.7	3.6	3.4	3.6	3.1	2.7	24.3	21.8	22.2	19.2	19.0
(Charleston)		(10.7	10.7	10.0)	(3.5	3.0	2.7)	(4.2	3.7	3.8)	(3.1	3.0)
Southwest	VIII	3.2	3.1	3.0	2.9	3.7	3.2	22.4	21.1	21.3	20.7	21.0
(Phoenix)	IX	(9.5	9.0	8.7)	(2.8	3.6	3.1)	(3.8	3.6	3.7)	(3.3	(3.3)
Mid-Atlantic	III	4.4	4.2	3.7	3.9	3.5	3.1	23.9	21.7	22.3	21.3	20.8
(Wash., D.C.)		(12.8	12.4	10.8)	3.8	3.4	3.0)	(4.1	3.7	3.8)	3.4	3.3)
Far West	IX	4.5	4.3	3.8	3.5	3.0	3.2	22.6	21.1	21.1	19.4	19.4
(L.A.		(13.0	12.6	11.2)	(3.4	2.9	3.1)	(3.9	3.6	3.6)	(3.1	3.1)
Northern Plain	VIII	3.2	3.1	3.0	2.9	3.7	3.2	22.4	21.1	21.3	22.0	21.6
(Bismarck)		(9.5	9.0	8.7)	(2.8	3.6	3.1)	(3.8	3.6	3.7)	(3.5	3.4)
Central Humid	IV	3.7	3.6	3.4	3.6	3.1	2.7	24.3	21.8	22.2	19.2	19.0
(Nashville		(10.7	10.7	10.0)	(3.5	3.0	2.7)	(4.2	3.7	3.8)	(3.1	3.0)
Southern Plain	VI	4.7	4.6	4.3	2.9	3.5	3.3	22.5	21.1	21.1	19.4	19.3
(Ft. Worth)		(13.7	13.4	12.5)	(2.8	3.4	3.2)	(3.9	3.6	3.6)	(3.1	3.1)
Central Plain	VII	3.8	3.9	3.5	2.9	3.8	3.4	21.3	20.3	20.3	20.5	20.3
(Omaha)		(11.1	11.4	10.3)	(2.8	3.6	3.3)	(3.7	3.5	3.5)	(3.3	3.2)
Pacific N.W.	X	2.4	2.4	2.0	3.1	4.5	3.8	22.6	21.1	21.1	19.0	19.7
(Seattle)		(7.1	6.7	5.7)	(3.0	4.4	3.7)	(3.9	3.6	3.6)	(3.0	3.1)
South Florida	IV	3.7	3.6	3.4	3.6	3.1	2.7	24.3	21.8	22.2	19.2	19.0
(Miami)		(10.7	10.7	10.0)	(3.5	3.0	2.7)	(4.2	3.7	3.8)	(3.1	3.0)

Note: Quantities in parenthesis represent price in $ per million BTU
Ref: FEA Forecast in Fed. Reg., Vol. 42, No. 125, 29 June 1977

*Values have been rounded to nearest tenth

Table III-22. Residential Energy Consumption in Fractions by Fuel Type in 1985 (FEA PIES Forecast)*

Climatic Regions	Electric	NG	Distillate Oil	LG	Coal
Eastern Great Lakes	.180	.395	.386	.035	.004
Midwest	.189	.594	.158	.056	.003
South East	.457	.347	.111	.083	.002
Southwest	.180	.729	.045	.046	.000
Mid-Atlantic	.284	.461	.225	.024	.006
Far West	.207	.767	.023	.003	.000
Northern Plain	.152	.693	.066	.089	.000
Central Humid	.457	.347	.111	.083	.002
Southern Plain	.218	.636	.069	.077	.000
Central Plain	.187	.638	.064	.110	.001
Pacific Northwest	.450	.351	.195	.003	.001
South Florida	.459	.347	.111	.083	.002

Notes: NG = Natural Gas

LG = Liquefied Petroleum Gases

*Ref. 31

Table III-23. 1990 Price of Energy to Residential User, in 1977 Dollars

Climatic Region	Electric and Thermal Energy Prices by Climatic Region, $/Million Btu	
	Electric	Thermal
Eastern/Great Lakes	14.8	4.5
Midwest	11.9	3.6
Southeast	10.7	3.7
Southwest	9.5	2.9
Mid Atlantic	12.8	3.9
Far West	13.0	3.4
Northern Plain	9.5	2.9
Central Humid	10.7	3.7
Southern Plain	13.7	2.9
Central Plain	11.1	2.9
Pacific Northwest	7.1	3.3
South Florida	10.7	3.7

Note: Thermal energy price based on natural gas and distillate oil fraction used in each region.

Table III-24. K Factors - Residential (Absorption Cooling)
$ x 10^{-2}/ft^2/day

Climatic Regions	Heating Season		Cooling Season	
	Single Residences	Low Rise Apartments	Single Residences	Low Rise Apartments
Eastern/Great Lakes	.142	.148	.196	.210
Midwest	.137	.164	.218	.270
Southeast	.154	.113	.161	.212
Southwest	.162	.101	.245	.266
Mid Atlantic	.129	.127	.174	.190
Far West	.233	.158	.181	.202
Northern Plain	.099	.119	.160	.170
Central Humid	.110	.100	.197	.171
Southern Plain	.145	.129	.252	.286
Central Plain	.114	.122	.158	.194
Pacific Northwest	.093	.071	.110	.137
South Florida	.132	.132	.186	.240
K Factors Weighted by Energy Demand per Region	.136	.141	.193	.241

Weighted U.S. K Factors Combined for Entire Year

Single Residences	.143
Low-Rise Apartments	.155

Note: Area in K factor refers to roof area reduced to collector area by a 60% collector packing fraction.

3.1.3.5 Energy Demand Level

The statistics available for determination of the range of demand levels to be encountered in the residential application sector are limited. Most of the information available pertains to average demand of a particular building class without identification of the range of values from which the average was determined. From the information already presented in Tables III-3, III-4, III-5, and III-20, it is estimated that single residence demand level could be represented sufficiently accurately for purposes of this screening analysis by houses ranging in floor area from 1000 to 2000 square feet, and low-rise apartment demand by buildings ranging in total floor area from 5000 to 15,000 square feet. Energy densities reported in Tables III-9 and III-10 permit the determination of daily energy demand levels, thermal as well as electric, as shown in Table III-25 for the two types of residential structures included in this analysis. It will be recalled that these data are used in the screening analysis in a qualitative manner only, by ranking applications with lower demand level preferentially higher if all other screening factors are equal.

3.1.3.6 Phase Relationships

Diurnal phasing relationships between demand and insolation are used in a qualitative manner in the screening process. Figure III-2 represents a schematic of the daily insolation profile. No scale has been provied for the ordinate, representing the solar flux. The band width for both winter and summer seasons on the time scale on the abscissa is representative of the variation in time of sunset and dawn over these seasons, with summer including June, July, and August, and winter including December, January, and February. Figures III-3 and III-4 represent typical demand profiles for single-family units and low-rise, multi-unit buildings, with summer cooling and winter heating shown on the same figure. Again, values are not provided for the magnitude of demand, since only a qualitative time phase comparison is desired to determine relative need for energy storage. It is apparent from these figures that space heating demand leads energy available from insolation, whereas air conditioning demand

Table III-25. Residential Demand Levels

	Single Residences Floor Areas from 1,000-2,000 ft^2			Low Rise Apartments Floor Areas from 5,000-15,000 ft^2		
	Btu/ft^2 per Day	kWh per Day	Btu per Day	Btu/ft^2 per Day	kWh per Day	Btu per Day
		kWh	10^3 Btu		kWh	10^3 Btu
Heating Season						
Thermal	139-600		139-1200	114-370		570-5550
Electrical	59	17.3-34.6		80	117-352	
Cooling Season						
Vapor Compression Cooling						
Thermal	20		20-40	34		170-510
Electrical	60-90	17.6-52.7		96-145	141-637	
Absorption Cooling						
Thermal	45-160		45-320	100-310		500-4650
Electrical	59	17.3-34.6		80	117-352	

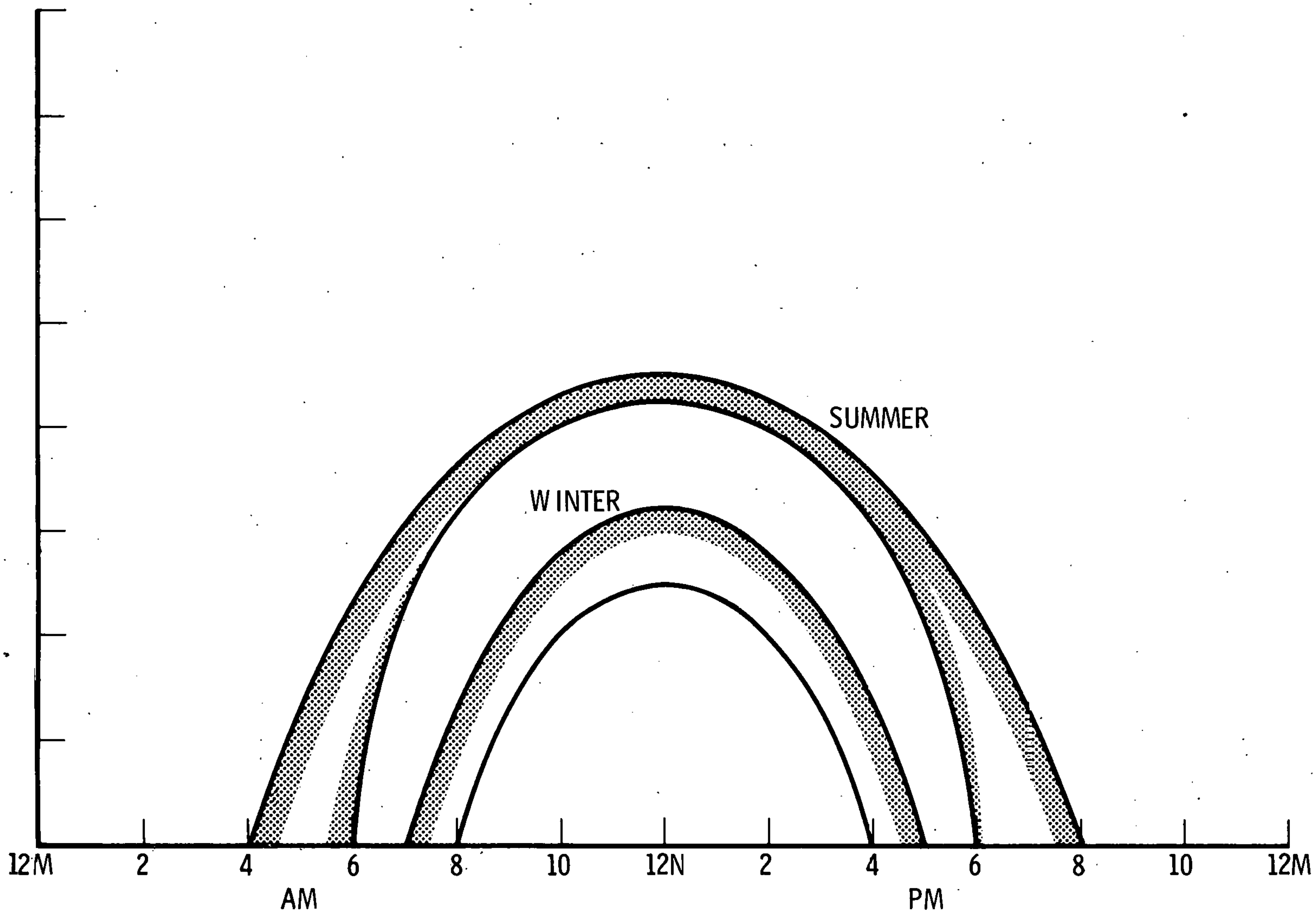


Figure III-2. Variation of Daily Insolation

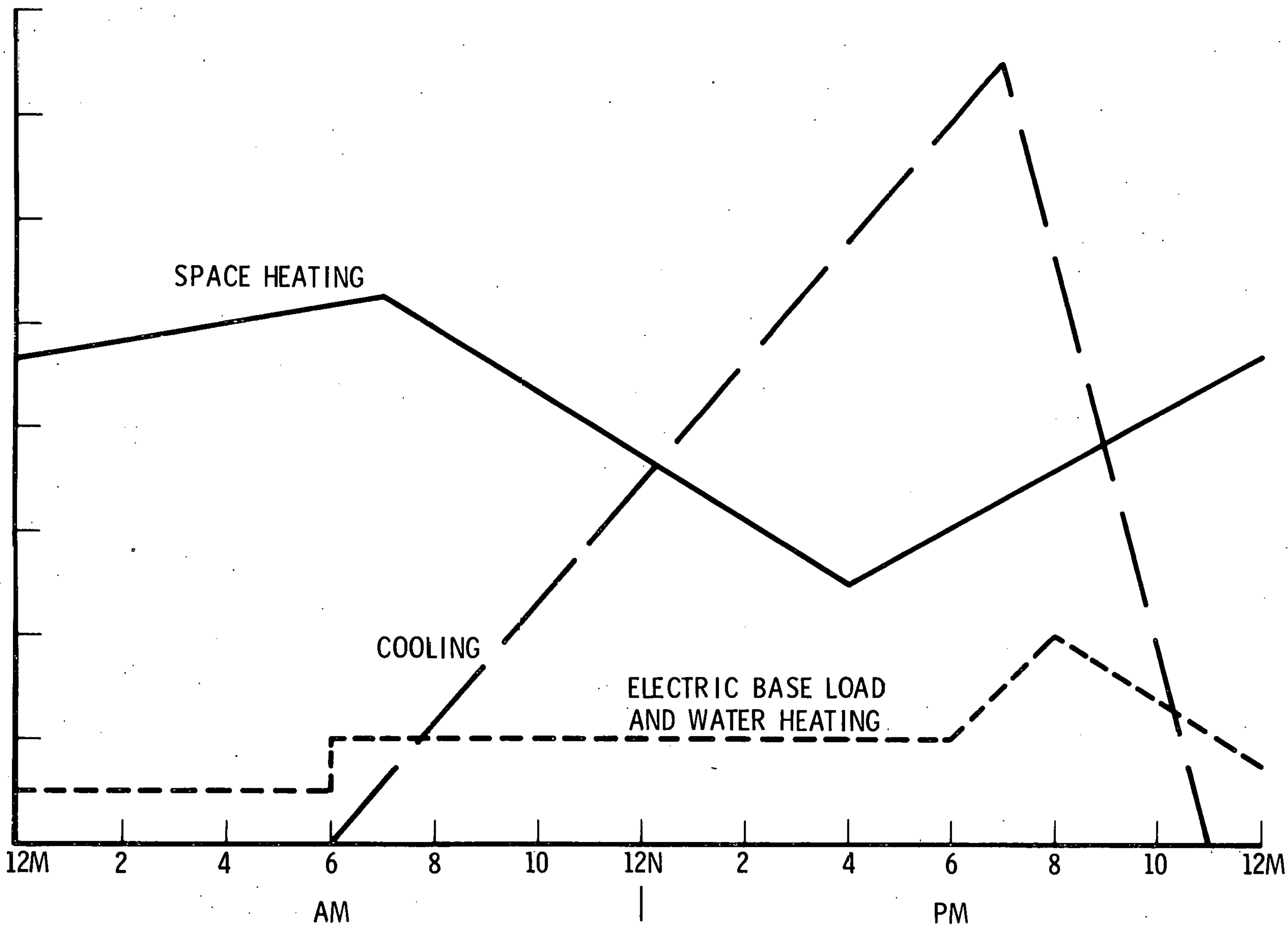


Figure III-3. Diurnal Demand of Low-Rise Apartments (Ref. 37)

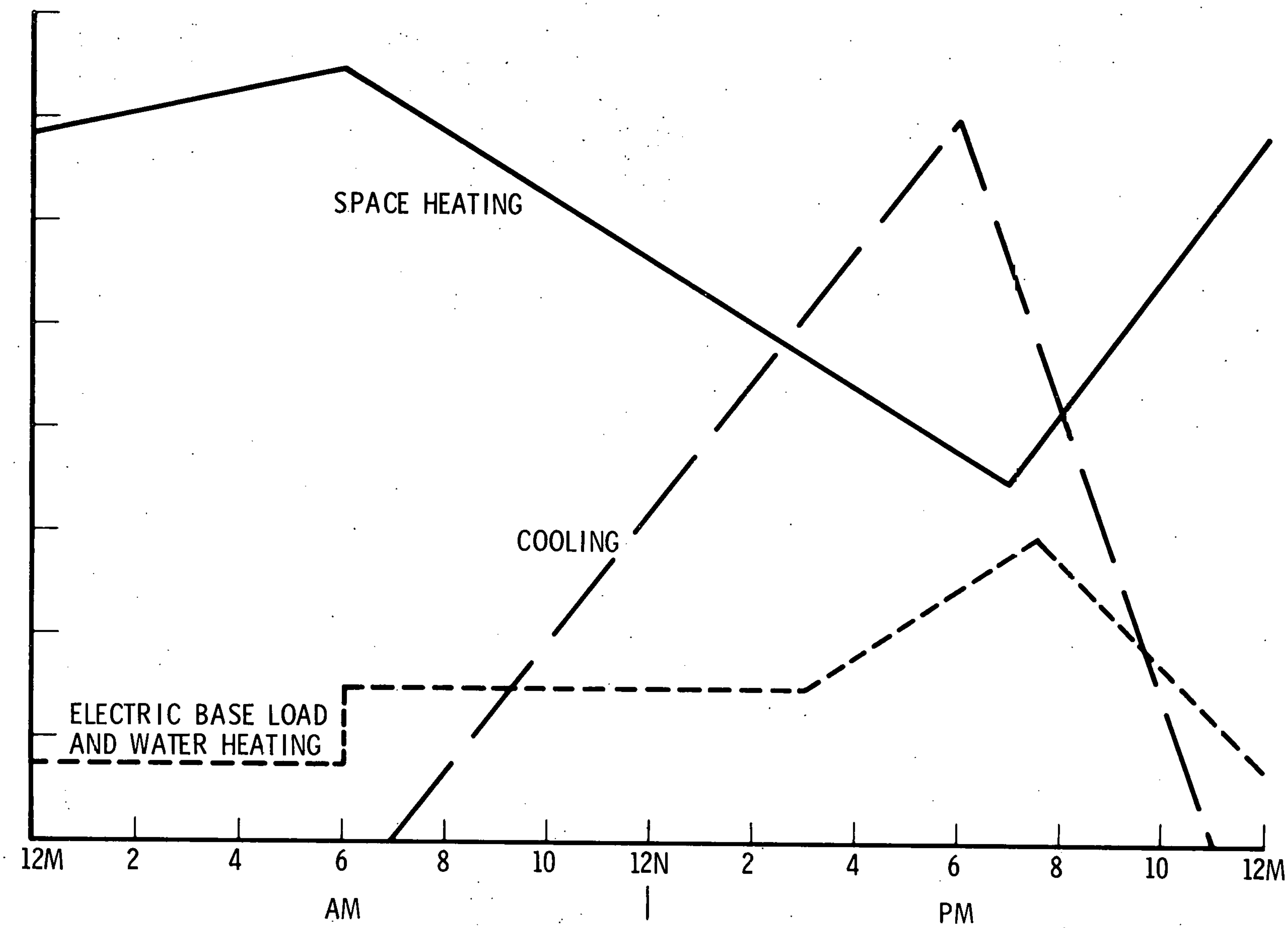


Figure III-4. Diurnal Demand of Single-Family Houses (Ref. 37) lags. Energy storage or utility backup is, therefore, required for both application classes. However, thermal energy storage for space heating will tend to be less efficient because it will require a longer storage period for energy produced during the preceding insolation period. Space cooling requirements, on the other hand, could be provided from stored energy that was collected earlier in the same day.

Seasonal demand data shown on Table III-25 indicate that the thermal demand peaks in the heating season, even compared against the thermal demand of an absorption cooling system in the cooling season. Electrical demand is, however, relatively constant over both seasons, if absorption cooling is used, but peaks in the summer if vapor compression cooling is used.

3.1.3.7 Reliability

As discussed in Section 2, the treatment of reliability, in the sense of permissible outage of power or thermal energy, can only be qualitative for this screening study since a number of subjective factors influence the selection of a minimum reliability value for rating purposes. The applications discussed in this report involve distributed power generation, energy sources which are associated with specific unit applications, thus allowing reliability requirements to be set by the characteristics of that application. Utilities, on the other hand, feed power into a distribution net which contains many different types of applications as well as many units of each application. The most demanding of these applications, in the context of reliability, determine the reliability requirement placed on the utility grid.

The presumption under which residential buildings will be rated for the reliability criterion is that limited outages will be no more than annoyances, that financial loss will not usually be involved (except for refrigerator spoilage), and that no hazard to life or health will be created. Backup will consist primarily of utility power. The reliability requirement placed on the utility can be reduced by use of limited storage to power lights and controls. It is believed that 95-99% reliability could easily be tolerated for either single-family or low-rise apartment buildings, with the possibility that even 90-95% reliability would be acceptable if that involved considerable savings in backup costs. An exception would be applications in those climatic regions where extreme cold could be anticipated during the winter season and where even several hours of space heating outage might become hazardous. It is presumed, however, that in such climates, standby space heating systems would commonly be used in any case because of the inability of the PTES to meet all of the heating requirements during this season. In the instance of a PV installation, heating is assumed to be provided by conventional means and the reliability requirement applies only to electrical house system needs; these are similar to the values quoted above.

3.1.3.8 Data Specific to Non-PTES Application

With certain assumptions, most of the data previously developed for the screening of PTES applications are suitable also for PV applications. The basic assumption is that no change in functional use of energy type occurs, i.e., all thermal loads except air conditioning continue to be served by conventional sources: natural gas, oil, or coal. Instead of using absorption cooling for air conditioning, however, an electrically driven vapor compression unit is assumed to be used, increasing the electic demand to that extent. The total energy consumption per region to be considered now is that of electric energy only, and the K factors are computed using only the cost of electrical energy in each region.

Table III-26 shows the total electrical demand per region computed by adding air conditioning load to the base load electrical demand discussed earlier in this report section. As in the instance of combined thermal and electrical demand, single residences exhibit a higher collective national demand than do low-rise apartments. In two regions, however, the opposite demand relationship appears to exist. The Eastern/ Great Lakes region appears to have a larger proportion of apartment buildings and thus the latter have a higher total energy demand, while the Far West region appears to have an intermediate season in which single-family residences require

Table III-26. Residential Building Sector, 1990 Total Regional Electric Energy Demand, in Btu x 10^{12} per Year

Climatic Regions	Single Residences	Low Rise Apartments
Eastern/Great Lakes	555	739
Midwest	168	144
Southeast	263	131
Southwest	86	25
Mid Atlantic	274	218
Far West	165	265
Northern Plain	88	64
Central Humid	217	148
Southern Plain	147	82
Central Plain	160	67
Pacific Northwest	53	31
South Florida	72	50
Totals	2248	1964

considerably less cooling than do low-rise apartments. These anomalies may be due to data deficiencies which have not been investigated further, since resolution of them would not affect the overall screening results.

Table III-27 shows the K_e factors computed for PV applications, with the subscript "e" distinguishing them from those previously presented for collectors producing both electrical and thermal energy. In the absence of thermal energy production, the K_e factor is invariant for all applications within a given price region and thus cannot be used as a ranking criterion. Ranking was instead performed by using the product of the energy demand per region and the regional K_e factor. The larger this product, the more interesting the application for PV application. Table III-27 also shows the values of this product for the two residential application classes for the heating and cooling seasons and for the total year. As in the instance of total electrical demand, single residences rank higher than do low-rise apartments.

Table III-27. Residential Building Sector, Ranking by All-Electric K_e Factors

Climatic Regions	K_e Factor in \$ 10^{-3}/ft^2/Day Heating	Cooling
Eastern/Great Lakes	.65	1.5
Midwest	.66	1.3
Southeast	.61	1.0
Southwest	.71	1.4
Mid Atlantic	.56	1.3
Far West	1.10	1.6
Northern Plain	.46	1.2
Central Humid	.48	1.1
Southern Plain	.82	1.6
Central Plain	.61	1.2
Pacific Northwest	.30	.83
South Florida	.73	1.0
U.S. Average	.64	1.25

K_e Factor × Energy Demand (U.S.)	Heating Season	Cooling Season	Total
Single	639	972	1611
Apartment	414	586	1000

3.2 COMMERCIAL AND INSTITUTIONAL BUILDING SECTOR

3.2.1 Quality of Data

Considerably less information is available from published sources concerning both the inventory and the energy consumption of commercial structures. The Bureau of the Census does not cover commercial building characteristics, except for floor area and volume of warehousing space. Trade associations can provide information on total square feet of usable floor area for some of these structures. However, the information needed most for marketing studies, that is, data which are sufficiently detailed on a geographic basis as well as by building type, can, at this time, only be purchased from private research firms and then only for new construction on a monthly or yearly basis. Total inventory-in-place cannot be obtained directly from any source. Even the purchased data are insufficient for solar energy application studies since measured energy consumption as a function of building type and geographic location is usually not available, nor is sufficient descriptive information available on building construction and design to permit calculation of the energy demand that is representative of the actual inventory in place. Another data item of importance to the assessment of solar applicability, that of the ratio of roof area to contained floor area, is not available, nor is information on surrounding areas such as parking lots which could be utilized for the installation of collectors.

The bibliography associated with this report chapter includes a number of regional energy consumption estimates based on assumed building characteristics, as well as a few summaries of measured energy consumption values for specific buildings in a few sample areas. Although a relatively complete and very informative study was recently performed by Jack Faucett Associates for the FEA (Ref. 31) covering energy consumption in the commercial sector, the data are presented for Census Divisions rather than for climatic regions, and are not segregated into building types of interest to this study. For example, office building consumption data are summed with data on the energy consumption of the businesses and trades which may utilize offices in the course of performing their business functions. As a consequence, building inventories and unit area energy consumption cannot be derived for the various structure categories. As mentioned, the actual number of buildings of various types in the commercial sector have never been enumerated, either as a total for the U.S. or for any geopolitical unit within the U.S. The Census of Commerce, in contrast to that of Housing and Population, does not concern itself with buildings or floor areas, except in the instance of warehousing. The few organizations which have reported estimates of commercial building inventory in the literature have used a variety of relatively complicated methods for arriving at estimates of building inventory. These methods generally involve analysis of annual construction reported either in the Commerce Departments Construction Reports, or the F. W. Dodge Construction Potential Reports issued by McGraw Hill Information Services Corporation. Data on numbers of various types of buildings and on floor area newly added each year over a period of several decades are available from these sources and can be related to parameters such as GNP, population, employment level in various business classifications, etc., to derive estimates of the unit floor area required to perform certain business functions. The levels of these business activities in a given year then lead to estimates of the total floor areas required to permit such activity levels, and thus to estimates of the total floor space inventory. The number of buildings required to contain the estimated floor area is then derived by averaging annual construction data over a period of time and from sample enumerations in a few cities which have been reported in the literature. In some instances, removals of buildings are estimated as well. The potential for error in these methodologies is evident.

Table III-28 contains some of the commercial floor area estimates found in the literature. Ref. 18 provides only a count of buildings in the indicated categories, together with building designs developed as typical for each class, but only for the purpose of determining heating and cooling

Table III-28. Comparison of Commercial/Institutional Building Inventories

Floor Space in $ft^2 \times 10^{-6}$

	A. D. Little (Ref. 13) 1970	Rand (Ref. 33) 1971	GE (Ref. 18) 1970	ITC (Ref. 23) 1975
Offices	3,380	4,250	14,277	4,382
Retail	4,210	4,570	23,035	5,647
Schools	5,040	6,020	8,238	5,856
Hospitals	1,500	1,660	2,176	1,787
Others	7,480	7,320	33,311	8,845
Total U.S.	21,610	23,820	81,037	26,517

loads. The floor areas shown in the table are the product of the number of buildings and of this typical floor area. The rather large discrepancy between the values shown for General Electric (GE) and the other entries in this table are probably due to the attempt to represent each building type by a single standard building which apparently deviates importantly from the actual average for that class. The entries for InterTechnology Corporation (ITC) tend to fall in line with those of Ref. 13 because the latter was used as a source of baseline data, and was adjusted only for a different disaggregation of building types, and, of course, growth in the inventory between 1970 and 1975.

Where more detailed enumeration data are available in the literature to compare against the estimates provided by various studies, other discrepancies become apparent. Table III-29 compares selected data items from a shopping center census prepared for the trade (Ref. 34) to the

Table III-29. Comparison of Data on Shopping Centers

Year	No. of Centers	Gross Leasable Area in Billion ft^2	Average Size in 1000 ft^2	Annual Compound Growth Rate, in Area, %
1964	7,600 (1)	1.010 (1)	133 (1)	
1970	23,896 (3)	n. e.	750 (3)	['70-'90 = 1.0 (3)**] '64-'72 = 6.3 (1)
1972	13,174 (1)	1.650 (1)	125 (1)	'72-'74 = 6.6 (1)
1974	15,074 (1)	1.874 (1)	124 (1)	
1975	13,000 (2)	0.847 (2)	63* (2)	['75-'90 = 5.7 (2)] '74-'76 = 11.7 (1)
1976	17,523 (1)	2.338 (1)	133 (1)	

* Used for model to derive heating and cooling loads

** Growth in no. of buildings. Area growth not given

(1): Shopping Center World, (Ref. 34)

(2): ITC, (Ref. 23)

(3): GE, (Ref. 18)

[ ] = Projections

n. e. = Not Estimated

estimates of GE (Ref. 18) and ITC (Ref. 23). The respective definition of shopping centers may vary between the sources to account for some of the differences. For example, the data from GE on this table are said to apply to retail malls which may or may not coincide exactly in definition, and thus coverage, with shopping centers. Should definitions be reasonably close, then the individual building loads and the regional energy demands calculated from these data would exhibit unacceptably large deviations.

When energy consumption data are to be derived from building inventories, other errors are possible since measured data are usually not available to cover the large variety of buildings. Previous studies have thus postulated standard building designs with assumed values for those heat transfer and other design parameters which help to define energy demand. Table III-30 shows as an example a comparison between three data sources which have assumed widely differing building sizes as characteristic of the indicated building classes. In addition, assumptions for heat transfer coefficients for walls, roofs, windows, and floors can and do vary between studies as do such parameters as ventilation rates and infiltration rates. As a consequence, as shown by Table III-31, energy consumption estimates for the commercial sector can vary considerably by source. Although different base years were used by the studies referenced on this table, the differences cannot be accounted for by the annual rate of growth of energy consumption, which has been held to between 2 and 3% over the years covered by these studies. Two values are shown for the ITC entry reflecting the assumption of either conventional vapor compression refrigeration or of solar powered absorption chilling to be used for space cooling. The value for the latter results from Aerospace analysis utilizing ITC baseline data.

The existing data base causes other problems with respect to geographic disaggregation. New construction data are normally made available for census regions and divisions, or by state, but not by a climatic regionalization scheme. Only two studies were found which attempted to provide building inventory by climatic region and which forecast growth in inventory in the same format. GE (Ref. 18) shows such

Table III-30. Comparison of Model Buildings Used for Energy Consumption Calculations Size in ft^2, Height in Number of Floors

	A. D. Little (Ref. 13)		ITC (Ref. 23)		GE (Ref. 18)	
	Size	Height	Size	Height	Size	Height
Offices						
Low Rise	40,000	3	12,000	3	20,000	2
High Rise	-	-	32,000	8	600,000	30
Retail Malls	67,000	1	65,000	1	750,000	1
Schools	40,000	1	25,000	1	52,000	1
Hospitals	60,000	4	13,600	5	20,000	4

Table III-31. Comparison of Energy Consumption Derived for the Commercial Sector by Various Sources

Source	Consumption Year	Energy Consumption in Quads
A. D. Little (Ref. 13)	1970	3.38
Ultra Systems (Ref. 35)	1972	7.10
Jack Faucett (Ref. 32)	1974	5.46
ITC* (Ref. 23)	1975	3.72 (Absorption Cooling) 3.16 (Vapor Compression Cooling)

*ITC provided only heating and cooling loads. Other loads added by Aerospace Corp. Includes all but 7.7% of commercial floor space as defined by ITC. Absorption cooling energy demand by Aerospace based on ITC cooling load estimate and absorption chiller COP of 0.7 and vapor compression COP of 3.

inventory in terms of numbers of buildings and provides both inventory-in-place as well as new-construction-added to the year 2000. It does this for the same climatic regionalization scheme already described in the report section covering residential housing (3.1). ITC (Ref. 23) provides inventory data both in terms of buildings and floor area out to 1990 but does not show new construction put in place. It adapts the same climatic regionalization scheme initially developed by GE (Ref. 18), also using BEA areas as the basic geoeconomic unit.

3.2.2 Baseline Data and Sources

The bibliography associated with this report section shows all of the sources reviewed. As mentioned earlier, only two sources were found which provided the space heating and cooling loads for the desired building types in the climatic regionalization desired for the screening analysis. As indicated previously for the residential building market, the 12 climatic regions used by both of these sources, GE (Ref. 18) and ITC (Ref. 23) are individually too large in area since they contain subregions whose climates vary considerably from that of the reference city whose climatological parameters were used for the determination of heating and cooling loads. However, better data could not be found in the existing literature.

Although G.E. (Ref. 18) provided forecasts of new construction put-in-place between 1970 and 2000, data which would be useful for market studies, the building models used for load calculations appear to deviate considerably from what may represent the actual average for each of the building classes included in the study, as already discussed in connection with Table III-30. It was also learned that G.E. is currently, under a DOE contract, revising its commercial building inventory. It was believed desirable, therefore, to base the screening analysis on the data of Ref. 23. Table III-32 shows all of the building size assumptions listed by that reference. Table III-33 lists the daily operating hours assumed for each building category and used in the determination of building loads. As already pointed out for shopping centers, these average sizes may not be representative of the true average or even of typical building size.

Table III-32. Average Building Size for Various Building Categories*

Building Type	Average Size (ft^2)
1. Restaurants	1,410
2. Stores, Service stations	4,400
3. Supermarkets	12,500
4. Churches	8,040
5. Offices	11,970
6. Schools	24,720
7. Hospitals	136,000
8. Shopping Centers	63,200
9. Motels	21,850
10. Warehouses	11,100
11. Libraries, Museums	16,300
12. Hotels	40,850
13. Nursing Homes	17,500
14. Social	11,100

*Ref. 23

Table III-33. Operating Hours for Various Commercial/ Institutional Classes of Buildings*

Classification	Average Operating Hours Per Day	Average Operating Hours Per Year
School	11	2500
Office	11	3500
Store	13	4000
Shopping Center	13	4000
Hospital	16	5840
Church	6	940
Restaurant	7	2500
Motel	16	5840
Warehouse	16	4540
Supermarket	13	4000
Nursing Home	16	5850
Social	6	940
Library	11	3400
Hotel	16	5840

*Ref. 23

However, these data were used as the best available data since study resources did not permit the primary research required to improve upon the data base.

3.2.3 Derivation of Specific Data Required for Screening

3.2.3.1 Thermal-to-Electric Ratios

In a manner similar to the method used for residential housing, heating and cooling loads as calculated by ITC (Ref. 23) were combined with hot water loads from G.E.(Ref. 18) and baseload electric demand from A. D. Little (Ref. 13). Cooling loads were assumed to be met either by conventional vapor compression refrigeration systems with a COP of 3, or by absorption chilling systems with a COP of 0.7. Using these data, total electric and thermal demand per unit floor area were calculated for each of the application classes, i.e., building types. The total energy demand per climatic region was based on the total floor areas in the regional inventories. These data also permitted the calculation of the thermal-to-electric ratios for each applications class for both cooling and heating seasons. Table III-34 shows these ratios for the two seasons and for both types of space cooling systems. As in the instance of residential housing, it is apparent that the cooling season demand offers promise for total energy systems only if absorption cooling is used. In contrast to the data shown previously for residential housing, concentrator systems do not appear desirable for many of the building categories even in the heating season because the thermal-to-electric ratios fall below 3. Also reversing the conclusions for residential applications, concentrator systems could be used for many building categories in the cooling season, if absorption cooling were to be employed. Flat plate collectors could be used for all of the building types in the total energy mode. In the case of restaurants, however, purely thermal panels would far exceed in area those producing both electric and thermal energy, and the installation would therefore not really constitute a total energy system.

Table III-34. Thermal/Electric Ratios - Commercial and Institutional - By Season and By Cooling System

	Eastern/Gt. Lakes (Boston)			Mid Atlantic (Washington D. C.)			South East (Charleston)			South Florida (Miami)			South West (Phoenix)			Northern Plain (Bismarck)			Midwest (Madison)		
	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.
Commercial																					
Offices	2.1	4.7	0.04	2.2	4.5	0.05	0.9	5.3	0.04	0.3	5.0	0.04	1.2	5.4	0.04	3.2	3.9	0.05	3.2	3.0	.05
Stores	3.8	7.3	0.02	3.7	7.0	0.02	1.9	8.4	0.01	1.4	8.0	0.02	2.3	8.6	0.01	5.5	6.0	0.02	5.4	4.7	.02
Shopping Centers	1.2	5.2	0.02	1.4	4.4	0.02	0.2	5.3	0.02	<0.1	4.7	0.02	4.8	4.5	0.02	2.0	3.8	0.02	2.0	3.1	.03
Restaurant*	13/11	23.0	0.06	12/10	16.4	0.08	6.6/5.5	22.3	0.06	4.5/3.6	17.5	0.07	8/6.7	15.5	0.08	17/15	12.1	0.10	17/15	8.7	.12
Motels	2.5	6.5	0.15	2.5	6.2	0.16	1.4	7.2	0.14	0.9	6.9	0.15	1.6	7.3	0.14	3.6	5.6	0.16	3.5	4.9	.18
Warehouses	1.3	2.3	0.03	1.4	2.1	0.03	0.5	2.7	0.02	<0.1	2.5	0.03	0.7	2.7	0.02	2.1	1.8	0.03	2.1	1.3	.03
Supermarkets*	2.7/1.6	6.7	0.02	2.8/1.7	3.2	0.03	1.4/0.5	7.3	0.02	0.8/0.4	6.6	0.02	1.6/0.75	6.7	0.02	3.8/2.6	5.4	0.02	3.8/2.5	4.7	.02
Hotels	2.0	4.5	0.19	2.0	4.1	0.20	1.1	4.8	0.18	0.6	4.3	0.19	1.3	4.4	0.19	2.8	3.6	0.21	2.8	3.0	.23
Institutional																					
Schools	1.9	3.7	0.08	1.9	3.1	0.06	0.8	3.8	0.06	0.03	3.4	0.06	1.0	3.4	0.06	2.8	2.6	0.07	2.7	2.2	0.07
Hospitals	1.1	3.5	0.09	1.1	2.8	0.10	0.6	3.3	0.09	0.4	2.9	0.10	0.7	2.6	0.10	1.5	2.5	0.10	1.5	2.2	0.10
Churches	1.6	2.8	0.03	1.5	1.9	0.03	0.8	2.6	0.03	0.5	2.0	0.03	1.0	1.6	0.03	2.2	1.3	0.03	2.2	1.0	0.04
Nursing Homes	0.9	2.3	0.09	0.9	2.2	0.09	0.5	2.5	0.08	0.3	2.4	0.08	0.6	2.6	0.08	1.3	2.0	0.09	1.2	1.7	0.09
Social	1.6	2.8	0.03	1.5	1.9	0.03	0.8	2.6	0.03	0.5	2.0	0.03	1.0	1.6	0.03	2.2	1.3	0.03	2.2	1.0	0.04
Libraries/ Museums	1.8	4.9	0.02	1.8	4.4	0.03	0.8	5.4	0.02	0.3	4.6	0.03	0.9	4.4	0.03	2.6	3.7	0.03	2.6	3.1	0.03
Days in Season	270	90		210	150		180	180		30	330		180	180		300	60		240	90	

H = Heating Season, CA = Cooling Season With Absorption Cooling, CV= Cooling Season With Vapor Compression Cooling

(Based Refs. 13 and 23) *Absorpt. Refrig./V.C. Refrigeration

Table III-34. Thermal/Electric Ratios - Commercial and Institutional - By Season and By Cooling System (continued)

	Far West (Los Angeles)			Central Humid (Nashville)			Southern Plain (Ft. Worth)			Central Plain (Omaha)			Pacific North West (Seattle)		
	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.	H	C.A.	C.V.
Commercial															
Offices	1.0	3.8	0.05	2.0	4.6	0.04	1.4	5.3	0.04	2.7	3.9	0.05	1.6	2.7	0.06
Stores	2.0	6.0	0.02	3.4	7.1	0.01	2.6	8.3	0.02	4.8	6.3	0.02	3.1	4.0	0.02
Shopping Centers	2.0	3.7	0.02	1.2	4.7	0.02	0.6	5.0	0.02	1.7	3.8	0.02	0.8	2.9	0.03
Restaurants*	7.2/6	10.1	0.11	11.4/9.7	17.5	0.07	8/7	19.7	0.07	15/13	12.2	0.10	10.3/9	7.6	0.13
Motels	1.5	5.7	0.24	2.4	6.5	0.15	1.8	7.1	0.14	3.1	6.0	0.16	2.1	4.5	0.19
Warehouses	0.5	1.8	0.03	1.3	2.2	0.03	0.8	2.6	0.02	1.8	1.9	0.03	1.0	1.4	0.03
Supermarkets*	1.5/0.6	5.4	0.02	2.7/1.6	6.4	0.02	1.8/.9	6.9	0.02	3.4/2.2	5.6	0.02	2.2/1.2	4.3	0.02
Hotels	1.1	3.5	0.21	1.9	4.2	0.19	1.4	4.6	0.19	2.5	3.6	0.21	0.9	5.8	0.16
Institutional															
Schools	0.9	2.6	0.07	1.7	3.3	0.06	1.2	3.6	0.06	2.4	2.7	0.07	1.4	1.9	0.07
Hospitals	0.6	2.3	0.10	1.0	3.0	0.09	0.8	3.0	0.09	1.3	2.4	0.10	0.9	2.1	0.11
Churches	0.9	1.2	0.04	1.4	2.2	0.03	1.2	2.3	0.03	2.0	1.3	0.03	1.3	0.8	0.04
Nursing Homes	0.5	2.0	0.09	0.8	2.3	0.09	0.6	2.5	0.08	1.1	2.1	0.09	0.7	1.6	0.10
Social	0.9	1.2	0.04	1.4	2.2	0.03	1.2	2.3	0.03	2.0	1.3	0.03	1.3	0.8	0.04
Libraries/ Museums	0.8	3.5	0.03	1.7	4.7	0.03	1.1	5.0	0.02	2.3	3.1	0.03	1.4	2.7	0.03
Days in Season	210	150		150	120		150	150		180	120		210	90	

H= Heating Season, C.A. = Cooling Season with Absorption Cooling, C.V. = Cooling Season with Vapor Compression Cooling

*Absorpt. Refrig/ V.C. Refrigeration

[redacted]

3.2.3.2 Market Size

The total energy consumption on a regional basis for this group of applications is shown on Table III-35. Table III-36 ranks the building types by total yearly consumption. It is to be noted, however, that regional inventories were obtained in Ref. 23 by distributing the national inventory on the basis of population of each region. This results in anomalies, such as the Washington, D.C., region being assigned Federal office space in the same per capita ratio as, for example, Bismarck, and higher educational institutions in the Boston area in the same ratio as for, say, Nashville. The data in Table III-36 are, therefore, subject to future correction.

3.2.3.3 Market Growth Rate

A somewhat different ranking is obtained when average annual growth rates are compared in Table III-37. Only retail stores and office buildings find themselves among the top five listings in both Tables III-36 and III-37. Shopping centers, which were tenth in rank in terms of total national energy consumption in 1975, appear to rival retail stores and supermarkets for second rank in terms of growth rate. In view of the data presented previously on Table III-29, shopping centers may actually rank much higher in energy consumption as well.

On the basis of these combined rankings, five building types have been selected for more detailed screening analysis. These are office buildings, retail stores, shopping centers, supermarkets, and schools. Market size and growth rate data specific to the 12 climatic regions are shown for these building classes on Tables III-38 through III-42. Because improvements in energy conservation over the next 10-15 years are not taken into account, the 1990 energy values shown on these tables are useful for internal comparison only. As stated earlier, although restaurants appear to have a favorable growth rate, their extremely high thermal-to-electric ratios would require a primarily solar thermal system to satisfy their energy demand, rather than a total energy system. This high thermal demand is caused by the high air change rates which kitchen facilities require.

Table III-35

COMMERCIAL AND INSTITUTIONAL BUILDINGS

TOTAL ENERGY CONSUMPTION BY REGION

	Total Yearly Energy Consumption in 1975 in 10^{12} Btu/yr
Eastern/Great Lakes	1005.2
Mid Atlantic	502.2
Midwest	468.7
South East	314.6
Central Humid	304.5
Northern Plain	259.8
Far West	249.8
Southern Plain	217.8
Central Plain	196.4
South Florida	91.6
South West	67.0
Pacific North West	46.1
TOTAL	3723

Note: Assumes Absorption Chillers for Refrigeration and Air Conditioning

Table III-36

COMMERCIAL AND INSTITUTIONAL BUILDINGS
TOTAL ENERGY CONSUMPTION BY BUILDING CLASS

	Total Yearly Energy Consumption in 1975 in 10^{12} Btu/yr
Office Buildings	686
Schools	683
Miscellaneous Retail Stores	631
Warehouses	362
Hospitals	292
Restaurants	254
Nursing Homes	170
Social and Recreational Buildings	160
Churches	115
Shopping Centers	100
Motels	98
Supermarkets	70
Hotels	69
Libraries, Museums	33
Total	3723

Table III-37

Commercial & Institutional Buildings
Average Annual Growth Rate Between 1975-1990

Building	Inventory, 10^6 ft^2 1975	1990	Average Annual Growth Rate %
Restaurants	443	1,021	5.8
Stores	2,805	6,460	5.7
Supermarkets	309	711	5.7
Shopping Centers	847	1,938	5.7
Offices	4,354	9,161	5.1
Hospitals	1,078	1,713	3.2
Nursing Homes	698	1,109	3.2
Schools	5,122	7,518	2.6
Libraries & Museums	291	427	2.6
Warehouses	3,208	4,489	2.3
Churches	792	1,107	2.3
Social & Recreational	1,099	1,537	2.3
Hotels	527	738	2.3
Motels	615	861	2.3

Table III-38. Data Base: Market Growth - Office Building Absorption Cooling

Region	10^6 ft^2 Floor Area 1975	10^6 ft^2 Floor Area 1990	10^{12} BTU Energy Demand 1975	10^{12} BTU Energy Demand 1990	Average Annual Growth
Eastern Great Lakes	1280	2650	182	377	5.0
Midwest	447	934	85	178	5.1
Southeast	374	785	59	124	5.1
Southwest	83	188	13	29	5.5
Mid-Atlantic	571	1142	94	188	4.7
Far West	434	1024	46	109	5.9
Northern Plain	233	492	47	99	5.1
Central Humid	363	726	57	114	4.7
Southern Plain	220	471	41	88	5.2
Central Plain	200	408	36	73	4.8
Pacific Northwest	66	146	8	18	5.6
South Florida	85	198	18	42	5.8
U.S. Total	4354	9164	686	1439	5.1

Table III-39. Data Base: Market Growth - Stores
Absorption Cooling

Region	10^6 ft^2 Floor Area 1975	10^6 ft^2 Floor Area 1990	10^{12} BTU Energy Demand 1975	10^{12} BTU Energy Demand 1990	Average Annual Growth %
Eastern Great Lakes	825	1873	168	381	5.6
Midwest	288	657	82	187	5.6
Southeast	241	554	53	122	5.7
Southwest	53	131	12	30	6.3
Mid-Atlantic	367	807	84	185	5.4
Far West	279	720	40	103	6.5
Northern Plain	150	347	46	106	5.7
Central Humid	234	513	50	110	5.4
Southern Plain	142	332	38	89	5.8
Central Plain	129	288	34	76	5.5
Pacific Northwest	42	102	8	19	5.9
South Florida	55	140	17	43	6.4
U.S. Total	2805	6464	632	1451	5.7

Table III-40. Data Base: Market Growth - Shopping Center Absorption Cooling

Region	10^6 ft^2 Floor Area 1975	10^6 ft^2 Floor Area 1990	10^{12} BTU Energy Demand 1975	10^{12} BTU Energy Demand 1990	Average Annual Growth %
Eastern Great Lakes	248	563	24	54	5.6
Midwest	86	196	12	27	5.6
Southeast	72	166	10	23	5.7
Southwest	16	40	2	5	6.3
Mid-Atlantic	110	241	15	33	5.4
Far West	84	217	6	15	6.3
Northern Plain	45	104	7	16	5.7
Central Humid	70	153	9	20	5.5
Southern Plain	42	99	7	16	5.7
Central Plain	39	87	5	11	5.4
Pacific Northwest	13	32	1	2	4.7
South Florida	16	41	3	8	6.8
U.S. Total	842	1939	100	230	5.7

Table III-41. Data Base: Market Growth - Supermarkets Absorption Cooling

Region	10^6 ft^2 Floor Area 1975	10^6 ft^2 Floor Area 1990	10^{12} BTU Energy Demand 1975	10^{12} BTU Energy Demand 1990	Average Annual Growth %
Eastern Great Lakes	91	207	17	39	5.7
Midwest	32	73	8	18	5.6
Southeast	27	62	6	14	5.8
Southwest	6	15	1	3	7.6
Mid-Atlantic	41	90	10	22	5.4
Far West	31	80	5	13	6.6
Northern Plain	17	39	5	12	6.0
Central Humid	26	57	6	13	5.3
Southern Plain	16	37	4	9	5.6
Central Plain	14	31	4	9	5.6
Pacific Northwest	5	12	1	2	4.7
South Florida	6	13	2	5	6.3
U.S. Total	312	716	70	159	5.6

Table III-42. Data Base: Market Growth - Schools
Absorption Cooling

Region	10^6 ft^2 Floor Area 1975	10^6 ft^2 Floor Area 1990	10^{12} BTU Energy Demand 1975	10^{12} BTU Energy Demand 1990	Average Annual Growth %
Eastern Great Lakes	1506	2169	186	268	2.5
Midwest	525	767	89	130	2.6
Southeast	440	647	55	81	2.6
Southwest	97	153	12	18	2.7
Mid-Atlantic	672	940	92	129	2.3
Far West	510	841	43	71	3.4
Northern Plain	274	403	50	73	2.6
Central Humid	427	594	56	77	2.1
Southern Plain	260	387	39	58	2.7
Central Plain	235	333	37	52	2.3
Pacific Northwest	77	120	8	13	3.3
South Florida	99	162	16	26	3.3
U.S. Total	5122	7516	683	996	2.5

Although schools do not rank high in growth rate, this building class was included because their daily load profiles are favorable. They are also more likely to comprise one-story structures than, for example, office buildings, and they would, in most parts of the country, have considerable open land area around them.

3.2.3.4 Energy Density

Energy densities have been calculated for five structure types and are shown on Tables III-43 through III-47. As indicated by the energy densities of shopping centers, office buildings, schools, supermarkets and retail stores, none of these buiding types allow all of the energy demand to be met by solar energy from roof-mounted collectors only. Of the five building types, considering the energy density criterion alone, the shopping center appears most suitable for total energy systems, particularly in the heating season. The energy density ratios for these five building types have been calculated as described for residential buildings and are shown in Tables III-48 through III-52. Shopping centers and office buildings appear to have the most favorable ratios in the sense of ability of roof-mounted PTES to supply most of the energy demand of their building types for, at least, one-story structures. None of them, however, can meet their energy requirements without utility service backup for either or both thermal and electric loads. In all of the building types examined, the cooling season appears to exhibit the lowest ratios, i.e., would require the greatest amount of utility backup, particularly with respect to electrical demand. This conclusion contrasts sharply with that stated for residential buildings where the heating season energy density ratios were lowest.

In order to obtain an indication of the effect of using concentrating (tracking) collectors, the energy density ratios were recalculated on the basis of the assumption that the available energy produced is proportional to direct normal insolation. These ratios, presented as Tables III-53 through III-57, show that the use of concentrating collectors would not alter the conclusions mentioned above, although the amount of required backup would be reduced. None of these

Table III-43. Data Base: Energy Density Match Office Buildings

Region	Average Insolation		Energy in BTU/FT² - Day									
			Heating Season (H. S.)				Cooling Season (C. S.)					
			Demand		Avail. Energy		Demand, V. C.		Demand, Absorption		Avail. Energy	
	H. S.	C. S.	Therm.	Elec.	Thorm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.
Eastern/Gr. Lakes (Boston)	739	1684	309*	145*	222	44	13	300*	679*	145*	505	101
Midwest (Madison)	923	1865	458*	145*	277	55	13	245*	440	145*	560	112
South East (Charleston)	945	1611	135	145*	284	57	13	323*	759*	145*	483	97
Southwest (Phoenix)	1256	2442	168	145*	377	75	13	327*	792*	145	733	147
Mid Atlantic (Wash. DC)	730	1662	318*	145*	219	44	13	294*	660*	145*	499	100
Far West (L. A.)	1404	2033	142	145*	421	84	13	273*	561	145*	610	122
Northern Plain (Bismarck)	806	2040	463*	145*	242	48	13	273*	561	145*	612	122
Central Humid (Nashville)	752	1745	294*	145*	226	45	13	289*	671*	145*	524	105
Southern Plain (Fort Worth)	996	1964	197	145*	299	60	13	321*	770*	145*	589	118
Central Plain (Omaha)	910	1862	389*	145*	273	55	13	275*	572*	145*	559	112
Pac. North-west (Seattle)	704	1945	240*	145*	211	42	13	217*	396	145*	584	117
South Florida (Miami)	1129	1586	46	145*	339	68	13	312*	726*	145*	476	95

* = Indicates Inadequate Available Energy to Meet Demand on Basis of 1 ft² of Roof Area to 1 ft² of Consuming Area. Assumes Flat Roof.

Notes: Available Thermal Energy is Assumed at 50% of Insolation, with Collector Packing Fraction of 0.6

Available Electrical Energy is Assumed at 10% of Insolation, with Collector Packing Fraction of 0.6

V. C. = Vapor Compression Cooling System, COP of 3

Absorpt. = Absorption Cooling System, COP of 0.7

Average Insolation is Daily Total Horizontal Insolation Averaged Over the Months in Season

Table III-44. Data Base: Energy Density Match Stores, Misc. Retail

Region	Average Insolation		Energy in BTU/FT^2 - Day									
			Heating Season (H.S.)				Cooling Season (C.S.)					
			Demand		Avail. Energy		Demand, V.C.		Demand, Absorption		Avail. Energy	
	H.S.	C.S.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.
Eastern/Gr. Lakes (Boston)	739	1684	573*	151*	222	44	6.5	406*	1105*	151*	505	101
Midwest (Madison)	923	1865	822*	151*	277	55	6.5	313*	702*	151*	560	112
South East (Charleston)	945	1611	286*	151*	284	57	6.5	443*	1261*	151*	483	97
Southwest (Phoenix)	1256	2442	339	151*	377	75	6.5	451*	1287*	151*	733	147
Mid Atlantic (Wash. DC)	730	1662	564*	151*	219	44	6.5	397*	1066*	151*	499	100
Far West (L.A.)	1404	2033	298	151*	421	84	6.5	322*	910*	151*	610	122
Northern Plain (Bismarck)	806	2040	151	151*	242	48	6.5	361*	910*	151*	612	122
Central Humid (Nashville)	752	1745	829*	151*	226	45	6.5	399*	1079*	151*	524	105
Southern Plain (Fort Worth)	996	1964	517*	151*	299	60	6.5	439*	1248*	151*	589	118
Central Plain (Omaha)	910	1862	385*	151*	273	55	6.5	369*	949*	151*	559	112
Pac. Northwest (Seattle)	704	1945	723*	151*	211	42	6.5	290*	598*	151*	584	117
South Florida (Miami)	1129	1586	460*	151*	339	68	6.5	429*	1196*	151*	476	95

* = Indicates Inadequate Available Energy to Meet Demand on Basis of 1 ft^2 of Roof Area to 1 ft^2 of Consuming Area. Assumes Flat Roof.

Notes:
Available Thermal Energy is Assumed at 50% of Insolation, with Collector Packing Fraction of 0.6
Available Electrical Energy is Assumed at 10% of Insolation, with Collector Packing Fraction of 0.6
V.C. = Vapor Compression Cooling System, COP of 3
Absorpt. = Absorption Cooling System, COP of 0.7
Average Insolation is Daily Total Horizontal Insolation Averaged Over the Months in Season

Table III-45. Data Base: Energy Density Match Shopping Centers

Region	Average Insolation		Energy in BTU/FT² - Day									
			Heating Season (H. S.)				Cooling Season (C. S.)					
			Demand		Avail. Energy		Demand, V. C.		Demand, Absorption		Avail. Energy	
	H. S.	C. S.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.
Eastern/Gr. Lakes (Boston)	739	1684	177	151*	222	44	6.5	332*	780*	151*	505	101
Midwest (Madison)	923	1865	302*	151*	277	55	6.5	257*	468	151*	560	112
South East (Charleston)	945	1611	34	151*	284	57	6.5	335*	806*	151*	483	97
Southwest (Phoenix)	1256	2442	62	151*	377	75	6.5	308*	676	151*	733	147
Mid Atlantic (Wash. DC)	730	1662	207	151*	219	44	6.5	304*	663*	151*	499	100
Far West (L. A.)	1404	2033	40	151*	421	84	6.5	361*	559	151*	610	122
Northern Plain (Bismarck)	806	2040	307*	151*	242	48	6.5	285*	585	151*	612	122
Central Humid (Nashville)	752	1745	187	151*	226	45	6.5	313*	702*	151*	524	105
Southern Plain (Fort Worth)	996	1964	85	151*	299	60	6.5	325*	754*	151*	589	118
Central Plain (Omaha)	910	1862	252	151*	273	55	6.5	283*	572*	151*	559	112
Pac. North-west (Seattle)	704	1945	124	151*	211	42	6.5	251*	442	151*	584	117
South Florida (Miami)	1129	1586	6.5	151*	339	68	6.5	313*	702*	151*	476	95

* = Indicates Inadequate Available Energy to Meet Demand on Basis of 1 ft² of Roof Area to 1 ft² of Consuming Area. Assumes Flat Roof.

Notes: Available Thermal Energy is Assumed at 50% of Insolation, with Collector Packing Fraction of 0.6
Available Electrical Energy is Assumed at 10% of Insolation, with Collector Packing Fraction of 0.6
V. C. = Vapor Compression Cooling System, COP of 3
Absorpt. = Absorption Cooling System, COP of 0.7
Average Insolation is Daily Total Horizontal Insolation Averaged Over the Months in Season

Table III-46. Data Base: Energy Density Match Supermarkets

Region	Average Insolation		Energy in BTU/FT² - Day									
			Heating Season (H.S.)				Cooling Season (C.S.)					
			Demand		Avail. Energy		Demand, V.C.		Demand, Absorption		Avail. Energy	
	H.S.	C.S.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.
Eastern/Gr. Lakes(Boston)	739	1684	286*	178(1)	222	44	6.5	385*	1014*	151*	505	101
Midwest (Madison)	923	1865	455*	178*	277	55	6.5	315*	715*	151*	560	112
South East (Charleston)	945	1611	95	178*	284	57	6.5	400*	1079*	151*	483	97
Southwest (Phoenix)	1256	2442	134	178*	377	75	6.5	385*	1014*	151*	733	147
Mid Atlantic (Wash. DC)	730	1662	312*	178*	219	44	6.5	260*	481	151*	499	100
Far West (L.A.)	1404	2033	107	178*	421	84	6.5	187*	819*	151*	610	122
Northern Plain (Bismarck)	806	2040	463*	178*	242	48	6.5	339*	819*	151*	612	122
Central Humid (Nashville)	752	1745	286*	178*	226	45	6.5	373*	962*	151*	524	105
Southern Plain (Fort Worth)	996	1964	163	178*	299	60	6.5	390*	1040*	151*	589	118
Central Plain (Omaha)	910	1862	390*	178*	273	55	6.5	347*	845*	151*	559	112
Pac. North-west (Seattle)	704	1945	217*	178*	211	42	6.5	300*	650*	151*	584	117
South Florida (Miami)	1129	1586	65	178*	339	68	6.5	381*	988*	151*	476	95

* = Indicates Inadequate Available Energy to Meet Demand on Basis of 1 ft² of Roof Area to 1 ft² of Consuming Area. Assumes Flat Roof.

Notes:
Available Thermal Energy is Assumed at 50% of Insolation, with Collector Packing Fraction of 0.6
Available Electrical Energy is Assumed at 10% of Insolation, with Collector Packing Fraction of 0.6
V.C. = Vapor Compression Cooling System, COP of 3
Absorpt. = Absorption Cooling System, COP of 0.7
Average Insolation is Daily Total Horizontal Insolation Averaged Over the Months in Season

(1) Assumes that V.C. is used for refrigerators and freezers

Table III-47. Data Base: Energy Density Match Schools

Region	Average Insolation		Energy in BTU/FT² - Day									
			Heating Season (H.S.)				Cooling Season (C.S.)					
			Demand		Avail. Energy		Demand, V.C.		Demand, Absorption		Avail. Energy	
	H.S.	C.S.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.	Therm.	Elec.
Eastern/Gr. Lakes (Boston)	739	1684	315*	169*	222	44	17.6	233*	622*	169*	505	101
Midwest (Madison)	923	1865	451*	169*	277	55	17.6	251*	367	169*	560	112
South East (Charleston)	945	1611	140	169*	284	57	17.6	316*	645*	169*	483	97
Southwest (Phoenix)	1256	2442	174	169*	377	75	17.6	301*	581	169*	733	147
Mid Atlantic (Wash. DC)	730	1662	322*	169*	219	44	17.6	289*	532*	169*	499	100
Far West (L.A.)	1404	2033	146	169*	421	84	17.6	267*	435	169*	610	122
Northern Plain (Bismarck)	806	2040	468*	169*	242	48	17.6	270*	447	169*	612	122
Central Humid (Nashville)	752	1745	298*	169*	226	45	17.6	296*	561*	169*	524	105
Southern Plain (Fort Worth)	996	1964	197	169*	299	60	17.6	308*	613*	169*	589	118
Central Plain (Omaha)	910	1862	405*	169*	273	55	17.6	272*	459	169*	559	112
Pac. Northwest (Seattle)	704	1945	245*	169*	211	42	17.6	241*	328	169*	584	117
South Florida (Miami)	1129	1586	52	169*	339	68	17.6	299*	572*	169*	476	95

* = Indicates Inadequate Available Energy to Meet Demand on Basis of 1 ft² of Roof Area to 1 ft² of Consuming Area. Assumes Flat Roof.

Notes:
Available Thermal Energy is Assumed at 50% of Insolation, with Collector Packing Fraction of 0.6
Available Electrical Energy is Assumed at 10% of Insolation, with Collector Packing Fraction of 0.6
V.C. = Vapor Compression Cooling System, COP of 3
Absorpt. = Absorption Cooling System, COP of 0.7
Average Insolation is Daily Total Horizontal Insolation Averaged Over the Months in Season

Table III-48

Data Base: Energy Density Ratios

Office Buildings

Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on Total Horizontal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.72	.30	38.8	.34	.74	.70
Midwest	.60	.38	43.1	.46	1.27	.77
Southeast	2.10	.39	37.2	.30	.64	.67
Southwest	2.24	.52	56.4	.45	.93	1.01
Mid-Atlantic	.69	.30	38.4	.34	.76	.69
Far West	2.96	.58	46.9	.45	1.09	.84
Northern Plain	.52	.33	47.1	.45	1.09	.84
Central Humid	.77	.31	40.3	.35	.78	.72
Southern Plain	1.52	.41	45.3	.37	.76	.81
Central Plain	.70	.38	43.0	.41	.98	.77
Pacific Northwest	.88	.29	44.9	.54	1.47	.81
South Florida	7.37	.47	36.6	.30	.66	.66

V.C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story, and twice if sufficient for at least 2 stories.

Table III-49

Data Base: Energy Density Ratios

Miscellaneous Retail Stores

Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on Total Horizontal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.39	.29	77.7	.25	.46	.67
Midwest	.34	.36	86.2	.36	.80	.74
Southeast	.99	.38	74.3	.22	.38	.64
Southwest	1.11	.50	112.8	.33	.57	.97
Mid-Atlantic	.39	.29	76.8	.25	.47	.66
Far West	1.41	.56	93.8	.38	.67	.81
Northern Plain	1.60	.32	94.2	.34	.67	.81
Central Humid	.27	.30	80.6	.26	.49	.70
Southern Plain	.58	.40	90.6	.27	.47	.78
Central Plain	.71	.36	86.0	.30	.59	.74
Pacific Northwest	.29	.28	89.8	.40	.98	.77
South Florida	.74	.45	73.2	.22	.40	.63

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story, and twice if sufficient for at least 2 stories.

Table III-50

Data Base: Energy Density Ratios

Shopping Centers

Available Energy/Demand Based on Floor
Area Equal to Roof Area

Available Energy Based on Total Horizontal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	1.25	.29	77.7	.30	.65	.67
Midwest	.92	.36	86.2	.44	1.20	.74
Southeast	8.35	.38	74.3	.29	.60	.64
Southwest	6.08	.50	112.8	.48	1.08	.97
Mid-Atlantic	1.06	.29	76.8	.33	.75	.66
Far West	10.53	.56	93.8	.34	1.09	.81
Northern Plain	.79	.32	94.2	.43	1.05	.81
Central Humid	1.21	.30	80.6	.34	.75	.70
Southern Plain	3.52	.40	90.6	.36	.78	.78
Central Plain	1.08	.36	86.0	.40	.98	.74
Pacific Northwest	1.70	.28	89.8	.47	1.32	.77
South Florida	52.15	.45	73.2	.30	.68	.63

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story, and twice if sufficient for at least 2 stories.

Table III-51

Data Base: Energy Density Ratios

Supermarkets

Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on Total Horizontal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.78	.25	77.7	.26	.50	.67
Midwest	.61	.31	86.2	.36	.78	.74
Southeast	2.99	.32	74.3	.24	.45	.64
Southwest	2.81	.42	112.8	.38	.72	.97
Mid-Atlantic	.70	.25	76.8	.38	1.04	.66
Far West	3.93	.47	93.8	.65	.74	.81
Northern Plain	.52	.27	94.2	.36	.75	.81
Central Humid	.79	.25	80.6	.28	.54	.70
Southern Plain	1.83	.34	90.6	.30	.57	.78
Central Plain	.70	.31	86.0	.32	.66	.74
Pacific Northwest	.97	.24	89.8	.39	.90	.77
South Florida	5.22	.38	73.2	.25	.48	.63

V.C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story, and twice if sufficient for at least 2 stories.

Table III-52

Data Base: Energy Density Ratios

Schools

Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on Total Horizontal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.71	.26	28.7	.43	.81	.60
Midwest	.61	.33	31.8	.45	1.53	.66
Southeast	2.03	.34	27.4	.31	.75	.57
Southwest	2.17	.44	41.6	.49	1.26	.87
Mid-Atlantic	.68	.26	28.4	.35	.94	.59
Far West	2.88	.50	34.7	.46	1.40	.72
Northern Plain	.52	.28	34.8	.45	1.37	.72
Central Humid	.76	.27	29.8	.35	.93	.62
Southern Plain	1.52	.36	33.5	.38	.96	.70
Central Plain	.67	.33	31.8	.41	1.22	.66
Pacific Northwest	.86	.25	33.2	.49	1.78	.69
South Florida	6.52	.40	27.0	.32	.83	.56

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story, and twice if sufficient for at least 2 stories.

Table III-53

Data Base: Energy Density Ratios
Office Buildings

Available Energy/Demand Based on Floor
Area Equal to Roof Area

Available Energy Based on Direct Normal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	1.02	.42	38.8	.34	.74	.70
Midwest	.84	.53	47.4	.51	1.40	.85
Southeast	2.63	.49	37.2	.30	.64	.67
Southwest	2.80	.65	58.09	.46	.96	1.04
Mid-Atlantic	1.04	.45	43.01	.38	.85	.77
Far West	4.08	.80	54.40	.52	1.26	1.26
Northern Plain	.85	.54	61.23	.59	1.42	1.09
Central Humid	.95	.38	41.91	.36	.81	.75
Southern Plain	2.05	.55	52.10	.43	.87	.93
Central Plain	1.02	.55	50.31	.48	1.15	.90
Pacific Northwest	1.06	.35	52.53	.63	1.72	.95
South Florida	9.58	.61	47.58	.32	.69	.69

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story and twice if sufficient for at least two stories.

Table III-54

Data Base: Energy Density Ratios
Miscellaneous Retail Stores
Available Energy/Demand Based on Floor Area Equal to Roof Area
Available Energy Based on Direct Normal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	.55	.41	77.7	.25	.46	.67
Midwest	.48	.50	94.82	.40	.88	.81
Southeast	1.24	.48	74.3	.22	.38	.64
Southwest	1.39	.63	116.18	.34	.59	1.00
Mid-Atlantic	.59	.44	86.02	.28	.53	.74
Far West	1.95	.77	108.81	.44	.78	.94
Northern Plain	2.61	.52	122.46	.44	.87	1.05
Central Humid	.33	.37	83.82	.27	.51	.73
Southern Plain	.78	.54	104.19	.31	.54	.90
Central Plain	1.04	.53	100.62	.35	.69	.87
Pacific Northwest	.35	.34	105.07	.47	1.15	.90
South Florida	.96	.59	76.86	.23	.42	.66

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story and twice if sufficient for at least two stories.

Table III-55

Data Base: Energy Density Ratios
Shopping Centers
Available Energy/Demand Based on Floor Area Equal to Roof Area
Available Energy Based on Direct Normal Insolation

	Heating Season		Cooling Season			
			V. C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	1.76	.41	77.7	.30	.65	.67
Midwest	1.29	.50	94.82	.48	1.32	.81
Southeast	10.44	.48	74.3	.29	.60	.64
Southwest	7.60	.63	116.18	.49	1.11	1.00
Mid-Atlantic	1.60	.44	86.02	.37	.84	.74
Far West	14.53	.77	108.81	.39	1.26	.94
Northern Plain	1.29	.52	122.46	.56	1.37	1.05
Central Humid	1.50	.37	83.82	.35	.78	.73
Southern Plain	4.75	.54	104.19	.41	.90	.90
Central Plain	1.58	.53	100.62	.47	1.15	.87
Pacific Northwest	2.04	.34	105.07	.55	1.54	.90
South Florida	67.80	.59	76.86	.32	.71	.66

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story and twice if sufficient for at least two stories.

Table III-56

Data Base: Energy Density Ratios
Supermarkets

Available Energy/Demand Based on Floor
Area Equal to Roof Area

Available Energy Based on Direct Normal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	1.10	.35	77.1	.26	.50	.67
Midwest	.85	.43	94.82	.40	.86	.81
Southeast	3.74	.40	74.3	.24	.45	.64
Southwest	3.51	.53	116.18	.39	.74	1.00
Mid-Atlantic	1.06	.38	86.02	.43	1.16	.74
Far West	5.42	.63	108.81	.75	.86	.94
Northern Plain	.85	.44	122.46	.47	.98	1.05
Central Humid	.98	.31	83.82	.29	.56	.73
Southern Plain	2.47	.46	104.19	.35	.66	.90
Central Plain	1.02	.45	100.62	.37	.77	.87
Pacific Northwest	1.16	.29	105.07	.46	1.05	.90
South Florida	6.79	.49	76.86	.26	.50	.60

V. C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story and twice if sufficient for at least two stories.

Table III-57

Data Base: Energy Density Ratios

Schools

Available Energy/Demand Based on Floor Area Equal to Roof Area

Available Energy Based on Direct Normal Insolation

	Heating Season		Cooling Season			
			V.C.		Absorption	
	T	E	T	E	T	E
Eastern Gt. Lakes	1.00	.37	28.7	.43	.81	.60
Midwest	.85	.46	34.98	.50	1.68	.73
Southeast	2.54	.43	27.4	.31	.75	.57
Southwest	2.71	.55	42.85	.50	1.30	.90
Mid-Atlantic	1.03	.39	31.81	.39	1.05	.66
Far West	3.97	.69	40.25	.53	1.62	.84
Northern Plain	.85	.46	45.24	.59	1.78	.94
Central Humid	.94	.33	30.99	.36	.97	.64
Southern Plain	2.05	.49	38.53	.44	1.10	.81
Central Plain	.98	.48	37.21	.48	1.43	.77
Pacific Northwest	1.03	.30	38.84	.57	2.08	.81
South Florida	8.48	.52	31.59	.37	.97	.66

V.C. = Vapor Compression Cooling System

Absorption = Absorption Cooling System

T = Thermal Ratio

E = Electrical Ratio

Entries are underlined once if available energy is sufficient for at least one story and twice if sufficient for at least two stories.

commercial building types would therefore utilize photovoltaic total energy systems in a stand-alone mode, even with the use of tracking collectors, although the latter would increase the number of two-story structures whose thermal demands could be wholly satisfied by the PTES.

Shopping centers appear to be able to meet more of their thermal and electrical demand with a PTES than any of the other structures, particularly their thermal needs, with office buildings, schools, supermarkets, and miscellaneous retail stores, following in that order.

3.2.3.5 Market Location

As discussed for residential buildings in the previous report section, the information about distribution of commercial building types between core cities, suburban areas, and rural areas would be of interest but is not available. The data that can be found in the literature encompass too small a sample, and often a nonrepresentative sample, to be useful to this analysis. An example of such a nonrepresentative, yet often quoted, sample is the office building survey published periodically by the Building Owners and Managers Association International (BOMA) whose 1976 report, Ref. 36, provides energy consumption data for 371 office buildings belonging to the Association (out of a total of 1023 buildings). The report shows 301 downtown office buildings averaging about 400,000 ft^2 in floor area and 70 suburban office buildings averaging 180,000 ft^2 in floor area. The substantial difference between these floor areas and the average floor area assumed for office buildings by this study, about 12,000 ft^2, appears to be caused by the fact that only major office building projects tend to belong to this Association and that the majority of member buildings are located in core cities in the Northeastern and Middle Atlantic regions of the U.S.

There are also no data on the relative growth rates between central cities and suburban areas for the commercial and institutional building types of interest to this study, nor are there data on correlations from any statistically valid source between the number of stories of specific building types and their location. Some qualitative conclusions are probably feasible with respect to shopping centers, schools, retail stores, and supermarkets, since these tend to follow population trends. Since population growth is more rapid in suburban areas, the inference can be drawn that these structures will also exhibit higher growth rates in these areas.

As already discussed in the previous report section dealing with residential structures, location criteria also include the effect of the cost of conventional energy in the 12 different climatic regions of the country on the competitiveness of photovoltaic total energy systems. Values for the K factor described previously were calculated for the five building types discussed in this section. However, the costs of competing conventional energy for these buildings reflect utility commercial rate structures which, in most areas differ from those applied to residential structures. Table III-23 provides energy price forecasts for the year 1990 under both residential and commercial rate structure assumptions. The distribution of energy consumption by fuel type also differs for commercial consumers from that previously shown for residential consumers. Table III-58 shows the distribution used in calculating the thermal energy costs reflected in the price schedule of Table III-59. These data were used in the computation of K factors for heating and cooling seasons and for the five building types as shown on Tables III-60 and III-61. Inspection of these two tables reveals that the highest affordable collector prices, proportional to high K values, are associated with miscellaneous retail stores and with supermarkets in the heating season, and with office buildings and supermarkets in the cooling season.

3.2.3.6 Energy Demand Level

On the basis of average building sizes from Ref. 23 and the unit area demand levels calculated for this study, Table III-62 has been prepared showing average demand levels for both electric and thermal energy in heating and cooling seasons for the five building classes of greatest interest. Because of the variation in demand level between the 12 climatic zones considered by this study, ranges of values are given in a number of instances.

Table III-58. Commercial Energy Consumption in Fractions by Fuel Type in 1985 (FEA PIES Forecast)*

Climatic Regions	Electric	NG	Distillate Oil	Residual Oil	LG	Coal	Other*
Eastern Great Lakes	.250	.208	.250	.183	.005	.001	.103
Midwest	.252	.328	.132	.121	.010	.002	.155
Southeast	.445	.248	.078	.028	.011	.001	.189
Southwest	.316	.418	.079	.039	.006	.000	.142
Mid-Atlantic	.364	.229	.207	.057	.004	.006	.133
Far West	.391	.428	.031	.004	.001	.000	.145
Northern Plain	.241	.410	.126	.074	.010	.000	.139
Central Humid	.445	.248	.078	.028	.011	.001	.189
Southern Plain	.281	.357	.080	.086	.009	.000	.187
Central Plain	.239	.443	.102	.018	.029	.001	.168
Pacific Northwest	.365	.230	.200	.034	.001	.001	.169
South Florida	.445	.248	.078	.028	.011	.001	.189

Notes: NG = Natural Gas
LG - Liquefied Petroleum Gases
* Kerosene, Wood, Etc.

*Ref. 31

Table III-59. 1990 Prices of Energy to Commercial User (in 1977 Dollars) $/Million Btu

Climatic Regions	Electric	Thermal
Eastern/Great Lakes	14.9	3.7
Midwest	12.0	3.3
Southeast	10.7	3.2
Southwest	9.0	3.6
Mid Atlantic	12.4	4.5
Far West	12.6	3.0
Northern Plain	9.0	3.6
Central Humid	10.7	3.2
Southern Plain	13.4	3.4
Central Plain	11.4	3.6
Pacific Northwest	6.7	4.0
South Florida	10.7	3.2

Based on Ref. 30

Table III-60. K Factors — Commercial/Institutional Sector Heating Season (in $ \times 10^{-2}/ft^2/Day$)

Climatic Regions	Schools	Offices	Stores	Shopping Centers	Super Markets
Eastern/Great Lakes	.100	.104	.131	.089	.113
Midwest	.119	.128	.155	.106	.138
Southeast	.076	.078	.098	.064	.088
Southwest	.098	.104	.134	.204	.115
Mid Atlantic	.109	.104	.134	.088	.116
Far West	.132	.134	.158	.158	.146
Northern Plain	.110	.118	.145	.096	.128
Central Humid	.074	.078	.098	.067	.088
Southern Plain	.106	.111	.137	.093	.120
Central Plain	.108	.114	.156	.094	.128
Pacific Northwest	.052	.056	.080	.043	.065
South Florida	.071	.077	.101	.072	.088

Note: The area term in the K factor definition refers to roof area reduced to collector area by a 60% collector packing fraction

Table III-61. K Factors — Commercial/Institutional Sector Cooling Season (in $ \times 10^{-2}/ft^2/Day$)

Climatic Regions	Schools	Offices	Stores	Shopping Centers	Super Markets
Eastern/Great Lakes	.291	.329	.293	.334	.302
Midwest	.209	.238	.299	.242	.299
Southeast	.222	.254	.220	.254	.228
Southwest	.307	.380	.336	.364	.357
Mid Atlantic	.273	.337	.323	.332	.277
Far West	.254	.297	.313	.293	.328
Northern Plain	.224	.282	.312	.277	.322
Central Humid	.222	.266	.247	.270	.256
Southern Plain	.304	.351	.296	.360	.316
Central Plain	.228	.276	.295	.272	.307
Pacific Northwest	.167	.204	.264	.213	.278
South Florida	.209	.260	.223	.250	.236

Table III-62. Commercial and Institutional Building Sector, Daily Average Demand Level

Category	Heating Season		Cooling Season			
	Thermal	Electrical	Vapor Compression Cooling		Absorption Cooling	
			Thermal	Electrical	Thermal	Electrical
<u>Office Buildings</u>						
Floor Area ~12,000 ft^2						
$Btu/ft^2/day$	45-460	145	13	200-330	400-800	145
kWh/day	-	510	-	700-1,160	-	510
Btu/day, 10^3	540-5,520	-	156	-	4,800-9,600	-
<u>Misc. Retail Stores</u>						
Floor Area ~4400 ft^2						
$Btu/ft^2/day$	150-830	150	6.5	290-450	700-1,200	150
kWh/day	-	193	-	374-580	-	193
Btu/day, 10^3	660-3,652	-	29	-	3,080-5,280	-
<u>Shopping Centers</u>						
Floor Area ~63,000 ft^2						
$Btu/ft^2/day$	65-310	150	6.5	230-320	440-800	170
kWh/day	-	2,770	-	4,250-5,900	-	3,140
Btu/day, 10^3	410-19,500	-	410	-	27,700-50,400	
<u>Supermarkets</u>						
Floor Area ~12,500 ft^2						
$Btu/ft^2/day$	65-460	180	6.5	180-400	500-1,000	150
kWh/day	-	660	-	660-1,465	-	550
Btu/day, 10^3	810-5,750	-	80	-	6,250-12,500	-
<u>Schools</u>						
Floor Area ~25,000 ft^2						
$Btu/ft^2/day$	50-470	170	18	230-320	360-650	170
kWh/day	-	1,250	-	1,700-2,350	-	1,250
Btu/day, 10^3	1,250-11,750	-	450	-	9,000-16,250	-

3.2.3.7 Phase Relationships

Qualitative diurnal thermal and electric demand profiles for three of the five building types of interest are shown on Figures III-5 through III-7. Similar profiles for retail stores and supermarkets could not be located in the literature. It is assumed, however, that these types of stores would not differ too greatly from the demand profiles for shopping centers shown on Figure III-7. An electric demand profile for a Southern California supermarket reported in Ref. 1 indicates, however, that the nighttime electric demand is higher relative to a shopping center because of the proportionally higher food refrigeration load. As in the case of residential buildings, heating demand appears to lead availability of insolation energy and thus will have to be partially supplied from thermal storage filled the previous day. Air conditioning demand partially lags insolation and can therefore be met from the same day's storage. Electric baseload differs considerably in the case of shopping centers from that of offices and schools in that a sizable fraction of the electric demand lags insolation, in fact, peaks during evening hours.

Ref. 37 served as a source for these profiles. Although space heating and air conditioning demand occurs during different seasons, they have been plotted together to reduce the number of figures. The vertical scale is absent because no attempt was made to accurately size demand either on an absolute or a relative basis.

3.2.3.8 Reliability

The qualitative treatment of reliability for commercial and institutional building applications differs from that of residential buildings as a result of the likelihood that outages will involve financial loss and that hazards to life or health may be created. Financial loss may be due to loss of business if office personnel cannot function, or if stores, shopping centers, or supermarkets must close. In the instance of supermarkets, the loss due to refrigerator spoilage may be considerable, as might be the case for restaurants located in shopping centers. Hazard to health or life may come about through elevator stoppage or malfunction,

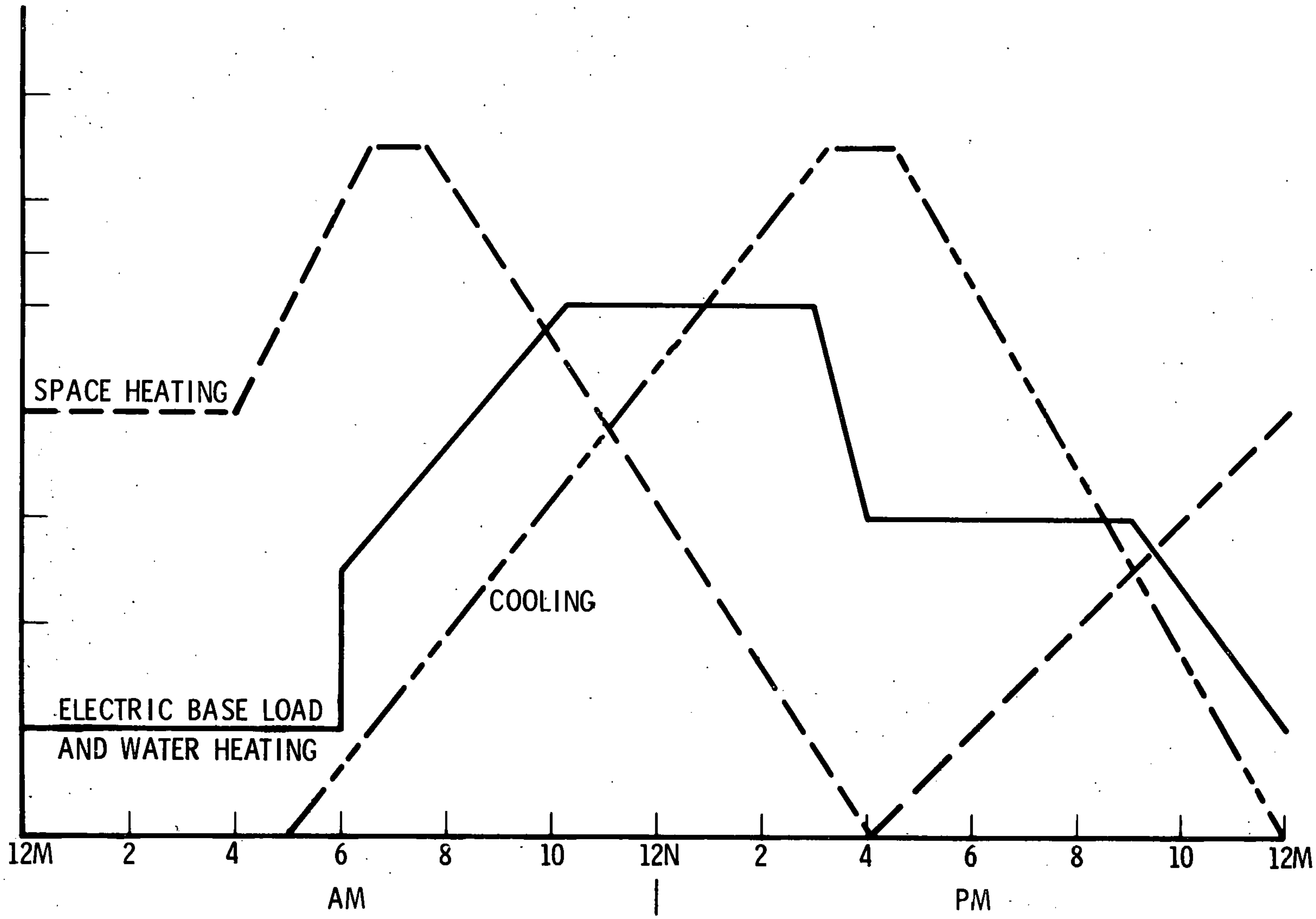


Figure III-5. Diurnal Demand of Elementary School (Ref. 37)

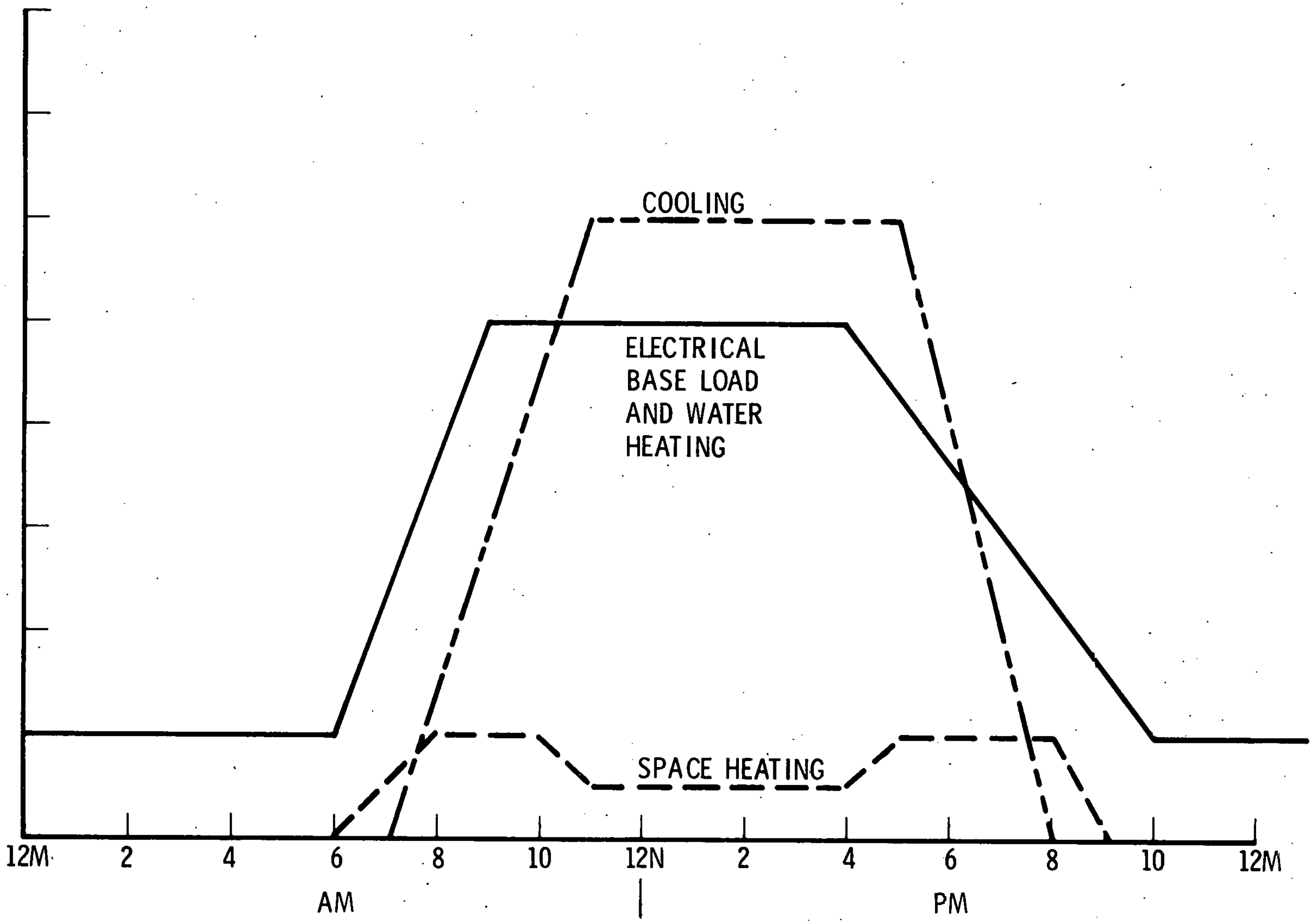


Figure III-6. Diurnal Demand of Office Building (Ref. 37)

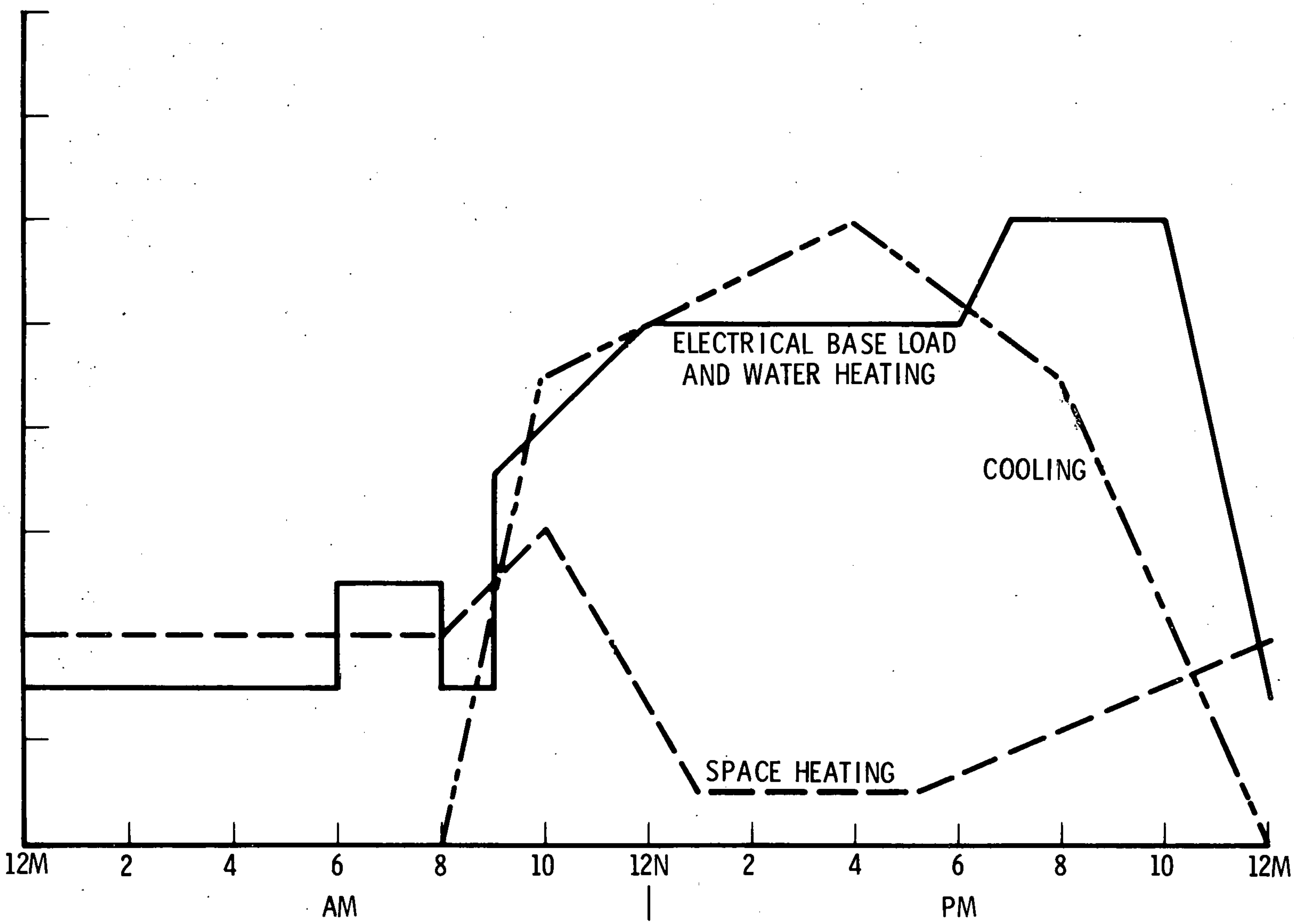


Figure III-7. Diurnal Demand of Local Shopping Center (Ref. 37) failure of booster pumps for fire protection water systems, failure of ventilating systems, etc. Most of these hazards will be avoidable with relatively small storage, or with standby engine generator systems backing up the utility connection. However, a 99% reliability requirement would most likely be imposed as a minimum requirement for energy service to commercial buildings.

In the instance of school buildings, the outage limits should be less critical. Hazard to life and health can again be avoided with small energy storage or with standby engine generator power. Financial loss factors, although present if school cafeterias lose refrigeration, are minimal if outages are no longer than several hours. It is presumed therefore that a reliability requirement of 95-99% would be acceptable in this case.

3.2.3.9 Data Specific to Non-PTES Applications

Much of the data developed for screening of PTES applications can also be used to screen applications for PV (electric-only) systems. It is presumed that no change in functional use of energy type occurs, except in the instance of air conditioning. That is, space heating and water heating will continue to utilize fossil energy sources where they are now used for this purpose. However, the air conditioning load will be taken on by an electrically driven vapor compression system rather than the absorption chilling unit assumed for PTES. As a consequence, most of the statistics previously developed for the PTES application to commercial and institutional building classes continue to be valid for PV screening, except for the total energy consumption per region and the K factors expressing a proportional ranking of affordable collector costs.

Table III-63 shows the total electric-only demand forecast for 1990 for the five application classes previously selected in preliminary screening. On a national basis offices rank first in demand, followed in order by schools, stores, shopping centers and supermarkets. Comparison with Table III-36 shows that this order coincides with that holding true when the sum of electric and thermal demand is used as the ranking parameter.

Table III-63. Commercial and Institutional Buildings Sector, 1990 Total Regional Electric Energy Demand, in Btu × 10^{12} per Year

Climatic Regions	Supermarkets	Stores	Shopping Centers	Schools	Offices
Eastern/Great Lakes	17.1	144.8	39.8	144.4	175.3
Midwest	5.6	45.3	12.4	52.2	57.2
Southeast	6.5	59.3	14.5	56.4	66.1
Southwest	1.5	14.2	3.3	13.0	16.0
Mid-Atlantic	6.9	73.7	18.5	74.1	85.2
Far West	5.2	53.9	17.2	61.0	69.1
Northern Plain	2.9	23.2	6.5	26.9	29.5
Central Humid	5.3	47.0	12.0	47.5	54.6
Southern Plain	3.8	35.2	8.5	33.3	39.5
Central Plain	2.6	23.1	6.1	24.4	27.7
Pacific Northwest	0.9	6.4	1.9	7.8	8.3
South Florida	1.7	20.4	4.4	16.7	21.3
U.S. Totals	60.0	546.5	145.1	557.7	649.8

As discussed already for residential applications, the K factor reduces, in the absence of T/E ratios, to the value of electric energy produced per unit area of collector, i.e., the price of electric energy in each climatic region per unit energy, times the energy produced per unit collector area. This product is invariant for all applications classes in each region and thus cannot be used as a ranking characteristic. Ranking was instead performed by using the product of the energy demand per region and its regional K factor. The larger this product, the more interesting the application.

Table III-64 shows the values calculated for the two main energy consuming seasons and the annual totals for this displaceable energy. This ranking scheme also places offices first, but follows them with stores, schools, shopping centers, and then supermarkets, in that order. The reversal of the second and third position in the ordered rank when compared to the ranking based on energy demand only is due to the higher proportion of stores in regions with higher K_e factor (higher priced utility power and/or higher insolation). The K_e factors are the same as those listed for the residential electric-only discussion.

Table III-64. Commercial and Institutional Building Sector Ranking by All-Electric K_e Factor

K_e Factor × Energy Demand (U.S.)

	Supermarkets	Stores	Shopping Centers	Schools	Offices
Heating Season	20	147	44	191	200
Cooling Season	39	395	95	323	420
Year Total	59	542	139	514	620

3.3 INDUSTRIAL SECTOR

3.3.1 Quality of Data

Numerous data sources covering many industrial processes are available from the open literature. Considerable statistics relative to industrial energy consumption and manufacturing establishment characteristics are also available from the U.S. Census. The availability of the specific data required for screening of industrial applications for suitability for photovoltaic energy systems is, however, quite limited. The extensive primary source research required for much of the desired data was not feasible for this study.

The major source of general statistics on industrial activity is the U.S. Census. Economic Censuses are taken every five years, in years ending with 2 and 7. Several of the economic sectors subject to Census enumeration, such as agriculture, mining, construction, and manufacturing, encompass activities whose energy needs can be met by electrical and thermal energy generated by photovoltaic total energy systems. This report section deals with the industrial (manufacturing) sector whose total energy consumption ranks third after the commercial and household sectors (see Table II-1).

Because the U.S. Census of Manufactures (Ref. 38) can provide some of the statistics to be used in the applications screening process, this study followed the industrial classification scheme used by the Census. Other sources of data used by this study also follow this classification system, thus easing the process of merging data from several sources. The Census classification system organizes industries generically in accordance with the Standard Industrial Classification (SIC) Code. In this code, two-digit numbers identify major divisions of economic activity. For example, two-digit numbers falling between 01 and 09 describe agricultural, forestry and fishery activities, 10 to 14 include mining activities, and 20 to 39 cover the manufacturing sector. The 20 major two-digit activity groups within the manufacturing sector are then further subdivided into 143 three-digit product groups and into 451 four-digit industries, with digits referring to the number of integers of the SIC code.

The Census defines manufacturing, in its simplest terms, as the mechanical and chemical transformation of inorganic and organic substances into new products. Certain assemblies of component parts also are included in this definition, as are certain auxiliary operations. Manufacturing establishments are fitted into the appropriate industry designation on the basis of their products. However, many of the establishments manufacture more than one line of product, some of which may not be so closely related as to fit into the same classification code. In that instance, the establishment is classified by its primary product, that which constitutes the largest fraction of the dollar value of its shipments. Thus, the energy statistics in the Census associated with an industry may not, in many cases, represent the energy usage of a specific process or product but, rather, a mix of processes or products.

Census data possess at least one additional weakness in terms of their use in the screening process. The energy statistics provided for a particular industry do not distinguish between a product made in several steps, some of which may be performed in different plants at separate locations, and a product manufactured in a single plant in a process encompassing all manufacturing steps from raw material receipt to product packing and shipment. Since the proportion of thermal-to-electrical energy may vary from step to step, the overall energy usage data provided by the Census offer insufficient information for the accurate determination of the thermal-to-electric ratio in the instance of a product manufactured in several separate locations. Similarly, a product produced in a single location by separate batch processing of each manufacturing step may have characteristic energy demand profiles which cause the process thermal-to-electric ratio to vary with time. Again, the Census energy consumption data offer no information concerning this characteristic, which is potentially important to an evaluation for PTES application. Most of the other process energy data generally available in the literature suffer the same defect, that of not identifying the location of the various process steps since that is establishment-peculiar. Additionally, although detailed descriptions of many processes leading to the same end-product are available in the literature, information about distribution of their use within a given industry is usually not available. Since differing processes often have different energy requirements, overall industry energy consumption statistics are of limited use in identifying the specific processes in actual use and their relevant characteristics, such as thermal-to-electric ratio.

Most other data sources reviewed for this study were found to provide information on either process heat requirements of a particular process or its electrical energy requirements, or, sometimes, the total energy consumption, without distinguishing between thermal and electric fractions. Rarely does the information provided permit association of the thermal energy needs at different temperature levels with the electrical usage of a specific process.

The Census of Manufactures provides energy usage by fuel type to the four-digit SIC code level on a national basis but only to the three-digit level on a state or smaller geographic unit basis. This makes application of the location-related screening criteria difficult. For example, the product group SIC 201, Meat Products, contains an industry group designated SIC 2011, Meatpacking. Different types of meat require different processing methods, and probably, different energy expenditures for processing. Different meats are also associated with different geographic locations; for example, beef is the major meat product of the southwestern states, with a much higher proportion of pork and poultry being packed in the Middle-West. The Census of Manufactures provides no data on energy needs to that level of product division.

This study found that available secondary data sources could, for the above reasons, provide only rough guidance in the screening of industrial applications for suitability of PTES. The references associated with this report section include several useful sources for summaries of process heat requirements. These are discussed in more detail below. A bibliography of other data sources not directly used in the preparation of this report is also provided in the Appendix. Many of these sources contain data which would be useful in the more detailed analyses to follow this screening activity. Such detailed analyses will be required to deal with specific plants within selected industries in order to have available accurate data dealing with such important decision-influencing parameters as specific thermal-to-electric ratios, the time dependence of energy demand, need for energy storage, component costs, prices and availability of competing energy sources, location factors, prevailing investment rating criteria such as payback period, and so forth.

3.3.2 Baseline Data and Sources

Preferred sources of data for this screening activity are surveys or other collections of data which already contain information of specific relevance to the screening criteria briefly described in Section 2 of this report. Only three such sources were found during the literature survey preceding initiation of the analysis. None of them provided the complete data base required, either individually or collectively, thus preventing the screening of industrial applications from proceeding to the same level of completion as was possible for the residential and commercial sectors. Two publications of the U.S. Census contain considerable data of utility to application screening. The 1972 Census of Manufactures (Ref. 38) provides data on energy consumption at the four-digit SIC industry level on a national level, the numbers of establishments within each four-digit group for each state, and the size of these establishments in terms of business volume as well as numbers of employees for some industries and for some states. It thus permits estimates of the energy consumption of an average, median, and modal sized establishment on a national basis, once an average energy consumption per production worker has been estimated. It does not permit these estimates on a state basis in every instance, however, because the establishment size distribution in terms of production workers is not available for some industry groups and states. An Annual Survey of

Manufactures issue devoted to updating industrial energy consumption for 1974 (Ref. 39) compiles energy consumption by fuel type (including electrical) for the 20 major industry groups classified by SIC code under the manufacturing sector, and also provides data on the split between electric energy generated in-plant and purchased electricity. As in the instance of Ref. 38, energy consumption is shown at the four-digit level only on a national basis, and on the three- and two-digit levels for state compilations, making application of the location-related screening criteria more difficult. This reference was also obtained in data tape format, permitting computer sorting to identify the more important energy consuming industry groups. Table III-65 shows a listing of four-digit industries rank-ordered by the total amount of purchased fuels; Table III-66 ranks these industries by purchased electricity and Table III-67 by the amount of electricity generated in-plant (minus that sold); and, finally, Table III-68 shows a ranking by the amount of natural gas purchased. The latter is of interest in determining those industries more likely to be affected by shortages of this fuel type. Only the top fifty industries are shown on these tables for each ranking, except in the instance of Table III-67, where only 42 industries were found to generate electricity in-plant in sizable quantity. The Census does not separately report energy consumption for process heat, nor does it report temperature levels of such process heat requirements.

Two data sources were found which conveniently organize and report process heat requirements of various industries by quantity at various temperature levels, and also provide data on the processes used in these industries, and, in some instances, on the variety of processes within an industry. Neither of them, however, reports electricity requirements associated with these processes. The first source, a study by Battelle Memorial Institute (Ref. 40), provides such data for 9 four-digit industries and 6 two-digit major activity groups. It lists process heat consumption at temperature levels up to 350°F separately from those at higher temperature

Table III-65. Industries Rank-Ordered by Total Purchased Fuels* (Top 50 in Rank)

INDUSTRY GROUP AND INDUSTRY	TOTAL PURCHASED FUELS (KWH EQUIV. X BILLION)	PURCHASED TOTAL FUEL OIL (KWH EQUIV. X BILLION)	NATURAL GAS (KWH EQUIV. X BILLION)
2911 PETROLEUM REFINING	409.2		345.2
3312 BLAST FURNACES AND STEEL MILLS	398.8	77.8	181.2
2869 INDUS. ORGANIC CHEMICALS, NEC.	270.2	15.2	212.9
2621 PAPERMILLS, EXC. BUILDING PAPER	149.3	52.6	49.8
2631 PAPERBOARD MILLS	139.9	60.1	51.3
3241 CEMENT, HYDRAULIC	134.9	12.4	60.3
2819 INDUSTRIAL INORGANIC CHEM., NEC.	69.5	9.2	46.6
2873 NITROGENOUS FERTILIZERS	69.1	1.3	64.8
2821 PLASTICS MATERIALS AND RESINS	45.5	7.3	23.1
3334 PRIMARY ALUMINUM	42.3		
2812 ALKALIES AND CHLORINE	40.5		15.9
2824 ORGANIC FIBERS, NONCELLULOSIC	38.2	13.9	8.3
3221 GLASS CONTAINERS	37.3	5.8	30.2
2865 CYCLIC CRUDES AND INTERMEDIATES	36.9	9.9	20.1
3321 GRAY IRON FOUNDRIES	28.7		12.4
3274 LIME	28.0	.3	8.2
3714 MOTOR VEHICLE PTS., ACCESSORIES	26.5	2.1	14.4
3711 MOTOR VEHICLES AND CAR BODIES	26.2	3.1	14.3
2822 SYNTHETIC RUBBER	24.1	.1	
2063 BEET SUGAR	23.7		10.0
3079 MISCELLANEOUS PLASTICS PRODUCTS	23.0	6.2	9.6
2611 PULPMILLS	22.5		9.1
2046 WET CORN MILLING	22.0	2.0	12.6
3331 PRIMARY COPPER	21.4	3.7	14.3
3251 BRICK AND STRUCTURAL CLAY TILE	20.3		15.4
3011 TIRES AND INNER TUBES	20.1	4.1	10.0
3229 PRESSED AND BLOWN GLASS, NEC	18.8	1.9	15.8
2823 CELLULOSIC MANMADE FIBERS	18.5	2.4	
2011 MEATPACKING PLANTS	18.5	1.8	11.9
3211 FLAT GLASS	17.8		13.9
2421 SAWMILLS, PLANING MILLS, GENERAL	17.2	3.5	5.5
2874 PHOSPHATIC FERTILIZERS	17.1	2.2	14.3
3273 READY-MIXED CONCRETE	17.0	3.8	2.2
3353 ALUMINUM SHEET, PLATE, AND FOIL	16.5		14.1
2411 LOGGING CAMPS, LOG CONTRACTORS	16.1		
2816 INORGANIC PIGMENTS	15.2		6.8
2813 INDUSTRIAL GASES	14.9	.1	10.9
3296 MINERAL WOOL	14.4	.9	9.4
2899 CHEMICAL PREPARATIONS, NEC	14.3	2.6	4.0
3462 IRON AND STEEL FORGINGS	14.3	2.6	10.0
2082 MALT BEVERAGES	12.7	3.2	8.0
2033 CANNED FRUITS AND VEGETABLES	12.5	2.4	8.6
3275 GYPSUM PRODUCTS	12.1	2.1	9.4
2075 SOYBEAN OIL MILLS	11.3	1.5	8.9
2262 FINISH. PLTS, MANMADE FIBER	11.3	2.8	4.5
3313 ELECTROMETALLURGICAL PRODUCTS	11.1		
2661 BUILDING PAPER AND BOARD MILLS	11.0	2.0	6.5
2062 CANE SUGAR REFINING	10.9	3.3	7.4
2051 BREAD, CAKE, RELATED PRODUCTS	10.7		6.1
2951 PAVING MIXTURES AND BLOCKS	10.4	2.5	2.7

*Ref. 39

Table III-66. Industries Rank-Ordered by Purchased Electric Energy* (Top 50 in Rank)

INDUSTRY GROUP AND INDUSTRY	ELECTRIC ENERGY PURCHASED QUANTITY (MILLION KWH)	ELECTRIC ENERGY GENERATED LESS SOLD (MILLION KWH)
3334 PRIMARY ALUMINUM	68699.2	8718.1
3312 BLAST FURNACES AND STEEL MILLS	49597.6	
2819 INDUSTRIAL INORGANIC CHEM., NEC.	42932.2	2220.7
2911 PETROLEUM REFINING	25824.2	
2621 PAPERMILLS, EXC. BUILDING PAPER.	18496.0	13033.5
2869 INDUS. ORGANIC CHEMICALS, NEC.	18330.6	9205.1
2812 ALKALIES AND CHLORINE.	12485.9	3133.7
3079 MISCELLANEOUS PLASTICS PRODUCTS.	11241.4	210.2
2813 INDUSTRIAL GASES	10660.5	
3241 CEMENT, HYDRAULIC	9904.7	457.0
2631 PAPERBOARD MILLS	9846.6	11988.1
3714 MOTOR VEHICLE PTS., ACCESSORIES.	9264.4	
3313 ELECTROMETALLURGICAL PRODUCTS.	9102.0	
2821 PLASTICS MATERIALS AND RESINS.	8131.0	273.2
2824 ORGANIC FIBERS, NONCELLULOSIC.	6840.1	1202.8
2421 SAWMILLS, PLAN>G MILLS, GENERAL	6777.7	308.5
3321 GRAY IRON FOUNDRIES.	6492.3	
2221 WEAV>G MILLS, MANMADE FIBER.	6168.4	62.7
3711 MOTOR VEHICLES AND CAR BODIES.	6155.3	
3011 TIRES AND INNER TUBES.	4636.6	
2211 WEAVING MILLS, COTTON.	4505.8	154.0
2865 CYCLIC CRUDES AND INTERMEDIATES.	4268.9	235.0
2281 YARN MILLS, EXCEPT WOOL.	4136.7	
2873 NITROGENOUS FERTILIZERS.	4093.6	476.2
3339 PRIMARY NONFERROUS METALS, NEC	4056.7	
2011 MEATPACKING PLANTS	4023.7	
3221 GLASS CONTAINERS	3896.2	
3353 ALUMINUM SHEET, PLATE, AND FOIL.	3770.7	
3662 RADIO, TV COMMUNICATION EQUIP.	3319.7	
2026 FLUID MILK	3165.9	
3721 AIRCRAFT	3052.0	
3465 AUTOMOTIVE STAMPINGS	2879.4	
3357 NONFER. WIREDRAWING, INSULATING.	2843.0	
2874 PHOSPHATIC FERTILIZERS	2755.8	
3325 STEEL FOUNDRIES, NEC	2677.1	
2611 PULPMILLS.	2563.9	2014.6
2834 PHARMACEUTICAL PREPARATIONS.	2537.8	
3531 CONSTRUCTION MACHINERY	2391.9	
3585 REFRIGERATION, HEATING EQUIP	2330.6	
2711 NEWSPAPERS	2318.4	9.1
3351 COPPER ROLLING AND DRAWING	2255.1	
3624 CARBON AND GRAPHITE PRODUCTS	2250.0	0.0
3069 FABRICATED RUBBER PRODUCTS, NEC.	2161.5	10.0
3674 SEMICONDUCTORS, RELATED DEVICES.	2140.5	0.0
3573 ELECTRONIC COMPUTING EQUIPMENT	2096.7	
3229 PRESSED AND BLOWN GLASS, NEC	2063.6	
2051 BREAD, CAKE, RELATED PRODUCTS.	2057.0	
2499 WOOD PRODUCTS, NEC	1999.4	49.2
3724 AIRCRAFT ENGINES, ENGINE PARTS	1930.7	
2752 COMMERCIAL PRINTING, LITHOGRAPH.	1927.7	

*Ref. 39

Table III-67. Industries Rank-Ordered by Electricity Generated In-House* (Less Sold)

INDUSTRY GROUP AND INDUSTRY	ELECTRIC ENERGY PURCHASED QUANTITY (MILLION KWH)	ELECTRIC ENERGY GENERATED LESS SOLD (MILLION KWH)
2621 PAPERMILLS, EXC. BUILDING PAPER. . .	18496.0	13033.5
2631 PAPERBOARD MILLS	9846.6	11988.1
2869 INDUS. ORGANIC CHEMICALS, NEC. . . .	18390.6	9205.1
3334 PRIMARY ALUMINUM	68699.2	8718.1
2812 ALKALIES AND CHLORINE.	12485.9	3133.7
2819 INDUSTRIAL INORGANIC CHEM., NEC. . .	42932.2	2220.7
2611 PULPMILLS.	2563.9	2014.6
2824 ORGANIC FIBERS, NONCELLULOSIC. . . .	6840.1	1202.8
2046 WET CORN MILLING	1112.9	830.1
2873 NITROGENOUS FERTILIZERS.	4093.6	476.2
3241 CEMENT, HYDRAULIC.	9904.7	457.0
2063 BEET SUGAR	196.5	446.0
2062 CANE SUGAR REFINING.	111.9	423.9
2421 SAWMILLS, PLAN>G MILLS, GENERAL. . .	6777.7	308.5
2821 PLASTICS MATERIALS AND RESINS. . . .	8131.0	273.2
2865 CYCLIC CRUDES AND INTERMEDIATES. . .	4268.9	235.0
2082 MALT BEVERAGES	1759.7	218.9
3079 MISCELLANEOUS PLASTICS PRODUCTS. . .	11241.4	210.2
2816 INORGANIC PIGMENTS	1415.8	172.1
2211 WEAVING MILLS, COTTON.	4505.8	154.0
2899 CHEMICAL PREPARATIONS, NEC	918.3	132.1
2262 FINISH. PLTS, MANMADE FIBER.	1060.7	109.1
2661 BUILDING PAPER AND BOARD MILLS . . .	1515.8	85.3
2861 GUM AND WOOD CHEMICALS	161.3	69.1
2221 WEAV>G MILLS, MANMADE FIBER.	6168.4	62.7
2499 WOOD PRODUCTS, NEC	1999.4	49.2
2647 SANITARY PAPER PRODUCTS.	1155.5	47.5
3069 FABRICATED RUBBER PRODUCTS, NEC. . .	2161.5	10.0
2711 NEWSPAPERS	2318.4	9.1
2411 LOGGING CAMPS, LOG CONTRACTORS . . .	310.6	7.8
2023 CONDENSED AND EVAPORATED MILK. . . .	476.1	6.7
2643 BAGS, EXCEPT TEXTILE BAGS.	1062.2	2.5
3545 MACHINE TOOL ACCESSORIES	698.7	1.7
2951 PAVING MIXTURES AND BLOCKS	593.8	1.6
2653 CORRUGATED, SOLID FIBER BOXES. . . .	1919.7	1.3
2083 MALT	258.7	1.2
2448 WOOD PALLETS AND SKIDS	125.1	1.1
3274 LIME	711.1	.9
2399 FABRICATED TEXTILE PRODS., NEC . . .	240.1	.5
3398 METAL HEAT TREATING.	832.1	.3
3316 COLD FINISHING OF STEEL SHAPES . . .	966.4	.2
3131 BOOT, SHOE CUT STOCK, FINDINGS . . .	47.2	.2

*Ref. 39

Table III-68. Industries Rank-Ordered by Purchased Natural Gas*
(Top 50 in Rank)

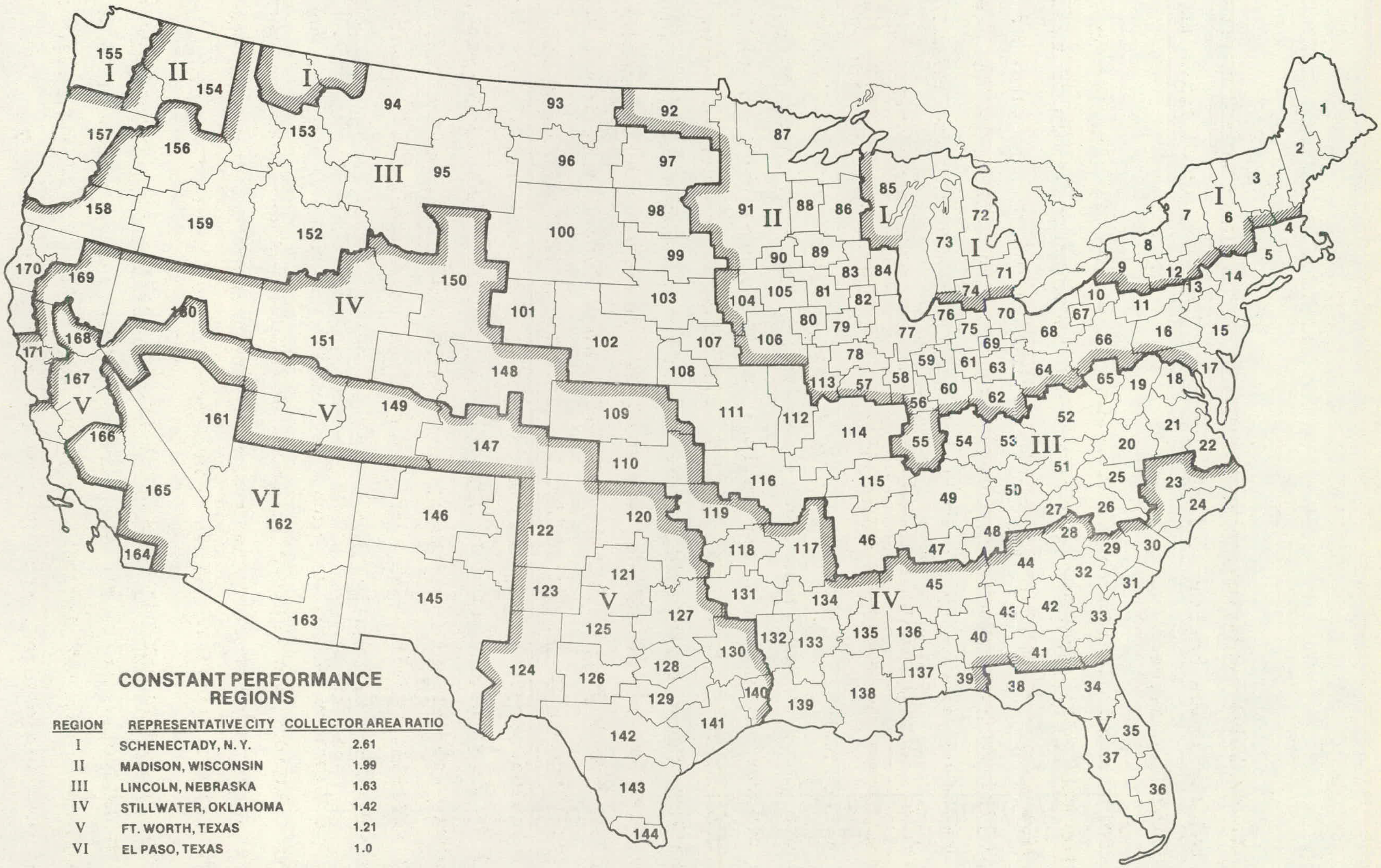
INDUSTRY GROUP AND INDUSTRY	TOTAL PURCHASED FUELS (KWH EQUIV. X BILLION)	PURCHASED FUEL OIL (KWH EQUIV. X BILLION)	TOTAL NATURAL GAS (KWH EQUIV. X BILLION)
2911 PETROLEUM REFINING	409.2		345.2
2869 INDUS. ORGANIC CHEMICALS, NEC	270.2	15.2	212.9
3312 BLAST FURNACES AND STEEL MILLS	398.7	77.8	181.1
2873 NITROGENOUS FERTILIZERS	69.0	1.3	64.8
3241 CEMENT, HYDRAULIC	134.8	12.4	60.3
2631 PAPERBOARD MILLS	139.8	60.1	51.3
2621 PAPERMILLS, EXC. BUILDING PAPER	149.3	52.6	49.8
2819 INDUSTRIAL INORGANIC CHEM., NEC	69.5	9.2	46.6
3221 GLASS CONTAINERS	37.2	5.8	30.2
2821 PLASTICS MATERIALS AND RESINS	45.5	7.3	23.1
2865 CYCLIC CRUDES AND INTERMEDIATES	36.9	9.9	20.0
2812 ALKALIES AND CHLORINE	40.5		15.8
3229 PRESSED AND BLOWN GLASS, NEC	18.7	1.9	15.8
3251 BRICK AND STRUCTURAL CLAY TILE	20.2		15.4
3714 MOTOR VEHICLE PTS., ACCESSORIES	26.5	2.1	14.4
3711 MOTOR VEHICLES AND CAR BODIES	26.2	3.1	14.3
3331 PRIMARY COPPER	21.3	3.7	14.3
2874 PHOSPHATIC FERTILIZERS	17.1	2.2	14.3
3353 ALUMINUM SHEET, PLATE, AND FOIL	16.5		14.1
3211 FLAT GLASS	17.7		13.9
2046 WET CORN MILLING	22.0	2.0	12.6
3321 GRAY IRON FOUNDRIES	28.7		12.4
2011 MEATPACKING PLANTS	18.5	1.8	11.9
2813 INDUSTRIAL GASES	14.8	.1	10.8
3011 TIRES AND INNER TUBES	20.1	4.1	10.0
2063 BEET SUGAR	23.7		10.0
3462 IRON AND STEEL FORGINGS	14.3	2.6	10.0
3079 MISCELLANEOUS PLASTICS PRODUCTS	23.0	6.2	9.6
3296 MINERAL WOOL	14.3	.9	9.4
3275 GYPSUM PRODUCTS	12.1	2.1	9.4
2611 PULPMILLS	22.5		9.1
2075 SOYBEAN OIL MILLS	11.3	1.5	8.9
2033 CANNED FRUITS AND VEGETABLES	12.5	2.4	8.6
2824 ORGANIC FIBERS, NONCELLULOSIC	38.2	13.9	8.3
3274 LIME	28.0	.3	8.2
2082 MALT BEVERAGES	12.6	3.2	8.0
2062 CANE SUGAR REFINING	10.8	3.3	7.3
3411 METAL CANS	8.3	.4	6.7
2816 INORGANIC PIGMENTS	15.1		6.7
2661 BUILDING PAPER AND BOARD MILLS	11.0	2.0	6.5
3341 SECONDARY NONFERROUS METALS	10.0	1.2	6.4
3295 MINERALS, GROUND OR TREATED	8.8		6.1
2051 BREAD, CAKE, RELATED PRODUCTS	10.6		6.1
3531 CONSTRUCTION MACHINERY	9.8	.6	5.9
3361 ALUMINUM FOUNDRIES	6.6		5.9
3325 STEEL FOUNDRIES, NEC	7.4	.4	5.7
3255 CLAY REFRACTORIES	7.1		5.5
2421 SAWMILLS, PLANING MILLS, GENERAL	17.2	3.5	5.5
3259 STRUCTURAL CLAY PRODUCTS, NEC	5.9	.2	5.2
2952 ASPHALT FELTS AND COATINGS	8.3		5.2

*Ref. 39

levels. It excludes, unfortunately, thermal energy requirements for process cooling and for space heating and cooling, applications which total energy systems could also serve.

The second data source, a report prepared by InterTechnology Corporation (Ref. 41), provides quantities and temperature levels of process heat requirements for 74 four-digit SIC industries out of the total of 451 four-digit industries included by the Census of Manufactures. It covers process heat requirements up to 550^{O}F but also excludes cooling needs. It also develops a regionalization scheme based on both insolation and on thermal collector performance (dependent on ambient temperatures) which results in the definition of 6 performance regions covering the continental U.S. Figure III-8 shows these regions as adapted by this study to follow BEA area boundaries, to match the regionalization scheme used for building applications, rather than the state and county boundaries used by InterTechnology Corporation (ITC). The insolation available at six cities, indicated also on Figure III-8, was used to characterize the insolation available in the 6 regions. Table III-69 shows these insolation values. This regionalization is preferred for the industrial sector rather than the 12 climatological regions used for the building sectors because the latter are based on factors affecting building energy demand, such as degree-days and humidity conditions in heating and cooling seasons, which have no important correlation with the energy demand of most industrial processes. The InterTechnology regionalization scheme is based primarily on calculated collector performance which, in turn, is based primarily on average annual insolation. Regions are defined as those geographic areas in which thermal collectors would exhibit relatively similar performance in terms of energy collected, and are therefore termed "equal performance regions" by ITC.

The Battelle and ITC reports (Refs. 40 and 41) both provide energy consumption estimates out to the year 2000. Future energy costs, as used by this study, are derived from the source also used for residential and commercial cost projections, Ref. 30, for the sake of consistency.



CONSTANT PERFORMANCE REGIONS

REGION	REPRESENTATIVE CITY	COLLECTOR AREA RATIO
I	SCHENECTADY, N. Y.	2.61
II	MADISON, WISCONSIN	1.99
III	LINCOLN, NEBRASKA	1.63
IV	STILLWATER, OKLAHOMA	1.42
V	FT. WORTH, TEXAS	1.21
VI	EL PASO, TEXAS	1.0

Figure III-8. Constant Performance Regions

Ref. 41

Table III-69. Regional Insolation for Industrial Applications Screening*

Performance Regions	Representative City	Insolation on Collector Tilted at Latitude, in 1000 $Btu/ft^2/yr$
I	Schenectady, N.Y.	393
II	Madison, Wisconsin	480
III	Lincoln, Nebraska	529
IV	Stillwater, Oklahoma	565
V	Ft. Worth, Texas	617
VI	El Paso, Texas	737

*From Ref. 41

3.3.3 Derivation of Specific Data Required for Screening

3.3.3.1 Process Heat Temperatures

As discussed in Section 4 of this report, it is probably desirable to limit average array temperatures in PTES to about 200°C to prevent excessive photovoltaic cell performance degradation. Although this would imply a lower limit on process temperatures which could be supplied by a photovoltaic total energy system, perhaps 190°C, the format of data available from the two principal sources of process heat requirements used by this analysis did not permit the use of 190°C (374°F) as a precise upper limit in selecting processes as candidates for PTES. Battelle Columbus Laboratories (Ref. 40) provided data on process heat quantities associated with specific industries in three steps, heat at less than 212°F, heat between 212° and 350°F, and heat at temperatures in excess of 350°F. The process heat data used from that reference are consequently those shown for temperatures of 350° or less. InterTechnology Corporation (ITC) listed its process heat requirements of the various industries analyzed in its report (Ref. 41) in steps of either 100°F or 150°F, ending at 550°F. Data used from that reference therefore include process heat requirements for temperatures of 400°F or less.

Table III-70 shows the selection of industries suitable for further screening analysis on the basis of process heat requirements at temperatures of 400°F or less. These industries are listed in order of quantity of total purchased fuels as previously shown on Table III-65. Only the top 50 industries based on this ranking scheme are shown. Process heat quantities are derived from both the Battelle and ITC reports (Refs. 40 and 41). As previously indicated, the Battelle report covers fewer industries than does the ITC report. The notes indicate that, in some instances, an industry listing includes more than one four-digit group. When the grouping is different in the two sources, the quantity of process heat given by ITC is in parenthesis. The quantity of purchased fuel shown in parenthesis in the first column then corresponds to the ITC grouping.

For some listings, the differences in heat quantities between the references occur because of differences in temperature limits, as discussed

Table III-70. Quantities of Process Heat at Less Than 400°F

SIC	Industry	Purchased Fuels 1974 kWh x 10^9	1976 (Note 1) Quantity of Process Heat at Less than 400°F, in kWh x 10^9 Ref. 41	Ref. 40	
2911	Petroleum Refining	409	17.5	52.7	
2869	Industrial Organic Chemicals	270	8.1	n.e.	Note 2
26xx	Pulp & Paper Products	331 (312)	340	(184)	Note 3
2819	Ind. Inorganic Chem	70	n.e.	n.e.	
2873	Nitrogen Fertilizers	69	1.7	0	
2821	Plastic Mat'l & Resins	46	n.e.	3.7	
2812	Alkalies & Chlorine	41	0.02	59.5	Note 4
2823	Cellulosic Man-Made Fibers	19	18.3	n.e.	
2824	Organic Fibers, Non-Cellulosic	38	6	n.e.	
3221	Glass Containers	37	0	8.0	Note 5
2865	Cyclic Crudes & Intermed	37	11.7	n.e.	
1477	Sulfur	35	10.3	12.8	
3711	Motor Vehicle Bodies	26	0.09	10.5	Note 6
2822	Synthetic Rubber	24	3	1.6	Note 7
2063	Beet Sugar	24	14.3	16.1	
3079	Misc. Plastics	23	0	n.e.	
2046	Wet Corn Milling	22	4.5	19.3	
3331	Primary Copper	21	n.e.	4.9	
3251	Brick & Struct. Tile	20	0	0	
3011	Tires & Tubes	20	2.9	n.e.	
2011	Meat Packing	19	13	14.5	
3211	Flat Glass	18	0	n.e.	
2421	Saw Mills	17 (37.2)	28.7	(24.6)	Note 8
2874	Phosphate Fertilizers	17	n.e.	3.8	
3273	Ready-Mix Concrete	17	0.1	(see 3271)	
2816	Inorganic Pigments	15	0	n.e.	
2813	Indust. Gases	15	0	n.e.	
2082	Malt Beverages	12.7	3.9	10.7	
2033	Canned Fruit & Veg.	12.5	1.2	9.3	
3275	Gypsum Products	12.1	5.1	4.1	
22xx	Textiles	17.2 (67.6)	27.7	(81.8)	Note 9
2075	Soybean Oil Mills	11.3	4.8	5.2	
2062	Cane Sugar Refining	10.9	7.8	9.4	
2051	Bread, Cake, Related Prod.	10.7	0.3	10.5	

Note (1) Data often represent only part of process heat usage for entire SIC code.
Note (2) "n.e." indicates no entry for this item in referenced report.
Note (3) Ref. 41 includes 2611, 21, 31, 53, 61. Ref. 40 includes 2611, 21, 31. Considerable by-products energy also used
Note (4) Most process heat obtained as waste heat from electric-power generation plants
Note (5) Ref. 40 includes 3211, 21, 29, 31, 96
Note (6) Ref. 41 includes 3711 and 3712. Ref. 40 includes, 3712, 3713, 3711
Note (7) Only SBR rubber covered
Note (8) Ref. 40 includes 2421, 35, 36, 92, 99. Considerable by-product energy also used.
Note (9) Ref. 41 covers primarily 2261, 62. Coverage of Ref. 40 not clear.

Table III-70. Quantities of Process Heat at Less Than $400^{\circ}F$ (Continued)

SIC	Industry	Purchased Fuels 1974 kWh x 10^9	1976 (Note 1) Quantity of Process Heat at Less than $400^{\circ}F$, in kWh x 10^9		
			Ref. 41	Ref. 40	
2022	Natural & Processed Cheese	6.1	3.5	n. e.	
2023	Condensed & Evap. Milk	5.9	2.3	n. e.	
2026	Fluid Milk	9.5	0.4	8.9	
2834	Pharmaceutical Preps.	8.8	9.2	n. e.	
2952	Asphalt Felts & Coatings	8.3	1.6	n. e.	
2048	Prepared Animal Feeds	7.7	0	11.4	
2435&6	Plywood and Veneer	9.4	32	(see 2421)	Note 10
2892	Explosives	7.6	0.2	n. e.	
2037&8	Frozen Fruits, Vegetables, Specialties	9.9	0.9	6.6	Note 11
2079	Shortenings & Cooking Oils	7.2	0.9	n. e.	
2841	Soaps & Detergents	6.9	0.3	n. e.	
2077	Animal & Marine Fats & Oils	6.5	5.8	4.4	
2032	Canned Specialties	5.8	0.2	n. e.	
2086	Bottled & Canned Soft Drinks	4.8	0.7	n. e.	
2085	Distilled Rectified & Blended Liquors	4.7	5.9	n. e.	
3271	Concrete Block & Brick	4.2 (27.7)	5.2	(4.2)	Note 12
2034	Dehydr. Fruits, Veg. Soup Mixes	3.3	1.3	n. e.	

Note (10) Considerable by-product energy also used.
Note (11) Ref. 40 covers 2037 only.
Note (12) Ref. 41 includes 3271, 2, 3.

above, or because a single listing was used to collect values for several industries. No explanation is available for differences apparent in other listings.

3.3.3.2 Market Size and Growth

One method of judging market size for industrial PTES is to evaluate the total amount of process heat which photovoltaic total energy systems might be able to supply. The process heat demand estimated by ITC (Ref. 41) to exist in 1976 at temperatures of 400°F or less was used to establish market size and was used also as a preliminary screening criterion to reduce the number of candidate industries by ranking their demand levels. Table III-71 indicates the rankings assigned to industries and product groups on this basis for the top 30 industries out of the 50 previously listed on Table III-70. The three industries, pulpmills (2611), papermills (2621), and paperboard mills (2631), shown collectively under the two-digit classification of pulp and paper products (2600) on this table, rank highest, with a process heat requirement of 346 kWh x 10^9 (1.18 x 10^{15} Btu). Shortening and cooking oil (2079) has the lowest rank on this list.

Growth in process heat requirements to the year 2000 was also estimated by ITC (Ref. 41) and is shown in Table III-71. This permits the estimation of average annual growth rates for the 30 ranking candidate industries. Ranking these candidate industries by growth rate results in an ordered listing which, as expected, appears to have no correlation with the list produced from ranking by process heat quantity. Table III-72 shows both rank lists. Process heat growth rates are not necessarily related to the growth in consumption of the products associated with the candidate industries. ITC (Ref. 41), in developing its estimates of process heat requirements for the year 2000, also considered changes in heat requirements due to changes in the processes involved, such as increased energy efficiency, or changes which may increase the fraction of process heat at temperatures higher than the 400°F considered a limit for PTES.

Table III-71. Process Heat Market Size and Growth

SIC	Industry	1976, Quantity of Process Heat at Less than 400°F, in Kwh x 10^9 (Ref. 41) (Note 1)	Rank (Note 2)	Process Heat in Year 2000 (Note 3) kWh x 10^9	Average Annual Growth Rate, %, 1976-2000
2911	Petroleum Refining	17.5	6	120 (.79)	8.4
2869	Industrial Organic Chemicals	8.1	12	55.5 (.58)	8.4
26xx	Pulp & Paper Products	346	1	810 (.67)	3.6
2819	Ind. Inorganic Chem	n.e.			
2873	Nitrogen Fertilizers	1.7	26	15.1 (.47)	9.5
2821	Plastic Mat'l & Resins	n.e.			
2812	Alkalies & Chlorine	0.02			
2823	Cellulosic Man-Made Fibers	18.3	5	18.3 (.62)	0
2824	Organic Fibers, Non-Cellulosic	6	14	24.4 (.61)	6.0
3221	Glass Containers	0			
2865	Cyclic Crudes & Intermed	11.7	9	80.5 (.77)	8.4
1477	Sulfur	10.3	10	12.7 (.67)	0.9
3711	Motor Vehicle Bodies	0.09			
2822	Synthetic Rubber	3	23	10.5 (.81)	5.4
2063	Beet Sugar	14.3	7	26.8 (.72)	2.7
3079	Misc. Plastics	0			
2046	Wet Corn Milling	4.5	20	7.9 (.52)	2.4
3331	Primary Copper	n.e.			
3251	Brick & Struct. Tile	0			
3011	Tires & Tubes	2.9	24	4.6 (.61)	1.9
2011	Meat Packing	13	8	17.1 (.68)	1.4
3211	Flat Glass	0			
2421	Saw Mills	28.7	3	33.9 (.66)	0.7
2874	Phosphate Fertilizers	n.e.			
3273	Ready-Mix Concrete	0.1			
2816	Inorganic Pigments	0			
2813	Indust. Gases	0			
2082	Malt Beverages	3.9	21	6.0 (.65)	1.8
2033	Canned Fruit & Veg.	1.2	29	1.6 (.69)	1.2
3275	Gypsum Products	5.1	18	8.3 (.70)	2.1
22xx	Textiles	27.7	4	70.9 (.67)	4.0
2075	Soybean Oil Mills	4.8	19	8.2 (.61)	2.3
2062	Cane Sugar Refining	7.8	13	9.7 (.72)	0.9
2051	Bread, Cake, Related Prod.	0.3			

Note (1) Data often represent only part of process heat usage for entire SIC code
Note (2) Rank based on process heat quantities provided in Ref. 41.
Note (3) Data from Ref. 41. Quantities in parenthesis represent fraction of total process heat estimated by Ref. 41 to be solar potential.

Table III-71. Process Heat Market Size and Growth (Continued)

SIC	Industry	1976, Quantity of Process Heat at Less than 400°F, in kWh x 10^9 (Ref. 41) (Note 1)	Rank (Note 2)	Process Heat in Year 2000 (Note 3) kWh x 10^9	Average Annual Growth Rate, %, 1976-2000
2022	Natural & Processed Cheese	3.5	22	5.7 (.63)	2.1
2023	Condensed & Evap. Milk	2.3	25	2.3 (.65)	0
2026	Fluid Milk	0.4			
2834	Pharmaceutical Preps.	9.2	11	65.2 (.61)	8.5
2952	Asphalt Felts & Coatings	1.6	27	2.8 (.68)	2.4
2048	Prepared Animal Feeds	~0			
2435&6	Plywood and Veneer	32	2	55.7 (.65)	2.3
2892	Explosives	0.2			
2037&8	Frozen Fruits, Vegetables, Specialties	0.9			
2079	Shortenings & Cooking Oils	0.9	30	1.7 (.66)	2.7
2841	Soaps & Detergents	0.3			
2077	Animal & Marine Fats & Oils	5.8	16	8.7 (.63)	1.7
2032	Canned Specialties	0.2			
2086	Bottled & Canned Soft Drinks	0.7			
2085	Distilled Rectified & Blended Liquors	5.9	15	10.6 (.64)	2.5
3271	Concrete Block & Brick	5.2	17	17.0 (.67)	5.1
2034	Dehydr. Fruits, Veg. Soup Mixes	1.3	28	2.0 (.65)	1.8
		607.4 (2.073 x 10^{15} Btu/yr)		1513.7 (5.17 x 10^{15} Btu/yr)	

Table III-72. Industries Ranked by Growth Rate in Process Heat Requirements to Year 2000*

SIC Code	Industry	Percent Annual Growth	Rank by Growth	Rank by Quantity of Process Heat
2873	Nitrogen Fertilizers	9.5	1	26
2834	Pharmaceutical Preps	8.5	2	11
2911	Petroleum Refining	8.4	3	6
2865	Cyclic Crudes & Intermed.	8.4	4	9
2869	Industrial Organic Chemicals	8.4	5	12
2824	Organic Fibers, Non-Cellulosic	6.0	6	14
2822	Synthetic Rubber	5.4	7	23
3271	Concrete Block & Brick	5.1	8	17
2200	Textiles	4.0	9	4
2600	Pulp & Paper Products	3.6	10	1
2063	Beet Sugar	2.7	11	7
2079	Shortenings & Cooking Oils	2.7	12	30
2085	Distilled Liquors	2.5	13	15
2046	Wet Corn Milling	2.4	14	20
2952	Asphalt Felts & Coatings	2.4	15	27
2075	Soybean Oil Mills	2.3	16	19
2435, 6	Plywood & Veneer	2.3	17	2
3275	Gypsum Products	2.1	18	18
2022	Natural & Processed Cheese	2.1	19	22
3011	Tires & Tubes	1.9	20	24
2082	Malt Beverages	1.8	21	21
2034	Dehydrated Fruits, etc.	1.8	22	28
2077	Animal & Marine Fats	1.7	23	16
2011	Meat Packing	1.4	24	8
2033	Canned Fruit & Vegetables	1.2	25	29
1477	Sulfur	0.9	26	10
2062	Cane Sugar Refining	0.9	27	13
2421	Saw Mills	0.7	28	3
2823	Cellulosic Manmade Fibers	0	29	5
2023	Condensed & Evaporated Milk	0	30	25

*From Ref. 41

If only the amount of process heat consumed at less than 400^{O}F is taken as a measure of market size, then the total market potential in 1976 consisted of about 2.1 quads out of a total of about 9.5 quads (Direct Heat and Process Steam, see Table II-4) estimated by other sources for the total amount of process heat at all temperature levels consumed in 1976.

The average annual growth rate of this market to the year 2000 is estimated at about 3.9% for the 30 candidate industries ranked on Table III-72.

3.3.3.3 Thermal-to-Electric Ratios

Thermal-to-electric ratio, T/E, is not believed to be a strong screening criterion for industrial applications. As discussed earlier, the available data base makes it difficult to determine the true T/E for any specific process or for any specific plant. Although specific process data are available in the literature, it would be difficult to relate them to specific plant sites. Information about actual processes used is often considered confidential. Thus, the Census and other data compilations available to this study do not correlate energy consumption data for specific industries to the distribution of process types. The collective nature of the data available for screening, such as the Census compilations, reach only to, at best, the four-digit SIC level of characterization which, in many industries, is above individual plant level. This prevents identification of the different process steps being carried out at different plant sites, with a probability that each process step involves a different T/E ratio. As a consequence, T/E ratios can, at best, be only rough guides in selecting industry candidates for more detailed examination. There can be no assurance that detailed examination of a specific plant within an industry will indeed disclose a T/E ratio close to that developed for the industry group in this report.

Because of the high proportion of process steam (at temperatures $\geq$212^{O}F) in the total process heat used by industry, it is considered likely that concentrator systems would be used in any industrial PTES application. Consequently, industries with T/E ratios between 3 and 12 are believed to be desirable candidates for further analysis (see Section 4 of this report). The Census (Ref. 39) provides national statistics to the four-digit level on total fuels purchased, both in physical units and in energy units. It also lists total purchased electrical energy for the same classification level. However, T/E ratios derived from these data are unsatisfactory as indicators of PTES compatibility since the total fuel energy shown contains some process heats at higher temperatures than are suitable for PTES, and also contains non-process-related thermal energy consumption, such as for space heating. Since data on process heat quantities at suitable temperature levels for these industries are available from Refs. 40 and 41, these were used in calculating T/E ratios. Even these, however, are only gross indicators of compatibility, since either thermal or electric energy production could be supplemented from other sources for those applications where PTES may not deliver sufficient energy. It is likely that industrial applications will not be stand-alone but will be located within the electric grid so that T/E ratios of less than 3 may permit use of a PTES with utility backup. On the other hand, provision of additional thermal energy to allow T/E's above 12 will require installation of stand-alone conventional process heat generating equipment. Although feasible, this approach would raise the cost of the system considerably above that of the PTES installation alone.

In spite of all the caveats discussed above, the rough T/E ratios that could be developed were judged to be useful in identifying industries of interest for more detailed examination as PTES applications. Table III-73 shows the annual (1974) electrical energy consumption of the 30 industries which were earlier (Table III-71) selected on the basis of the market size criterion. This table shows several T/E ratios for each industry. Column 2 contains the ratios determined by using the total purchased fuel and electric energies listed by the 1974 Annual Survey of Manufactures (Ref. 39). These ratios do not correctly represent those industries in which part of the thermal demand is generated from internally generated process waste, such as the pulp and paper industry. As discussed above, they also are incorrect in the instances of those industries in which

Table III-73. Thermal-to-Electric Ratios for Top Ranking Process Heat Using Industries

SIC	Industry	1974 Electric Consumption (Note 1) kWh x 10^9	(Note 2) T/E	(Note 3) T/E Ref. 41	Ref. 40	
2911	Petroleum Refining	25.8	15.9	0.7	2.0	
2869	Industrial Organic Chemicals, NEC	27.6	8.8	0.9	-	
26xx	Pulp & Paper Products	61.4 (57.9)	4.1 (4.0	5.7	3.2	
2819	Ind. Inorganic Chem					
2873	Nitrogen Fertilizers	4.6	14.7	0.4	0	
2821	Plastic Mat'l & Resins					
2812	Alkalies & Chlorine					
2823	Cellulosic Man-Made Fibers	0.6	30.8	30.5	-	
2824	Organic Fibers, Non-Cellulosic	8.0	4.3	1.4	-	
3221	Glass Containers					
2865	Cyclic Crudes & Intermed	4.5	8.0	1.5	-	
1477	Sulfur	n.a.	-	-	-	Note 4
3711	Motor Vehicle Bodies					
2822	Synthetic Rubber	1.7	14.2	1.8	0.9	
2063	Beet Sugar	0.6	37.3	23.8	26.8	
3079	Misc. Plastics					
2046	Wet Corn Milling	1.9	10.3	2.4	10.2	
3331	Primary Copper					
3251	Brick & Struct. Tile					
3011	Tires & Tubes	4.6	4.4	0.6	-	
2011	Meat Packing	4.0	4.6	3.3	3.6	
3211	Flat Glass					
2421	Saw Mills	7.1 (12.2)	2.3 (3.0)	4.0	3.0	
2874	Phosphate Fertilizers					
3273	Ready-Mix Concrete					
2816	Inorganic Pigments					
2813	Indust. Gases					
2082	Malt Beverages	2.0	6.0	2.0	5.4	
2033	Canned Fruit & Veg.	1.2	10.4	1.0	5.3	
3275	Gypsum Products	0.9	13.4	5.7	4.6	
22xx	Textiles	1.6 (27.3)	10.6 (2.4)	17.3	3.0	
2075	Soybean Oil Mills	1.4	8.1	3.4	3.7	
2062	Cane Sugar Refining	0.5	19.2	15.6	18.8	
2051	Bread, Cake, Related Prod.					

Table III-73. Thermal-to-Electric Ratios for Top Ranking Process Heat Using Industries (Continued)

SIC	Industry	1974 Electric Consumption (Note 1) kWh x 10^9	(Note 2) T/E	(Note 3) T/E Ref. 41	(Note 3) T/E Ref. 40
2022	Natural & Processed Cheese	0.7	8.7	5.0	-
2023	Condensed & Evap. Milk	0.5	11.8	4.6	-
2026	Fluid Milk				
2834	Pharmaceutical Preps.	2.5	3.5	3.7	-
2952	Asphalt Felts & Coatings	0.6	13.8	2.7	-
2048	Prepared Animal Feeds				
2435&6	Plywood and Veneer	2.3	4.1	13.9	-
2892	Explosives				
2037&8	Frozen Fruits, Vegetables, Specialties				
2079	Shortenings & Cooking Oils	.6	12.0	1.5	-
2841	Soaps & Detergents				
2077	Animal & Marine Fats & Oils	0.6	10.8	9.7	7.3
2032	Canned Specialties				
2086	Bottled & Canned Soft Drinks				
2085	Distilled Rectified & Blended Liquors	0.3	15.7	19.7	-
3271	Concrete Block & Brick	0.3 (1.8)	14.0 (15.4)	17.3	2.3
2034	Dehydr. Fruits, Veg. Soup Mixes	0.3	10.0	4.3	-

Note (1) Purchased electricity plus that generated on site less sold. From Ref. 39.

Note (2) Based on all thermal energy in purchased fuels less that consumed in generating internally-used electric energy. From Ref. 41.

Note (3) Based on process heat from Refs. 40 and 41. Underlined values fall within desired T/E range of 3 to 12 for concentrator systems

Note (4) Electric energy not available

sizable quantities of process heat are required at temperatures above 400°F. Columns 3 and 4 represent T/E's based on the process heat requirements at temperature levels of 400°F or less, as determined by Refs. 40 and 41, divided by the total electrical consumption. Sixteen entries in these last two columns which fall between 3 and 12 in T/E ratio, are underlined and are retained as candidates for the next step in the selection process. The rationale for using candidates from both process heat data sources is evident from inspection of these column listings. The assumptions which were used by the authors, or the data which formed the basis for their estimates, were different enough to bring about considerable variation in the T/E ratios derived from them. Because of the difficulty in determining which source to accept as the more reliable, it was believed prudent to use both sources on an equal basis at this step in the analysis.

It must be emphasized that selection of the 16 candidate industries was only performed to ease the task of reducing the large set of potential screening candidates to a smaller, more manageable number for the final screening. It is not intended to imply that the other industries do not represent a potential PTES market. As pointed out earlier, industries with T/E ratios of less than 3 may still be suitable applications for PTES if some of their electrical needs can be met with utility power.

3.3.3.4 Criteria Specific to Industrial PTES Applications

The sixteen industries and industry groups selected on the basis of thermal-to-electric ratio still represent too large a group for development of the additional data base required by the remaining screening criteria. Other criteria important to industrial applications permit further selective reduction of the candidates to a manageable set. One of these criteria is the value of the energy required in the manufacture of a product. The higher the fraction of product cost which is due to energy consumption in the manufacturing process, the more sensitive the industry will be to increased conventional energy prices. It is assumed that such an industry will also be more receptive to the use of alternate energy sources.

The only readily available source of data relating the value added during manufacture to the energy consumed is the 1972 Census of Manufacture (Ref. 38), which reports both the total value added as well as the cost of the energy used in the manufacturing process. However, it reports these data only for 1971. The steep increases in energy prices after 1973 will undoubtedly have increased the fraction of the total-value-added which is due to energy consumed, but this, presumably, will not affect the relative ranking of these industries with reference to this characteristic. For this reason, the data from Ref. 38 have been used in computing the percent of energy value in total-value-added, as shown in Table III-74, for those industries previously selected on the basis of T/E ratio.

Another industrial application characteristic that is of interest is the distribution in size of establishments in a given industry since size should relate directly to the level of energy demand. It is believed that establishments with larger energy demand will also be more sensitive to higher energy prices. Furthermore, they will be more capable of coping with the higher initial cost of PTES, and should be more willing to adapt life-cycle costing in evaluating PTES in relation to conventional energy sources.

The 1972 Census of Manufactures (Ref. 38) provides the distribution of the establishments within a given industry among several size classes, with the size indicator being the number of employees per establishment. This information permits estimation of mean, median, and modal establishment size. The latter is, of course, that size class containing the largest number of establishments. Knowledge of the size of the modal-sized establishment of a given industry is considered most useful for describing characteristics such as typical energy consumption levels. Table III-74 shows modal size of establishments within each of the listed industries. Although the national data on which this table is based permit determination of this size characteristic for all of the industries of interest, the Census, (Ref. 38) is less complete in coverage by state, making this characteristic less useful as a location criterion. Some of the size data are questionable; for example, for saw mills, planing mills, and fruit

Table III-74. Selected Characteristics of Industries with T/E Ratios Between 3 and 12*

SIC Code	Industry	T/E Ratio	% of Energy Value in Total Value Added, %, 1971	Modal Establishment, 1972 Average No. of Production Workers	Average Energy Consumed by by Modal Establishment, 1971, kWh × 10^6/Yr
2611	Pulp Mills		13.6	270	845
2621	Papermills	5-6	14.5	129	214
2631	Paperboard Mills		15.4	126	312
2421	Sawmills, Planing Mills	3-4	3.9	2	.18
2261	Textile Finishing	3-6	6.9	27	12.6
2011	Meatpacking	3-4	3.8	2	.43
2834	Pharmaceutical Products	3-4	.9	6	1.2
2077	Animal, Marine Fats and Oils	7-10	7.7	23	28.7
3275	Gypsum Products	4-6	10.1	143	193
2075	Soybean Oil Mills	3-4	9.9	50	95.3
2046	Wet Corn Milling	2-10	11.4	457	1012
2082	Malt Beverages	2-6	2.2	244	101
2022	Natural and Processed Cheese	5	5.0	2	.55
2023	Condensed and Evaporated Milk	4-5	4.2	26	18.2
2033	Canned Fruit and Vegetables	1-6	2.6	2	.28
2034	Dehydrated Fruits and Vegetables	4-5	4.0	106	No Data

*Based on Ref. 38

and vegetable canning, the modal-sized establishment is indicated to have only two production workers on the average. However, these represent the best data available to this study.

Data on the total energy consumed by an industry, and the total number of production workers in that industry, both from Ref. 38, permit the computation of the national average energy consumption per production worker. The average number of production workers per modal-sized establishment permits estimation of the national average energy consumption of such establishments in each industry of interest. This characteristic is also shown on Table III-74.

Table III-75 shows the six top ranking industries when measured against the three characteristics discussed above. Five of these top six industries appear in every column. These five industries were examined in greater detail with respect to the remaining screening criteria.

3.3.3.5 Process Details

As has already been discussed, a recent InterTechnology Corporation (ITC) report (Ref. 41) provides information on process details as well as process heat requirements at several temperature levels up to 550°F. This report treats the three industries in the pulp and paper group (SIC 2611, 2621, 2631) as a unit. The major process steps in this industry group and the associated approximate process heat temperatures are:

Digestion .... 370°F
Pulp Refining........... 150°F
Black Liquor Treatment... 280°F
Pulp and Paper Drying.... 290°F
Chemicals Recovery.......1900°F

Electrical energy usage is primarily for log handling and chips preparation and for in-process transport, such as for conveyor and pump operation. The quantities of process heat required by the entire industry at temperatures permitted to PTES are given by ITC for the year 1976 as follows:

Table III-75. Ranking of Industries by Three Characteristics, Listed by SIC Code*

Rank	By Percentage of Energy Value in Total Value Added	By Modal Establishment Size**	By Average Energy Consumption of Modal Establishment
1	2631	2046	2046
2	2621	2611	2611
3	2611	2082	2631
4	2046	3275	2621
5	3275	2621	3275
6	2075	2631	2082

Legend

2046 - Wet Corn Mills
2075 - Soybean Oil Mills
2082 - Malt Beverages
2611 - Pulp Mills
2621 - Paper Mills
2631 - Paperboard Mills
3275 - Gypsum Products

* Based on Ref. 38

** Measured for ranking purpose in numbers of production workers per establishment.

Up to and including 150°F......		208×10^{12} Btu
At about 300°F.................		652×10^{12} Btu
At about 400°F.................		301×10^{12} Btu
	Total	1161×10^{12} Btu
		(340×10^{9} kWh)

This figure represents about 80% of the total process heat requirement of 1470×10^{12} Btu (430×10^{9} kWh).

The two major steps requiring process heat in the gypsum products industry (SIC 3275) are:

Calcining at about 320-340°F

Plaster Board Drying...300°F

Electrical energy is used for crushing mined gypsum rock, for screening and grinding, and for conveyor and stirrer operation. The quantities of process heat as given by ITC are:

Up to and including 300°F		7.5×10^{12} Btu
At about 350°F		9.9×10^{12} Btu
	Total	17.4×10^{12} Btu
		(5.1×10^{9} kWh)

This figure represents about 83% of the total process heat requirement of 20.9×10^{12} Btu (6.1×10^{9} kWh).

For wet corn milling (SIC 2046), the ITC report indicates process steps and associated process heat temperatures as follows:

Steeping	115-125°F
Steepwater Evaporation ..	212-350°F (or steam at line pressure)
Germ Drying	212-350°F
Fiber Drying	212-350°F
Starch Drying	below 144°F

Electric energy is used for cleaning of incoming corn, for the degermination mill, for mechanical dewatering of the corn germ for oil extraction, for breaking up starch slurries with hammer mills, for fiber sieving, and for starch and gluten separation operations.

The quantities of process heat at temperature levels permissible to PTES are given by ITC as:

Up to and including	150°F......	0.77×10^{12} Btu
At about	250°F......	2.74×10^{12} Btu
At about	300°F......	1.89×10^{12} Btu
At about	350°F......	10.10×10^{12} Btu
	Total	15.50×10^{12} Btu
		(4.5×10^{9} kWh)

This figure represents about 84% of the total process heat requirement of 18.4×10^{12} Btu (5.4×10^{9} kWh).

3.3.3.6 Location Factors

The selection of promising industrial PTES applications would be aided by knowledge of the geographic distribution of energy consumption within a given industry. The Census of Manufactures does not, however, indicate energy consumption by state or smaller area at the four-digit SIC code level. Although a figure for the national average energy consumption per production worker in an industry can be obtained from the Census, the data on the number of production workers per state at the four-digit level are incomplete for most industries, so that this method of estimation is not feasible. A qualitative indication of industry concentration by geographic area is available from the Census in the form of a listing of the number of establishments within a four-digit industry in every state. A further data refinement separately shows the number of establishments with 20 or more production workers. Figures III-9 through III-13 show the distribution of such establishments for the five industries selected earlier in the study. It must be understood, however, that the distribution of establishments will not accurately represent the distribution of energy consumption, which is, of course, related to the size of these establishments.

The previously discussed ITC report (Ref. 41) shows 1975 production by state for pulp mills, SIC 2611. For gypsum products, SIC 3275, the same reference provides 1974 energy consumption estimates by state. Since energy consumption is closely proportional to production, Table III-76, in showing pulp production by state, is also indicative of energy consumption for this

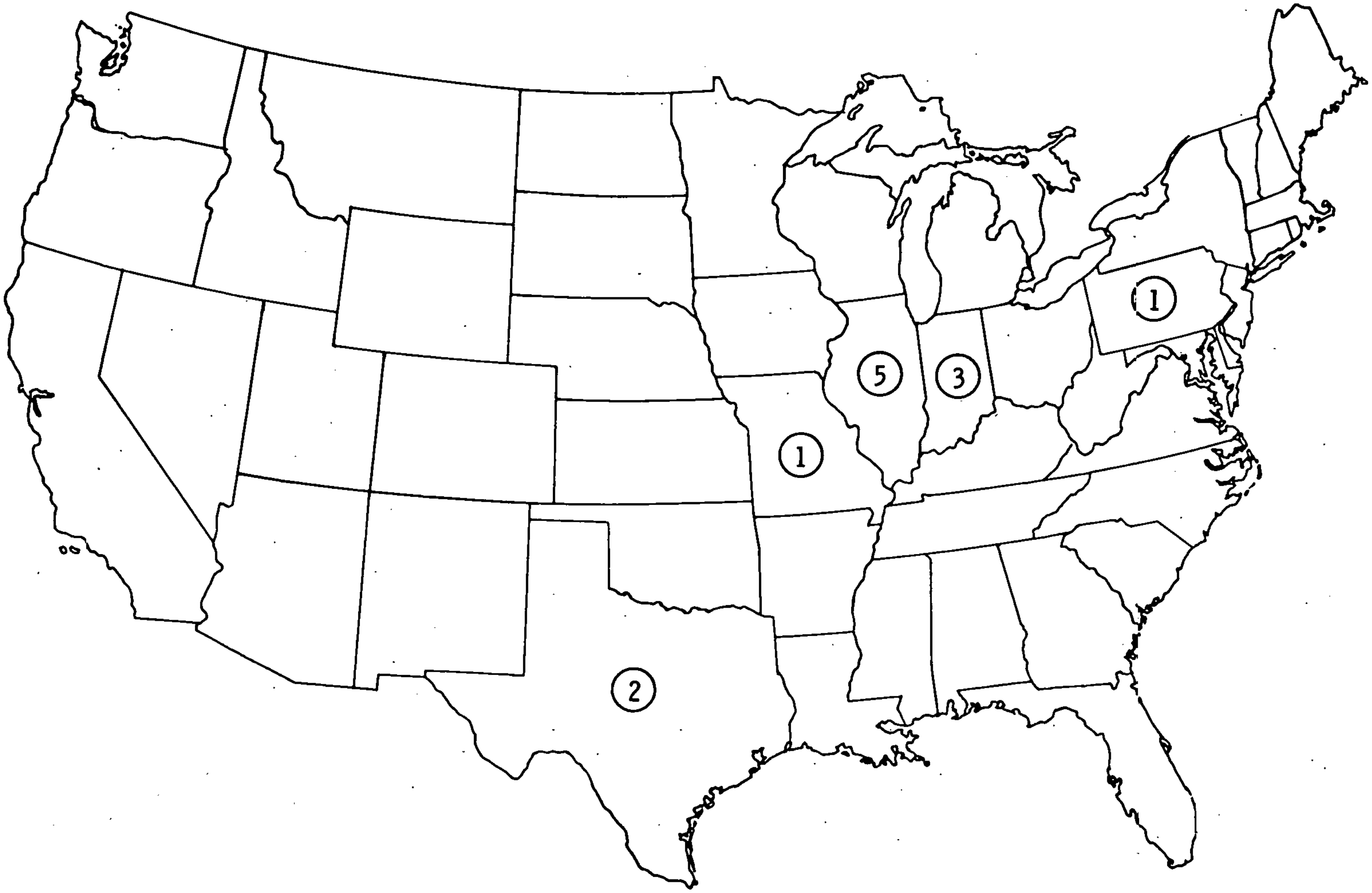


Figure III-9. 2046 Wet Corn Milling
1972 Distribution by State of Mills Employing
More Than 20 Workers
(number of mills per state in circle)

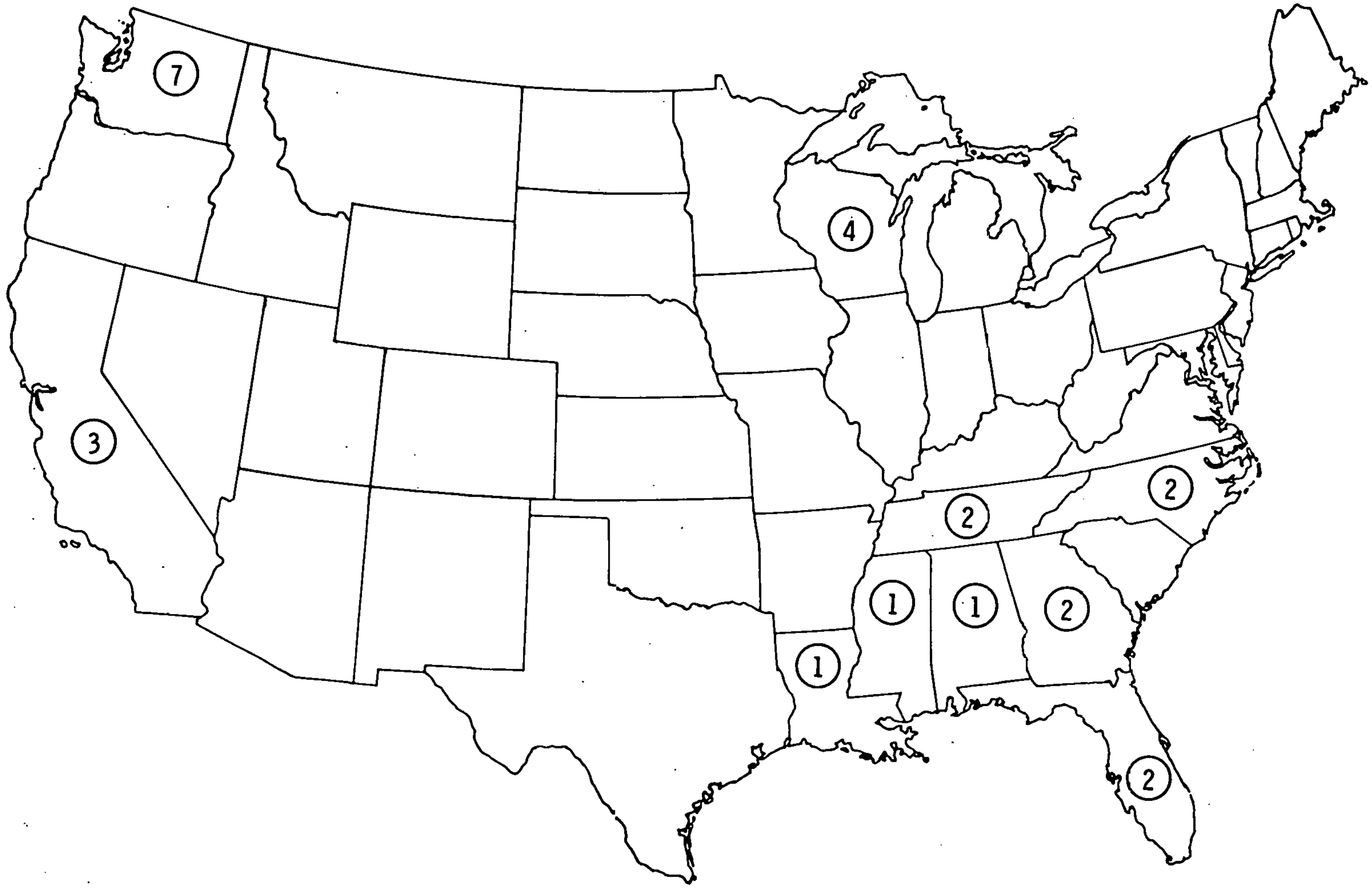


Figure III-10. 2611 Pulpmills
1972 Distribution by State of Mills Employing
More Than 20 Workers
(number of mills per state in circle)

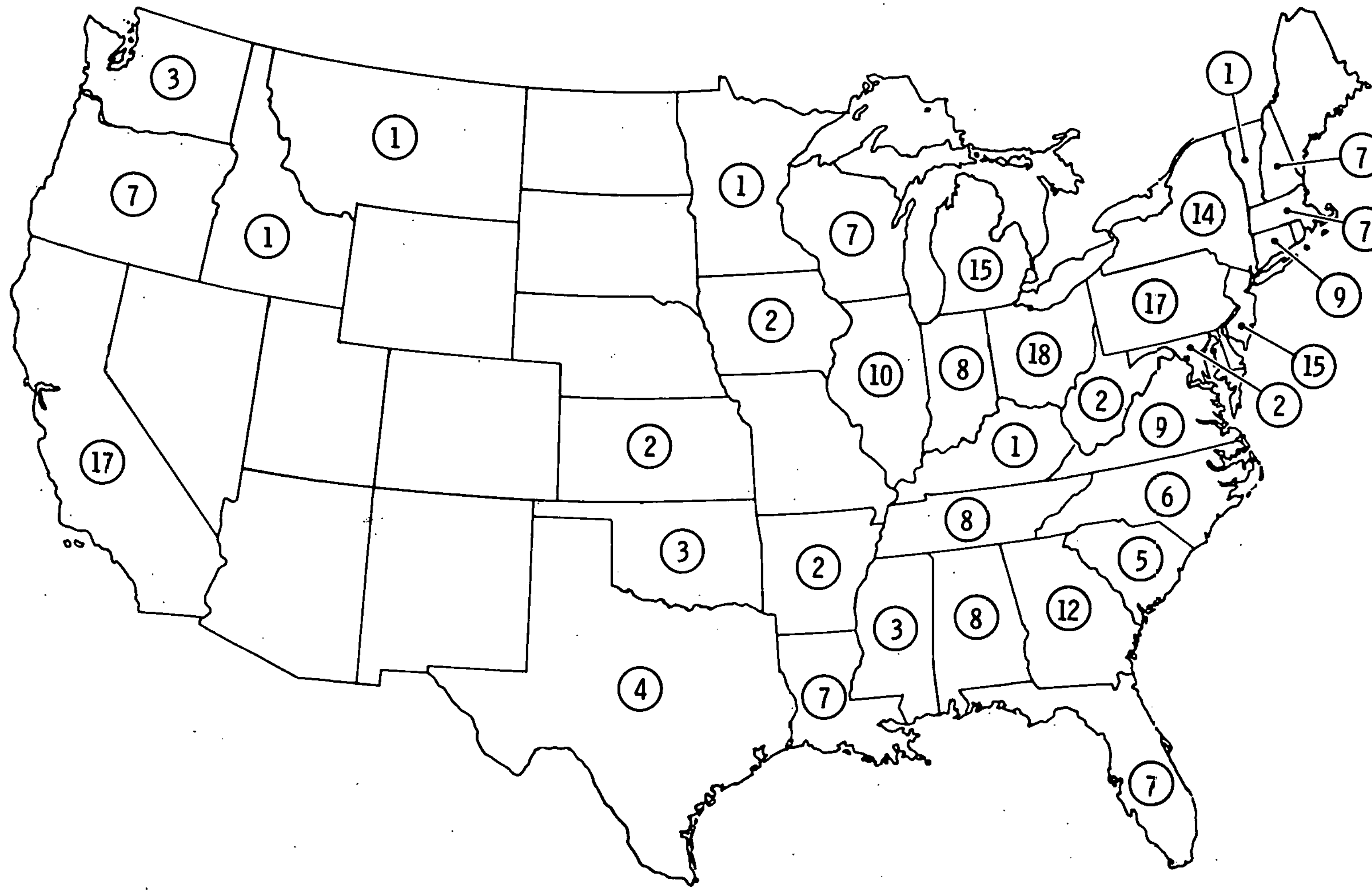


Figure III-11. 2631 Paperboard Mills
1972 Distribution by State of Mills Employing
More Than 20 Workers
(number of mills per state in circle)

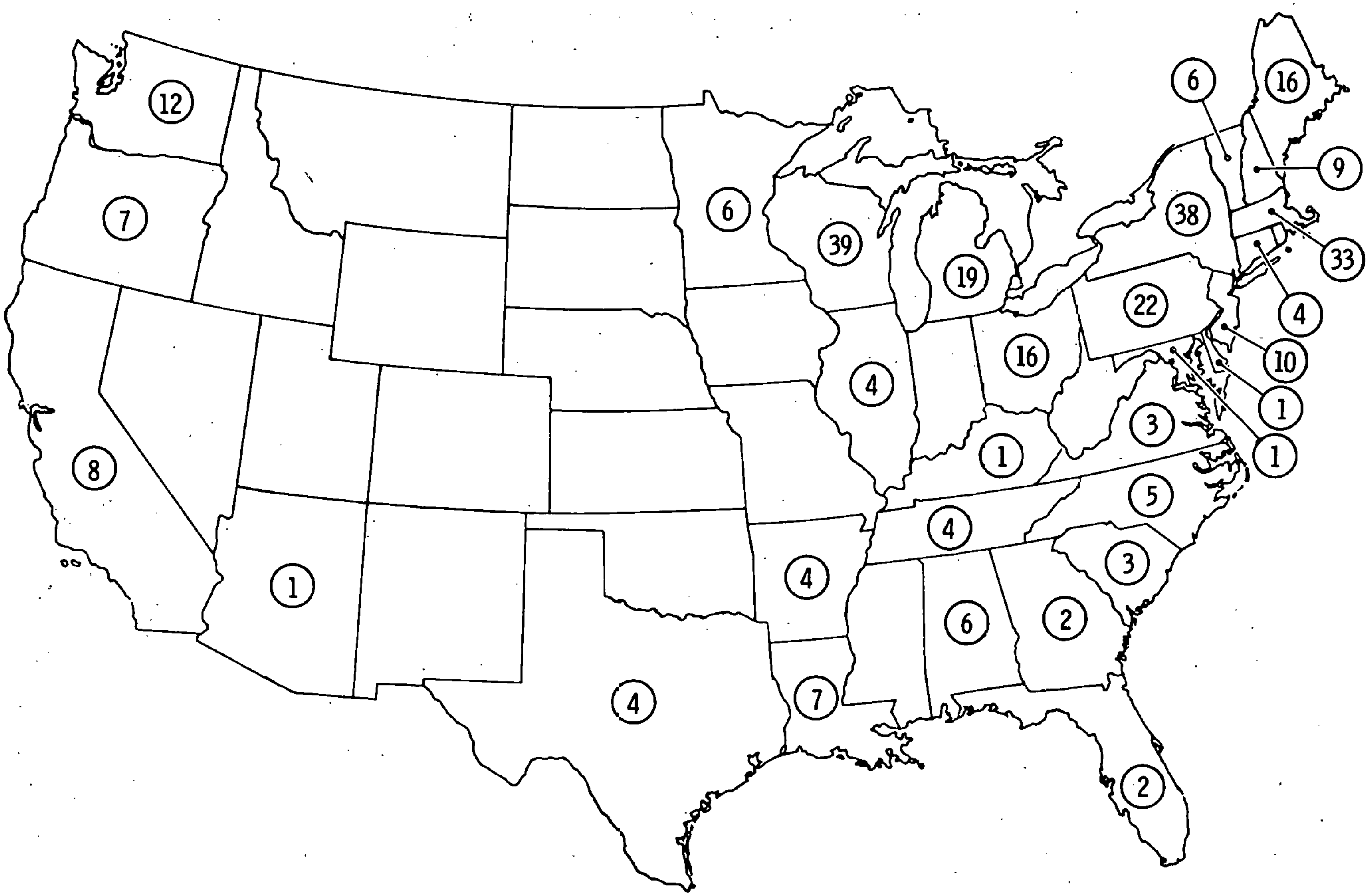


Figure III-12. 2621 Paper Mills
1972 Distribution by State of Mills Employing
More Than 20 Workers
(number of mills per state in circle)

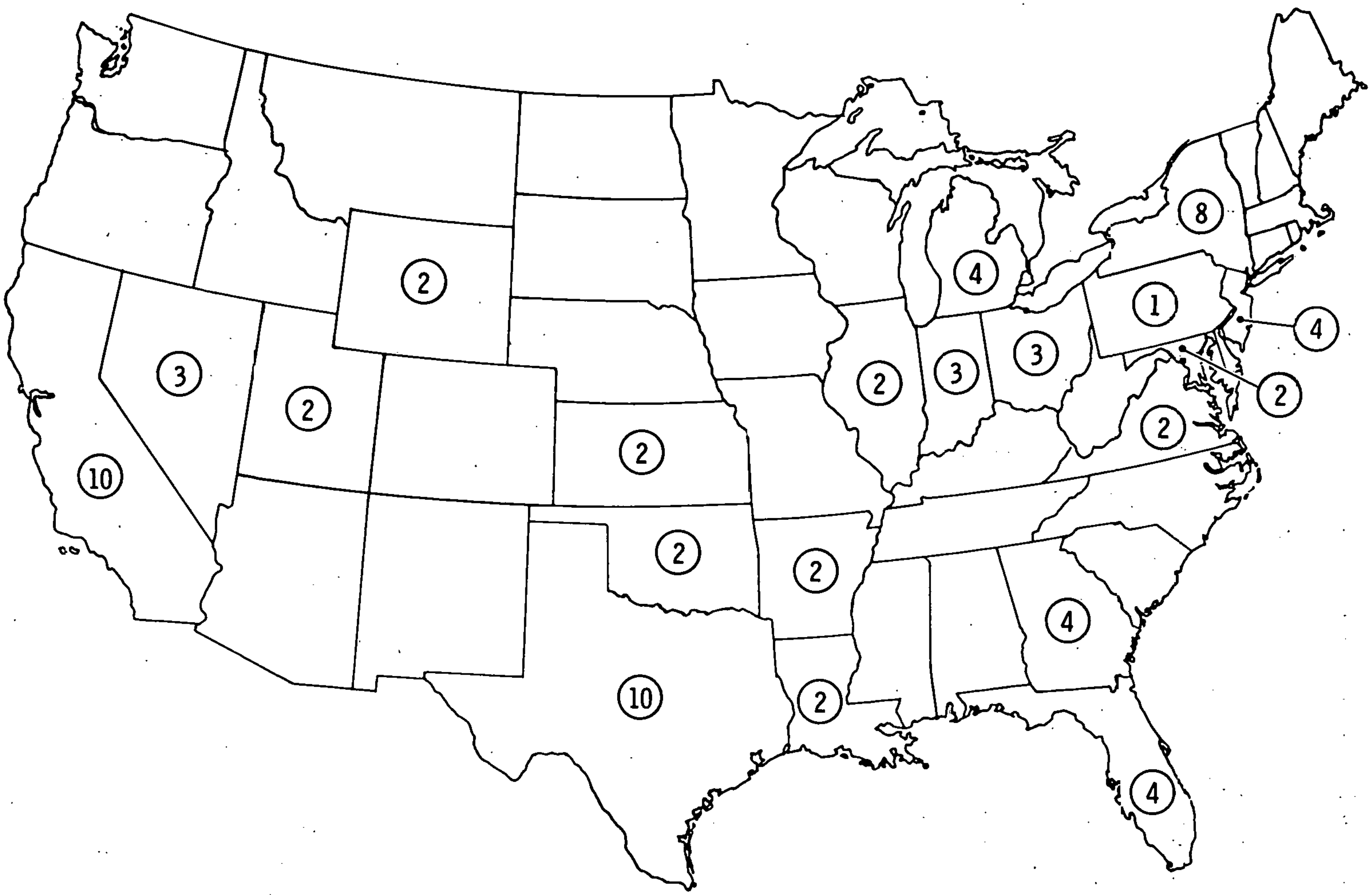


Figure III-13. 3275 Gypsum Products
1972 Distribution by State of Establishments Employing
More Than 20 Workers
(number of establishments per state in circle)

Table III-76. Production of Pulp by States in 1975*

State	Pulp Production (in 10^3 Tons) Total	Rank
Alabama	3, 343.78	2
Alaska	171.82	31
Arizona	222.82	30
Arkansas	1, 511.74	14
California	899.09	18
Colorado	33.82	36
Connecticut	166.45	32
Delaware	--	
D. C.	--	
Florida	2, 327.62	5
Georgia	3, 818.98	1
Hawaii	--	
Idaho	255.04	27
Illinois	134.23	33
Indiana	233.56	29
Iowa	96.65	34
Kansas	26.85	38
Kentucky	354.37	23
Lousiana	3, 252.51	3
Maine	2, 143.72	8
Maryland	237.59	28
Massachusetts	38.92	35
Michigan	1, 079.23	16
Minnesota	670.62	20
Mississippi	2, 182.65	7
Missouri	16.10	39

*Ref. 41

Table III-76. Production of Pulp by States in 1975*
(Continued)

State	Pulp Production (in 10^3 Tons) Total	Rank
Montana	322.16	25
Nevada	--	
New Hampshire	338.53	24
New Jersey	257.19	26
New Mexico	--	
New York	903.25	17
N. Carolina	1,769.20	11
N. Dakota	--	
Ohio	617.47	21
Oklahoma	702.04	19
Oregon	2,294.86	6
Pennsylvania	529.41	22
Puerto Rico	33.55	37
Rhode Island	--	
S. Carolina	1,865.31	9
S. Dakota	--	
Tennessee	1,111.44	15
Texas	1,750.41	12
Utah	--	
Vermont	13.42	40
Virginia	1,821.54	10
Washington	2,959.87	4
W. Virginia	--	
Wisconsin	1,638.18	13
Wyoming	--	
Totals	42,141.49	

*Ref. 41

industry by state. Out of the top ten producing states, 72% of the pulp is manufactured below the 39th parallel. Of all of the states listed in Table III-76, 64% of the pulp is produced below the 39th parallel, i.e., in regions receiving higher than U.S. average insolation. It is of interest to note the disparity in the data of Fig III-10 and Table III-76. The former is based on the Census of Manufactures (Ref. 38) which tends to omit listings of establishments of less than 10 employees from its geographic distribution tables and thus shows only 10 states containing pulp mills. Table III-76 (based on Ref. 41), on the other hand, shows a total of 40 states producing pulp. Whether this disparity is due to the inclusion of establishments neglected by the Census because of small size, or other reasons, is not clear. Although similar data are not available for SIC 2621 and SIC 2631, paper and paperboard manufacture is usually close to the source of pulp. It is therefore believed reasonable to assume similar fractions of energy consumption in high insolation regions for these latter industries.

The situation appears to be reversed in the instance of gypsum products, as shown on Table III-77, which directly relates energy consumption to mill location by state. Only 42% of the total energy consumption of this industry occurs in states below the 39th parallel.

Other location factors previously discussed in relation to residential and commercial building applications, such as distribution of establishments between central city and suburban or rural locations, are perhaps even more important in industrial applications because the higher energy consumption of industrial processes makes a requirement for collector area excess to building roof area much more likely. These factors can only be treated qualitatively in this screening analysis which did not permit the in-depth research necessary for a more detailed location definition. However, the nature of the five selected industries allows the qualitative conclusion that their establishments would most likely be located in rural or near-rural areas in smaller communities. Pulp and paper mills are generally located near wood resources, corn milling is done near corn

Table III-77. 1974 Energy Used in Production of Calcined Gypsum (Stucco) and Wallboard*

	Estimated Energy Consumption	
	10^9 Btu	Rank
Arizona	85	13
Arkansas	172	11
California	749	1
Colorado	85	13
Connecticut	85	13
Delaware	85	13
Florida	365	6
Georgia	430	5
Illinois	85	13
Indiana	257	8
Iowa	598	4
Kansas	172	12
Louisiana	172	12
Maryland	172	12
Massachusetts	85	13
Michigan	295	7
Montana	85	13
Nevada	256	9
New Hampshire	85	13
New Jersey	365	6
New Mexico	172	12
New York	636	3
Ohio	253	10
Oklahoma	172	12
Pennsylvania	85	13
Texas	731	2
Utah	172	12
Virginia	172	12
Washington	85	13
Wyoming	172	12
U.S. Total	7333	

*Ref. 41

production areas, and gypsum product plants are also located near raw material sources and tend to be removed from residential areas due to environmental considerations. Thus it can be assumed with reasonable certainty that land for additional collector area excess to roof area would be available to these industries.

Location criteria also include the cost of conventional energy in those geographic regions in which the industries are located, as well as the energy level available from insolation in those areas. Table III-78 provides FEA industrial price projections for 1990 by FEA Demand Region for the energy sources commonly used by industrial customers. Figure III-14 defines these FEA regions. Table III-79 shows the distribution of energy consumption by fuel type used in calculating the thermal energy prices listed in Table III-80, also as a function of FEA Demand Region. Figs. III-8 through III-13 and Table III-69 permit estimation of available energy, both thermal and electric, in each state for the five industries selected. K factor values (see section 3.1.3 for an explanation of K factor) computed from this data base for the five selected industries are shown in Table III-81. These represent weighted averages of the factors derived for each state, with the number of establishments per state as the weighting parameter.

3.3.3.7 Phase Relationships

The three industries in the pulp and paper group combine both batch and continuous processes. The preparation of logs for chipping, the chipping operation itself, and the chip digestion operation are generally batch processes. The preparation of the paper or paperboard from the pulp can be either a batch or continuous process, with the latter predominant in current practice. No information was obtained concerning the number of shifts with which such plants are generally operated.

Wet corn milling is generally a continuous process, running in most plants at 3 shifts per day and 7 days per week.

Table III-78. 1990 Industrial Energy Prices in $/Million Btu*

FEA Region	Electric	Natural Gas	Distillate Oils	Residual Oils	Liquefied Gas	Coal
New England (I)	13.7	3.9	3.63	3.1	3.9	1.9
N. Y. /N. J. (II)	9.6	3.2	3.68	3.2	4.0	1.8
Mid Atlantic (III)	10.8	3.0	3.82	3.3	4.2	1.7
South Atlantic (IV)	10.0	2.7	3.8	3.0	4.2	1.9
Midwest (V)	10.4	3.0	3.6	3.2	3.8	1.6
Southwest (VI)	12.5	3.2	3.6	3.1	3.9	1.6
Central (VII)	10.3	3.3	3.5	3.2	3.8	1.6
North Central (VIII)	8.7	3.1	3.7	3.4	3.8	1.3
West (IX)	11.2	3.1	3.6	3.1	3.9	1.7
Northwest (X)	5.8	3.7	3.6	3.1	3.9	1.8

*From Ref. 30, FEA PIES Projection

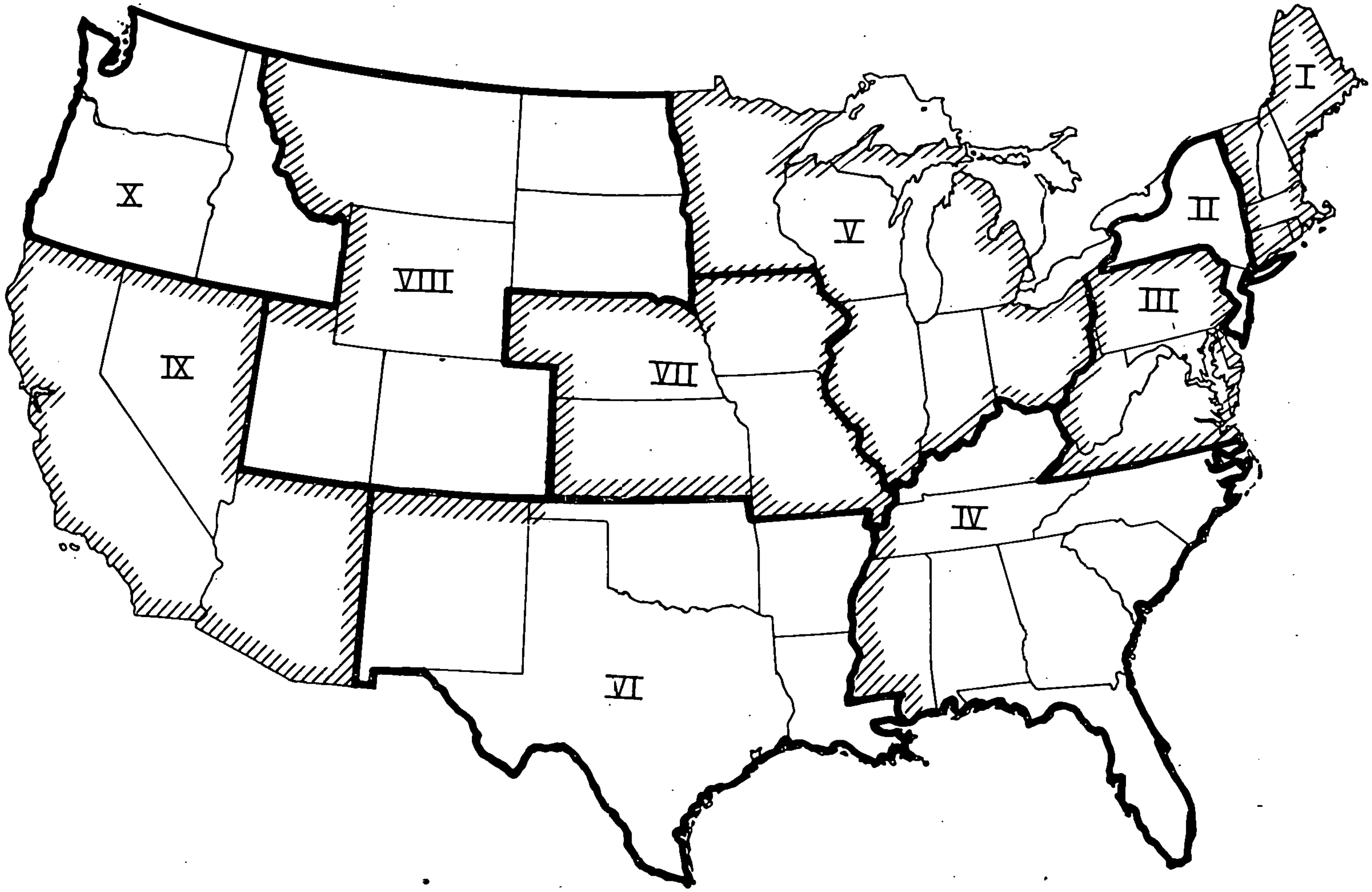


Figure III-14. FEA Regions for Energy Cost Data

Table III-79. 1985 Industrial Energy Consumption in Fractions by Fuel Type*

FEA Region	Electricity	Natural Gas	Distillate Oils	Residual Oils	Liquefied Gas	Coal	Metallurgical Coal	Other
New England (I)	.295	.284	.021	.084	.038	.217	.000	.062
N. Y. /N. J. (II)	.216	.180	.000	.000	.000	.322	.100	.183
Mid Atlantic (III)	.166	.106	.000	.000	.000	.312	.339	.077
South Atlantic (IV)	.311	.260	.014	.013	.010	.287	.083	.022
Midwest (V)	.169	.248	.002	.001	.003	.278	.203	.096
Southwest (VI)	.078	.454	.017	.062	.020	.142	.004	.223
Central (VII)	.178	.431	.037	.010	.081	.168	.010	.086
North Central (VIII)	.099	.255	.034	.027	.008	.424	.121	.031
West (IX)	.133	.367	.023	.009	.028	.189	.030	.222
Northwest (X)	.261	.338	.085	.015	.007	.246	.000	.047

*Based on Ref. 31, FEA PIES Projection

Table III-80. 1990 Industrial Energy Prices in $/Million Btu

FEA Region	Electric	Thermal
New England (I)	13.7	3.11
N.Y./N.J. (II)	9.6	2.30
Mid Atlantic (III)	10.8	2.03
South Atlantic (IV)	10.0	2.36
Midwest (V)	10.4	2.28
Southwest (VI)	12.5	2.89
Central (VII)	10.3	2.97
North Central (VIII)	8.7	2.13
West (IX)	11.2	2.73
Northwest (X)	3.8	3.00

Table III-81. Total Energy (PTES) K Factors for Five Selected Industries, Weighted Averages

SIC Code	Industry	K Factors* 10^{-3} \$/ft^2/Day
3275	Gypsum Products	3.59
2631	Paperboard Mills	3.21
2611	Pulp Mills	3.17
2621	Paper Mills	3.09
2046	Wet Corn Milling	2.52

*Based on 1990 Energy Price Forecasts (PIES Model), six Performance Regions (Ref. 41) and weighted by number of establishments of each industry per state. Area units in K are floor area reduced to collector area by a 60% collector packing fraction.

Gyspum products are produced in a batch process. Whether or not more than one shift operation is practiced is generally more a question of demand for the product rather than a requirement of the process.

3.3.3.8 Reliability Requirements

No quantitative information concerning permissible outages in the five selected industries was available. As with most industrial operations, however, it can be assumed that unscheduled outages are costly and must be avoided. Reliability requirements will therefore be high for all of the selected industries, and energy storage as well as backup energy sources are a likely requirement. This will be particularly true for continuous processes.

3.3.3.9 Energy Demand Level

The average energy demand level of the modal-sized establishment in each of the five selected industries has already been discussed in connection with Table III-74. The largest average plant energy consumption for modal-sized units appears to occur in wet corn mills, followed by pulp mills, paperboard mills, paper mills, and finally gypsum product factories. However, actual consumption is considerably larger in the pulp and paper industry because that industry is accustomed to utilize much of its waste materials, such as wood residues and black liquor, for generation of steam for both process heat and generation of electric power. This tendency towards in-plant generation of electricity and use of waste products for process heat supply is expected to intensify with increasing cost of purchased fuels and electricity. Quantitative data on energy generated from wastes were not available. The data in Table III-74 are, however, useful in comparing potential PTES applications since the PTES is intended to displace purchased energy.

3.3.3.10 Data Specific to Non-PTES Application

The constraints on suitable industrial PTES candidates as a result of limits on process heat temperatures and T/E ratios, and the data available on growth rates, aided in reducing the number of potential candidates to manageable size for final screening. These constraints are absent in the instance of purely electric applications. The data base for screening such applications is also less extensive than was the case for PTES applications. Only four selection criteria could be readily supported from the available data in the literature reviewed by this study. These were the total quantity of electric energy used (equivalent to market size), the quantity of electric energy generated in-house, the value added in cost of electric energy during manufacture, and the demand level of the typical establishment. The use of the in-house generation criterion rests on the assumption that an industry which already generates in-house some of the electricity it uses will be more receptive to additional in-house generation from unconventional sources such as solar. This receptivity may be due to financial reasons, i.e., cost, or to the fact that an independent power source is important to a particular industry, or both. The existence of proprietary conventional generating capacity may also be an asset if solar power is adopted, since it can provide standby or backup generating capacity without new investment. If one makes the assumption that growth in electrical consumption parallels that of process heat, a fifth criterion, that of market growth, can also be used.

Table III-82 shows quantitative data of use in screening the five selected candidates as potential purely electric PV applications. These industries were selected from Table III-69 on the basis of possessing not only large in-house power generation capacity but also of having the closest match between in-house generating capacity and purchased electric power. Three of these industries, SIC 2631, 2046, and 2063, are shown to generate more power in-house than is purchased from the grid. However, the quantities shown on this table include power generated only from purchased fuels as shown in the 1974 Annual Survey of Manufactures (Ref. 39). When power generated from waste materials is added, in-house power may well exceed that purchased from the grid by a larger margin, and the remaining two industries, SIC 2611 and 2621, may also be found to generate more power than they purchase.

Of particular interest is the fact that four of these industrial PV (electric only) candidates are the same as those selected for PTES

Table III-82. Industries with Closest Match Between Purchased Electric Energy and Generated (Less Sold) Energy

	SIC Codes (2)				
	2621	2631	2611	2046	2063
Quantity of Purchased Electric Energy, kWh x 10^6/yr, 1974	18,495	9,847	2564	1113	197
Quantity of Generated Electric Energy (Less Sold), 1974, kWh x 10^6/yr (1)	13,033	11,989	2015	830	446
Total, kWh x 10^6	31,529	21,825	4579	1943	643
Total, Btu x 10^{12}	108	75	16	6.6	2.2
Total Value of Electric Energy Used, \$ x 10^6 yr, 1972	235	145	31.7	14.4	7.6
Total Value Added During Manufacture, \$ x 10^6 yr, 1972	2,909	1,995	307	331	311
Percent of Electric Energy Value in Value Added, %, 1972	8.1	7.3	10.3	4.3	2.4
Average Number of Production Workers in Modal Size Establishment, #1972	129	126	270	457 (3)	148
Electric Energy Usage by Modal Sized Establishment, kWh x 10^6/yr, 1972	37	39.6	155	81.8	8.4

Data Sources: Ref.(38), Ref.(39)

Note (1) Generated from purchased fuels. That amount additionally generated from waste materials may be sizable, but its value is not readily available

Note (2) 2621 Papermills
2631 Paperboard Mills
2611 Pulpmills
2046 Wet Corn Milling
2963 Beet Sugar Refining

Note (3) Next to Modal. Insufficient Data for True Modal Size application. This coincidence may be due to the fact that industries requiring low-temperature process steam have an added incentive for in-house power generation since their process heat requirement can be met, in part, by the exhaust steam from the turbines powering their generators. Thus, there exists some indirect overlap in the screening criteria for PTES and PV, i.e., a search for large consumers of low temperature process heat also identifies industries with economic justification for in-house power generation.

The base years for some of the data entries on Table III-82 differ by 3 years as a result of the need to use different references for these data items. The 1974 Annual Survey of Manufactures (Ref. 39) was the source of the data on the first two rows of this table, while the 1972 Annual Census of Manufactures (Ref. 38) had to be used to derive the data on the remaining rows.

The discussion of energy density match, phase relationships, and reliability in connection with the PTES candidates, also applies to the electric-only PV industrial candidates. This is not true, however, in the case of the K_e factors, which differ because of the absence of the thermal energy price component. Table III-83 contains weighted K_e factors for the five candidate electric-only applications, as determined on the basis of the electricity price and the insolation level for each state in which plants are located. As in the instance of PTES applications, the weighting is based on the number of establishments per state. Locations of SIC Code 2611, 2621, 2631, and 2046 establishments have already been shown on Figures III-9 to III-12. Locations for SIC 2063, beet sugar, are shown on Fig. III-15.

Table III-83. Electric-Only K_e Factors for Five Selected Industries

SIC Code	Industry	Weighted Averages: K_e Factors 10^{-3} \$/ft^2-Day
2046	Wet Corn Milling	1.55
2631	Paperboard Mills	1.48
2621	Paper Mills	1.42
2063	Beet Sugar Refining	1.39
2611	Pulp Mills	1.35

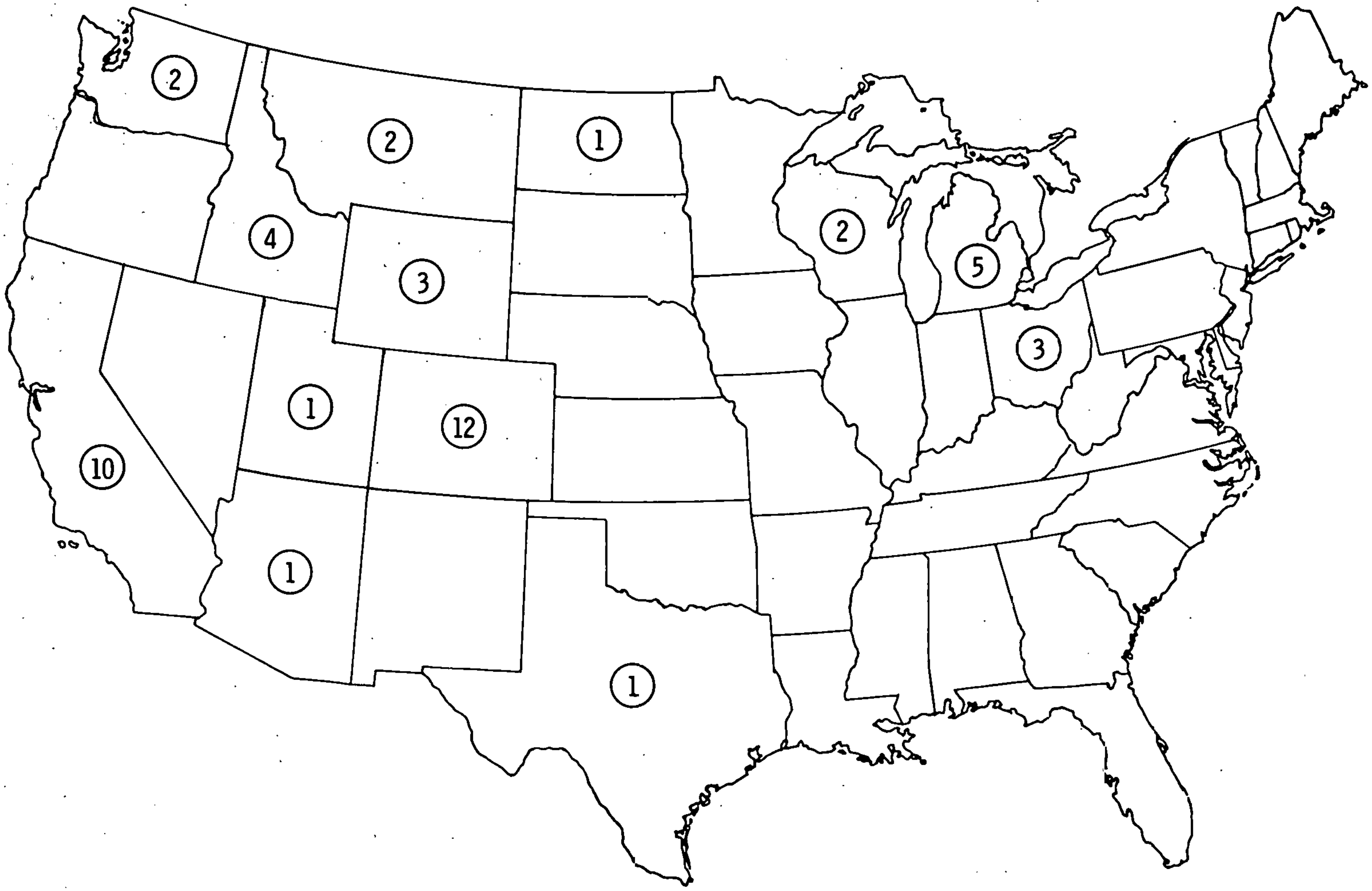


Figure III-15. 2063 Beet Sugar
1972 Distribution by State of Establishments Employing
More Than 20 Workers
(number of establishments per state in circles)

3.4 AGRICULTURAL SECTOR

3.4.1 Quality of Data

Much statistical and engineering information is available for the agricultural sector. The Agricultural Extension Service of the USDA, the many agricultural experiment stations associated with universities and agricultural colleges, and the various societies and professional associations concerned with agricultural engineering and science have conducted massive research and experimentation and produced extensive publication of relevant material, including information on applications for solar thermal systems. The Census of Agriculture (Ref. 42) also provides good statistical information on the physical and financial characteristics of farms, on inventories of livestock, and on land use. It does not, however, contain information on energy consumption except in terms of dollars expended on total purchases of various fuels, without any discrete allocation to individual crop or livestock operations. The Census also does not allocate these expenses on any chronological scale except as totals for the year covered by the Census. Summaries of energy consumption for various agricultural operations can be found in a data base (Ref. 43) developed by the FEA in cooperation with the US Department of Agriculture for 1974 (and later also for 1976). These summaries are prepared by state and by commodity but provide monthly energy consumption profiles only for irrigation. Additional chronological data for some of the other operations can be obtained from a data tape available from the USDA which was the source tape for Ref. 43. Other agricultural energy consumption data, segregated by agricultural operation type, can be obtained from so-called crop budgets prepared by various state extension services as well as by the University of Oklahoma's Firm Enterprise Data System (FEDS). These budgets are available for various crops and types of livestock and often show expenditures for fuel and electricity on a monthly basis. However, they show these data for hundreds of crop production areas and sub-areas because of the unique conditions associated with each area. Energy consumption in physical or in energy units would have to be derived from listed costs with the aid of conversion factors based on local energy prices. Additionally, many papers in the literature describe studies or experiments involving energy consumption in various farm operations but are usually referenced to specific areas only. They thus often reflect unique conditions from which it is difficult to drive national statistics or engineering coefficients applicable throughout the country.

The data problem associated with screening the agricultural sector for suitable applications is thus not one of scarcity but of great variety in the data which are available. Energy consumption of farm operations are affected by many variables which differ from county to county as well as for different cropping areas within counties. Soil conditions, water tables, weather, traditional practices, newly developing practices, local market conditions, local costs of supplies, equipment and energy sources all combine to make the state summaries in the FEA/USDA data base (Ref. 43) inaccurate for individual farms within these states and, conversely, prevent the extension of many conclusions drawn from the examination of data for specific cropping areas to the national scene. For example, in a particular cropping area the drying energy consumption may actually exceed irrigation energy consumption because rainfall is high, irrigation is minimum, and harvesting is done early, with the grain still at high moisture content in order to meet local market conditions. In another region in the same state, which is more arid than the former, irrigation is heavy and harvesting may occur later. Thus the grain moisture content is low and drying may be accomplished with ambient air circulation with a relatively low expenditure of energy. Similar degrees of variation apply to other crop and livestock operations.

Several tables illustrate data dependence on location and the specific soil, weather, and agricultural practice variables associated with location. Table III-84 summarizes the U.S. irrigation energy consumption in Btu/acre for the crops requiring the most irrigation. One cannot draw the conclusion, however, that alfalfa is the largest consumer of irrigation energy per acre in this country. Table III-85 shows, that, in the state of Texas, rice requires more irrigation per acre than alfalfa. This table also clearly illustrates the location dependence of irrigation requirements for

Table III-84. U.S. Irrigation Summary by Commodity, 1974*

Crop	Total Irrigation Energy, Btu × 10^9	Acres Irrigated (in 1,000)	Btu/Acre (in 1,000)
Corn	45,732	5,716	8,000
Grain Sorghum	36,347	3,516	10,338
Cotton	31,238	4,215	7,411
Alfalfa	29,803	2,611	11,416
Winter Wheat	20,213	2,724	7,420
Rice	15,084	2,339	6,448
Hay	10,693	1,360	7,863

*Ref. 43

Table III-85. Energy for Irrigation, Variation Among States in 1974, in Btu x 10^3/Acre/Year*

	Corn	Grain Sorghum	Cotton	Alfalfa	Winter Wheat	Rice	Hay
Texas	10,238	10,238	7,678	12,795	7,679	15,356	-
Nebraska	7,180	5,409	-	7,846	3,243	-	6,492
Kansas	12,134	8,824	-	12,682	4,963	-	10,437
Arizona	23,408	19,595	27,482	31,857	17,785	-	15,720
New Mexico	28,026	20,810	27,482	38,581	18,552	-	35,257
California	4,150	3,452	4,851	5,429	1,398	1,382	2,776

Ref. 43

other crops. In the instance of alfalfa, the number of cuttings per year is also a variable with location. Table III-86 shows variations in corn drying practice, both within the state of Iowa and between neighboring states. Table III-87 indicates the effect of drying method on energy requirements. It compares the heated air method with alternatives in which heat energy is used to remove only part of the moisture, with ambient air circulation allowed to remove the remainder. The penalty for the lower energy consumption of the combined method is a considerably longer dryer through-put time, which is costly because of larger bin capacity. The combined method is obviously more suited for PTES application, as revealed by the T/E ratios.

Table III-86. Methods of Drying of Corn, Iowa and Selected States, 1976*

In Percent of Harvest

	Naturally	Supplemental Heat, On-Farm	Supplemental Heat, Off-Farm
Iowa Districts			
North Central	23.9	74.6	1.5
West Central	34.4	65.2	0.4
East Central	29.3	68.7	2.0
South Central	34.0	64.5	1.5
Iowa Average	29.3	68.9	1.8
Illinois Average	13.0	85	2.0
Indiana Average	11.8	86.6	1.6
Wisconsin Average	44.8	52.9	2.3

*Ref. 44

Table III-87. Energy Comparisons for Various Methods of Corn Drying*

	Energy Consumption, Btu per Bushel				
Moisture Content (1)	High Temperature Dryer		Bin Dryer	Total Energy	Thermal/ Electric Ratio
	Heat	Fan	Fan (2)		
28-15	32,500	700	-	33,200	46
28-24-15	9,400	200	7,700	17,300	1.2
28-22-15	13,500	300	7,300	21,100	1.8
28-20-15	18,000	400	5,600	24,000	3
28-18-15	23,100	500	200	23,800	33

(1) First 2 digits indicate moisture content at harvest; next two indicate moisture content after completion of high temperature drying; final two digits indicate moisture content reached prior to storage.

(2) Equivalent energy for electric fan to cool and complete drying at 1 cfm/bushel.

*Ref. 45

Since much of the engineering data reported in the literature concerning agricultural energy consumption are empirical and were derived in the context of local conditions, little comparison of data is possible. The bibliography associated with this report section exemplifies the large size and diversity of the agricultural data base.

Because of this data variability, the screening procedure used for the other economic sectors could not be applied. Instead, available data were reviewed to explore potential areas of applicability of photovoltaics in agriculture and to define the scope of further, more detailed analyses. Such analyses will be required in order to gain a better understanding of the parameters which will influence decisions concerning photovoltaic applicability. Also, because of the variability of the data base, exploration and definition will be confined to a few examples which are typical only of the areas in which they are located. Extension of the data thus developed to the national level will be difficult. Such national statistics probably would require a methodology similar to that used in developing the FEA/USDA data base (Ref. 43), i.e., the summing of data points derived for hundreds of individual production areas. However, even the resources of the FEA and USDA, were apparently too little to acquire sufficient data points to achieve this objective. Detailed examination of the source data tape for Ref. 43 disclosed, for example, the absence of drying data for several crops in several states.

3.4.2 Baseline Data and Sources

A number of sources agree that, among on-farm energy consuming operations, irrigation ranks next to mobile operations, i.e., those operations which are performed by tractors, combines, and trucks. The FEA/USDA data base (Ref. 43), on which Table III-88 is based, contains information which confirms this fact. This table also shows that energy consumed in plants manufacturing fertilizers and pesticides exceeds that for any crop operation. When this energy expenditure is added to that shown earlier for functional uses in agriculture in Table II-6 of Section 2, the total energy consumed in 1974 by the agricultural sector increases to about 2 quads. The FEA/USDA data base does not provide an equivalent energy

Table III-88. U.S. Farm Energy Consumption by Operations*

	Current Energy Usage (1974) Electrical Btu × 10^9	Fossil Fuel Btu × 10^9	Total Btu × 10^9	
Crop Operations				
Mobile	-	518,722	518,722	70% is short range mobile
Irrigation	65,748	195,004	260,752	
Fertilizer	-	(621,181)	(621,181)	Energy invested in manufacture
Pesticides	-	(95,272)	(95,272)	Energy invested in manufacture
Crop Drying	2,928	102,383	105,311	
Miscellaneous	6,614	182,078	188,692	
	75,290	1,714,640	1,789,930	
Livestock Operations				
Mobile	-	132,028	132,028	55% is short range mobile
Water Supply	5,478	3,571	9,049	
Heating & Ventilating	10,796	36,295	47,091	
Cooling	4,587	-	4,587	Refrigeration of milk products
Miscellaneous	13,365	18,172	31,537	Lighting, etc.
	34,226	190,066	224,291	
Total Agriculture	109,516	1,904,706	2,014,221	

*Ref. 43

consumption figure for livestock feed which is not grown by the livestock operator. Since many livestock operators purchase their feed and since this feed contains manufactured food supplements, livestock energy consumption should also be larger than shown on Table III-88.

For the U.S., about 70% of the mobile operations performed on farms are short-range in terms of distance from the farm house and may, therefore, given the availability of more efficient motive storage batteries, also become prospects for photovoltaic power. At present, the high horsepower level of tractors and other mobile machinery makes the energy density and charge/discharge characteristics of current secondary batteries unsuitable for such applications. Because of this, irrigation power is the largest potential application for photovoltaics on the farm and is followed in market size by crop drying and by heating and ventilating for livestock. Irrigation characteristics were therefore used as the initial screening criterion in reducing the many variables in U.S. agricultural operations to a manageable set for further exploration. Table III-89 lists the 18 top ranking states in terms of irrigation energy consumption. This table shows that 95% of the energy expended nationally for irrigation appears to be consumed by the fifteen top ranking states, fourteen of which are west of the Mississippi and Missouri rivers. An Aerospace Corporation study, (Ref. 46) applied five criteria to the selection of six of these states having the greatest potential for solar-thermal-electric powered irrigation. These criteria also apply in screening for photovoltaic applications and are:

1. Large irrigation acreage per state
2. Potential growth in irrigation acreage
3. High energy use per acre
4. High level of insolation
5. Poor prospects for continued low cost fossil energy supplies.

When these criteria were applied in a weighted scoring process, the six top-ranked states were found to be the same as the top six states indicated in Table III-89.

Table III-89. Energy Consumption for Irrigation by State Ranked by Total Consumption*

State	Consumption in Btu 10^9 Total	Consumption in Btu 10^6 per Acre	Cumulative Consumption in %	Fraction of Total State Acreage Irrigated
Texas	77,184	8,774	29.6	0.371
Nebraska	31,612	6,656	41.7	0.265
Kansas	23,825	10,350	50.8	0.106
Arizona	22,248	23,590	59.3	0.674
New Mexico	21,217	25,871	67.4	0.688
California	16,637	3,611	73.8	0.505
Washington	12,825	10,114	78.7	0.233
Oklahoma	8,705	12,102	82.0	0.065
Idaho	6,680	5,799	84.6	0.255
Colorado	6,660	4,051	87.2	0.267
Oregon	5,604	7,353	89.4	0.226
Arkansas	4,480	2,641	91.1	0.216
Florida	4,184	2,355	92.7	0.729
Nevada	2,551	12,518	93.7	0.390
Utah	2,478	8,786	94.7	0.231
Mississippi	1,191	3,727	95.2	0.055
Wyoming	1,163	5,165	95.7	0.125
Montana	1,089	3,360	96.1	0.034
Total U.S.	260,748	7,437	100	0.103

*Ref. 43

Some of the groundwater irrigation-related characteristics of these states are shown on Table III-90. Arizona leads in energy intensity per acre because it has the highest seasonal water demand per acre and one of the lowest water tables among the six states. It also irrigates practically all of its harvested crop land from groundwater. On the other hand, Kansas has the lowest percent of irrigated land and also shares with Texas the lowest rank with respect to water applied per season. The states of Arizona and Kansas thus represent the range of groundwater irrigation conditions to be found among the top six states and were therefore selected for further detailed exploration with respect to photovoltaic farm applications. This selection process was based on groundwater irrigation statistics only since this represents the most energy-intensive form of irrigation.

Figures for the energy consumption in various farm operations for these two states are presented in Tables III-91 to III-94. These data are from the source tape on which the FEA/USDA data base (Ref. 43) is based, since the published document does not provide this degree of detail. Comparison of Tables III-91 and III-93 emphasizes the considerably higher irrigation requirements in Arizona caused by differences in climate, water table depth, soil type, etc. Some data deficiencies in the source are evident for Arizona; no data are given on energy consumption in grain handling, grain drying for corn, and truck energy consumption. Corn in Arizona is generally harvested at moisture contents ranging from 18 to 19% and must be dried to 14% for storage. Wheat is usually not dried in any state. Other incongruencies are visible in the energy consumption values for mobile operations, which appear to be much larger per acre in Kansas than in Arizona. These tables show only those major field crops to be included in the discussion of "typical" farms to follow.

Tables III-92 and III-94 show energy consumption in selected livestock operations, averaged over the two states. Again the livestock types chosen correspond to those included in the "typical" farms to be discussed later. In the case of hogs, the average energy consumption per head differs markedly between the two states and may indicate inaccuracies

Table III-90. Irrigation Characteristics of Selected States*

	% Acres Irrigated	Irrigated Land, Acres × 10^3	Irrigation Energy 10^6 Btu/Acre	Average Ft of Lift: Ground Water	Average Ft of Lift: Surface Water	Ft of Water Applied per Season	Mean Daily Insolation kW-hr/m^2
Arizona	100	552	40.8	350	0	5.50	5.81
California	76.1	4,250	3.8	110	10	3.17	5.23
Kansas	7.7	2,230	10.8	180	15	1.50	4.65
Nebraska	19.8	4,070	30.9	100	20	1.83	4.36
New Mexico	68.8	634	33.8	350	5	2.50	5.81
Texas	34.5	7,090	10.4	200	40	1.50	5.23

Note: Acreage and irrigation energy data in this table based on land actually harvested in 1974 (rather than all existing crop land) and irrigated by groundwater only.

*Ref. 46

Table III-91. Kansas Farm Operations, Energy for Selected Crops, 1974 State Totals, in 10^6 Btu

	Corn	Grain Sorghum	Winter Wheat	Alfalfa
Preplant	848, 722	1, 189, 687	5, 150, 434	102, 425
Plant	182, 990	300, 387	812, 559	20, 119
Cultivate	240, 253	378, 181	-	-
Harvest	496, 484	555, 134	1, 969, 614	1, 690, 325
(Subtotal)	(1, 768, 449)	(2, 423, 389)	(7, 932, 607)	(1, 812, 869)
Pickup	523, 151	1, 003, 967	4, 130, 771	323, 568
Truck	614, 229	461, 261	1, 566, 636	402, 790
Farm Auto	400, 075	360, 738	1, 139, 454	116, 426
Grain Handling	18, 557	17, 037	31, 373	-
Crop Drying	1, 317, 880	48, 460	-	165, 231
Irrigation	12, 332, 536	3, 134, 396	1, 620, 976	1, 632, 405
Electric Overhead	29, 522	56, 656	204, 780	18, 260
Miscellaneous*	8, 917, 265	7, 880, 311	11, 381, 758	408, 762
Totals	25, 921, 664	15, 386, 215	28, 008, 355	4, 880, 311
Total Acres (1000)	1, 730	3, 320	12, 000	1, 070
Irrigated Acres (1000)	1, 041.5	364	334.7	131.9
Irrig. Energy per Irrigated Acre	11.8	8.6	4.8	12.4

*Invested Energy in Fertilizer and Pesticide Production and Others

Table III-92. Kansas Farm Operation - Energy Use for Selected Livestock, 1974

	State Totals in 10^6 Btu		
	Beef-Stocker	Beef-Feeder	Hogs
Feed Handling	2,680,159	932,765	21,280
Waste Disposal	91,000	14,980	9,100
Livestock Handling	221,500	-	-
(Subtotal)	(2,992,659)	(947,745)	(30,380)
Farm Vehicles	247,500	-	11,500
Farm Auto	823,375	-	223,750
Lighting	3,726	145,179	751
Water Supply	12,819	549	6,130
Space Heating	-	-	10,605
Ventilating	-	-	3,543
Water Heating	-	-	-
Other	50,000	17,807	-
Totals	4,130,079	1,111,280	286,659
Total Heads (1000)	1978	2240	3186
Average Energy per Head	2.1	0.5	0.09

Table III-93. Arizona Farm Operations Energy Use for Selected Crops, 1974

State Totals in 10^6 Btu

	Corn	Grain Sorghum	Winter Wheat	Alfalfa	Cotton
Preplant	8,817	72,474	110,679	13,493	601,641
Plant	2,795	17,009	28,927	2,764	47,068
Cultivate	2,764	35,986	-	-	239,682
Harvest (Subtotal)	4,418 (18,794)	23,708 (149,177)	31,679 (171,285)	116,262 (132,519)	86,760 (975,151)
Pickup	3,150	46,305	78,750	32,507	374,692
Truck	-	-	-	36,438	-
Farm Auto	1,058	37,926	43,042	60,751	221,382
Grain Handling	-	-	-	-	-
Crop Drying	-	19,482	-	254,229	-
Irrigation	138,628	2,624,604	2,912,344	4,474,525	7,662,962
Electric Overhead	171	2,509	4,266	3,669	7,280
Miscellaneous*	48,550	859,268	1,482,149	1,751	1,887,371
Totals	210,351	3,739,274	4,691,836	4,996,389	11,128,838
Total Acres (1000)	10	147	250	215	427
Irrigated Acres (1000)	6	135.7	165.9	142.3	282.5
Irrig. Energy per Irrigated Acre	23.1	19.3	17.6	31.4	27.1

*Invested Energy in Fertilizer and Pesticide Production and other miscellaneous consumption

Table III-94. Arizona Farm Operations - Energy Use for Selected Livestock, 1974

	State Totals in 10^6 Btu	
	Beef-Stockers	Hogs
Feed Handling	195,625	27.3
Waste Disposal	3,875	23,500
Livestock Handling	38,375	1,500
(Subtotal)	(237,875)	(25,072.3)
Farm Vehicles	345,750	750
Farm Auto	225,250	9,750
Lighting	713.3	638.2
Water Supply	1,781.6	266.2
Space Heating	-	54.6
Ventilation	-	4,833
Water Heating	-	2,085.3
Totals	811,370	43,404
Total Heads (1000)	372	117
Average Energy per Head	2.2	0.37

in the source tape, as may the absence of data on energy used in livestock handling and water heating for hogs in Kansas. The four tables, III-91 to III-94, show subtotals for those operations which are likely to be performed by short range mobile units such as tractors, and which may become potential users of photovoltaic energy if and when battery improvements permit.

Two consultants were contacted to obtain more detailed data on farm operations in these two states. Dr. R. T. Bogle, Assoc. Professor of Agricultural Economics at Kansas State University, provided additional information on Kansas farm operations. Dr. Scott Hathorn, Jr., extension economist with the University of Arizona, assisted with data on Arizona. In addition to more detailed information on farm operations, these consultants were also requested to define typical farms for the regions with which they were familiar. The intent was to develop energy consumption profiles for such farms. Because of the variability of energy consumption data with location, statewide averages were not considered suitable for the intended purpose. However, although information on irrigation energy consumption is available by county and by cropping regions within counties, energy consumption in most other farm operations could not be established to that level of geographic detail. In those cases, statewide averages had to be used.

In Kansas it was found that, statewide, 95% of the irrigation water consists of pumped groundwater. However, in the western counties of Kansas as much as 99% of the irrigation is from groundwater sources and thus leads to a higher energy consumption. For this reason, the Kansas data are reported for six counties in West Kansas, i.e., Grant, Edwards, Finney, Meade, Thomas, and Wichita. The selection of a single county in Arizona, Cochise, was made in consultation with Dr. Hathorn and is based in part on data in Ref. 46, which indicate higher than average irrigation energy usage for Cochise County and a high growth rate in the price of natural gas and electric energy in recent years.

In addition to providing additional statistical data, the consultants provided insight into local farming practices in the selected regions as follows:

Kansas-Western Counties

Most of the current irrigation is by flood or gravity systems rather than by sprinkler systems. The former is preferred, where feasible, because it is less energy-intensive. However, gravity irrigation requires level land whereas sprinkler irrigation can be applied to rolling land. Because of its level nature and lower irrigation energy costs, gravity irrigated land is more expensive. Pre-plant irrigation is prevalent and is increasing in use. Up to one third of the total seasonal water requirement of a crop can be applied in advance of seeding but will involve some losses as a result of evaporation and percolation, thus increasing the total yearly water requirement by about 10 to 15%. Three quarters of the irrigated land in Kansas is watered by gravity systems, with most of the remaining irrigation performed by center pivot sprinklers. The latter are increasing in use as more land is brought into production. Selected irrigation statistics for the six counties of interest are shown on Table III-95. Although, on a statewide basis, over 60% of the wells are operated with natural-gas-powered engines, the six selected counties use natural gas for 82% of their wells. Electricity is the next most popular energy source. Tailwater recovery systems, which are gaining in popularity, use mostly electric power for their operation. Such systems are primarily applicable to land under gravity irrigation and involve pumping irrigation water run-off back to the main distribution header. In Western Kansas 98% of the corn acreage is irrigated. Over 33% of the grain sorghum but only less than 10% of the wheat is irrigated. Dry cropland is used to grow fallow wheat or sorghum and is allowed to lie idle every second year. The farmer's decision on which crops are to be grown in a given year depends on market forecasts and thus varies from year to year. The crop mix also varies between counties because growing costs vary between counties. Table III-96 exemplifies this crop mix variation, which also influences irrigation energy

Table III-95. West Kansas Counties Irrigation Data, 1976

	Grant	Edwards	Finney	Meade	Thomas	Wichita
Wells, No.	600	850	1,600	700	800	1,040
Pumping Depth, Average, ft	350	75	180	200	220	140
Pumping Rate, Average, gpm	800	1,000	1,000	1,200	700	300
Irrigation by Gravity, in %	85	7	59	85	65	98
Irrigation by Sprinkler, in %	15	93	41	15	35	2
Natural Gas Used for Pumping, in % of Total Energy for Pumping	100	79	96	85	53	66

Table III-96. Percent Distribution of Irrigated Harvested Crop Acreage in Western Kansas Counties, 1974*

Crop	Percent of Total Acres					
	Grant	Edwards	Finney	Meade	Thomas	Wichita
Corn	50.8	36.0	43.7	40.4	83.8	66.5
Grain Sorghum	22.0	21.5	9.3	15.7	3.0	6.3
Wheat	22.7	15.4	32.1	29.8	8.1	23.2
Alfalfa	4.4	25.8	14.8	14.0	5.0	3.4
Soybeans	.1	1.3	.1	.1	.1	.6
Total	100.0	100.0	100.0	100.0	100.0	100.0
Acreage Harvested	123,850	48,010	194,100	80,650	66,550	94,700

*Ref. 46

requirements from year to year and from region to region. Table III-97 provides irrigation schedules for several crops. It also indicates that some irrigation can take place during almost every month of the year in the regions or on the farm on which these crops are grown. The amount of water deposited into the soil each month depends on weather, on crop consumptive need, on winter rainfall, and on pre-plant irrigation practice.

The average West Kansas farm is primarily a cash-crop producing operation. On the basis of an examination of the characteristics of 181 such farms, a hypothetical "typical" farm was defined. On irrigated land it grows 425 acres of corn, 200 acres of wheat, 150 acres of grain sorghum and 50 acres of alfalfa. On non-irrigated land it grows 175 acres of fallow wheat and 75 acres of fallow sorghum. It is important to note that not all of a farm's land is necessarily contiguous. Although land is usually bought or rented in 160 acre parcels, some parcels may be larger or smaller. Some of these parcels may be several miles from the main buildings of the farm and may be non-contiguous, probably making distributed photovoltaic power generation a requirement. However, if the parcel of land is too small to warrant a separate well, or if the water table is too low, irrigation cannot be used and the land will be dry-farmed.

Of the 181 farms examined, 32 had beef cow herds averaging 65 cows per herd, 78 farms had an average of 167 feeder cattle, and 10 farms fed an average of 144 market hogs. In most cases, only one of these livestock types was raised on a given farm, but the "typical" farm was assumed to raise all three types, in numbers equal to the average values mentioned above.

A "typical" crop farm meeting the above definition (except for livestock) would have a net income on its balance sheet of $18,700, would require the labor of 2 men, have an operating capital of about $250,000, own real estate valued at $270,000, and rent real estate valued at $550,000. This net income could not tolerate a substantial increase in operating expenses as a result of additional debt burden incurred in the purchase of

Table III-97. West Kansas Counties Irrigation Profiles

	Alfalfa	Corn	Grain Sorghum	Wheat
January		o	o	
February			o	
March				
April	x			x
May	x	x		x
June	x	x	x	
July	x	x	x	
August	x	x	x	
September	x	x	x	
October				o
November		o		o
December		o	o	

o = potential pre-plant irrigation

x = growing season irrigation

PV systems. Such a system would therefore have to result in immediate cost savings at least equal to its interest and operating expenses.

Arizona-Cochise County

In 1974 about 96% of the harvested cropland was irrigated (about 100% of the field crops) and about 16% of the irrigated land was serviced by sprinkler systems, 90% of which were of the center pivot type. As in the case of Kansas, pre-plant irrigation is commonly practiced except when delays in the operations schedule may have made it necessary to plant dry. An exception are wheat and barley, two crops which are commonly planted dry and "watered up". Table III-98 provides selected irrigation statistics for Cochise County, while Table III-99 indicates approximate irrigation schedules as a county-wide average. The average pumping depth, compared to Kansas, is greater. As in the case of Kansas, some irrigation is taking place every month of the year, although irrigation intensity is greatest during the months of June and July. Although about 68% of the irrigation energy derives from natural gas used in internal combustion engines direct-coupled to pumps, only about 50% of the pumps are driven by such engines. The remaining pumps are operated by electric motors. At the present time, this electricity is provided by the Arizona Electric Power Cooperative using natural gas for power generation. A coal-fired generating plant is now under construction and will become the prime source of electric power in the county.

Agricultural production in Arizona and in Cochise County is very specialized. The farm complement is divided into field crop farms, specialty crop farms (e.g., vegetable or tree farms), range cow-calf ranches, and some hog farms. Only three of the latter existed in 1977 in the county. Rarely does a farm mix livestock operations with crop enterprises.

Only cotton and corn are commonly dried after harvest in the county. Only about 20% of the cotton is dried, usually after delivery to the gin, which is normally operated by a cooperative. This 20% represents the cotton picked early in the morning and containing dew. About 90% of the

Table III- 98 Cochise County, Arizona, Irrigation Data*

	Cropping Areas					
	Kansas Settlement	Stewart	Bowie	Elfride-McNeal	San Simon	Total County
Pumping Depth Average, feet	420	310	435	320	340	
Pumping Rate Average, feet	800	800	1,200	800	800	
Wells, No.						1,709
Natural Gas Used in Pumping, % of Total Pumping Energy						68
Irrigation by Gravity, %						88
Irrigation by Sprinkler, %						12

*Ref. 46

Table III-99. Cochise County, Arizona, Irrigation Profiles

	Alfalfa	Corn	Grain Sorghum	Wheat	Cotton
January				x	
February	x			x	
March	x		o	x	o
April	x	o	o	x	
May	x	x o		x	x
June	x	x	x	x	x
July	x	x	x		x
August	x	x	x		x
September	x	x	x		x
October	x				
November	x			x	
December				x	

o = potential pre-plant irrigation

x = growing season irrigation

corn requires drying, being harvested usually at 18-19% moisture content, which must be reduced to 14% for storage. In the instance of both crops, drying is usually completed within a few hours after harvest. The other crops in the county are field dried. Alfalfa, if it is to be used by a feed mill, may be brought to the mill for drying before grinding, but this is not a common practice in Cochise county.

Variation in the crops grown by a farm depend on market prospects and government farm programs, as well as on local soil conditions and on the availability and cost of water in the locality. Variation of crops with time on a county-wide basis is shown on Table III-100. Variation between cropping areas within the county in a single year is shown on Table III-101.

The "typical" farm for this county was assumed to be located in the Kansas Settlement crop area. It is a field crop farm and all of its harvested acreage are irrigated. The harvested acreage includes 250 acres of cotton, 300 acres of corn, 250 acres of grain sorghum, 150 acres of wheat, and 50 acres of alfalfa. In some years as much as 30% of this acreage may lie fallow, depending upon prospects for crop profitability. Although not typical for such a farm, it was decided to determine the effect on the farm's energy profile of adding 500 head of hogs and 300 head of stocker beef (cows and calves).

Neither consultant was able to provide energy consumption data for the many operations involved in crop and livestock farming, although their data on number of wells, average pumping lift, and average flows would have permitted calculation of irrigation energies.

3.4.3 Results

The data base developed for screening agricultural PV and PTES applications, as described above, is clearly much more limited than that for the other sectors. The primary causes for this result were the time limits on the study and the great variety in the data base. Considerable effort was expended on attempting to assemble a data base which would provide quickly accessible information on energy consumption in agricultural operations as a function of location and time of year. This effort was not

Table III-100. Percent Distribution of Irrigated Harvested Crop Acreage in Cochise County, Arizona*

Crop	Percent of Total Acres 1960	1965	1970	1976
Cotton	25.7	17.2	13.7	10.2
Wheat and Barley	3.8	4.4	24.5	37.6
Milo and Corn	55.4	64.1	49.3	37.2
Alfalfa Hay	14.3	8.8	8.0	6.0
Sugar Beets			1.5	2.2
Other	.8	5.5	3.0	6.8
Total	100.0	100.0	100.0	100.0
Acreage Harvested	68,000	79,700	108,418	171,400

*Ref. 46

Table III-101. Crop Mixes for Typical Farms, Cochise County, 1977

	Cropping Areas: Kansas Settlement	Stewart	Bowie	Elfrida-McNeal	San Simeon
Acres Operated	960	800	1100	500	450
Cotton	25%	20%	90%	40%	75%
Corn	30	50	5	35	8
Grain Sorghum	25	25	-	-	7
Wheat	15	5	-	-	-
Alfalfa	5	-	5	5	10

successful, except for the acquisition of the source data tape for Ref. 43, which provides state-averaged data only and appears to be incomplete and of questionable accuracy. Although two consultants were able to provide much useful information concerning irrigation and general farming practice, they could not supply quantitative energy consumption data for other farm operations.

The source tape for Ref. 43 contains monthly energy consumption values for most crop and livestock operations per state. These were used to construct a month-by-month energy use profile for the typical farms defined for Kansas and Arizona (i.e., typical except for the added livestock complement). These profiles excluded all farm auto, and truck consumption as well as "invested energy", the term used in Ref. 43 to describe the energy cost of the fertilizer and pesticide used on each crop. These profiles thus do include the energy consumption of short-range mobile equipment such as tractors.

Tables III-102 and III-103 list the typical farm crop and livestock components for the two farms, as well as the total monthly energy consumptions for these farm components. In addition, the data of Section 3.1 were used to approximate farm house energy consumption, to be added in arriving at total farm consumption. These tables show irrigation energy separately, as well as included in the crop operation total. The difference in value between the columns labeled "irrigation" and "all crop operations" is primarily due to short range mobile operations and to drying energy requirements. The monthly energy consumption figures for each farm were developed by deriving monthly per-acre values for each crop, and per-head values for each livestock type, from the source tape for Ref. 43. These unit consumptions were then multiplied by the size of the corresponding farm components to get the total farm values.

Inspection of Tables III-102 and III-103 shows that, during the heavy irrigation months in the summer season, irrigation energy demand dominates all other farm operations. Figures III-16 and III-17 emphasize this fact. Also, the addition of livestock to these "typical" crop farms

Table III-102. Typical West Kansas Farm 1974 Energy Use

Typical Farm Description (1976)

Crop	Acreage	Livestock	Heads
Irrig. Corn	425	Beef-Stocker	65
Dry Wheat	175	Beef-Feeder	167
Irrig. Wheat	200	Hogs	144
Dry Sorghum	75		
Irrig. Sorghum	150		
Irrig. Alfalfa	50		
	1,075		376

Demand Profile of Entire Farm, in Btu × 10^6

	Irrig.	All Crop Operats.*	All Livestock**	Farm House	Total Farm
January	-	43.6	29.8	31	104
February	-	43.6	30	31	104
March	-	74.2	31.2	31	136
April	80.4	250.	22.4	31	304
May	436	624.	7.0	4.3	635
June	136	461	6.9	4.9	472
July	2,425	2,649	6.8	4.9	2,660
August	2,514	2,643	6.9	4.9	2,655
September	150	357	7.0	4.9	369
October	-	1,128	9.1	4.3	1,141
November	1,187	1,940	7.2	31	1,978
December	1,029	1,491	14.9	31	1,536

*Includes irrigation but excludes farm truck and auto consumption

**Excludes farm auto and truck consumption

Table III-103. Typical Arizona (Cochise County) Farm 1974 Energy Use

Typical Farm Description (1977)

Crop	Acreage	Livestock	Heads
Cotton	250	Hogs	500
Corn	300	Beef	300 (Stocker)
Sorghum	250		
Wheat	150		
Alfalfa	50		
	1,000		800

Demand Profile in Btu × 10^6

	Irrig.	All Crop Operations*	All Livestock**	Farm House	Total Farm
January	573	794	55	16.5	866
February	573	967	55	16.5	1,039
March	605	1,045	9.5	16.5	1,071
April	2,703	2,925	7.1	3.2	2,935
May	2,964	3,076	5.2	5.9	3,087
June	3,555	3,745	5.0	5.9	3,756
July	3,166	3.281	4.9	5.9	3,292
August	2,985	3,065	4.9	5.9	3,076
September	2,768	2,843	6.5	5.9	2,855
October	2,178	2,437	6.0	3.2	2,446
November	78	215	35.7	16.5	267
December	573	668	35.6	16.5	720

*Includes irrigation but excludes farm auto and truck consumption

**Excludes farm auto and truck consumption

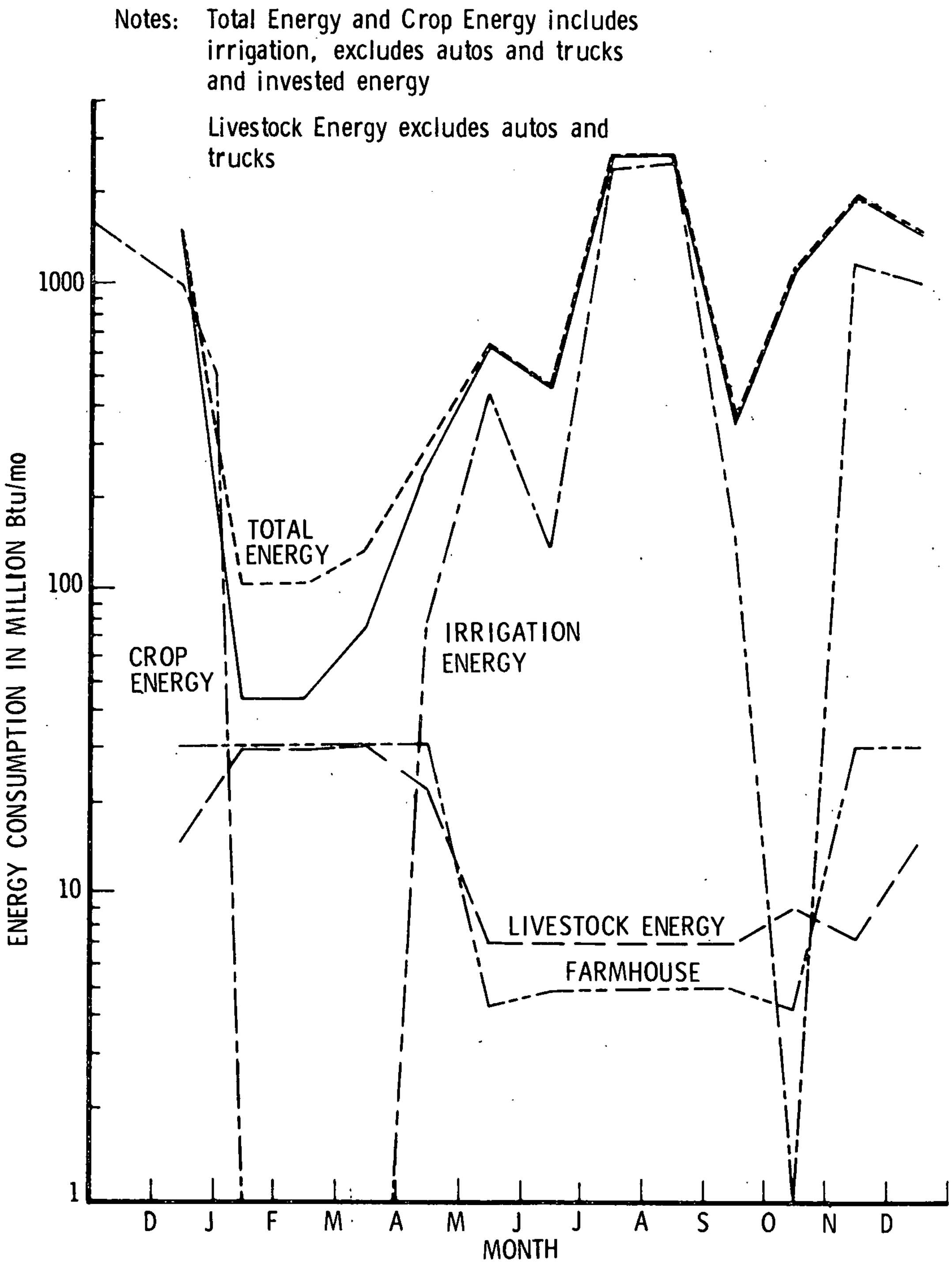


Figure III-1.6. Energy Consumption of Typical West Kansas Farm (Livestock Added)

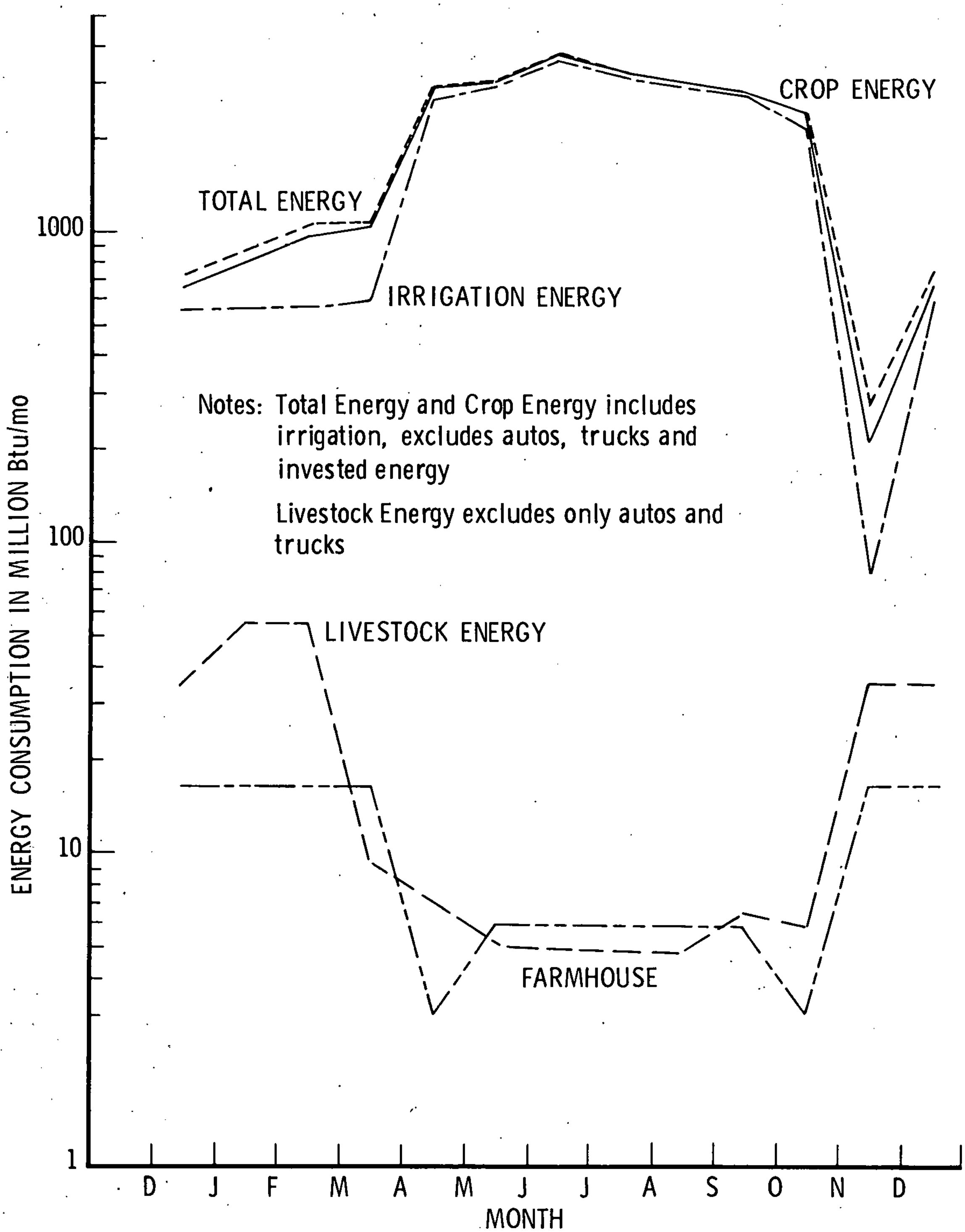


Figure III-17. 1974 Energy Consumption of Typical Cochise County (Arizona) Farm (Livestock Added) will not materially flatten energy profiles unless many more livestock are carried on the farms than was assumed for these typical enterprises. Whether the capacity of these farms is sufficient to feed the additional livestock was not determined. Cost comparisons between photovoltaic and conventional irrigation energy sources were not performed. Thus, no documentable conclusions can be offered as to the farm energy profile and the array price required which would allow PV to become cost competitive. It is likely, however, that the Arizona farm profile on Fig. III-17 is more desirable, offering almost six months of relatively flat demand. In contrast, the Kansas profile appears more difficult to meet with a cost-effective PV system. It may be feasible in certain regions to design farm crop complements which, in aggregate, provide more favorable crop demand profiles. However, given the realities of traditional farm practices and of farm economics, this may not be practical.

It may also be possible to find farm areas where irrigation energy consumption per acre is considerably lower and where, therefore, existing combined livestock-crop operations may exhibit relatively flat energy profiles over most of the year. However, such areas are not likely to be found in the irrigation-energy-intensive regions of the Western states where the use of solar power could make an important contribution to the reduction of fossil fuel consumption.

3.4.4 Conclusions and Recommendations for the Agricultural Sector

The work done to date in the agricultural sector has not been extensive enough to permit the selection of any of its segments for more definitive analysis by a screening and ranking approach. This effort does permit, however, some conclusions which may assist in defining the scope of a mission analysis effort covering this sector. These are:

1. The three largest energy consuming activities associated with most U.S. farms are short-range mobile operations, the manufacture of the fertilizer and pesticide used by these farms, and the irrigation of crops. Of these, the activity most immediately accessible to electric power generated by PV is crop irrigation. Mobile equipment power requires battery

performance not yet attainable. Manufacture of fertilizer on the using farm is possible but not likely, because both investment cost and operating complexity may be too high. It is also evident that crop operations consume far more energy than livestock operations, about eight times as much, and should therefore be of primary interest in subsequent analyses.

2. Irrigation energy requirements are concentrated in the U.S. West and in states with good insolation. Power needs peak in summer months, coincident with peaking insolation. However, previous cost studies of photovoltaic applications have shown that fractional yearly usage of the energy produced by PV tends to reduce the required breakeven array price. Such fractional usage thus tends to push cost competitiveness of the PV system against conventional fuels further into the future.

3. The examination of typical farm operations in two representative states, Kansas and Arizona, suggests that it is unlikely that the full power generated by a PV system sized to meet peak irrigation demand of a single farm could be used on that farm for conventional farm operations for more than 50% of the year even if mobile equipment were battery powered. It is also unlikely that traditional farm practices or economic realities would permit the alteration of typical farm and livestock complements merely for the purpose of flattening the energy demand profile. However, such irrigation demand profiles could be flattened, and the peak power demand could be reduced, by pumping groundwater during the non-growing season and storing it for use to meet peak demand of the main irrigation season. The cost of open reservoir storage has been only briefly examined by Aerospace Corp. (Ref. 46) in connection with studies of solar-thermal-electric power for irrigation, and has been found to be too high. Additional effort in investigation of the various alternative storage means is considered necessary.

4. It is also desirable to examine the power demands of a variety of potentially sizable rural consumers of electric energy to determine rational combinations of such consumers which could yield aggregate load profiles closely matching the ideal generation profile of a PV system in any

given region. It is, consequently, desirable to investigate the feasibility of selling power to local electric utilities since these already serve such aggregates of consumers.

5. At a minimum, potentially large rural consumers whose power needs should be examined are:

a. Crop packing and processing industries located near crop producing areas, whose operations are timed to phase with crop harvests. That is, these industries either start operation during the harvest season, or peak in this and the post-harvest season although operating all year. In addition to crop packing establishments, such industries include cotton gins, feed mills, flour mills, etc. However, since the entire food and kindred products group (SIC 20) used only 95,600 x 109 Btu in 1974, as against 260,750 x 109 Btu for irrigation, many additional consumers would be required in order to flatten the demand curve.

b. Water transmission and distribution systems which pump water from remote sources to local reservoirs. Such systems do operate all year, particularly in the Southwest where freezes would not obstruct the flow of water in canals and aqueducts. Such systems could, presumably, increase their shipments during the winter months and thus absorb additional power. As the water table drops in heavily irrigated regions (a current problem), the importation of water from other, remote, sources will become essential and power requirements for such purposes will increase.

c. Cooperative power generating or distribution systems such as REA's in regions where sufficient crop diversity exists among different farms to flatten the system load profile.

d. Tree crop farms whose irrigation needs extend over most of the year and which could utilize trickle irrigation to reduce power requirements.

e. Vegetable crop farms which also could use trickle irrigation and which grow several crops per year.

f. Greenhouse operations and hydroponic farms which have increased winter energy consumption and which could benefit from a PTES system to provide space heating in the winter. This segment is, however, a minor energy consumer at this time.

g. Specialized livestock producers with energy needs for farrowing, brooding, space and water heating, ventilation, feed preparation, feed and waste handling, etc.

h. Cooperatives set up for the purpose of manufacturing fertilizer during the non-growing season. It is not known whether such specialized cooperatives now exist or what the scale of such seasonal operations must be to compete with commercial suppliers able to utilize their plants all year at constant production rates. Fertilizer use is increasing, however, and shortages of natural gas for raw material may alter the methods and economics of this industry, making the investigation of such rural cooperatives of interest, particularly for nitrogen-based fertilizers. Consideration should be given to possible utilization of thermal energy from a PTES in such manufacturing operations.

6. The economics of a typical farm enterprise, such as that described for Arizona, make investment in private PV generating facilities difficult. For example, the average estimated value of all the machinery and equipment on an average farm (approximately 1000 acres) in Cochise County, Arizona, was $27,000 in 1974. Only 52 farms out of 668 had an equipment value exceeding $70,000. The economics of utility-owned or cooperative-owned, distributed as well as central, PV generating systems, should be investigated as more viable alternatives.

7. The activities of the U.S. Census should be expanded to include data gathering of special interest in connection with solar energy applications. Such data should include, at a minimum, actual energy budgets per type of fuel for various farm operations, on a per-acre and per-head of livestock basis, and on a monthly or weekly schedule. Data on crop and livestock complements of the average farm as well as on the distribution of such complements over the county should be included. Timing information for various farm operations and fertilizer consumption per crop and per acre would also be of value.

In addition, information about details of farm cooperative operations should be included, such as the packing and processing operations in which they engage and their energy needs. Furthermore, industries using farm products as raw materials and located near farm production areas should be included.

8. The FEA/USDA data base (Ref. 43) should be updated and corrected where necessary. The published data should be expanded to provide information on energy consumption in every state by month for every crop and livestock type and for every major farm operation. Such data are provided now only for irrigation and then only as U.S. averages for individual crops.

4. SCREENING

4.1 CRITERIA

As discussed in earlier sections of this report, the primary objective of the applications screening activity was the selection of PV and PTES applications for detailed analysis on the basis of criteria emphasizing (a) maximum displacement of fossil energy brought about by full market penetration of such applications, and (b) attractiveness for early commercialization and full market penetration based on economic factors and institutional considerations. A secondary objective relates to the presumption that selection of application classes for test and demonstration will emphasize similar characteristics and that the procedures and data base used by this study for the selection of applications for detailed conceptual design and economic analysis will, therefore, also provide information supporting decisions on test and demonstration programs.

The criteria deemed to be most important in the screening process have already been briefly discussed in Section 2 of this report. A more detailed description of the rationale for their use and the rating bases associated with these criteria is given in this section. Figure IV-1 provides graphic material to supplement the description of the screening criteria and the rating procedure.

4.1.1 Thermal to Electric Ratio

Applications are clearly preferable whose thermal and electric energy demand match the ability of the photovoltaic total energy system (PTES) to produce these forms of energy, or which, at the least, are able to utilize all of the thermal energy produced. When flat plate, non-concentrating arrays can be used, such as for applications to heating and cooling of structures or for hot water process heat, PTES collectors using Si cells will operate at T/E energy ratios between 3 and 6, depending on collector heat loss, time of day, and insolation conditions. Flat plate Si arrays can produce hot water or hot air at temperatures of up to 60°C

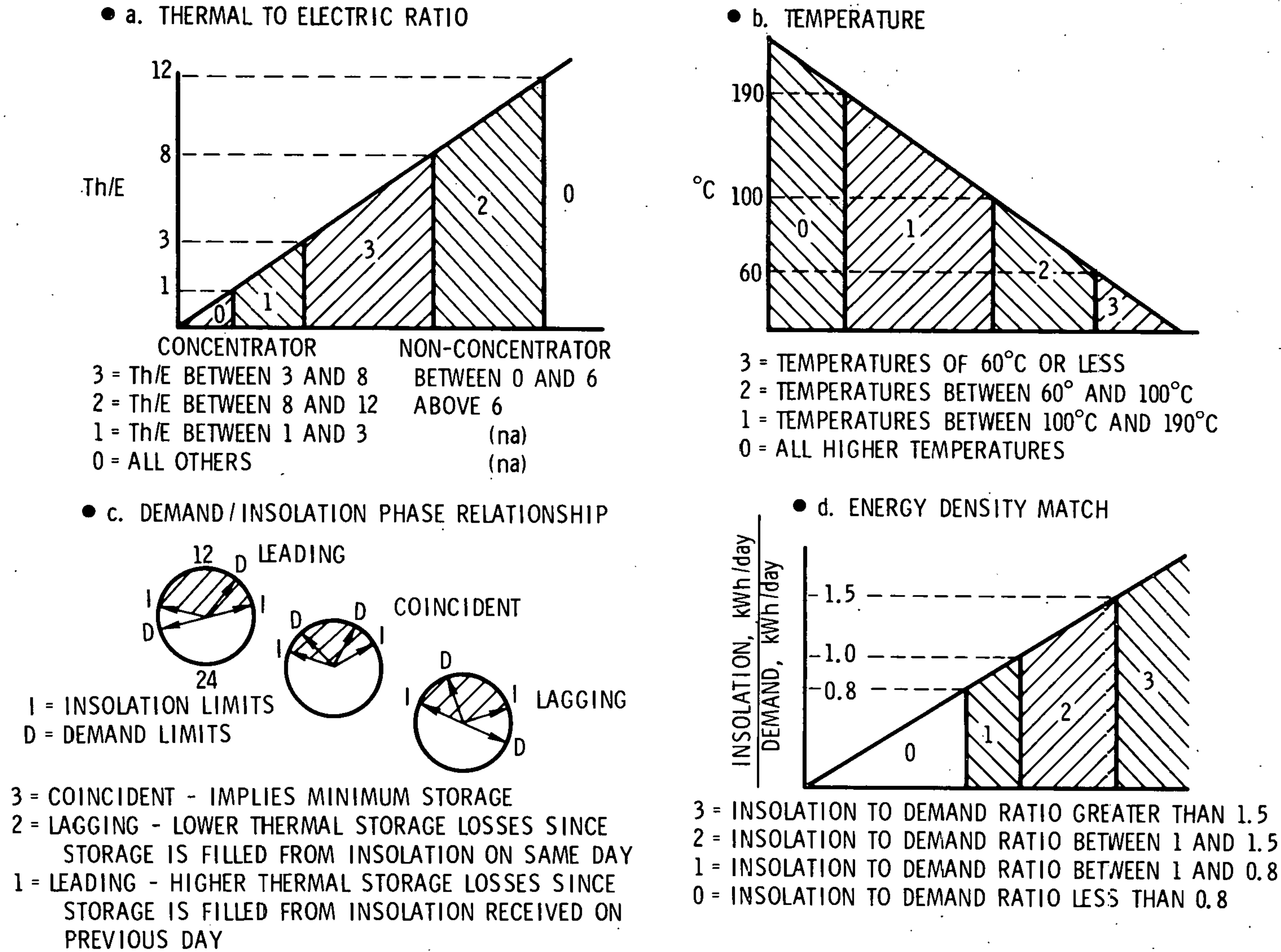
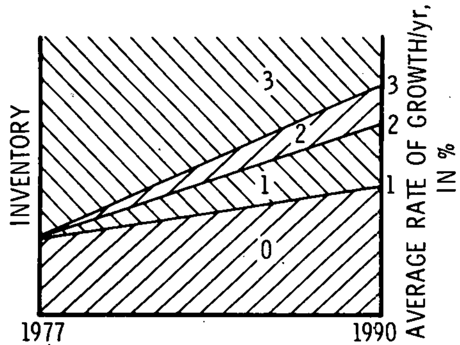


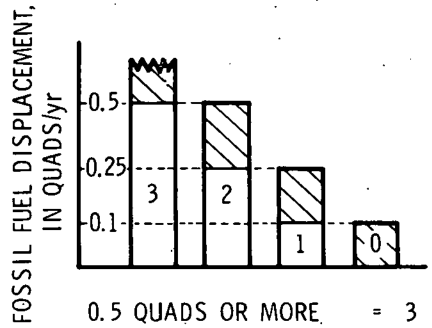
Figure IV-1. Criteria Ratings

- a. MARKET GROWTH RATE



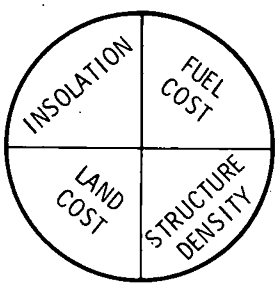
GREATER THAN 3% = 3
BETWEEN 2 AND 3% = 2
BETWEEN 1 AND 2% = 1
LESS THAN = 0

- b. MARKET SIZE



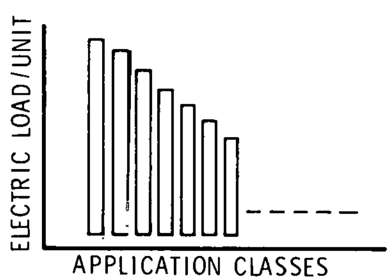
0.5 QUADS OR MORE = 3
0.25 TO 0.50 QUADS = 2
0.10 TO 0.25 QUADS = 1
LESS THAN 0.10 QUADS = 0

- c. MARKET LOCATION



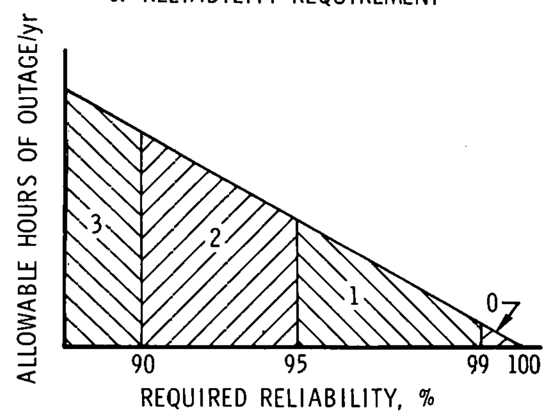
ALL FOUR FACTORS ARE FAVORABLE 3
ONLY THREE FACTORS ARE FAVORABLE 2
ONLY TWO FACTORS ARE FAVORABLE 1
ONLY ONE OR NONE OF THE FACTORS ARE FAVORABLE 0

- d. ELECTRIC POWER DEMAND LEVEL



NO RATINGS - TO BE RANKED BY AVERAGE UNIT ELECTRIC DEMAND

e. RELIABILITY REQUIREMENT



LOWER RELIABILITY REQUIREMENTS OF APPLICATION CLASSES REDUCE COST OF STORAGE AND OF STANDBY POWER

RELIABILITY REQUIREMENT	RATING
90% OR LESS	3
BETWEEN 90 AND 95%	2
BETWEEN 95 AND 99%	1
BETWEEN 99 AND 100%	0

Figure IV-1. Criteria Ratings (continued)

(140°F) if thermal energy in this form is desirable. Low-concentration collectors, using Si cells for higher temperature applications up to about 90°C (200°F), will produce T/E ratios as high as 8. High-concentration GaAs arrays, operating at temperatures up to about 200°C (400°F), develop T/E ratios of about 6.

When applications require more thermal energy than is available from the PTES collector, supplementary thermal panels or other heat sources are presumed to be available. When the temperature requirement of the application is compatible with the use of flat-plate collectors, a low T/E ratio can readily be accommodated by supplementing the combined thermal/electric PTES collector with additional air-cooled electric-only panels. Such an application would also receive a high compatibility rating. It is recognized that a lower limit exists for thermal demand, below which it is uneconomic to use PTES panels, with the associated active heat transfer system. This minimum level has not been established and was consequently not considered during the screening process.

A low rating under this criterion implied only low compatibility for total energy system application but did not bias judgment on suitability for pure-electric system use.

Rating Basis

For a concentrating PTES, a T/E ratio of less than 3 implies the possible dumping of thermal energy and the consequent loss of the economic value of this energy. Ratios between 3 and 8 imply a fairly good match between generation and demand, minimizing dumping or supplementary thermal energy generation. Ratios above 8 imply the need for supplemental thermal collectors or for fossil energy sources for thermal energy, which may bring about higher life cycle costs for the installation. For the case of non-concentrating arrays, high T/E ratios were not allowed to influence the rating to a major degree, although it was assumed that the requirement for addition of purely thermal absorber panels is a disadvantage in terms of cost and collector area requirements. A lower rating was also assigned when the active cooling system (i.e. thermal energy) was needed only during a fraction of the year. The rating scale is shown on Fig. IV-1.

4.1.2 Temperature

Three temperature levels were considered important to the screening process. Residential and commercial applications require hot water or steam for space heating, domestic hot water, and for absorption air conditioning. The latter use requires thermal energy at temperatures from about 90°C (200°F) to 105°C (220°F), while about 60°C (140°F) is sufficient for space heating and domestic hot water supply. Industrial process heat applications have arbitrarily been limited to about 190°C (375°F) to prevent average array temperatures from exceeding 200°C (390°F). Temperatures up to 60°C (140°F) are readily available from non-concentrating flat plate water-cooled arrays using Si cells. It is not clear at what application temperature requirement the switch to concentrating systems should be made, and when GaAs arrays in a high concentration system would become preferable. It is assumed that the 190°C process heat requirements will call for the use of relatively high concentration GaAs arrays.

Rating Basis

There was insufficient data at this time on which to base preference for temperature requirements of potential applications, except for the knowledge that Si cell electric conversion efficiency decreases rapidly with increasing temperature, and that the step to higher-efficiency GaAs cells is costly. Ratings were therefore based on temperature steps largely determined by demand temperature levels up to the maximum of 190°C which is materials controlled. Fig. IV-1 also shows the rating scale for this criterion.

4.1.3 Demand/Insolation Phase Relationship

Compatibility between a photovoltaic energy source and the requirements of a given application also depends strongly on the supply/demand phase relationships for both thermal and electrical energy. The ideal phase relation, of course, is that in which supply and demand are roughly coincident in time, thereby minimizing the need for energy storage or for energy from backup sources. Phasing in which thermal demand lags supply was preferred to that in which demand leads because thermal storage losses would be greater in the latter case. (The stored energy would have been collected in the previous diurnal cycle.) In many cases, of course, the supply/demand phase relationship cannot be classified simply as lagging, leading, or coincident. For example, in the case of a three-shift industry, all three phase relationships are present. In such cases, the lower rating was assigned.

Rating Basis

This criterion is unrelated to the quantitative relationships between insolation and demand but is based on implied storage and backup requirements resulting from leading, lagging, and coincident phasing. Its rating scale is shown on Fig. IV-1.

4.1.4 Energy Density Match

This criterion is primarily of interest in relation to the evaluation of photovoltaic applications to buildings. It attempts to provide a relative ranking of applications on the basis of required land area in excess of available roof area, in order to provide the energy needs of the structure from the solar source only. It measures the ratio of the energy available from insolation or the structure, per unit roof area, to the energy consumed by the structure, also per unit roof area. In computing this ratio it was assumed that inclined collectors are mounted on a flat roof and so spaced as to avoid shadowing; thus only about 60% of the roof area is available for collection of solar energy. The energy density computation was based on an average daily demand in kWh/day during the highest demand season of the year. Energy demand exceeding that available from the insolation received by roof-mounted collectors could be satisfied by utility-supplied energy or other means such as use of additional land for collectors. The use of such other means of satisfying excess demand were assumed to offer cost disadvantages.

Rating Basis

If energy collectible on the roof is insufficient to meet the structure's energy demand during the maximum demand season, then either supplementary utility service or collector area excess to roof area is required. The former was considered undesirable because it reduced potential fossil fuel displacement; the latter involved added land and structural cost.

Ratios of energy available from insolation to energy demand in excess of 1 are desirable, to permit some disparity in phasing and to allow accumulation of stored energy to compensate for periods of reduced insolation. The rating scale for this criterion is also shown on Fig. IV-1.

4.1.5 Market Growth Rate

Markets grow when removals from inventory as a result of wearing-out or obsolescence are exceeded by new additions. Significant photovoltaic penetration of markets with little or no growth would, in general, require retrofitting photovoltaic power into existing applications. Penetration of these markets may be more difficult because of technical, institutional, and financing factors. Photovoltaic applications in these areas will also probably be more expensive, as a result of the probable additional investment required to retrofit energy conservation measures in order to reduce energy consumption and make solar energy more cost-effective. New additions to the market imply energy conserving characteristics already integral to the design. In the field of structures, inventory growth has generally been between 1.5 and 2%, with specific types, such as shopping centers and malls, as well as fast-food franchises, growing much more rapidly.

Rating Basis

Applications with higher growth rates are more desirable, with rates exceeding 2% per year between now and 1990 being preferred. The rating scale for this criterion is shown on Fig. IV-1.

4.1.6 Market Size

Market size can be expressed by reference to a number of parameters. Considered most significant in view of national energy goals is that of fossil fuel displacement potential. It is to be noted that consumption of electric energy produced by steam plants translates to a fossil fuel consumption about three times as large when energy equivalents are compared. The losses in energy conversion are smaller for the conversion of natural gas, oil, diesel fuel and gasoline into usable thermal energy. This implies that this criterion should be concerned less with numbers of individual applications than with the total fossil fuel displacement that penetration of photovoltaics into a particular applications class could accomplish. Another major judgmental factor influencing the ratings awarded under this criterion will be the actual penetration, or percent of total available market, that solar energy might predictably attain.

Rating Basis

The total projected U.S. energy consumption in 1990 is 117 quads, of which 94.5 quads are from fossil sources. Application classes which, upon maximum probable penetration, would produce fossil-fuel displacements exceeding 0.25 quads/year on a national basis in 1990 were preferred.

4.1.7 Market Location

Specific residential, commercial, and industrial applications can exist predominantly in either rural, suburban, or urban environments or in combinations thereof. Agricultural applications are, of course, primarily rural, although some suburban areas still contain sizable agricultural components. Except for single family residences, urban area applications are collector-area constrained because of higher density of construction and greater use of multi-story construction. They may also have a greater collector shadowing problem because of height variations among neighboring structures. Smoke and smog will also contribute to reductions in insolation in urban areas. Locations can further be regionalized in terms of relative insolation and of prevailing or anticipated pricing of competing energy sources. Electric energy costs vary by a factor of 7 over the nation, while natural gas costs can vary by as much as 6 and coal by 4. Land costs are also an important regional characteristic impacting solar energy cost-effectiveness.

Rating Basis

Photovoltaic power should be most competitive in regions of high insolation, high competitive energy cost, low structure density, and for many application classes, in rural areas where land costs are lower. The rating for this criterion is therefore based on the relative strength of these four factors: insolation, fuel costs, structure density, and land costs. Its rating scale is shown on Fig. IV-1.

4.1.8 Unit Demand Level

Level of demand of load points which are characteristic of an applications class is a useful criterion inasmuch as the cost of energy from competing power sources is expected to increase more rapidly with decreasing load than does the cost of energy from photovoltaic sources. Further, some of the competing sources have minimum sizes below which equipment limitations prevent effective power generation. There also exists the potential that a larger number of smaller load points will permit higher rates of production of photovoltaic units of similar design, thus allowing learning curve effects to reduce unit cost. This factor also reduces development and engineering cost per unit. Further, lower unit investment cost should contribute to earlier adoption of the new technology. All of these factors point to increasing competitiveness of photovoltaic power in the instance of smaller load demand, in certain classes of applications. In other application classes, however, such as in industrial applications, some of the advantages of larger size may outweigh those listed above for small loads. Since the methods of financing for industries differs from those for buildings, the larger an industrial establishment, the easier it may obtain debt or equity financing for the higher initial cost of a PV system. Industrial establishments have higher energy consumption and larger firms should therefore be more receptive to alternative energy sources promising future cost savings. They may be more accustomed to life cycle costing methods and to the use of long-range planning, both of which should support strong interest in the application of PV systems.

Rating Basis

No information on optimum photovoltaic energy system size for the various potential applications is available at this time. Numerical ratings could therefore not be assigned. Application classes were ranked by probable average unit electric demand, with preference afforded to the smaller demand levels in the case of building applications, and larger demand in the case of industrial applications.

4.1.9 Reliability Requirement (Permissible Outage)

Photovoltaic solar energy conversion systems are subject to inherent limitations on service reliability because of the unavoidable diurnal, seasonal, and weather-related variations in insolation and because it is too expensive to provide sufficient energy storage (and the extra array area to fill the storage) to smooth out these variations. Applications requiring a very highly reliable energy source are therefore less compatible with photovoltaic systems than are applications in which an occasional outage can be tolerated. The utility backup required to avoid outages may be expensive.

Rating Basis

The numerical ratings indicated in Fig. IV-1 are arbitrary and based only on engineering judgment.

4.1.10 Value Added by Energy Consumption in Manufacture

This criterion is of interest only in the evaluation of industrial applications. The more energy intensive a manufacturing process is, the higher is the percentage of the final product cost due to the cost of energy used in its manufacture, and the more concerned should be the industry with the increasing cost of energy from conventional sources. Presumably, this would lead an energy-intensive industry to greater receptivity toward proposals for alternative energy sources. Concurrently, the greater displacement of conventional energy sources by PV in such industries would also address the goal of reduced fossil energy consumption.

Rating Basis

Numerical ratings were not assigned to this criterion. Applications were rank ordered, with preference given to those applications with higher fractions of value added ascribable to the cost of energy consumed during the manufacturing process.

4.1.11 Ratio of In-house Generated Electricity to Purchased Electricity

This criterion is also only used for the screening of industrial applications. It is known that many commercial and residential building complexes generate their own electric power by gas turbine or diesel driven generator sets and that the Department of Housing and Urban Development is attempting to increase such use through their MIUS (Modular Integrated Utility Systems) program. The Department of Energy is similarly examining on-site cogeneration of electrical and thermal energy in industry. However, such in-house power generation is not as yet typical of any of the building classes included in this screening, although it can be considered typical of some of the industry groups which were evaluated. The rationale for the use of this criterion is based on the assumption that in-house power generation indicates receptivity toward the concept of distributed power as against central station power and that it implies availability of trained manpower for operation of power generation systems. In those industries which use purchased fuels for in-house generation there is also the presumption that an independent power supply is desirable. The existence of such generating facilities, whether using purchased fuels or by-product waste materials, also offers a source of backup power to a PV installation independent of a utility connection, and may also reduce the need for energy storage.

Rating Basis

Here also numerical rating were not assigned because of the strongly qualitative judgment implied by this criterion. Instead, industrial applications are rank ordered on the basis of the fraction of the total electric energy consumption which is generated in-house.

It is understood that the ease of commercialization of a particular PV application will probably be influenced also by characteristics such as the nature of the utility interface which it requires, the ability to use DC current directly without inversion to AC, and the existence of government incentives. Although these characteristics could constitute important criteria in the selection of test and demonstration subjects, they were not addressed by this study because of the absence at this time of a quantitative data base to support any judgment concerning them.

4.2 RANKING

4.2.1 Weights of Rating Criteria

The weight which should be accorded the various rating criteria in the application screening process was estimated prior to application ranking by a panel of five staff members familiar with both solar technology as well as with market-oriented characteristics of the candidate applications. Separate sets of criteria weights were developed by ballot for the building and the industrial screening criteria. Weights were also estimated separately for application of the criteria for PV and PTES systems. Table IV-1 summarizes these weight assignments. Absence of a criterion weight in this table indicates that the criterion was not used in evaluating the indicated system/application set.

The inapplicability of the T/E ratio and the temperature criteria to the evaluation of PV (electric-only) system applications is self-evident. The seasonal profile match criterion was not used for industrial applications because process heat demand, in contrast to space heating and cooling, is relatively invariant with season (for the applications being considered) so that the seasonal profile would not have made a suitable discriminant. Energy density ratios also were not evaluated for industrial applications because the industrial energy demand is commonly too large to allow the ratio of energy received per unit roof area to the energy demand per unit roof area to become a meaningful criterion. This is because it is believed that the collector area required for industrial applications will, in most cases, far exceed the available roof area.

Table IV-1

Criteria Weights Used for Ranking

	Buildings		Industries	
	PTES	PV	PTES	PV
Thermal/Electric Ratio	11	-	13	-
Temperature	10	-	14	-
Profile Match - Diurnal	15	19	17	24
Profile Match - Seasonal	12	18	-	-
Energy Density Ratio	11	15	-	-
Market Size	11	12	15	19
Market Growth	10	14	13	19
Location Factors	13	15	19	27
Reliability	7	7	9	11
	100	100	100	100

4.2.2 <u>Building Scores</u>

Total scores for each application were derived by multiplying the individual criteria ratings derived for each applications class by the appropriate weight and then summing the resulting weighted ratings. Because of the subjective nature of the scoring method used for screening, the weighted criteria ratings for each applications class are shown in subsequent tables. These ratings, together with the weights of Table IV-1, should permit the reader to adapt application scores to reflect any differing perceptions of either weights or ratings.

Table IV-2 provides the scores for all of the building applications surviving the preliminary screening previously reported in Sections 3.1 and 3.2. The scores on this table are for the application of PTES utilizing the thermal energy produced in the winter season for space heating and water heating, and in the summer season for space cooling (using absorption chillers) and for water heating. The higher scores received by low-rise apartments over those of single-family housing are due to the more favorable T/E ratio and market growth rate of low-rise apartments. The low market growth expectations associated with single-family housing are also the primary reason that three out of the four commercial building types score higher than single-family housing. The rating basis used for the market size criterion handicaps single-family housing in that it gives the same rating for all application classes whose annual energy demand exceeds 0.5 quads. This does not adequately reflect the major new building market represented by single-family housing, which, at only an estimated 1% per year growth rate, amounts to about 800 to 900 million square feet of new construction per year by 1990. Even at the 5%-plus growth rates of the commercial buildings in the final set of applications, their new construction markets will be in the range of 200 to 400 million square feet per year. In new construction, single-family houses rank second behind low-rise apartments with an annual rate of about 1200 x 10^6 ft^2 and offices rank third with about 450 x 10^6 ft^2 annually by 1990. If average demand level were used as an additional discriminant, it would also

Table IV-2

Rankings - Building Applications Using PTES with Absorption Cooling

	Buildings						
	LRA	Office	Stores	SFH	Schools	Shopp. Ctr.	Supermkt.
Thermal/Electric	33	22	22	22	22	22	22
Temperature	20	20	20	20	20	20	20
Profile Match, Diurnal	22.5	30	20	22.5	30	20	20
Profile Match, Seasonal	24	36	36	24	12	36	36
Energy Density Ratios	5.5	11	0	11	11	11	5.5
Market Size	33	33	33	33	33	11	0
Market Growth	30	30	30	10	20	30	30
Location Factors	26	13	26	26	26	26	26
Reliability	14	0	0	14	7	0	0
Total Score	208	195	187	182.5	181	176	159.5

Demand Level Ranking

Heating Season	3	5	2	1	6	4	
Cooling Season	2	4	3	1	6	5	

LRA = Low Rise Apartments

SFH = Single Family Houses

tend to favor single-family housing, as shown by the ranking on Table IV-2. In spite of the scores shown on this table, the two residential application classes would thus appear to be the most interesting candidates for further study of PTES (absorption cooling) applications in buildings, followed closely by office buildings, miscellaneous retail stores, schools, and so on. It is to be noted that the difference in ranking scores between retail stores and shopping centers is due to market size. Technical factors associated with these two application classes are similar since shopping centers are assemblies of retail stores. As a consequence, mission analysis should probably treat these classes in combination.

A variation of the application of the PTES concept provides for the use of thermal energy only for space heating and water heating, with space cooling performed by an electrically driven, conventional vapor compression machine. The scores received by building classes evaluated for this PTES system are shown on Table IV-3. The T/E ratios of the PTES are less favorable to this type of cooling method, resulting in massive dumping of thermal energy in the cooling season. On the other hand, the reduction of the temperature from the 100°C required for the absorption chiller to the 60° or less which is sufficient for space and water heating, favor this system. The single-family house now ranks third in score, even without consideration of its large market potential. When its new construction and retrofit markets are considered, single-family housing should again follow low-rise apartments in order of preference for further study attention, followed by offices, miscellaneous retail stores, schools, and so on.

A final building application variation involves an all-electric PV system which provides power for baseline electric needs and for air conditioning. All heating needs are met by conventional heating systems assumed to use fossil fuels. The scoring of the six candidate application classes for this type of system is shown on Table IV-4. As in the preceding case, low-rise apartments lead the ranking order, and are followed by single-family houses, stores, offices, and so on.

Table IV-3

Rankings - Building Applications Using PTES with Vapor Compression Cooling

	Buildings						
	LRA	Offices	SFH	Stores	Schools	Shopp. Ctr.	Supermkt.
Thermal/Electric	11	5.5	11	5.5	5.5	5.5	5.5
Temperature	30	30	30	30	30	30	30
Profile Match, Diurnal	22.5	30	22.5	15	30	15	15
Profile Match, Seasonal	18	36	18	36	12	36	36
Energy Density Ratios	5.5	5.5	16.5	0	3	5.5	5.5
Market Size	33	33	33	33	33	11	0
Market Growth	30	30	10	30	20	30	30
Location Factors	26	13	26	26	26	26	26
Reliability	14	0	14	0	7	0	0
Total Score	190	183	181	175.5	166.5	159	148

LRA = Low Rise Apartments

SFH = Single Family Houses

Table IV-4

Rankings - Building Applications Using PV with Vapor Compression Cooling

	Buildings						
	LRA	SFH	Stores	Offices	Schools	Shopp. Ctr.	Supermkts.
Profile Match, Diurnal	38	38	38	47.5	47.5	38	38
Profile Match, Seasonal	36	36	36	36	18	36	36
Energy Density Ratios	7.5	22.5	0	0	0	0	0
Market Size	36	36	36	36	36	12	0
Market Growth	42	14	42	42	28	42	42
Location Factors	30	30	30	15	30	30	30
Reliability	14	14	0	0	7	0	0
	203.5	190.5	182	176.5	166.5	158	146

LRA = Low-Rise Apartments
SFH = Single Family Houses

4.2.3 Industrial Scores

Table IV-5 shows the scores developed for industrial PTES applications, using the same balloting method and personnel that were used for the building applications. The industries listed on this table are those which survived the preliminary screening described in Section 3.3 of this report. Three SIC industries, 2611, 2621, and 2631 have been scored as one group under the heading of pulp and paper mills, because the process heat data available from the ITC report that was used as a source (Ref. 41) was presented as a group total. Considering only the formal screening criteria, the pulp and paper group ranks highest for this PTES application, with wet corn milling ranking lowest. However, when the other characteristics shown on the bottom of the table and discussed in detail in Section 3.3 are considered as well, wet corn milling may move to second rank. The large process energy demand represented by the pulp and paper group dominates these scores, and, if electric consumption and purchased fuel consumption is a guide, is due primarily to the paper mill industry, SIC 2621, which consumed over 54% of the group's electricity in 1974. However, the actual process heat consumption is also a function of the amount of internally generated waste products available for such purposes. Pulp mills probably have proportionally more waste products available for such thermal and electric generation than the other two members of this group. Geographic distribution also favors this industry, as shown by Figure III-10. Pulp mills are therefore believed to be the preferred candidate out of the top ranking group.

The other photovoltaic system evaluated for industrial application was the all-electric PV system. The scoring results for this system are shown on Table IV-6. Pulp mills again appear to be the highest ranking industry, considering both the formal criteria and the rankings by other characteristics indicated on the bottom of the table. Wet corn milling would rival paper mills for second rank.

Table IV-5

Ranking - Industrial Applications
Using PTES for Process Heat and Electric Power

	Pulp/Paper Mills	Gypsum Prod.	Wet Corn Milling
Thermal/Electric	39	39	39
Temperature	14	14	14
Market Size	45	0	0
Market Growth	39	26	26
Location Factors	57	38	19
Profile Match, Diurnal	17	17	17
Reliability	0	0	0
Total Score	211	134	115

	Pulp/Paper Mills	Gypsum Prod.	Wet Corn Milling
Ranking in % of Energy Value in Total Value Added	1	3	2
Ranking in Size of Typical Establishment	2	3	1
Ranking by Average Energy Consumption of Typical Establishment	2	3	1
Ranking by % of Process Heat Accessible to PTES	3	2	1
Ranking by % of Electricity Generated in House	1	3	2

Table IV-6

Ranking - Industrial Applications
Using PV for Electric Power

	Pulp Mills	Paper Mills	Wet Corn Milling	Paper Board	Beet Sugar Refining
Market Size	0	19	0	0	0
Market Growth	57	57	38	57	38
Location Factors	54	24	24	24	24
Profile Match, Diurnal	24	27	54	27	27
Reliability	0	0	0	0	0
Total Score	135	127	116	108	89

Ranking by Electricity Generated In-House

3	1	4	2	5

Ranking by % of Energy Value in Total Value Added

1	2	4	3	5

Ranking by Size of Typical Establishment

2	4	1	5	3

Ranking by Energy Consumption of Typical Establishment

1	4	2	3	5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The primary objective of this study, that of identifying a set of photovoltaic applications possibly viable in the post-1985 time period and of sufficient potential interest to warrant more detailed mission analysis and conceptual design study, has been achieved. Secondary objectives have also been accomplished. These include the identification of applications of potential interest for test and demonstration and the highlighting of deficiencies in the data from secondary sources for needed market-related studies. This study has called attention to these data deficiencies by carefully noting those assumptions that were necessary because of lack of firm, quantitative data, and by flagging instances when questionable data had to be used in the absence of better information.

It is believed that the selection process described in this report has made it possible to assign priorities for study attention to a number of potentially viable photovoltaic total energy or all-electric applications. The screening criteria used encompass both technical and market-related decision factors. Although not all of these factors could be treated quantitatively, they did, in combination, provide a "holistic" judgment of the suitability of potential applications. Other factors will contribute to the determination of the potential for commercialization of the selected application classes but these were not treated in this study. They include questions of utility interfaces, consumer acceptance, system costs, breakeven costs against conventional energy sources, special design characteristics, etc. These are the type of decision factors that should be the subject of the detailed mission analyses to be performed on the application classes identified by this study.

Of the major energy consuming sectors, manufacturing ranked highest in demand (in 1974) with a consumption of over 20 quads. It was followed by transportation at somewhat less than 17 quads, residential housing with about 11 quads, and then the commercial sector with about 5.4 quads of energy consumption. However, only about 6-7 quads of the manufacturing sector's consumption can be considered accessible to thermal energy deliverable by solar systems (PTES) and about 2 quads to electricity from PV. The transportation sector's potential in terms of electrically powered mobile applications is unknown but the 1974 electricity usage of this sector was only 0.1% of the total 17 quads of energy consumed. The residential sector is thus probably the largest market for PTES or PV.

Of the residential demand, 88% was used for space heating and water heating, 2.7% was used for air conditioning, and the remainder was for miscellaneous electrical baseload. The temperature levels of the thermal demand, and the characteristics of the electrical demand for the housing sector, are such that all of this demand could be satisfied by either PTES or PV. Some 71% of the commercial energy demand is for space heating and cooling, and for water heating, and can also be satisfied by either PV or PTES, as can the remaining baseload electric demand. Other studies, whose results have been reported here, indicate, however, that only somewhat over 2 quads of the current process heat requirement in the manufacturing sector is at temperatures which could be delivered by a PTES. Presumably, most of the 2 quads of electrical energy required by this sector could be satisfied by PV.

It is obvious that the goal of maximizing fossil fuel displacement is best met by solar systems which are capable of providing energy in both thermal and electrical form. Further, it appears clear from the results reported here that residential housing should be of greatest interest for further exploration in the context of mission analysis. Although considerable attention has already been paid to single-family housing, the screening study results point to low-rise apartments as possibly having even greater potential as applications for photovoltaic systems, either in the form of PV or PTES. The higher growth rate of apartment buildings (except for mobile units which will have very high growth) implies that a larger number of apartment units will be constructed annually by 1990 than single-family units. Much of this growth will occur in solar-favored regions of the country. Attention is also directed to the relatively high growth rates of apartments in rural areas. The thermal-to-electric demand ratios are more favorable for apartments than for single houses, making PTES more likely as an economically viable system. Although the photovoltaic portion of a PTES is modular, the cost of space heating and cooling portions are favorably affected by increased scale. The larger energy demand of apartment buildings over single houses therefore also favors PTES for this applications class from the point of view of potentially lower system cost per peak watt. However, the inability to supply all of the required energy from the roof area of a low-rise apartment is a disadvantage. The mobile home segment of the single home market, although presently small, is of special interest because installation cost of photovoltaic systems in a factory environment could be considerably lower than for field installation by conventional contractor crews.

Office buildings also rank high as potential mission analysis candidates, particularly for PTES application. Because of lack of data on the distribution of numbers of stories in office buildings, the proportion of such buildings offering a market potential to photovoltaic systems is uncertain. This is based on the assumption that only roof area would be available for collector installation, thus making the collection of a significant fraction of the building energy demand less feasible with increasing building height. However, two- or three-story office building construction appears common on suburban sites. Some of the statistics available at this time also indicate that average office building floor areas for new construction between 1970-1976 ranged between 10,000 and 15,000 ft^2 (Ref. 47), also implying low-rise construction and probably increasing rates of construction at suburban locations. Offices, in addition, exhibit a particularly favorable diurnal load profile and appear to be large consumers of energy as a class.

Retail stores as a general class, encompassing both individual stores and collection of stores into shopping centers or malls, rank fourth in interest for further analysis. Their projected annual market growth rate is high; the combined energy demand is considerable. Primarily because of somewhat less favorable diurnal load profiles, this applications class ranks behind offices in priority.

The screening of industrial applications for suitable study candidates has identified pulp and paper mills as preferred for both PTES and PV system application analysis. Although based on a considerably smaller data base than was available for building applications, this conclusion derives from (a) comparisons of process heat requirements, i.e., temperature levels of the process heat and quantity of energy projected to be consumed in 1990; (b) from consideration of location in solar-favored regions; and (c) from industry preference for rural location. In addition, these industries already generate a large part of their thermal and electric energy needs at the plant site. Solar power could therefore either supplement this in-house generation capacity, or the latter could serve as backup for the solar generation system. Wet corn milling appears to be another candidate for industrial PTES or PV application, but ranks behind the pulp and paper industry. A firm decision on industrial PV or PTES candidates should await more specific data on individual plant sites such as actual T/E ratios, load profiles, available land area, etc.

The review of the agricultural sector identified irrigation as the nearest-term potential PV application, with the possibility that battery-powered farm machinery may become a later application, if and when improved battery systems become available. A major problem associated with agricultural applications appears to be their seasonal nature. Thus, relatively level energy demand for irrigation can be expected to range only from 3-6 months depending on such variables as location, weather, and farming practice. Energy demand on the typical farm is considerably lower during the remaining months, indicating a possibly lower cost-effectiveness of PV in this application sector than in the others examined by this study. It is therefore of particular importance to direct future study attention to combinations of rural energy consumers, which, in the aggregate, could produce a demand profile over most of the year which matches the generating capacity of the PV system. Among such potential users, attention should be directed to winter season water transport from remote sources to local reservoirs, to local winter season pumping of groundwater and storage for growing season consumption, to local manufacture of fertilizer outside of the irrigation season, and to local food processing and packing industries.

5.2 RECOMMENDATIONS

More investigation into the details of the industrial candidates is recommended before establishment of a preference within the pulp and paper industry, or between this industry and the wet corn milling industry. Additional effort should be expended on a review of the mining sector and of electrolytic processes within the manufacturing sector to identify electric power consuming operations meeting all or most of the selection criteria.

A number of rural power requirements, both on and off the farm, should be examined in order to determine feasible consumer combinations which may make photovoltaic power generation for irrigation economically viable.

In addition to recommending that the top ranking application classes discussed earlier become the subjects of further, more detailed analyses, an important recommendation flows from the difficulties experienced in performance of this screening study. It is believed desirable that cooperative efforts between the DOE and agencies of the Department of Commerce and others be instituted as soon as possible to improve statistical data of prime importance to photovoltaic market forecasting. In particular, it is suggested that arrangements be made to increase the coverage both in scope and in detail of the Censuses of Housing, Commerce, and Manufactures.

The Census of Housing should be expanded to provide data on the sizes of house and apartment units as a function of location. Mode, mean, and median values should be provided. Information about the distribution of the number of stories of single residences as well as of apartment buildings as a function of location would also be highly desirable, as would data on distributions of type of roof and building orientation. The type of parking facilities for apartments and their geographic and size distributions by type would be important information, as would energy consumption for various end-uses as a function of location and season. Regionalization of these data should be by county as well as by state, central city, suburban, or rural area classification. Highly desirable would be a regionalization by BEA area (Bureau of Economic Analysis Area) as defined by the Commerce Department because of the economic activity projections well into the future available by that regionalization scheme.

The Census of Commerce should be expanded to include statistics on floor area and type and size of buildings by number of stories for the various economic segments covered by this Census. The statistics pertaining to office space in separate buildings associated with these segments should be segregated, as should be information about those spaces which can be associated with major energy consuming activities. For example, restaurant energy consumption should be associated with number of guest seats and floor area. Energy consumption by end use should be reported for each segment and building type covered. Type of building roof and roof and building orientation should be reported. Data on type and size of parking facilities associated with various building classes are required. Roof area of enclosed parking structures should be reported. The regionalization of these statistics should be the same as described for residential housing. This Census should be expanded to include institutional buildings such as schools.

The Census of Manufactures should be expanded to provide more data on the buildings associated with each industry. Energy consumption data by end use should be reported, rather than only quantities of purchased fuels and electric power, and should include energy generated from waste products. Energy data should be reported by plant site as well as by industry as a whole. Regionalization should again be at the county level down, at least, to the four-digit SIC code. Data reported to the BEA area level would also be desirable.

The Census of Agriculture should be expanded to provide more information on energy use as a function of time of year and of location, and on the composition of farms as a function of location. It should include data on operation of farm cooperatives and industries based on farm products, particularly those industries traditionally located near farming areas.

6. REFERENCES

1. Mission Analysis of Photovoltaic Solar Energy Systems, Vol. I to III, ATR-76(7476-01)-1, The Aerospace Corporation, 1975.

2. Mission Analysis of Photovoltaic Solar Energy Conversion, Vol. I to IV, SAN/1101-77/1, ATR-77(7574-07)-1, The Aerospace Corporation, 1977.

3. Conceptual Design and Systems Analysis of Photovoltaic Systems, Vol. I to III, ALO-3686-14, General Electric Company, Space Division, 1977.

4. Conceptual Design and Systems Analysis of Photovoltaic Power Systems, Vol.I to V, ALO-2744-13, Westinghouse Electric Corporation, 1977.

5. Photovoltaic Systems Concept Study, Vol. I to IV, ALO-2748-12, Spectrolab, Inc., 1977.

6. Survey of Near-Term (1976-1985) Civilian Applications in the United States, Vol. II of Mission Analysis of Photovoltaic Solar Energy Conversion, SAN/1101-77-1, ATR-77(7574-07)-1 (Vol. II), The Aerospace Corporation, 1977.

7. Photovoltaic Power Systems, Market Identification and Analysis, Draft Final Report (DOE Contract EG-77-C-01-4022), InterTechnology Corporation, 1977.

8. Photovoltaic Power Systems, Market Identification and Analysis, Draft Final Report (DOE Contract EG-77-C-01-2533, BDM Corporation, Nov. 1977.

9. The Economics of Adopting Solar Photovoltaic Energy Systems in Irrigation, COO/4094-2, Lincoln Laboratory/MIT, 1977.

10. End Use Energy Consumption Data Base, Series 1 Tables, FEA Unpublished Document.

11. Energy Use and Conservation in the Residential Sector: A Regional Analysis, R-1641-NSF, The Rand Corporation, 1975.

12. Solar Heating and Cooling of Buildings (Phase O), Vol. I to III, NSF-RA-N-74-023A, Westinghouse Electric Corporation, 1974.

13. FEA Project Independence Blueprint, Vol. I, Residential and Commercial Energy Use Patterns 1970-1990, A. D. Little, 1974, (no report number).

14. Patterns of Energy Consumption in the United States, (GPO #4106-0034), Stanford Research Institute, 1972.

15. Comprehensive Evaluation of Energy Conservation Measures, EPA-230/1-75-003, Mathematica, Inc. and Peat, Marwick, et al, 1975.

16. Sourcebook for Energy Assessment, BNL 50483, Brookhaven National Laboratory, 1975.

17. Solar Heating and Cooling of Buildings (Phase O), NSF/RA/N-74-022A, Vol. I to III, TRW Systems, 1974.

18. Solar Heating and Cooling of Buildings, Phase O, Feasibility and Planning Study, Vol. I, II, III, NSF-RA-N-74-021B/PB235-432, General Electric Company, 1974.

19. Application Analysis of Solar Total Energy to the Residential Sector, Draft Final Report (Contract ALO/EG-77-C-04-3787-3) IGT Project # 8987, Institute of Gas Technology, 1978.

20. Characteristics of New One-Family Homes: 1974, Construction Reports, C25-74-13, Bureau of the Census, Aug. 1975.

21. Structural Characteristics of the Housing Inventory/1970 Census of Housing, HC (7)-4, Bureau of the Census, 1973.

22. Characteristics of New Housing, Construction Reports, C25-75-13, Bureau of the Census, 1976.

23. InterTechnology Corporation Proposed Systems Level Plan for Solar Heating and Cooling Commercial Buildings, National Solar Demonstration Program, Vol. I, II, III, ITC #030576/COO-2688-76-6, InterTechnology Corp., 1976.

24. Southwestern United States Insolation Climatology/Solar Thermal Conversion Mission Analysis, Vol. III, ATR 74(7417-16)-2, The Aerospace Corporation, 1974.

25. Hourly Insolation and Meteorological Data Bases Including Improved Direct Insolation Estimates, ATR-78(7592)-1, The Aerospace Corporation, 1977.

26. Availability of Direct, Total, and Diffuse Solar Radiation to Fixed and Tracking Collectors in the USA, SAND 77-0885, Sandia Laboratories, 1977.

27. Part E, Urban and Rural Housing, Characteristics/Current Housing Characteristics/Current Housing Reports, Annual Housing Survey: 1975, H-150-75 E, Bureau of the Census, 1977.

28. B. J. Frieden, et al, The Nation's Housing, Joint Center for Urban Studies, M.I.T., April 1977.

29. Housing Data for Modular Integrated Utility System Economic Analysis, Vol. I, II, HUD-DSC-3, Decision Sciences Corporation, 1974.

30. Energy Price Projections, FEA, 1977 pp 20021-20041, Federal Register, Vol. 42, No. 73, 15 April 1977.

31. FEA PIES Model Report for the Year 1985 (Scenario 69), Private Communication, Dr. E. MacRae, DOE Energy Information Administration, 14 April 1977.

32. Energy Consumption in Commercial Industries by Census Division - 1974 JACKFAU-77-143-3, Jack Faucett Assoc., 1977.

33. Energy Conservation in Public and Commercial Buildings, P-5093, The Rand Corporation, 1973.

34. "Shopping Center Census", Shopping Center World, pp. 15, January 1977.

35. A Market Study of Energy Related Equipments for the Commercial Buildings Sector, FEA/D-76010/PB 248 618, Ultrasystems, Inc., 1975.

36. "1976 Downtown and Suburban Office Building Experience Exchange Report/For Calendar Year 1975", Building Owners and Managers Association International, 1976.

37. MIUS Community Conceptual Design Study, JSC-10650, NASA TM X-58174 Lyndon B. Johnson Space Center, 1976.

38. 1972 Census of Manufactures, Vol. I to III, Bureau of the Census, 1976.

39. Fuels and Electric Energy Consumed, Annual Survey of Manufactures 1974, M74(AS)-4.2, Bureau of the Census.

40. Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat, Vol. I to III, (no report number) Battelle Columbus Laboratories, 1977.

41. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, Vol. I to III, COO/2829-76/1, ITC 00028-1, InterTechnology Corporation, 1977.

42. 1974 Census of Agriculture, Vol. I to V, Bureau of the Census, 1977.

43. Energy and U.S. Agriculture: 1974 Data Base, Vol. I and II, FEA/D-76/459, Economic Research Service, USDA, 1976.

44. Corn for Grain/Harvesting, Handling, and Drying Methods, 1973-1976, Report #146, Iowa Crop and Livestock Reporting Service, 4 March 1977.

45. Solar Energy Applications in Agriculture, Potential Research Needs and Adoption Strategies, A-184/NSF/RA-760021, Agric. Exper. Station, University of Maryland, 1976.

46. Solar Powered Irrigation Systems Study, Vol. I, II, ATR-78(7693-01)-2, The Aerospace Corporation, 1978.

47. Commercial Buildings Inventory/Commercial Energy Consumption Data Base Development Project, Preliminary Report under ERDA Contract EC-77-C-01-2161, General Electric Marketing and Business Services, Bridgeport, Connecticut, 20 October 1977.

Appendix

BIBLIOGRAPHY

Sources of General Interest

1. Area Economic Projections 1990, GPO Stock #003-024-00490-9, U.S. Department of Commerce, 1975.

2. County Business Patterns 1973, United States, CBP-73-1, Bureau of the Census, 1974.

3. Walter Dupree, et al, Energy Perspectives 2, U. S. Department of the Interior, June 1976.

4. Energy Information in the Federal Government/Energy Information Locator System, FEA/B-75/375, PB-246-703, Federal Energy Administration, 1975.

5. National Gas Supply and Demand 1970-1990 Staff Report #2, Federal Power Commission, 1972.

6. Energy Availabilities for State and Local Development: A Methodological and Data Overview, ORNL-TM-5890, Oak Ridge National Laboratory, 1977.

7. 1972 County and City Data Book/Cumulations to BEA Areas, ORNL-NSF-EP-79, Oak Ridge National Laboratory, 1974.

8. Forecast of Likely U.S. Energy Supply/Demand Balances for 1985 and 2000 and Implications for U.S. Energy Policy, DIBA/EAD-77/1/PB-266-240, U.S. Department of Commerce, 1977.

9. National Energy Outlook 1976, FEA-N-75/713, Federal Energy Administration, 1976.

10. National Electric Rate Book, U.S. States, GPO #1976-211-346/36, Federal Power Commission, May 1976.

11. Population Estimates and Projections/Current Population Reports, Series P-25, No. 704, Bureau of the Census, 1977.

12. Fuel and Energy Price Forecasts EPRI EA-411, Vol. I, II, Electric Power Research Institute/Foster Associates, Inc., 1977.

13. Fuel and Energy Price Forecasts/Quantities and Long-Term Marginal Prices, EPRI EA-433, Electric Power Research Institute/SRI International, 1977.

14. Energy Availabilities for State and Local Development, 1974 Data Volume, ORNL/TM-5890/S3, Oak Ridge National Laboratory, 1977.

15. Typical Electric Bills 1977, FPC R 90, Federal Power Commission, 1978.

16. The Energetics of the United States of America: An Atlas, BNL 50501-R, Brookhaven National Laboratory, Oct. 1977.

17. Energy Availabilities for State and Local Development: 1972 Data Volume, ORNL/TM-5890/S1, Oak Ridge National Laboratory, September 1977.

18. The Technical and Economic Feasibility of U.S. District Heating Systems Using Waste Heat from Fusion Reactors, BNL 50516, Brookhaven National Laboratory, 1976.

19. A Systems Analysis of the Economic Utilization of Warm Water Discharge from Power Generating Stations Bulletin #48, Engineering Experiment Station, Oregon State University, 1974.

20. National Program Definition Study for the Non-Electrical Utilization of Geothermal Energy, ANCR-1214, Aerojet Nuclear Company, 1975.

21. Conceptual Study for Total Utilization of an Intermediate Temperature Geothermal Resource, ANCR-1260, Idaho National Engineering Laboratory, ERDA, 1976.

22. Future Developments in Waste Heat Utilization, Circular #49/PB-249-346, Engineering Experiment Station, Oregon State University, 1975.

23. Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada, NBS Building Series 96, National Bureau of Standards, 1977.

24. International District Heating Association, Proceedings of the 67th Annual Meeting of the Int. District Heating Association, 1976, IDHA, 1977.

25. Technical and Economic Feasibility of Thermal Energy Storage, COO-2558-2, General Electric Company, Space Division, 1976.

26. Waste Heat Management Guidebook NBS Handbook #121, National Bureau of Standards, 1977.

27. Analysis of Energy Usage on Long Island from 1975 to 1995/The Opportunities to Reduce Peak Electrical Demands and Energy Consumption by Energy Conservation, Solar Energy, Wind Energy, and Total Energy Systems, TIC NP-21332, Dubin-Mindell-Bloome Association, 1975.

28. Energy Use and Climate/Possible Effects of Using Solar Energy Instead of Stored Energy, M74-66/PB 245-203, The Mitre Corporation, 1975.

Sources of Total Energy Applications Data

29. Total Energy Systems, Urban Energy Systems, Residential Energy Consumption, PB-221-374, Federal Council on Science and Technology, 1972.

30. Economic Evaluation of Total Energy: Guidelines, HUD-DSC-2, Decision Sciences Corporation, 1973.

31. Marketing Considerations for a Modular Integrated Utility System, Contract #NASA-2022, ABT Associates, Inc. (no date).

32. The Potential Benefit of an Advanced Integrated Utility System, JSC-09964/NASA TMX 58170, Lyndon B. Johnson Space Center, 1975.

33. Conceptual Design Study for the Application of a Solar Total Energy System at the North Lake Campus, Dallas County Community College District, SAND 76-0512, Sandia Laboratories, 1976.

34. Assessment of Total Energy Systems for the Department of Defense, Vol. I, II, SRI EGU-2513/AD-781-816, Stanford Research Institute, 1973.

35. Evaluating Integrated Utility Systems, (no report number), National Academy of Sciences, 1974.

36. Application of Solar Total Energy to a Mixed-Load Community, SAND 75-0542, Sandia Laboratory, 1975.

37. MIUS Technology Evaluation, Thermal Energy Storage Materials and Devices, ORNL-HUD-MIUS-23, Oak Ridge National Laboratory, 1975.

38. Technology Assessment of Modular Integrated Utility Systems, Vol. I, Summary Report, ORNL/HUD/MIUS-24, Oak Ridge National Laboratory, 1976.

39. Feasibility Study of Solar Energy Utilization in Modular Integrated Utility Systems, ADL 78036/DRL T-1128, Arthur D. Little, Inc., 1975.

40. MIUS Systems Analysis; The Effects of Thermal Energy Storage and Solid Waste Incineration Options on MIUS Cost and Fuel Consumption, ORNL/HUD/MIUS-26, Oak Ridge National Laboratory, 1976.

41. Application of Modular Integrated Utilities Systems Technology/Draft Environmental Impact Statement, HUD-PDR-EIS-75-1D, U. S. Department of Housing and Urban Development, 1975.

42. Initial Comparisons of Modular-Sized, Integrated Utility Systems and Conventional Systems for Several Building Types, JSC-09076/NASA TMX-58140, Lyndon B. Johnson Space Center, 1976.

43. MIUS Technology Evaluation/Prime Movers, ORNL-HUD-MIUS-11, Oak Ridge National Laboratory, 1974.

44. MIUS Systems Analysis/Comparison of MIUS and Conventional Utility Systems for an Existing Development, ORNL/HUD/MIUS-20, Oak Ridge National Laboratory, 1976.

45. MIUS Technology Evaluation/Compression Refrigeration Systems for Air Conditioning, ORNL/HUD/MIUS-19, Oak Ridge National Laboratory, 1976.

46. Investigation of Storage System Designs and Techniques for Optimizing Energy Conservation in Integrated Utility Systems, Vol. I, II, III, NAS 9-14628/T1139,3, Battelle Columbus Laboratories, 1976.

47. MIUS Technology Evaluation/Preliminary Subsystem Recommendations for Near-Term Concepts, ORNL/HUD/MIUS-17, Oak Ridge National Laboratory, 1976.

48. MIUS Technology Evaluation/Thermal Energy Conveyance, ORNL/HUD/MIUS-22, Oak Ridge National Laboratory, 1976.

49. MIUS Technology Evaluation/Lithium Bromide-Water Absorption Refrigeration, ORNL-HUD-MIUS-7, Oak Ridge National Laboratory, 1974.

50. Procedures for Feasibility Analysis and Preliminary Design of Total Energy Systems at Military Facilities, CERL TR-E-96, Booz, Allen, and Hamilton for U.S. Army Construction Engin. Res. Laboratory, 1976.

51. Solar Total Energy Systems, Vol. I, II, ATR-78(7692-01)-1, The Aerospace Corporation, 1978.

52. Commercialization Planning for Solar Total Energy Systems, Space Division, General Electric Company, December 1977.

53. Analysis of a 1000-Home Solar Total Energy Community Using Clear Air Solar Intensity, SAND-75-0097, Sandia Laboratories, 1975.

Sources of Building Applications Data

54. General Housing Characteristics, U.S. Summary, 1970 Census of Housing, HC(1)-A1, Bureau of the Census, 1971.

55. Geographic Aspects of the Housing Inventory/1970 Census of Housing, HC(7)-7, Bureau of the Census, 1973.

56. Part B, Indication of Housing and Neighborhood Quality/Current Housing Reports, Annual Housing Survey; 1975, H-150-75 B, Bureau of the Census, 1977.

57. Part A, General Housing Characteristics/Current Housing Reports, Annual Housing Survey: 1975, H-150-75A, Bureau of the Census, 1977.

58. Project Sage/Solar Assisted Gas Energy. Int. Report #1, Southern California Gas Company, April 1976.

59. Evaluation of the Air-to-Air Heat Pump for Residential Space Conditioning, FEA/D-76/340/PB-255-652, Gordian Associates, Inc., 1976.

60. Energy Consumption Data Base/Vol. III, Ch. 7/Household Sector, Energy and Environmental Analysis, Inc., for FEA, 1977.

61. Study for Defining the Number of Residential and Non-Residential Projects/National Solar Demonstration Program, COO/2683-76/2, General Electric Company (Space Division), 1976.

62. The Computer Program for Heating and Cooling Loads in Buildings, Building Science Series #69, National Bureau of Standards, 1976.

63. Evaluation of Heating Loads in Old Residential Structures, HUD-HAI-7/PB 277-167, Hittman Associates, 1974.

64. A Methodology for Projecting the Electrical Energy Demand of the Residential Sector in California, R-995-NSF/CSRA, The Rand Corporation, 1973.

65. All Electric Homes in the United States/Annual Bills - January 1, 1975/Cities of 50,000 and More, FPC R-87, Federal Power Commission, 1975.

66. Implications of Residential Solar Space Conditioning on Electric Utilities, F-C4209, The Franklin Institute Research Laboratories, 1976.

67. National Program for Solar Heating and Cooling of Buildings/Project Data Summaries, Vol. I - Commercial and Residential Demonstrations, ERDA 76-127, ERDA, 1976.

68. Residential Energy Consumption/Single Family Housing, HUD-HAI-2, Hittman Associates, Inc., 1975.

69. Residential Energy Consumption/Multi-Family Housing, HUD-HAI-4, Hittman Associates, Inc., 1974.

70. Solar Heating of Buildings and Domestic Hot Water, TR-835/DN687065, Civil Engin. Laboratory, Port Hueneme, 1976.

71. Assessment of Solar Heating and Cooling Technology, LA-6379-MS, Los Alamos Scientific Laboratory, 1977.

72. Residential Energy Use, An Econometric Analysis, R-1297-NSF, The Rand Corporation, 1973.

73. Projections of Demand for Housing by Type of Unit and Region, Agriculture Handbook #428, Forest Service, USDA, 1972.

74. A Methodology for Projecting the Electrical Energy Demand of the Commercial Sector in California, R-1106-NSF/CSRA, The Rand Corporation, 1973.

75. Energy Conservation in Non-Residential Buildings, R-1623-NSF, The Rand Corporation, 1976.

76. The Commercial Demand for Energy: A Disaggregated Approach, ORNL/CON-15, Oak Ridge National Laboratory, 1978.

77. Evaluation of Building Characteristics Relative to Energy Consumption in Office Buildings, FEA/D-76/006/PB-248-774, Enviro-Management and Research, Inc., 1975.

78. Total Electric Buildings/Physical and Technical Data on Commercial and Industrial Installations, TVA, May 1973.

79. Physical Characteristics, Energy Consumptions, and Related Institutional Factors in the Commercial Sector, FEA/D-77/040/FEA/Hittman Associates, February 1977.

80. Estimating Land and Floor Area Implicit in Employment Projections Vol. I, II, PB 200-069, Ide Associates, Inc., 1970.

81. Buildings 832 and Small Neighborhood Applications for Sandia Laboratories Solar Energy System Test Bed, SAND 75-0202, Sandia Laboratories, 1975.

82. Energy Conservation: Implications for Building Design and Operation, Proceedings of a Conference held in Bloomington, Minn., May 23, 1973, University of Minnesota, 1973.

83. Energy Consumption in Commercial Buildings in Philadelphia, (no report number), National Electric Manufacturers Assn./National Electrical Contractors Assn., 1974.

84. American Hospital Association, Hospital Statistics, 1975 Annual Survey, AHA #2448, 1976.

85. Proceedings of the Conference on Energy Conservation in Commercial, Residential, and Industrial Buildings Held at the Fawcett Center for Tomorrow, Ohio State University, Ohio, May 1974, PB-240-306, National Science Foundation, 1974.

86. Northview Junior High Solar Energy Demonstration Project, COO/2624-1, Honeywell Systems and Research Center, 1976.

87. Definition of Reference Buildings and HVAC Parameters for Heating and Cooling by Conventional and Solar Energy Systems, AHEM #9065-0, Ayres and Hayakawa Energy Management, 1976.

88. Technology Evaluation Report, Commercial Buildings, ERDA Report #COO/2683-76/1, General Electric Company, 1976.

89. P. R. Achenbach, "Effective Energy Utilization in Buildings", paper presented 3rd Urban Technology Conference, Boston, September 1973.

90. Cost/Benefit Analysis Report and Supporting Opinion Survey, Commercial Buildings, ITC Report #011976, ERDA COO/2688-76/1, InterTechnology Corporation, 1976.

91. Subject Statistics/1972 Census of the Wholesale Trade, WC 72-S-4, Bureau of the Census, 1975.

92. Miscellaneous Subjects/1972 Census of Retail Trade, RC-72-S-3, Bureau of the Census, 1975.

93. 1972 Census of Selected Services, Bureau of the Census, 1976.

94. Area Statistics, United States, 1972 Census of Wholesale Trade, WC 72-A-52, Bureau of the Census, 1975.

95. Area Statistics, United States, 1972 Census of Retail Trade, RC 72-A-52, Bureau of the Census, 1975.

96. Area Statistics, United States, 1972 Census of Selected Service Industries, SC 72-A-52, Bureau of the Census, 1975.

97. A Study of the Physical Characteristics, Energy Consumption, and Related Institutional Factors in the Commercial Sector, HIT 630, FEA/D-76/053, PB-249-470, Hittman Associates, Inc., 1975

98. Energy Consumption Analysis of Buildings in the New York Area, (Exhibit #172, NDK-1, PSC Case #26292) by Flack & Kurtz for Con Ed, N.Y., April 1973.

99. An Investigation of Methods to Improve Heat Pump Performance and Reliability in a Northern Climate, Vol. I, II, III, EPRI EM-319, PP544-1, Westinghouse Electric Corporation, 1977.

100. Optimization Studies of Solar Absorption Air Conditioning Systems, Report #NSF/RANN/SE/GI-39117/PR/76/2, University of Maryland, 1972.

101. Development of a Solar Powered Residential Air Conditioner (Generator Optimization), NAS8-31437/N76-24702, Chrysler Corporation Space Division, 1976.

102. D. K. Miller, "The Performance of Water-Cooled Lithium Bromide Absorption Units for Solar Energy Applications", Heating, Piping/Airconditioning, Jan. 1976.

Sources of Industrial Applications Data

103. A Study of Energy Conservation Potential in the Meat Packing Industry, PB 261-663/FEA/D-76/291, Johns - Manville Corporation, 1976.

104. An Economic Methodology for Solar-Assisted Industrial Process Heat Systems: The Effect of Government Incentives, UCRL-522544, Lawrence Livermore Laboratory, 1977.

105. State Projections of Industrial Fuel Needs, PB-263-338, Federal Power Commission, 1976.

106. John G. Myers, et al, Energy Consumption in Manufacturing, The Conference Board, Ballinger Publishing Company, 1974.

107. Jeffrey M. Duke, Patterns of Fuel and Energy Consumption in the U.S. Pulp and Paper Industry, American Paper Institute, 1974.

108. Energy Use Patterns in U.S. Manufacturing for the Period 1950 -1970, ORNL-MIT-169, Oak Ridge National Laboratory, 1973.

109. Energy Consumption Data Base, Vol. III, Chapter 4/Manufacturing Sector, for FEA by Energy and Environmental Analysis, Inc., 1977.

110. Technical and Economic Feasibility of Solar Augmented Process Steam Generation, COO-2732-1, Thermo-Electron Corporation, 1976.

111. Industrial Applications of Solar Total Energy, Vol. I to V, SAN-1132-2/MDC G6772, McDonnell Douglas Astronautics Company, 1977.

112. A Study of Inplant Electric Power Generation in the Chemical, Petroleum Refining, and Paper and Pulp Industries, FEA/D-76/321/PB 255-659, Thermo Electron Corporation, 1976.

113. Electricity Demand by Manufacturing Industries in the United States, ORNL-NSF-EP-87, Oak Ridge National Laboratory, 1975.

114. Environmental Considerations of Selected Energy Conserving Manufacturing Process Options, Vol. I to XV, EPA-600/7-76-034, EPA/AD Little, 1976.

115. U. S. Department of Commerce, U. S. Industrial Outlook 1977, GPO 003-008-00174-2, January 1977.

116. A Methodology for Projecting the Electrical Energy Demand of the Manufacturing Sector in California, R-991-NSF/CSRA, The Rand Corporation, 1973.

117. Evaluation of New Energy Sources for Process Heat, NSF-OEP 74-18055-1/PB-245604, Dow Chemical Company, 1975.

118. Solar Energy for Process Steam Generation, TE 5392-34-75, Thermo Electron Corporation, 1974.

Sources of Agricultural Application Data

119. J. M. Flink, "Energy Analysis in Food Processing Operations: Dehydration Process", paper presented at 36th Annual Meeting of Institute of Food Technologists, Anaheim, 1976.

120. B. J. Bond, "Using Waste Heat in Agricultural Production", Proceedings of National Symposium on Electrical Energy for the Food Chain", 1976, Food and Energy Council, 1976.

121. Energy and the Food System, ATR-77(8104)-1, The Aerospace Corporation, 1977.

122. Energy and U.S. Agriculture: Irrigation Pumping, 1974, Agric. Econom. Report #376, Econ. Res. Service, U.S. Department of Agriculture, 1977.

123. D. C. Ludington, "Refrigeration Requirements for Farm Milk Cooling Tanks", paper #75-3523, Meeting of Am. Soc. of Agric. Engin., December 1975.

124. Energy for Rural Development, (no report number) National Academy of Sciences, 1976.

125. Photovoltaic Power in Less Developed Countries, COO-4094-1, MIT/Lincoln Laboratory, 1977.

126. D. Dvoskin and E. O. Heady, Energy Requirements of Irrigated Crops in the Western United States, Misc. Report, Iowa State University, 1976.

127. Handbook of Agricultural Charts, Agric. Handbook #504, U.S. Department of Agriculture, 1976.

128. The U.S. Food & Fiber Sector: Energy Use and Outlook, 93rd Congress, 2nd Session, 38-906, Committee Print, U.S. Dept. of Agric. for the U.S. Senate, 20 Sept. 1974.

129. Design Guidelines for Agricultural Soil Warming Systems Utilizing Waste Heat, EPA 600/3-76-026/PB 252-251, Environmental Research Laboratory, EPA, 1976.

130. Energy Uses in Nebraska Agriculture, CC-255, University of Nebraska - Lincoln College of Agriculture, 1973.

131. Energy Use in Agriculture/Now and for the Future, Report #68, Council for Agricultural Science and Technology (CAST), 1977.

132. The Proceedings of "Energy - Key to Food Production"/A National Symposium on Electrical Energy for the Food Chain, September 1976 in St. Louis, Missouri, The Farm Electrification Council, 1977.

133. D. J. Arnholt, J. A. Rupp, Farmers Guide for Electric Grain Drying, Public Service Indiana, 1974.

134. A Guide to Energy Savings: For the Field Crops Producer, For the Poultry Producer, For the Orchard Grower, For the Dairy Farmer, For the Livestock Producer, For the Vegetable Producer, (A series of booklets), FEA/USDA, 1977.

135. U.S. Agricultural Production under Limited Energy Supplies, High Energy Prices and Expanding Agricultural Exports, CARD Report #69, Center for Agricultural and Rural Development, Iowa State University, 1976.

136. Energy Consumption Data Base, Vol. III, Chapter 1, Agricultural Sector, for FEA by Energy and Environmental Analysis, Inc., 1977.

137. Solar Energy Utilization: A Bibliographic Guide, ARS-NE-74, Agric. Res. Service, U.S. Department of Agriculture, 1976.

138. Israelsen, O. W. and Hansen, V. E., Irrigation Principles and Practices, Third Edition, John Wiley and Sons, Inc., 1962.

139. Ruttan, V. W., The Economic Demand for Irrigated Acreage, Published for Resources For the Future, Inc., by The Johns Hopkins Press, 1965.

140. Acreage, U.S. Department of Agriculture, Crop Reporting Board, Statistical Reporting Service, June 30, 1977.

141. Agricultural Statistics, U.S. Department of Agriculture, 1976.

142. "Irrigation Survey", Irrigation Journal, Brantwood Publication Inc., Elm Grove, Wisconsin, 1975.

143. Hathorn Jr., Scott, Crop-Water Profile, Cochise, Graham, Maricopa, Pima, Pinal Counties, Arizona, U.S. Department of Agriculture, Cooperative Extension Service, The University of Arizona. October 1977.

144. Bogle, T. R., Groundwater and Irrigation, A Study of Six Western Kansas Counties, U.S. Department of Agriculture, Cooperative Extension Service, Kansas State University, October 1977.

145. 1972 Obers Projections, Regional Economic Activity in the U.S., Series E' Population, Supplement, Agricultural Projections, Volumes 1, 3 and 4, Prepared by the U.S. Department of Agriculture, Economic Research Service for the U.S. Water Resources Council, May 1975.

146. Crop Consumptive Irrigation Requirements and Irrigation Efficiency Coefficients for the United States, U. S. Department of Agriculture, Soil Conservation Service, June 1976.

147. *On the Nature and Distribution of Solar Radiation*, Watt Engineering Ltd., Cedaredge, Colorado, Report HCP/T 2552-01, Prepared for U.S. Department of Energy, Division of Solar Technology under Contract EX-76-C-01-2552, March 1978.

148. *Krenz, R. D., Firm Enterprise Data System, Area Budgets*, U. S. Department of Agriculture, Economic Research Service, Oklahoma State University, Department of Agricultural Economics, 1975.

149. Jewell, W. J., *Energy, Agriculture and Waste Management*, Ann Arbor Science Publishers, 1977.

150. Leach, G., *Energy and Food Production*, IPC Science and Technology Press, 1976.

151. *Feasibility of Solar Energy for Feedlot Operation and Irrigation Pumping*, Agricultural Research Service, U. S. Department of Agriculture.

152. G. Roa, et al, "Grain Drying in Stationary Bins with Solar Heated Air", *Solar Energy*, Vol. 18, pp 445-449.

153. *Energy Consumption, Conservation and Projected Needs for Texas Agriculture*, PB-243-327, Texas Governor's Energy Advisory Council, 1 January 1975.

154. *The Utilization of Solar Energy for Feedmill and Irrigation Operations*, Texas Tech University, 1976.

155. G. Sloggett, *Energy Used for Pumping Irrigation Water in the United States, 1974*, Oklahoma State University, June 1976.

156. *Energy Use for Food in the United States*, ORNL-NSF-EP-57, Oak Ridge National Laboratory, October 1973.

157. J. S. Steinhart, et al, "Energy Use In the U.S. Food System", *Science*, Vol. 184, pp 307-316.

158. D. Pimentel, et al, "Food Production and the Energy Crisis", *Science*, Vol. 182, pp 443-449.

159. G. H. Heichel, "Agricultural Production and Energy Resources", *American Scientist*, Vol. 64, January - February 1976, pp 64-72.

160. D. Proctor, et al, "Solar Energy for the Australian Food Processing Industry", *Solar Energy*, Vol. 19, pp 63-72.

161. 1977 Agricultural Engineers Yearbook, June '77 - '78, American Society of Agricultural Engineers, May 1977.

162. R. Vance Morey, et al, "Practices for the Efficient Utilization of Energy for Drying Corn", Transactions of the ASAE, pp 151-155, 1976.

163. G. H. Heichel, "Agricultural Production and Energy Resources", American Scientist, Vol. 64, pp 64-72, January-February 1976.

164. D. L. Van Dyne and J. L. Chain, "A Method of Estimating Technical and Economic Feasibility of Solar Heating Systems for Broiler Houses and Other Farm Buildings", Agricultural & Resource Economics Information Series A-10, University of Maryland.

165. Economic Feasibility of Heating Maryland Broiler Houses with Solar Energy, MP 898, University of Maryland, February 1977.

166. V. Cervinka, et al, "Energy Requirements for Agriculture in California", University of California, Davis, January 1974.

167. G. H. Foster, et al, Solar Grain Drying, Progress and Potential, Agriculture Information Bulletin No. 401, Agricultural Research Service, November 1976.

168. W. H. Peterson, et al, "Solar-Electric Drying of Corn in South Dakota", Transactions of the ASAE, Vol. 19, No. 2, pp 349-353, 1976.

169. B. A. Stout, Energy for Agriculture, A Computerized Information Retrieval System, Agricultural Engineering Department, Michigan State University, July 1977.

170. Potential for Energy Conservation in Agricultural Production, Report No. 40, Council for Agricultural Science and Technology, 6 February 1975.

171. R. N. Brewer, Potential for Conversion and Utilization of Solar Energy in Poultry Production, PB-244-375, Auburn University, 28 January 1975.

172. G. C. Shove, Solar Grain Drying Conference Proceedings, Urbana-Champaign, Illinois, 11-12 January 1977.

173. R. Vance Morey, et al, "Simulation of Solar Energy Grain Drying - Minnesota Contribution", University of Minnesota, June 1976.

174. R. Vance Morey, et al, "Field Evaluation of Solar Energy Grain Drying", University of Minnesota, December 1976.

175. N. K. Whittlesey, et al, Impacts of Energy Price Changes on Food Costs, Bulletin 822, Washington State University, April 1976.

176. R. O. Pierce and T. L. Thompson, "Solar Grain Drying in the North Central Region -- Simulation Results", Meeting of American Society of Agricultural Engineers, Paper No. 76-3517, 14-17 December 1976.

177. R. V. Morey and D. W. Petersen, "Evaluation of the Feasibility of Solar Energy Grain Drying", Meeting of American Society of Agricultural Engineers, Paper No. 77-3013, 26-29 June 1977.

178. P. K. Avlani and W. J. Chancellor, "Energy Requirements for Wheat Production and Use in California", Meeting of American Society of Agricultural Engineers, Paper No. 75-1557, 15-18 December 1975.

179. P. D. Thompson, "Solar Energy for Milking Parlor Heating and Cooling", Meeting of American Society of Agricultural Engineers, Paper No. 75-3521, 15-18 December 1975.

180. J. Maghsood, "A Study of Solar Energy Parameters in Plastic-Covered Greenhouses", J. Agric. Engrg. Res., Vol. 21, pp 305-312, 1976.

181. R. P. Singh, "Energy Consumption and Conservation in Food Sterilization", Food Technology, pp 57-60, March 1977.

182. F. N. Reece, "Use of Partial-House Brooding and Solar Energy in Broiler Houses", Feedstuffs, pp 72-75, 24 January 1977.

183. "Solar Energy Generates Power in the Parlor", Dairy Herd Management, pp 34-35, August 1976.

184. M. B. Green, "Energy in Agriculture", paper presented at the Annual Meeting of the Society of Chem. Industry, in Stirling, on 1 July 1976, Chem. & Ind., pp 641-646, 7 August 1976.

185. W. Lockeretz, et al, "A Comparison of the Production, Economic Returns, and Energy Intensiveness of Corn Belt Farms That Do and Do Not Use Inorganic Fertilizers and Pesticides", PB 243 639, Center for the Biology of Natural Systems, Washington University, July 1975.

186. T. Lukes, Research on the Application of Solar Energy on the Food Drying Industry, California Polytechnic State University, 1975.

187. W. Lockeretz, et al, "Energy in Corn Belt Crop Production", PB 247 467, Washington University, July 1975.

188. G. L. Kline, "Solar Collectors for Low Temperature Grain Drying", American Society of Agricultural Engineers, 26-29 June 1977.

189. G. A. Kranler, et al, "Grain Drying with Supplemental Solar Heat", Meeting of American Society of Agricultural Engineers, Paper No. 75-3001, 22-25 June 1975.

190. J. M. Krochta, et al, "Solar-Energy Cooling and Freezing of Food: A Computer Analysis", Food Technology, pp 61-76, March 1977.

191. Industrial Energy Study of Selected Food Industries, PB-237 316, Development Planning and Research Associates, Inc., July 1974.

192. Energy and Food: Energy Used in Production, Processing, Delivery and Marketing of Selected Food Items, CSPI Energy Series VI, Center for Science in the Public Interest, 1975.

193. R. Klepper, et al, "Economic Performance and Energy Intensiveness on Organic and Conventional Farms in the Corn Belt: A Preliminary Comparison", Economics of Organic Farms, Amer. J. Agr. Econ., February 1977.

194. Research on the Application of Solar Energy to the Food Drying Industry, PB 238 073, California Polytechnic State University, October 1974.

195. Energy Use in Agriculture: Now and For the Future, Report No. 68, Council for Agricultural Science and Technology, August 1977.

196. Efficient Energy Management with Low Temperature Grain Drying, Food and Energy Council, Energy Management Series, November 1976.

197. Proceedings of Symposium on Use of Solar Energy for Poultry and Livestock Production, Auburn University, Alabama, 9-10 November 1976.

198. G. E. Meyer, "Solar Heated Air Drying of Soybean Seed and Shelled Corn: Experimental Studies", Meeting of American Society of Agricultural Engineers, Paper No. 75-3002, 22-25 June 1975.

199. J. W. Sorenson, "Energy to Perform Agricultural Operations: Harvesting and Processing", paper presented at Meeting of Texas Chapter of American Society of Agronomy, Dallas, 22 February 1974.

200. Proceedings - Solar Energy, Food - Fuel Workshop, The University of Arizona, 5-6 April 1976.

201. M. A. Sabbah, "Simulation of Solar Grain Drying Using the Logarithmic Model", Meeting of American Society of Agricultural Engineers, Paper No. 77-3012, 26-29 June 1977.

202. P. D. Thompson, et al, "Milking Parlor Solar Heating System Performance", Meeting of American Society of Agricultural Engineers, Paper No. 76-3571, 14-17 December 1976.

203. Solar Crop Drying Conference Proceedings, Weaver Laboratories, North Carolina State University at Raleigh, 30 June 1977.

204. W. W. Gunkel, Energy Requirements for New York State Agriculture -- Part 1 (Food Production), Part 2 (Indirect Energy Inputs), No. 405:11/74, Department of Agricultural Engineering, New York State College of Agriculture, Cornell University, 1974.

205. Grain Drying Manual, EEI No. 61-25-2M, Edison Electric Institute, New York, 1969.

206. D. L. Larson, et al, Energy Requirements for Irrigated Crop Production, Paper No. 217, Arizona Agricultural Experiment Station.

207. K. L. Chen, et al, "Minimum Energy Designs for Selected Irrigation Systems", Meeting of American Society of Agricultural Engineers, Paper No. 76-2037, 27-30 June 1976.

208. C. D. Baird, et al, "Utilization of Solar Energy for Greenhouse Heating", Meeting of American Society of Agricultural Engineers, Paper No. 75-3503, 15-18 December 1975.

209. W. H. Peterson, et al, "Solar-Electric Drying of Corn in South Dakota", Meeting of American Society of Agricultural Engineers, Paper No. 75-3003, 22-25 June 1975.

210. W. H. Gardner, "Influence of Soil Temperature on Growth of Selected Plants and Associated Heat Flow and Distribution in Soil", Circular 598, Washington State University, October 1976.

211. D. G. Overhults, et al, "Drying Soybeans with Heated Air", Transactions of the ASAE, pp 112-113, 1973.

212. G. C. Misener, "A Mass-Energy Economic Model of a Dairy Farm", Transactions of the ASAE, pp 364-368, 1976.

213. A. Alam and G. C. Shove, "Simulation of Soybean Drying", Transactions of the ASAE, pp 134-136, 1973.

214. D. D. Snethen, et al, "Winter Operation of a Modified, Open-Front Finishing House for Swine", Transactions of the ASAE, pp 364-365, 1974.

215. M. R. Paulsen, "Drying Analysis of Grain Sorghum", Transactions of the ASAE, pp 537-540, 1973.

216. C. D. DesChenes, et al, "Multiple Use Solar Heat Collection and Storage System for Grain Drying", 1976 Meeting of Am. Society of Agric. Engin., ASAE Paper No. 76-3514, 14-17 December 1976.

217. E. E. Williams, "Solar Grain Drying & Collection Evaluation", 1976 Meeting, Am. Soc. of Agric. Engin., ASAE Paper No. 76-3512, December 1976.

218. D. C. Sanders and R. W. Skaggs, "Crop and Soil Temperature Response to Soil Warming in the Southeast", Meeting of Am. Soc. of Agric. Engin., ASAE Paper No. 75-3541, December 1975.

219. G. R. Bodman, et al, "Environmental Control Systems for Calf Nurseries", 1973 Meeting of Am. Soc. of Agric. Engin., ASAE Paper No. 73-4552, 1973.

220. F. W. Hall, et al, "Energy Utilization on Selected Michigan Farms", Meeting of Am. Soc. of Agric. Engineers, ASAE Paper No. 75-3017, June 1975.

221. C. D. Baird, "Utilization of Solar Energy for Greenhouse Heating", Meeting of Am. Soc. of Agric. Engin., ASAE Paper No. 75-3503, December 1975.

222. I. P. Schisler, "Waste Heat Utilization from Power Plants in Agriculture; I - Soil Warming and Crop Growth", Meeting of Am. Soc. of Agric. Engin., ASAE Paper No. 75-3530, December 1975.

223. G. C. Shove, "Potential Energy Use in Low-Temperature Grain Conditioning", Transactions of the ASAE, pp 58-60, 1970.

224. D. R. Mears, "Methods of Accelerating Forage Drying", Transactions of the ASAE, pp 531-533, 1970.

225. H. A. Hughes and J. B. Holtman, "Systems Analysis of Energy Consumption in Beef Production", Transactions of the ASAE, pp 1161-1166, 1974.

226. W. L. Roller, "Energy Costs of Intensive Livestock Production", Meeting of Am. Soc. of Agric. Engin., ASAE Paper No. 75-4042, June 1975.

227. L. B. Driggers, "Energy Consumption in Swine Confinement Buildings", Meeting of the Amer. Soc. of Agric. Engin., ASAE Paper No. 76-4537, December 1976.

228. G. E. Rehkungler, et al, "Commercial Food Processing Systems", Meeting of Am. Soc. of Agric. Engin., ASAE Paper No. 75-6024, June 1975.

229. L. E. Stetson, et al, "Irrigation System Management for Reducing Peak Electrical Demands", Transactions of the ASAE, pp 303-306 and 311, 1975.

230. L. E. Stetson and S. O. Nelson, "Power Factors and Electrical Demands of Center-Pivot Irrigation Machines", Transactions of the ASAE, pp 673-676, 1975.

231. B. Nolen, et al, Energy Consumption in Louisiana Agriculture, Louisiana State University, June 1976.