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ABSTRACT

The purpose of this study was to establish the technical and economic feasibility of using solar energy for the heating and cooling of buildings. Five selected building types in 14 selected cities were used to determine loads for space heating, space cooling and dehumidification, and domestic service hot water heating. Relying on existing and proven solar and conventional climatic control hardware, three references designs were selected for detailed cost evaluation in each of the 14 cities and five building types. Mathematical models were constructed of the reference systems. A computer simulation of the reference systems with specified inputs to the program determined the overall system performance. A series of computer programs determined system cost and percent solar utilization for each of the reference systems. The market penetration analysis was integrated into the cost programs. The social impact of solar energy was assessed by a random telephone survey in three cities. Environmental and economic impact forecasts are calculated. Three proof-of-concept experiments were recommended. Phase 1 and 2 development plans were prepared, and a utilization plan for implementation and commercialization of solar energy systems was prepared. (Author/MLF)

NSF/RA/N-74-022A

# SOLAR HEATING AND COOLING OF BUILDINGS

## (PHASE O)

## VOLUME I
## EXECUTIVE SUMMARY

MAY 31, 1974

Prepared for:

**National Science Foundation**
**RANN / Research Applied to National Needs**
**Washington, D.C., 20550**

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TRW REPORT NO. 25168.001



TRW
SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH • CALIFORNIA

## FOREWORD

This Phase 0-Final Technical Report for the "Solar Heating and Cooling of Buildings" was prepared for the National Science Foundation, RANN-Public Technology Projects Office, Washington, D.C., in fulfillment of Contract NSF C-853. This report, consisting of three volumes, i.e., Volume I-Executive Summary, Volume II-Final Report, and Volume III-Appendices, covers the work performed from 29 September 1973 to 31 May 1974. Together they document and summarize the results of the Phase 0 portion of this contract effort. The work was conducted under the technical direction of Mr. Ray Fields, Deputy Director of the NSF Public Technology Projects Office.

Distribution of this document is established by the Contracting Officer, Mr. Barry Brown or his authorized representative. Communications relative to this contract should be directed to the above Administration Contracts Official at the National Science Foundation, Grants & Contracts Office, Contracts Branch, General Contracts Section, 1800 G Street, N.W., Washington, D.C., 20550.

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Acknowledgement is expressed to the various members of the TRW Technical Staff named below for their valuable contributions to this effort:

| | |
|---|---|
| Yale Katz | Regional Climatic Conditions |
| Douglas Stenhouse | Building Types and System Requirements |
| Marshall Huberman | Proof-of-Concept Experiments |
| Pat Karahan | Capture Potential Analysis |
| George Ogawa | Systems Definition |
| Rim Kaminskas | Systems Definition |
| Arnie Halpern | Systems Analytical Modeling |
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| Charles Schumann | Systems Design/Operation |
| Goldie Gold | Computer Programming & Data Reduction |
| Richard Schremser | Computer Programming & Data Reduction |

In addition, several study team subcontractors were used to support the TRW study effort. These included the following organizations:

Arizona State University-Systems Definition; Social, Economic, Environmental Impact.

- Professor John I. Yellott - Co-Manager of Subcontract
- Dr. Bayard Wood - Co-Manager of Subcontract
- Dr. Lee Florschuetz - Systems Definition
- Dr. Charles Backus - Systems Definition
- Dr. Jeffery Cook - Building Types
- Dr. Robert Hershberger - Building Types
- Dr. William Harris - Social, Economic, Environmental Impact
- Dr. Don Plantz - Social, Economic, Environmental Impact
- Dr. David Gourley - Social, Economic, Environmental Impact
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- Dr. Bruce Campbell - Social, Economic, Environmental Impact
- Dr. Donald Evans - Social, Economic, Environmental Impact
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- Mrs. Bobbie Newton - Project Office Secretary

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Dr. George O. G. Löf - Systems Definition

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Edward Speyer - Advanced High Temperature Collectors

Finally, program direction, guidance, reviews, suggestions, and comments were provided by Ray Fields (NSF Public Technology Office Study Program Manager) and various other members of the NSF-RANN organization, i.e., Richard Green, Dr. Lloyd Herwig, Charles Hauer, Dr. Charles Chen, John DeGobbio, and Sidney Sternberg.

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CONTENTS (Continued)

# 1. INTRODUCTION

## 1.1 GENERAL

This Volume I-Executive Summary together with the Volume II-Final Report, and the Volume III-Appendices encompasses the work that was performed under Contract NSF C-853 and entitled "Solar Heating and Cooling of Buildings-Phase 0".

## 1.2 STUDY OBJECTIVES

The purpose of this study was to establish the technical and economic feasibility of using solar energy for the heating and cooling of buildings. Specifically these objectives included:

- The establishment of functional, performance, and operational requirements for solar water heating, space heating and cooling systems for a range of building types (i.e., Construction Review Classifications) and sizes in differing climatic regions of the U. S.
- An assessment of the market capture potential for solar heating/cooling applications (including water heating) and identification of the most cost-effective system/building/region combinations for proof-of-concept experiments.
- An assessment of the impact of the introduction and exploitation of solar heating/cooling on energy suppliers and conventional heating and cooling and service industries.
- A study of the social and environmental impact of solar heating/cooling of buildings.
- A study of the projected first costs, present value, and equivalent costs (including operation and maintenance costs) of solar heating/cooling systems.
- The development of recommendations for proof-of-concept experiments in solar heating and cooling of buildings. These recommendations will provide a set of alternative experiments which have varying (a) percentages use of solar power, (b) sets of measurements for assessment of user acceptance and engineering performance,

(c) time-phased schedules, (d) systematic studies of the likelihood of acceptance and utilization by society, and (e) probable costs to the Federal Government for research and development.

- The development of plans for Phase 1 project operations in solar heating and cooling of buildings.
- The development of preliminary Phase 2 plans in solar heating and cooling of buildings.
- The development of a strategy for achieving acceptance of solar heating and cooling systems by financial and architectural organizations, builders, and owners.

In all instances the rationale for the approach taken and the recommendations provided were to be delineated. In addition, the Recommended Phase 1 Plan shall include sufficient information (i.e., Technical Approach, Work Statement, Manpower Loading, Schedules, and Costs) to permit early evaluation and implementation by the National Science Foundation.

## 1.3 GUIDELINES & CONSTRAINTS

In conducting this Phase 0 study various guidelines and constraints were established by NSF. These included:

- Establish and classify at least four (4) climatic regions and provide rationale for selection
- Building type classifications are to be in accordance with Construction Review
- Both new and existing buildings should be considered
- Solar heating and cooling of buildings shall include solar water heating
- Marketing and cost projections shall include the 1980, 1990, and 2000 time periods

In addition to the above, the various system designs and Proof-ofConcept-Experiments must be cost effective, reliable, and maintainable, and consistent with the practices and building codes applied to conventional systems. Furthermore, whenever possible the use of commercially available subsystems and components should be considered. This would apply to all concepts, particularly in those cases where augmentation by conventional systems would be necessary.

## 1.4 SIGNIFICANT STUDY RESULTS

MARKET CAPTURE POTENTIAL

- The market capture potential for solar hot water and space heating, using currently-available glazed collectors, energy storage systems, and control components is large, reaching about $1 billion/year bv the year 2000. The majority of this market is for new construction rather than retrofit applications.

- Hot water heating systems are substantially more competitive than space heating systems for all building types and regions. This reflects the lower costs for hot water systems, as well as the stability of the hot water load throughout the year.

- Solar cooling of buildings, using current lithium bromide gas absorption refrigeration systems, is not cost-competitive to any significant extent during this century. However, modest reductions in peak cycle temperature requirements and/or system costs could reverse this situation.

- Multi-family low-rise apartments are the most advantageous markets for solar energy systems (SES). Capture rates reach 26 percent for hot water and 16 percent for space heating in the year 2000. Schools have only slightly lower capture rates, but constitute a far smaller total market due to the low number of total starts.

- Market capture for single family residences is lower than for apartments, primarily because of preferential electrical utility rates. The lowest capture rate is for commercial buildings This low capture is due to the low hot water and space heating requirements (for shopping centers, the year-round load is primarily a cooling one), and low fuel rates.

- Among the four major regions of the country (West, Northeast, South, and Central) the South and West regions account for 70% of the total new contruction market capture for SES's in the year 2000.

- The yearly retrofit market represents about 25 to 35 percent of the total SES installations during the time interval from 1980 to 2000.

- Although the yearly dollar market for SES's is large by the year 2000, the total energy contribution varies from about 0.13 to 0.24 quads (1 quad=$10^{15}$ Btu) per year, depending on the availability of government incentives, abolition of preferential electric utility rates or a SES cost reduction of 25%.

- One reason for this low total energy capture is that the total installed solar energy system costs, converted to a cost per unit area of collector, and including all markups, generally range from about $20/ft$^2$ down to $13/ft$^2$ depending on system size and function.

- In order for the SES market to increase significantly, a much more extensive effort is required to integrate the solar system design with the building design in order to reduce the incremental capital costs. It is realistic to achieve a 1.5 quad level of solar heating and cooling of buildings by the year 2000 if this effort were initiated. This would constitute about 4% of the total building heating and cooling load or about 1% of our total national energy requirements in that year

SOCIAL AND ENVIRONMENTAL ASPECTS

- In general, the public is favorably disposed towards solar energy utilization, anticipates it to be in widespread use within the next decade, and expects that its successful implementation will require a joint effort between government and industry.

- The public's optimism concerning solar energy utilization and their willingness to use it personally are influenced by the degree to which they perceive the energy crisis to be "real".

- The level of public knowledgeability concerning solar energy is significantly greater in cities having active solar energy demonstration and research activities (Minneapolis and Phoenix) compared to a city with no such activity (Kansas City).

- The amount of energy consumed in producing solar heating and cooling equipment is modest. The original energy investment is usually returned by an operating SES in less than a year. Depending on the system design, the raw materials requirements are generally a few percent or less of 1972 consumption rates, even by the year 2000.

- It is evident that some building code revisions will be required to permit the widespread introduction of solar energy systems. For example, in the area of energy conservation and consumption, a shift to performance-oriented rather than prescriptive codes will be required in order to encourage utilization of SES's. While we do not forsee any major technical obstacles in this area, building codes are an extremely important part of the building industry infrastructure.

- Quality standards must be established and approvals and certifications by the cognizant agencies must be obtained to avoid any opposition to SES's by the insurance industry.

- In determining the maximum mortgage liability a home buyer can assume, the financial community must be educated to consider the operating savings associated with solar energy. Unless the financial community recognizes the capital payback which results from lower operating costs, the market for solar energy will be restricted to the higher income segment of home buyers.

## CONCLUSIONS AND RECOMMENDATIONS

- The SES market and the associated energy savings are highly dependent on SES costs. In order to achieve significant levels of energy savings, the cost of current systems must be reduced substantially. For this reason we have oriented our Phase 1 activities towards the evaluation of integrated low-cost solar system designs which require consideration of the entire building as an energy package. An important part of these systems is a variable pressure ratio heat pump that permits 1) the use of lower-temperature solar heat during the heating season, and 2) reduced conventional energy consumption during the cooling season.

- In order to assure the timely and successful implementation of SES's, it is mandatory that the building industry infrastructure (code agencies, financial institutions, insurance companies, labor, government regulators, etc.) become involved at the very beginning of the effort.

# 2. STUDY METHODOLOGY

The Phase 0 solar heating and cooling of buildings study was carried out in a logical and sequential manner. The methodology consisted of the following:

a) Eighteen climatic regions were identified (nine for the heating season and nine for the cooling season)

b) Five building types were selected

c) Fourteen cities were selected

d) Four system functions were defined

e) Building loads were calculated for hot water, space heating and cooling, and dehumidification

f) Three Reference System designs were identified

g) System Operation Requirements were determined

h) Cost analyses and capture potential assessments were conducted

i) The social, environmental, and economic impact of the use of solar energy systems was determined

j) Three Proof-of-Concept Experiments were recommended

k) Phase 1 & 2 Development Plans were prepared

l) A Utilization Plan for implementation and commercialization of solar energy systems was prepared.

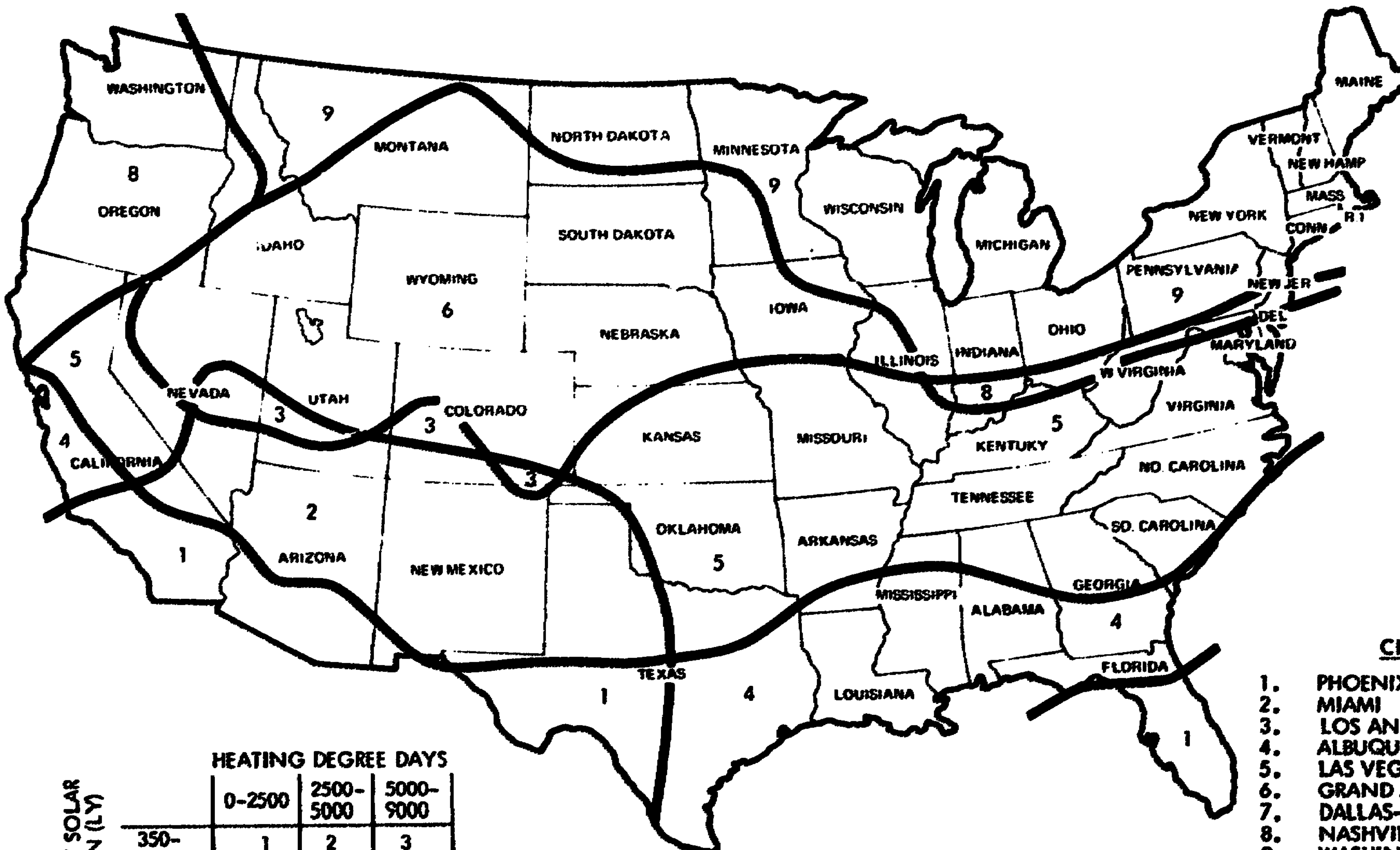
This section summarizes the results of items a) to g). The remainder of the items are summarized in Sections 3 to 8.

## 2.1 CLIMATIC REGIONAL CLASSIFICATIONS

The country was divided into representative heating and cooling regions in terms of average daily solar insolation and degree-days for both the heating and cooling seasons. Nine climatic regions were identified for each season. The matrices defining each climatic region and the geographic boundaries of these regions are shown on Figures 2-1 and 2-2.

## 2.2 BUILDING TYPES

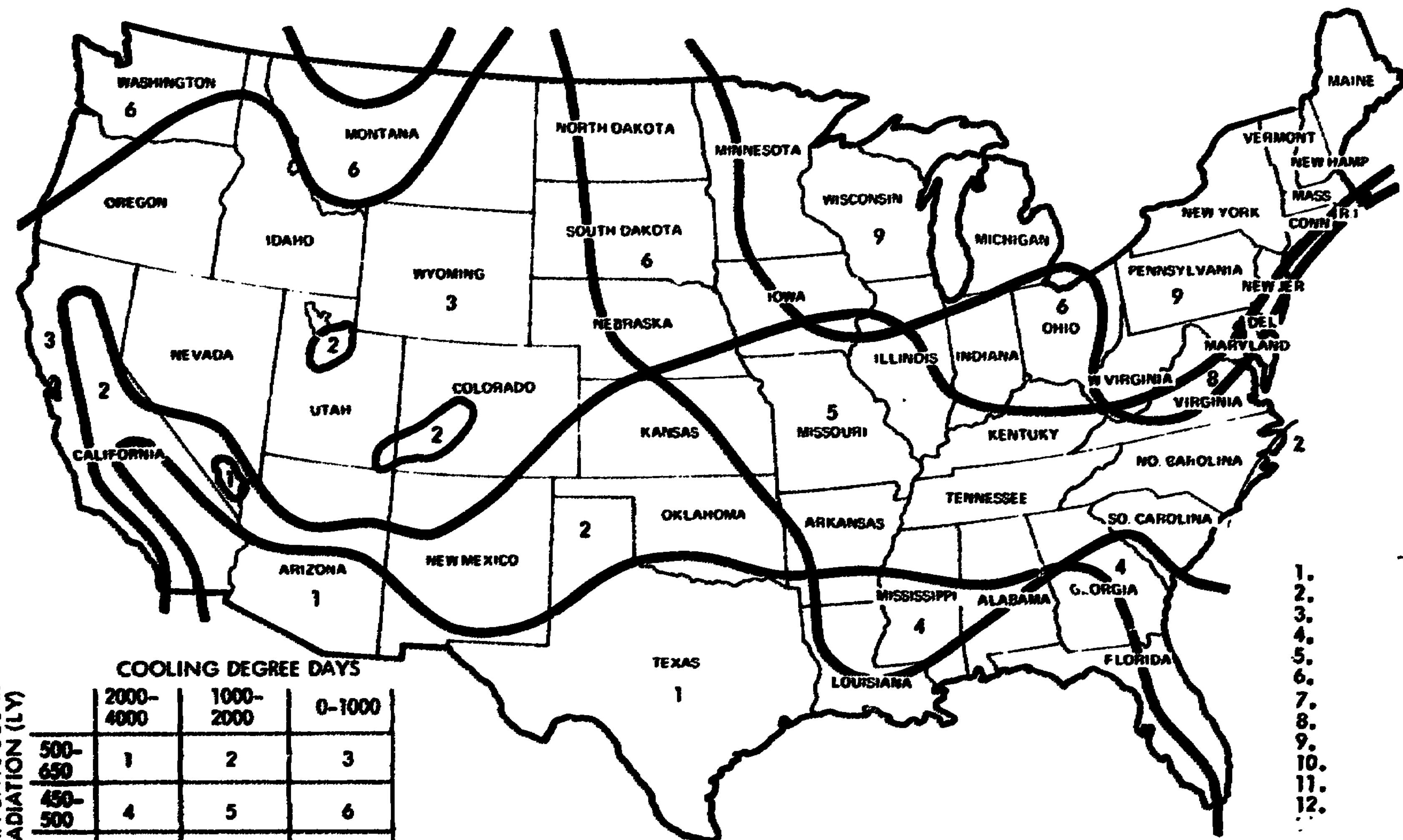
Using the U. S. Dept. of Commerce Construction Review classifications, Standard Metropolitan Statistical Area data, and the Standard Industrial Classification Manual, a total of 14 building types were initially identified. These were further reduced to five which represented up to 83% of the total building construction market and as a group had the highest capture




| MEAN DAILY SOLAR RADIATION (LY) | HEATING DEGREE DAYS 0-2500 | 2500-5000 | 5000-9000 |
|---|---|---|---|
| 350-450 | 1 | 2 | 3 |
| 250-350 | 4 | 5 | 6 |
| 175-250 | 7 | 8 | 9 |

| | CITY | REGION |
|---|---|---|
| 1. | PHOENIX | 1 |
| 2. | MIAMI | 1 |
| 3. | LOS ANGELES | 1 |
| 4. | ALBUQUERQUE | 2 |
| 5. | LAS VEGAS | 2 |
| 6. | GRAND JUNCTION | 3 |
| 7. | DALLAS-FORT WORTH | 4 |
| 8. | NASHVILLE | 5 |
| 9. | WASHINGTON, D. C. | 5 |
| 10. | SALT LAKE CITY | 6 |
| 11. | SEATTLE-TACOMA | 8 |
| 12. | CHICAGO | 9 |
| 13. | BOSTON | 9 |
| 14. | NEW YORK | 9 |

Figure 2-1. Regional Climatic Classification for the Heating Season (November-April)




| MEAN DAYS SOLAR RADIATION (LY) | COOLING DEGREE DAYS 2000-4000 | 1000-2000 | 0-1000 |
|---|---|---|---|
| 500-650 | 1 | 2 | 3 |
| 450-500 | 4 | 5 | 6 |
| 450 | 7 | 8 | 9 |

| | CITY | REGION |
|---|---|---|
| 1. | PHOENIX | 1 |
| 2. | MIAMI | 4 |
| 3. | LOS ANGELES | 3 |
| 4. | ALBUQUERQUE | 2 |
| 5. | LAS VEGAS | 1 |
| 6. | GRAND JUNCTION | 2 |
| 7. | DALLAS-FORT WORTH | 1 |
| 8. | NASHVILLE | 5 |
| 9. | WASHINGTON, D. C. | 5 |
| 10. | SALT LAKE CITY | 2 |
| 11. | SEATTLE-TACOMA | 6 |
| 12. | CHICAGO | 9 |
| | BOSTON | 9 |
| 14. | NEW YORK | 8 |

Figure 2-2. Regional Climatic Classification for the Cooling Season (May-October)

potential. They are characterized typically by their respective floor areas. The building types selected were

- Residential
  1) Single family detached residence - 1,400 sq. ft.
  2) Eight unit apartment building - 6,400 sq. ft. (800 sq. ft./unit)
- Commercial
  3) Two-story office building - 10,000 sq. ft.
  4) Shopping center - 15,000 sq. ft.
- Educational
  5) Elementary school - 9,600 sq. ft.

The above building types were used to establish the heating, cooling, and year-round domestic hot water loads.

## 2.3 SELECTED CITIES

Fourteen cities with significantly large populations were selected for evaluation. Additional criteria for their selection included availability of solar insolation data, building starts, fuel consumption, fuel availability, and per capita energy consumption projections for 1980, 1990 and 2000. They encompassed only eight of the nine defined climatic regions since it was determined that there was no area in the U. S. which satisfied the requirements of Region 7. The 1970 census data were used to identify large population centers. An effort was made to select cities which were not adjacent to the regional boundary lines, to cover as much of the U. S. as possible and to include two or three cities in the densely populated areas. Pertinent data regarding these cities is provided on Table 2-1.

## 2.4 LOAD DETERMINATION

The five selected building types in the fourteen selected cities were used to determine the space heating, space cooling and dehumidification and domestic service hot water heating loads,

Table 2-1. Pertinent Data for Selected Cities

| No. | Name of City | Heating Season Climatic Region | Cooling Season Climatic Region | Altitude (Ft above Sea Level) | Latitude (in Degrees) | 1970 Population (SMSA) | City Rank |
|---|---|---|---|---|---|---|---|
| 1 | Phoenix | 1 | 1 | 1117 | 33 | 968,487 | 34 |
| 2 | Miami | 1 | 4 | 7 | 25 | 1,267,792 | 25 |
| 3 | Los Angeles | 1 | 3 | 99 | 34 | 7,032,075 | 2 |
| 4 | Albuquerque | 2 | 2 | 5310 | 35 | 315,774 | 98 |
| 5 | Las Vegas, Nevada | 2 | 1 | 2162 | 36 | 273,288 | 117 |
| 6 | Grand Junction,Col. | 3 | 2 | 4849 | 39 | 20,170 | — |
| | (Denver) | (3) | (2) | (5280) | (39) | (1,227,529) | (27) |
| 7 | Ft. Worth | 4 | 1 | 544 | 32 | 762,086 | 43 |
| 8 | Nashville | 5 | 5 | 577 | 36 | 540,982 | 61 |
| 9 | Washington, D.C. | 5 | 5 | 14 | 39 | 2,861,123 | 7 |
| 10 | Salt Lake City | 6 | 2 | 4220 | 40 | 557,635 | 58 |
| 11 | Seattle | 8 | 6 | 386 | 47 | 1,421,869 | 17 |
| 12 | Chicago | 9 | 9 | 658 | 42 | 6,978,947 | 3 |
| 13 | Boston | 9 | 9 | 15 | 42 | 2,753,700 | 8 |
| 14 | New York | 9 | 9 | 19 | 40 | 11,528,648 | 1 |

Population data source: 1973 Edition of the <u>World Almanac</u> - pp. 142

dehumidification and domestic service hot water heating loads.

In calculating hot water heating energy requirements, city water temperatures were identified for each month of the year together with individual building type consumption patterns and a desired temperature of 140°F.

For calculating space heating, space cooling and dehumidification loads, we used indoor design criteria of 68°F for the winter season and 78°F (50% RH) for the summer season. Coefficients of transmission for the building envelopes were selected with a view towards conserving energy. Design assumptions for interior heat gains and ventilation requirements were based on recommendations in the ASHRAE Handbook of Fundamentals and the Chicago Code. Space heating loads incorporated the use of a thermal recovery unit. The calculations of space heating, space cooling and dehumidification loads are typical thermal loads rather than peak loads. Average monthly maximum/minimum ambient temperature values were distributed over a diurnal swing to produce design values for eight three-hour time intervals to represent the conditions for a typical day for each month of the year. For the cooling season, coincident values of wet and dry bulb temperatures were used to determine change in enthalpy. Annual loads for the selected building types and cities are shown in Table 2-2.

## 2.5 REFERENCE SYSTEM DESIGNS

Relying on existing and proven solar and conventional climatic control hardware, three reference designs were selected for detailed cost evaluation in each of the fourteen cities and five building types. The systems were designated Reference System A for domestic hot water system, Reference System B for hot water and space heating, and Reference System C for hot water, space heating and space cooling. For all three reference systems glazed metallic collectors employing water or water/ethylene glycol mixtures were used. For the space cooling function, a hot-water-fired lithium-bromide gas absorption refrigeration system was employed.

Table 2-2. Summary of Annual Space Heating & Cooling Loads (Btu x $10^3$) for 14 Selected Cities & 5 Building Types



| No. | City | Building Type | For Space Heating | For Space Cooling | Total Annual |
|---|---|---|---|---|---|
| 1. | Phoenix | Store | 0 | 1,792,850 | 1,792,850 |
| | | Elementary School | 70,705 | 516,870 | 587,575 |
| | | Apt. House | 66,376 | 190,592 | 256,968 |
| | | Single Family Det. Res. | 20,877 | 64,900 | 85,977 |
| | | Office Building | 34,825 | 546,330 | 581,155 |
| 2. | Miami | Store | 0 | 2,773,910 | 2,773,910 |
| | | Elementary School | 9,360 | 792,110 | 801,470 |
| | | Apt. House | 2,184 | 274,880 | 277,064 |
| | | Single Family Det. Res. | 939 | 92,560 | 93,499 |
| | | Office Building | 4 | 855,320 | 855,324 |
| 3. | Los Angeles | Store | 0 | 705,292 | 705,292 |
| | | Elementary School | 64,055 | 149,903 | 213,958 |
| | | Apt. House | 57,816 | 40,200 | 98,016 |
| | | Single Family Det. Res. | 18,397 | 18,353 | 36,750 |
| | | Office Building | 18,285 | 139,072 | 157,357 |
| 4. | Albuquerque | Store | 0 | 881,681 | 881,875 |
| | | Elementary School | 143,619 | 245,997 | 389,616 |
| | | Apt. House | 168,384 | 81,232 | 249,616 |
| | | Single Family Det. Res. | 51,971 | 29,402 | 81,373 |
| | | Office Building | 89,935 | 252,554 | 342,699 |
| 5. | Las Vegas, Nev. | Store | 0 | 1,445,716 | 1,445,716 |
| | | Elementary School | 85,479 | 415,408 | 500,887 |
| | | Apt. House | 94,928 | 157,016 | 251,944 |
| | | Single Family Det. Res. | 29,422 | 53,606 | 83,028 |
| | | Office Building | 45,491 | 436,989 | 482,480 |
| 6. | Denver, Colo. | Store | 6,993 | 606,382 | 609,375 |
| | | Elementary School | 212,995 | 171,974 | 384,969 |
| | | Apt. House | 244,880 | 50,008 | 374,934 |
| | | Single Family Det. Res. | 75,589 | 19,326 | 94,915 |
| | | Office Building | 145,840 | 168,772 | 314,612 |
| 7. | Ft. Worth | Store | 0 | 1,553,745 | 1,553,745 |
| | | Elementary School | 73,162 | 429,112 | 502,274 |
| | | Apt. House | 83,984 | 158,200 | 242,184 |
| | | Single Family Det. Res. | 26,008 | 54,183 | 80,191 |
| | | Office Building | 30,069 | 459,974 | 490,043 |
| 8. | Nashville | Store | 0 | 1,188,383 | 1,188,383 |
| | | Elementary School | 110,867 | 344,234 | 445,101 |
| | | Apt. House | 134,536 | 118,800 | 253,336 |
| | | Single Family Det. Res. | 126,536 | 41,384 | 82,970 |
| | | Office Building | 63,852 | 364,414 | 428,266 |
| 9. | Washington, D.C. | Store | 0 | 943,973 | 943,973 |
| | | Elementary School | 112,117 | 267,194 | 379,311 |
| | | Apt. House | 161,784 | 87,200 | 248,984 |
| | | Single Family Det. Res. | 49,892 | 31,566 | 81,458 |
| | | Office Building | 78,866 | 276,715 | 355,581 |
| 10. | Salt Lake City | Store | 5,828 | 685,085 | 690,913 |
| | | Elementary School | 202,620 | 199,455 | 408,075 |
| | | Apt. House | 237,160 | 61,976 | 335,168 |
| | | Single Family Det. Res. | 73,198 | 22,900 | 96,098 |
| | | Office Building | 138,531 | 202,836 | 341,367 |
| 11. | Seattle | Store | 0 | 307,709 | 307,739 |
| | | Elementary School | 158,569 | 68,212 | 226,781 |
| | | Apt. House | 201,592 | 16,384 | 217,913 |
| | | Single Family Det. Res. | 62,359 | 8,179 | 70,538 |
| | | Office Building | 87,712 | 63,446 | 151,158 |
| 12. | Boston | Store | 2,883 | 551,999 | 554,882 |
| | | Elementary School | 175,994 | 143,015 | 319,009 |
| | | Apt. House | 219,440 | 45,536 | 264,976 |
| | | Single Family Det. Res. | 67,598 | 17,473 | 85,071 |
| | | Office Building | 115,192 | 143,415 | 258,607 |
| 13. | Chicago | Store | 7,127 | 674,985 | 682,112 |
| | | Elementary School | 190,637 | 187,465 | 378,102 |
| | | Apt. House | 2[illegible]5,216 | 60,448 | 295,664 |
| | | Single Family Det. Res. | 72,425 | 22,260 | 94,685 |
| | | Office Building | 135,609 | 192,000 | 327,609 |
| 14. | New York | Store | 130 | 774,801 | 774,931 |
| | | Elementary School | 149,550 | 215,444 | 364,994 |
| | | Apt. House | 188,760 | 69,104 | 257,864 |
| | | Single Family Det. Res. | 58,228 | 25,375 | 83,603 |
| | | Office Building | 93,346 | 219,098 | 312,444 |

A number of methods were used in selecting the three Reference Systems. They include:

- Review by consultants who are experts in this field.
- Review of literature, including government reports on subject. In particular, this included results from NSF/RANN studies being conducted at University of Wisconsin, University of Pennsylvania, and Colorado State University, jointly with the University of Wisconsin and Honeywell, Inc.
- Using engineering experience to delete costly features which do not significantly improve performance.
- Consideration of the development status of applicable components including a survey of solar system component vendors.

Mathematical models were constructed of the Reference Systems, and the resulting quantitative data generated resulted in some changes in the systems components, controls, and operating modes to enhance performance and reduce initial and operating costs.

### 2.5.1 Hot Water (Reference System A)

The Reference System (System A) for furnishing hot water only is shown in Figure 2-3.

#### 2.5.1.1 Principles of Operation

Operation is initiated with the flow of water into Collector, SC-1. If the temperature of the fluid, which is a mixture of water and ethylene glycol, in the Collector exceeds that of the fluid in the Storage Tank, ST-1, the fluid will flow from the Collector to the Storage Tank with circulation provided by Pump, P-1. If, however, the temperature of the Collector is less than that of storage, then the pump is inactivated. This is implemented by temperature sensors $T_{5a}$ and $T_{5b}$ which control the motor of the Pump, P-1.

As hot water is taken from the system, make-up cold water will flow through the control Valve, V-7, either from the finned coil in the storage Tank or directly through to the Water Storage Heater Unit, HW-1. The temperature of the cold water is sensed on the output side of the Valve, at $T_7$, causing the Valve to close, thus forcing the water to flow through the finned coil in the Storage Tank to absorb heat. When the fluid becomes excessively heated during periods of high insolation, the temper-

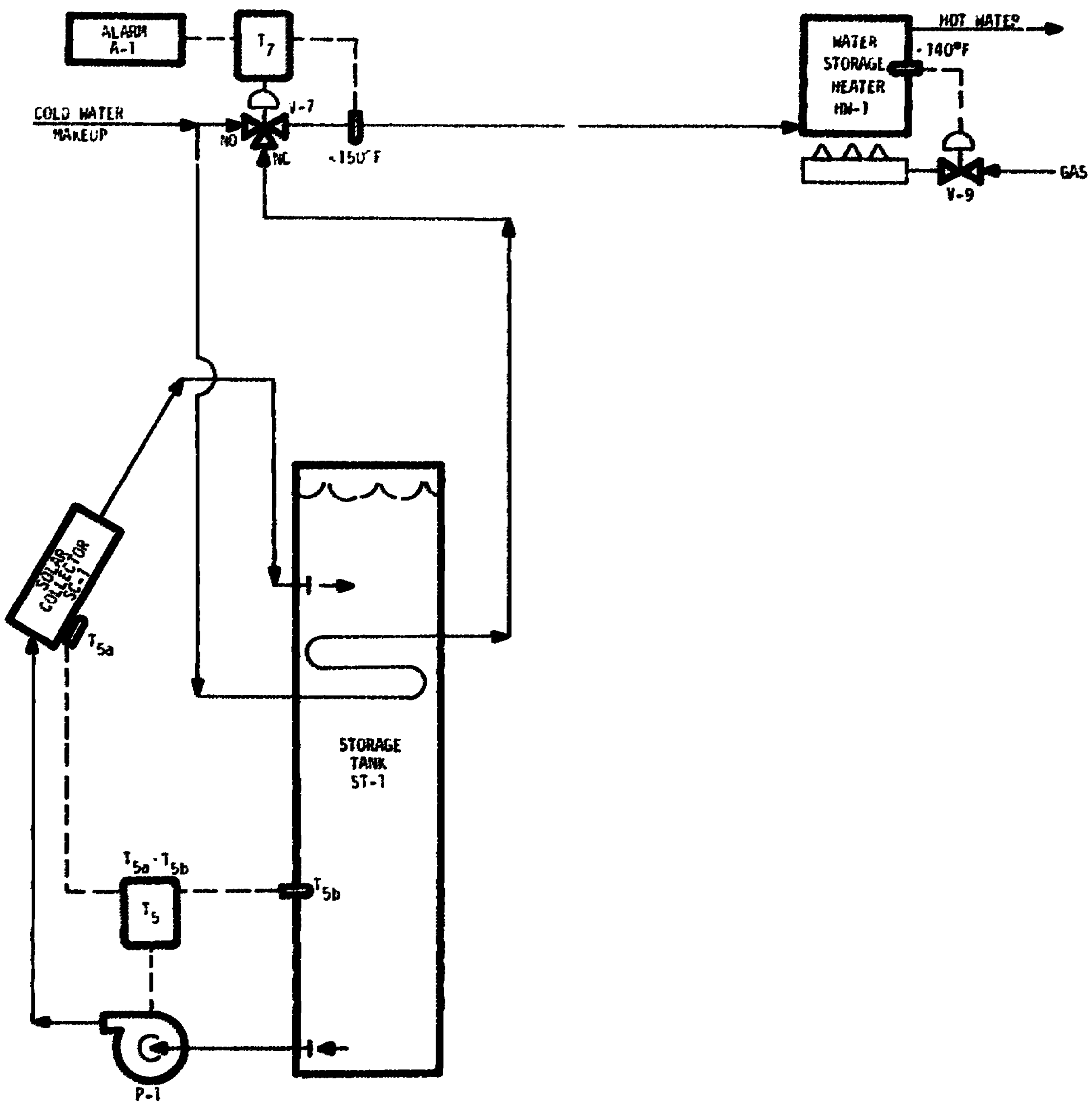



Figure 2-3. Reference Hot Water System (System A)

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ature of the fluid leaving the heat exchanger coil might exceed 150°F. When this occurs, the Sensor $T_7$ causes the Valve, V-7, to introduce cold water until the temperature falls below 150°F. Every time Valve V-7 introduces cold water in this way, it turns on the Alarm, A-1. The purpose of this is to provide an indication of the event that Valve V-7 is locked in this position.

The water from either source is then conducted to a standard Hot Water Heater, HW-1. It maintains water at temperatures of at least 140 ± 5°F through the use of auxiliary power.

### 2.5.2 Hot Water and Space Heating (System B)

The selected Reference System (System B) for supplying hot water and space heating to buildings is shown in Figure 2-4.

#### 2.5.2.1 Principles of Operation

The part of the system necessary to supply hot water--i.e., the Collector, Storage, and the Hot Water Storage and Heat Unit--is basically the same as the Reference A Hot Water System. However, the sizes of some components, and their performance characteristics, would change because of the additional requirements imposed by the space heating load.

The space heating portion of this system operates, to satisfy thermostat demands, in one of three automatically selected modes:

1) Solar Heating. This is the normal mode, using solar power only. Hot fluid from either the Collector or the Storage Tank furnishes heat to the Preheat Coil, PC-1.

2) Auxiliary Boost. This is the mode in which part of the heat is supplied from solar sources by the Preheat Coil, PC-1, and the remainder of the required heating is furnished by the Heating Coil, HC-1, using the Auxiliary Heater, HW-2.

3) Auxiliary Heating. This is the mode in which all the heating is accomplished by means of the Heating Coil, HC-1, through the use of the Auxiliary Heater, HW-2, which is set to produce hot water at 120°F. In this mode, the temperature of the fluid from wither the Collector or the Storage Tank is below some specified value, e.g., 70°F. The flow of this fluid is stopped by turning off the motor driving the pump, P-3.

Controls are of the "bang-bang" type, i.e., they are either fully on for as long as required, or off completely.

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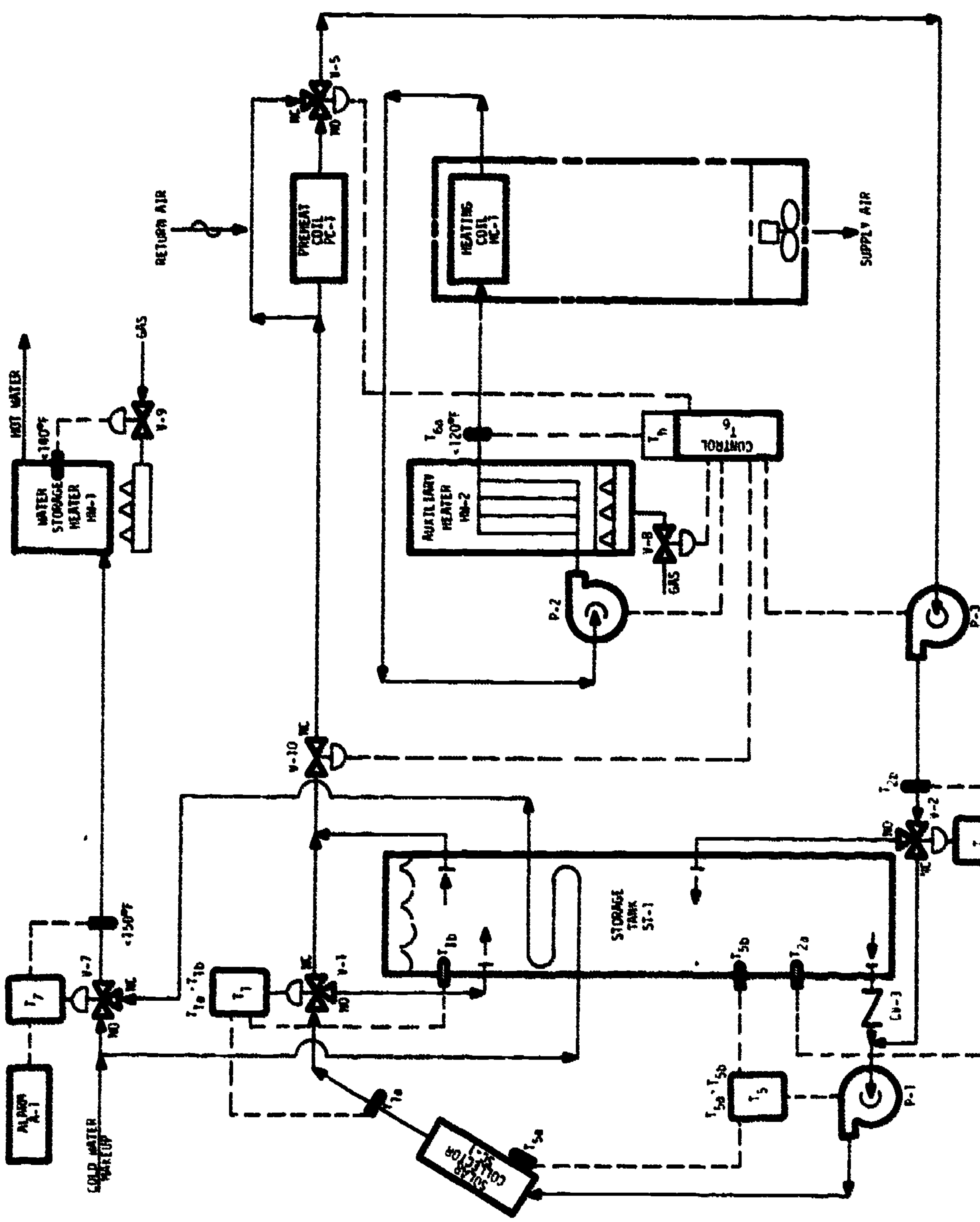


Figure 2-4. Reference Hot Water & Space Heating Sy tem (System B)

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### 2.5.3 Combined Hot Water Space Heating and Cooling System (System C)

The selected Reference System (System C) to furnish the combined functions of hot water heating, space heating and cooling is shown in Figure 2-5.

Description

The system operates in either the heating or cooling mode as manually selected through the control unit. The system furnishes hot water as required irrespective of the mode selected.

Heating Mode

Signals from the control unit will connect components as they exist in the Hot Water and Space Heating portion of the Reference System. If the fluid flowing from the Auxiliary Heater, HW-2, leads to excessively hot air from the duct, control of the heat input to HW-2 will be switched to a second Aquastat set at a lower temperature, e,g., 160°F.

Cooling Mode

The system operates in the cooling mode in two ways, i.e., either the air conditioner is powered entirely by the solar energy system, or completely from the auxiliary heater.

Auxiliary Powered Operation

The system when in the auxiliary powered mode operates in the following manner. A signal from the control unit will change the position of Valve, V-6, so that the fluid can flow (1) through the Pump, P-2, (2) through the Auxiliary Heater, HW-2, (whose temperature is controlled at 210°F by means of a standard Aquastat), (3) through the coils of the generator, G-1, (4) through the Valve, V-3 (which will be changed in position by temperature measurements made by sensors $T_{3a}$ and $T_{3b}$ and Controller, $T_6$, and (5) back to Valve, V-6.

Cooling of the return air from the building, circulated by a fan, is accomplished in the Air Conditioner, AC-1, in the following way:

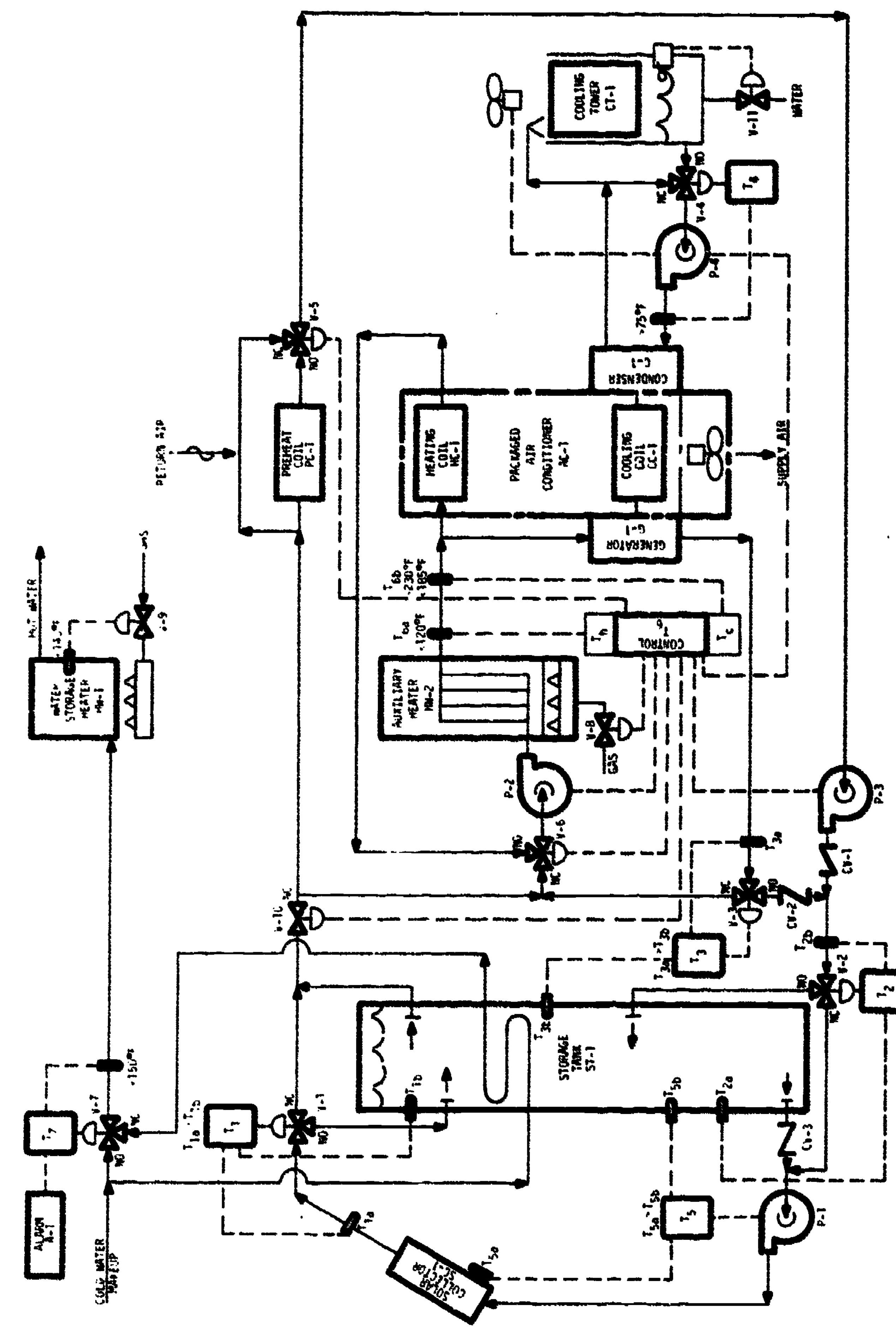


Figure 2-5. Reference Hot Water, Space Heating & Cooling System (System C)

1) The generator, G-1, provided with heat from the fluid, causes the refrigerant, water, to evaporate at low pressure (66 mm of mercury, for instance), and compresses the vapor

2) The steam is condensed in Condenser, C-1, at low temperature (e.g., 90°F), and the resulting liquid water is allowed to enter the Cooling Coil, CC-1, through an Orifice, at a lower pressure (6 mm of mercury)

3) The warm air in the air stream causes the water in the Cooling Coil, CC-1, to evaporate, and thus cool the building

4) The steam at low pressure is absorbed by the lithium bromide and cooled (e.g., at 75°F).

5) After exchanging heat this mixture is recirculated to the generator.

The heat rejected from the Condenser, C-1, and the Absorber, must now be exhausted to the external atmosphere. This is accomplished by circulating cool water through a coil around the Absorber and then another coil around the Condenser which is forced to flow to a Cooling Tower, CT-1, by means of a Pump, P-4.

The Cooling Tower, CT-1, cools the water by the action of both evaporation and counterflow forced air convection. The cooled water collects in a sump at the base of the Cooling Tower, CT-1. The water lost through evaporation is replenished from the main water supply automatically by means of a level sensor controlling a valve. The water leaving the Cooling Tower will be at the ambient wet-bulb temperature, or somewhat higher, depending on the cooling load (approximately 10°F).

The temperature of the coolant and the fluid supplied to the Generator determine the maximum cooling rate that can be supplied under these conditions. The heating input that must be supplied to the Generator is equal to the required cooling load divided by the coefficient of performance, which is 0.65. Because of the considerable mass in the generator structure and associated hardware in the air conditioner, a lag of 20 minutes at start-up will follow the thermostat signal before actual cool air becomes available.

Solar Powered Operation

When the system is operating on solar power only, the Air Conditioner operates as described above, but obtains its thermal power from either the Storage Tank or the Solar Collector. In this mode, the fluid flows through the Valve, V-10, through the Valve, V-6, and then to the Generator, G-1. This fluid returns through the Valve, V-3, either to the Storage Tank or to the Pump, P-1, and then back to the Collector. The logic for the Valve, V-3, is the same as previously described.

## 2.6 COMPUTER SIMULATION OF REFERENCE SYSTEMS

The general approach was to represent each system as a network analog, similar to a circuit diagram in electrical analysis. The response of the system (which is determined through a simultaneous set of total linear differential equations) to internally generated values of incoming solar radiation, and externally supplied ambient air, water temperature data, load demands as function of time, and wind speed values was obtained with the aid of the SINDA program. Other inputs to the program included internal characteristics of the collector including size, number of glazings, material of the abosrber plate, absorber absorptivity and emissivity, tube spacing, and external characteristics such as angle of tilt, azimuth orientation, and latitude of location site. The program calculates among other quantities, total required auxiliary energy (after subtracting the supplied solar energy), as a function of collector area, and varying storage volumes. A single program was prepared which simulates any of these Reference Systems. It contains three sections which model the Hot Water System, the Hot Water and Space Heating, and the Hot Water and Space Heating or Cooling Systems. By combining these sections (depending on whether or not a demand exists) the overall system performance is determined.

## 2.7 SYSTEM OPERATIONAL REQUIREMENTS

A matrix of system attributes and components/functions was developed on a format for considering the operational requirements for the various reference system configurations. The principal attributes which were analyzed for each component included reliability, durability, maintainability, and life safety. A failure modes and effect analysis were performed for the collector. Components were ranked with respect to frequency of repair. The results of this effort are shown in Table 2-3. The three reference systems were shown to be quite serviceable and well-adapted to the specific cost/performance needs. They are operational over 99% of the time, repairable in about 2 hours when there is a failure, and even considering the possibility of nighttime or weekend failures, the mean down time was in the order of a day for the more complex reference system designs.

Table 2-3. Reference System "C" Rank Order of Frequency of Repair for Components

| Rank | Component | No. in System (n) | Failure Rate (Failures/ Year) | System Failure Rate ($n\lambda$) | System Frequency of Repairs In 10 Years |
|---|---|---|---|---|---|
| 1 | Solenoid Valve 3-Way | 7 | 0.100 | 0.700 | 7.0 |
| 2 | " " 2-Way | 4 | 0.100 | 0.400 | 4.0 |
| 3 | Electrical Sensors | 13 | 0.050 | 0.650 | 6.5 |
| 4 | Electrical Controllers | 7 | 0.067 | 0.469 | 4.7 |
| 5 | Circulating Pumps | 4 | 0.067 | 0.268 | 2.7 |
| 6 | Cooling Tower | 1 | 0.200 | 0.200 | 2.0 |
| 7 | Check Valves | 3 | 0.043 | 0.129 | 1.3 |
| 8 | Solar Collector Assembly | 1 | 0.100 | 0.100 | 1.0 |
| 9 | Absorption Cycle Heat Pump | 1 | 0.100 | 0.100 | 1.0 |
| 10 | Auxiliary Heater Gas Fired | 1 | 0.083 | 0.083 | 0.83 |
| 11 | Heating Coil | 1 | 0.020 | 0.020 | 0.20 |
| 12 | Preheat Coil | 1 | 0.020 | 0.020 | 0.20 |
| 13 | Storage Tank | 1 | 0.018 | 0.018 | 0.18 |

2.8 COST ANALYSIS

The cost analysis takes as inputs the climatic conditions and loads for the various building types in each city and through a series of computer programs determines system cost and percent solar utilization for each of the Reference Systems. The market capture analysis was integrated into the cost programs since these tasks were interrelated. The market penetration analysis was a natural outgrowth of the cost program because the inputs to that analysis were direct outputs of the cost program.

The basic output were sets of curves showing the capital costs as a function of system utilization and cumulative costs as related to years of operation.

From the results of the cost analyses it became evident that solar systems have a clear cost advantage for hot water heating when compared to conventional systems using electricity for commercial buildings. The solar system is at a disadvantage for the single family residence largely because of the preferential electrical rate structure currently given to them. However, if the rate structure for new single family residences is brought into line with commercial building rates then the solar hot water heating system will also become cost competitive in that extremely important area. For an 8-unit apartment building the hot water heating system would be cost effective today and even more so in 1980 (see Figures 2-6, 2-7, 2-8, and 2-9).

Hot water heating is the particular functional requirement where solar energy shows its greatest relative cost advantage. The load is relatively constant and the solar system can be made small and highly effective throughout the year. Only in cities where electricity costs are low (i.e., Seattle, Nashville, and Las Vegas) due to the availability of hydroelectric power, does the conventional system show a long-term cost advantage over the solar energy system.

The solar climate control system for hot water and space heating shows an advantage for most apartments, schools, and a few office buildings (see Figure 2-10). However, if the heat generation in the building becomes large compared to heat losses, heating requirement occurs only

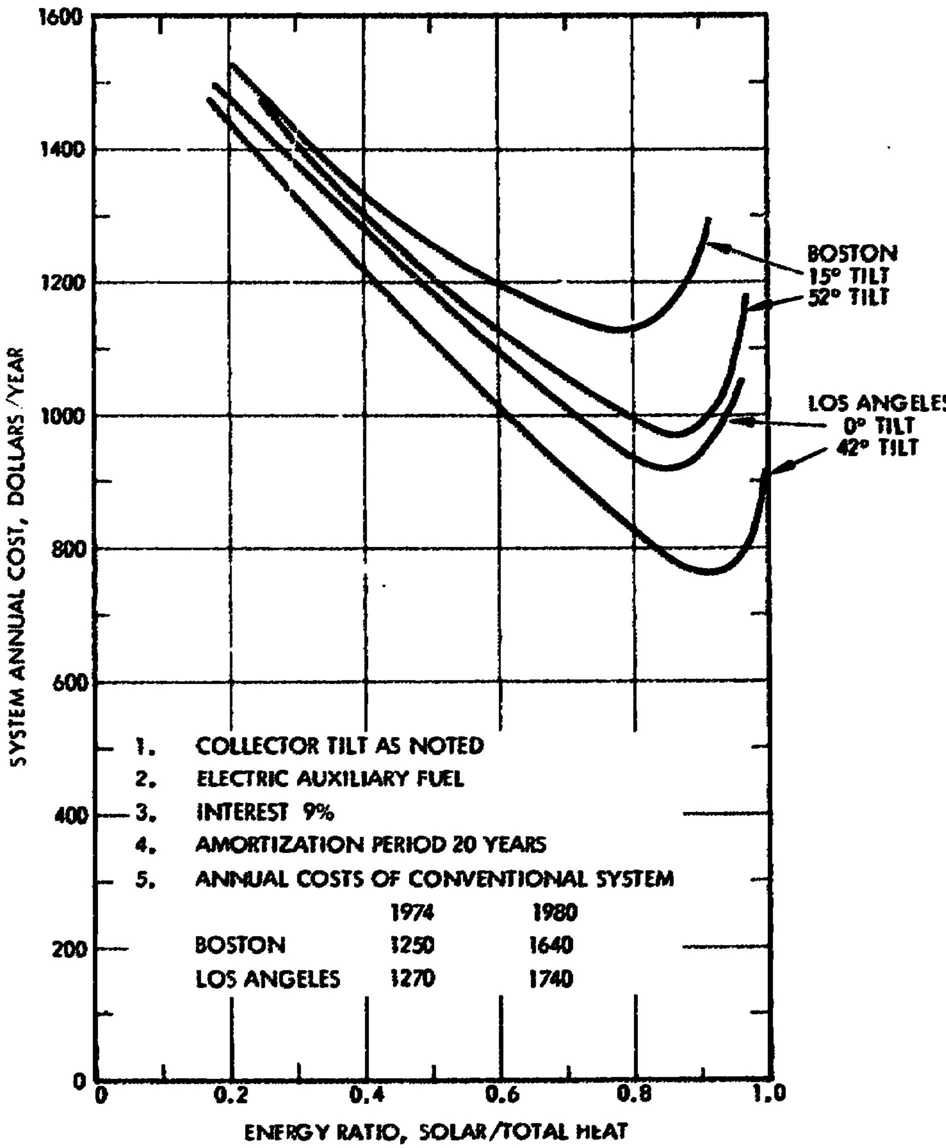


Figure 2-6. Annual Costs for Hot Water Heating Systems for 8 Unit Apartment Building

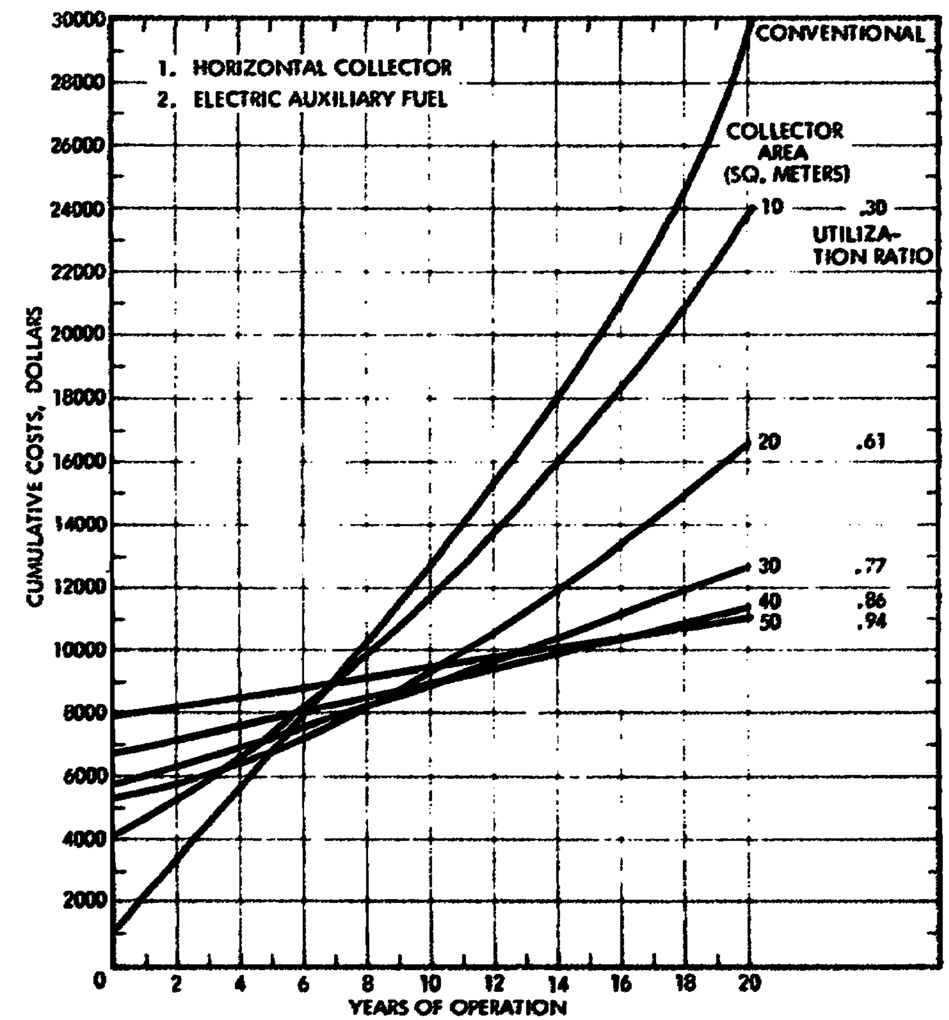


Figure 2-7. Cumulative Costs for Hot Water Heating System for 8 Unit Apartment Building in Los Angeles

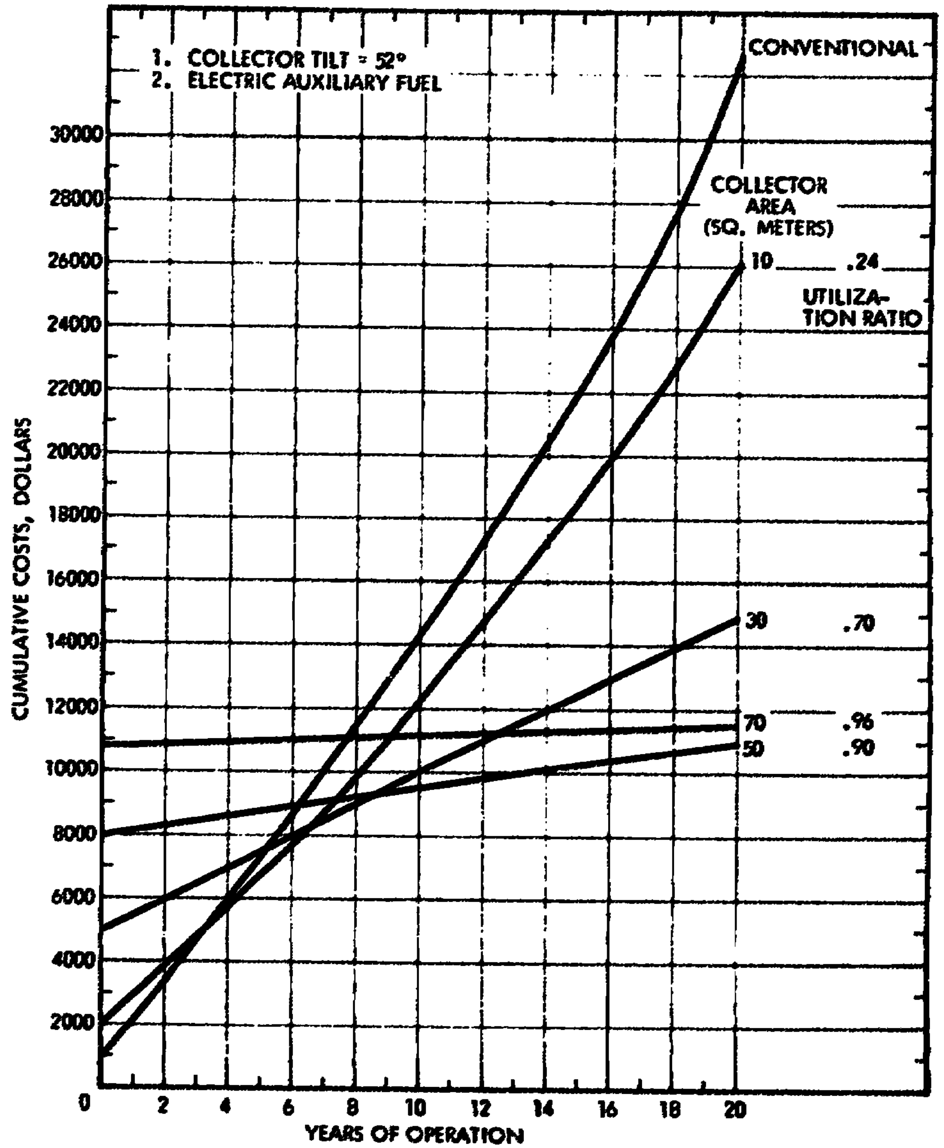


Figure 2-8. Cumulative Costs for Hot Water Heating System for 8 Unit Apartment Building in Boston

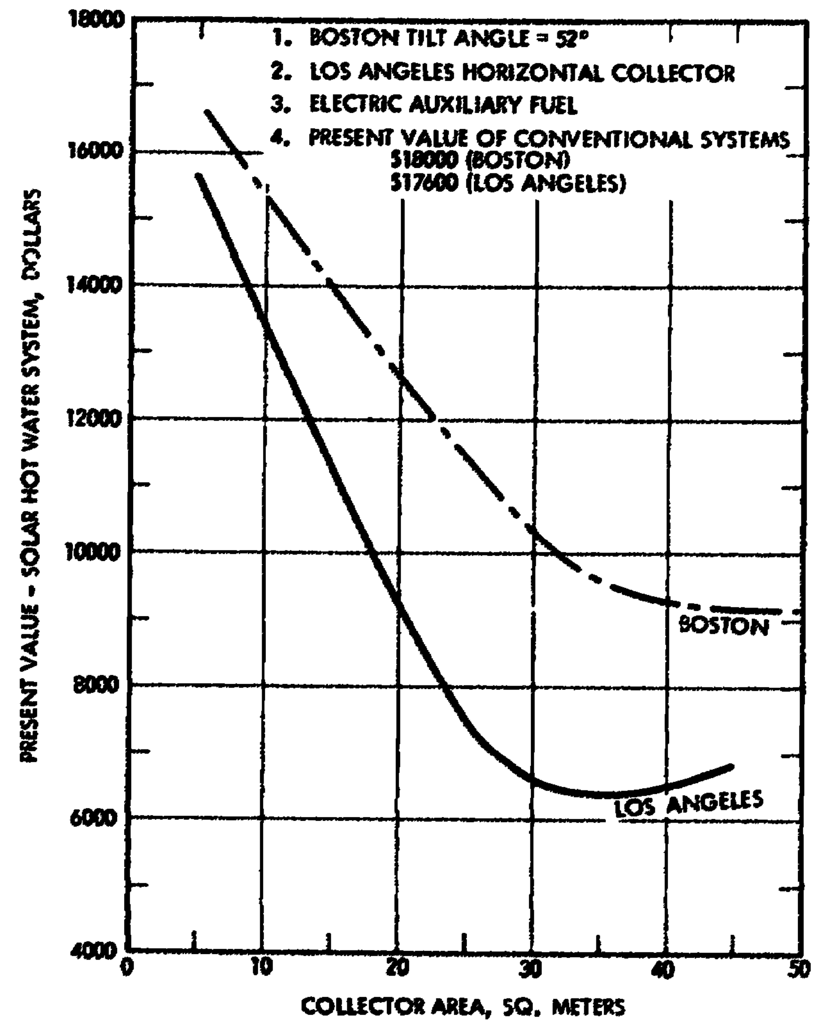


Figure 2-9. Present Value of Combined Solar/Auxiliary System for Hot Water Heating System for 8 Unit Apartment Building

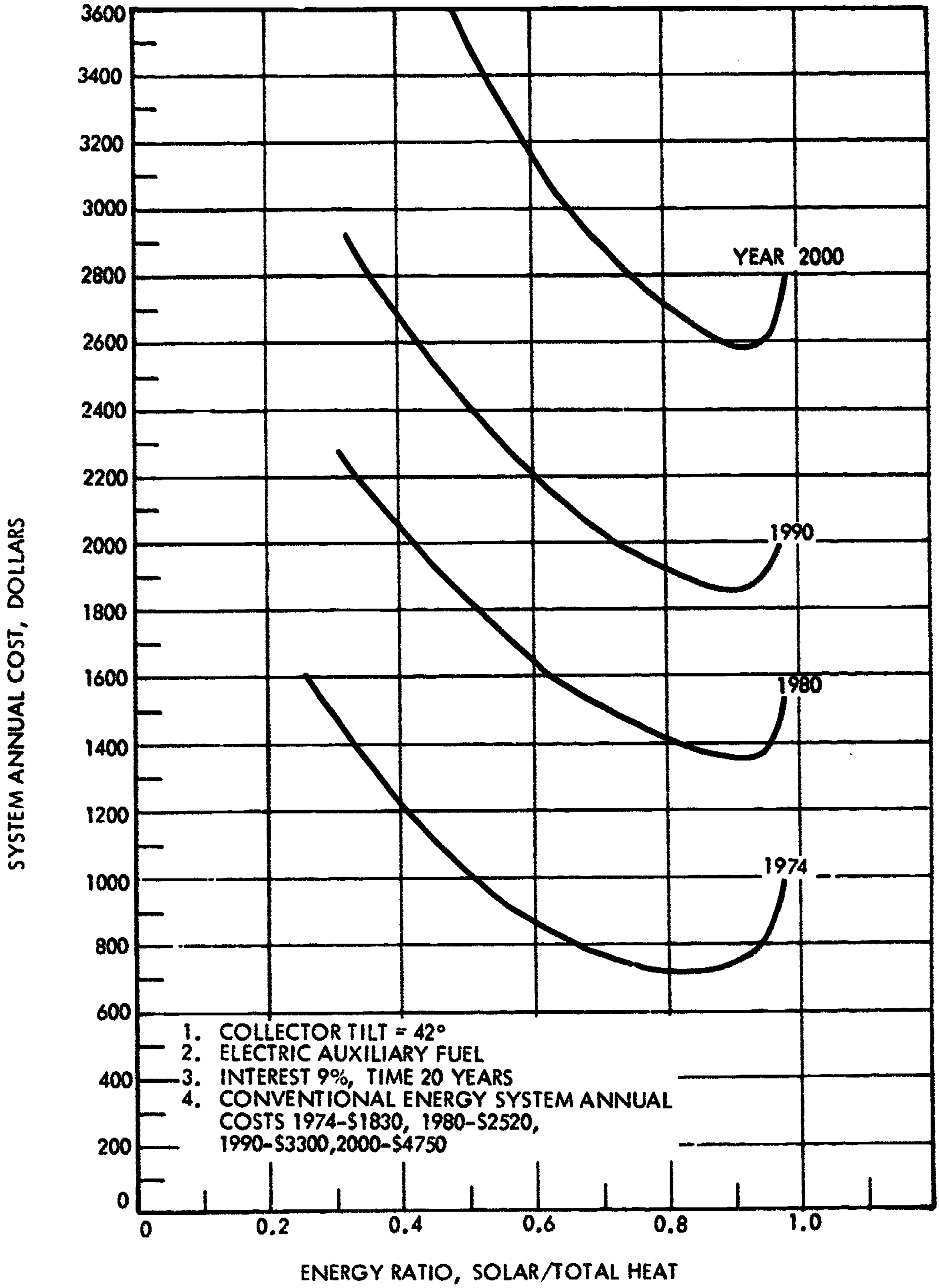


Figure 2-10. Total Annual System Cost for Hot Water Plus Space Heating for 8 Unit Apartment Building in Los Angeles

during the coldest months of the year. This is not compatible with the low solar insolation during the heating season and hence the incremental cost for satisfying these loads is high. Therefore, the solar space heating system becomes less competitive under these circumstances. Thus, solar heating systems for some office buildings and most shopping centers become more expensive than the conventional systems because of the sizable internal heat generation. For the single family residence, the solar space heating is penalized by the preferential electric heating rates and is currently more costly than the conventional systems. A change in this rate structure could alter the costs in favor of the solar heating system.

A second factor that reduces the cost effectiveness of the solar space heating system for single family residences is the high unit cost of the system since the cost of the auxiliary equipment is prorated over a comparatively small collector area (in comparison to apartments and commercial buildings). This disadvantage would disappear for a larger single family residences. In this study, a 1400-square-foot residence with energy conserving contruction was chosen as an example. Since many new residences are larger than 1400 square feet or may not employ the energy conserving construction techniques assumed for this building type, the solar energy space heating system would become more cost effective.

The complete solar climate control system using the absorption refrigeration system (Reference System C) has a cost advantage over conventional systems only if government incentives are available or major improvements in technology of the absorption refrigeration unit can be achieved. The high temperature (180° to 210°F) requirement for these cooling units reduce the performance of the solar energy system while increasing costs substantially. In addition, the much higher coefficient of performance of the mechanical compression refrigeration systems compared to the absorption systems results in a considerable cost leverage for the amount of electrical energy for these conventional cooling units. Furthermore, the absorption system usually requires a water tower for heat rejection, which is more expensive than a comparable air cooled mechanical unit. Therefore, it will be necessary to considerably improve the absorption unit performance through selecting cycles or materials to improve the COP, or reduce the required operating temperatures, before the overall solar heating and cooling system can be cost-competitive with conventional systems.

# 3. CAPTURE POTENTIAL ASSESSMENT

## 3.1 METHODOLOGY

The methodology for determining Solar Energy System (SES) market capture is depicted in Figure 3-1.

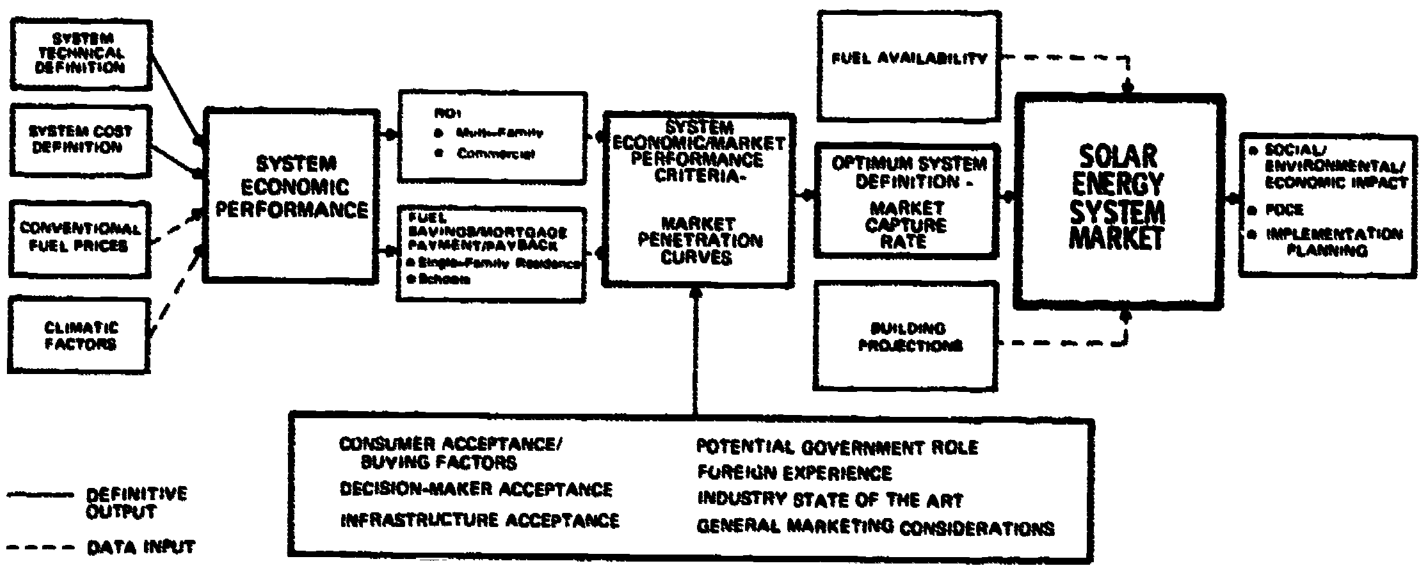


Figure 3-1 Solar Energy System Market Capture Forecast Methodology

Key points concerning this methodology are as follows:

<u>System Economics</u>

The economics of each system is determined by technical performance and capital cost. We assumed cost escalation at an average annual compound inflation rate of 4.5%, and subtracted SES system cost reductions of about 1.2% per year between 1980 and 1990, and about 0.7% per year between 1990 and 2000.

<u>Economic Performance</u>

The economic performance of each system is determined by fuel price and availability, and climatic factors, in addition to technical and cost considerations. Thus, economic performance takes regional factors into consideration. Tables 3-1 and 3-2 summarize the major factors affecting economic performance and market capture by SMSA (extrapolated to regions), building type, and reference system. Analysis of these tables provides an instructive insight into actual capture potential results.

Table 3-1. Quantitative Factors Affecting Economic Performance and Market Potential by City

| Factors Affecting Market / Statistical Metropolitan Area | Electric Fuel Prices | Climate: Solar Insolation | Climate: Temperature | Labor Rates | Percent Penetration of Electricity: Commercial | Percent Penetration of Electricity: Residential | Building Starts |
|---|---|---|---|---|---|---|---|
| Los Angeles | High | Good | High | High | Medium | Medium | High |
| Phoenix | Medium | Good | High | Medium | Medium | High | High |
| Denver | Medium | Fair | Low | Medium | Medium | Medium | Medium |
| Albuquerque | Medium | Good | Medium | Low | Medium | Medium | Low |
| Miami | High | Good | High | Medium | Medium | High | High |
| Dallas | Medium | Good | Medium | Low | Medium | High | High |
| Washington, D. C. | Medium | Fair | Medium | Medium | Medium | Low | High |
| New York | High | Fair | Low | High | Low | Medium | High |
| Boston | Medium | Poor | Low | High | Low | Medium | Medium |
| Chicago | High | Poor | Low | High | Medium | Medium | High |
| Nashville | Low | Good | Medium | Low | High | High | Medium |
| Seattle | Low | Poor | Medium | Medium | High | High | Medium |
| Salt Lake | Low | Good | High | Low | Medium | Low | Medium |
| Las Vegas | Low | Good | High | High | High | High | Medium |
| Ideal | High | Good | High | Low | High | High | High |
| Impact on Capture Potential | High | Medium | Low | Medium | High | High | High |

Table 3-2. Quantitative Factors Affecting Economic Performance and Market Potential by Building Type and Reference System

| Factors Affecting Market / Building Type | Electric Fuel Prices | Internal/External Heat Load | Heating + Hot Water/ Total Load | Actual Load | Unit System Cost | Finance Charge | Percent Electric Fuel Penetration | Building Starts |
|---|---|---|---|---|---|---|---|---|
| Multi-Family Apartment Unit | High | Medium | High | Medium | Low | High | High | High |
| Shopping Center | High | High | Low | Small | High | High | Low | Medium |
| Office Building | Low to High | Medium | Low | Medium | High | High | Low | Medium |
| School | Medium | High | High | Large | Medium | Low | Medium | Low |
| Single Family Residence | Los | Low | High | Small | High | Medium | High | High |
| Reference System | | | | | | | | |
| a) Hot water | Depends mostly on building type | N/A | N/A | Steady | Low | N/A | Depends Mostly on building type | 100 |
| b) Hot water plus space | | N/A | N/A | High at wrong time of year | Medium | N/A | | 100 |
| c) Hot water plus space plus air conditioning | " | N/A | N/A | Smooths out monthly variations | High | N/A | " | 70 |
| Ideal | | Low | High | High | Low | Low | High | High |
| Impact on Capture Potential | | High | High | Medium | High | Medium | High | High |

Economic Performance Criteria -- Market Capture

The capture potential forecast is based on the assumption that SES market growth will follow the normal S-shaped curve over time and over a given set of conditions. These conditions measure system economic performance and reflect our determination of key buying factors and other qualitative purchase decision criteria (identified in Figure 3-1) relevant to each building type.

Because buying factors and the decision-making process do differ among building types, we have defined a separate set of conditions and have designed a separate set of curves for each building type: single-family residence (SFR), low-rise multi-family (MF), schools, and commercial buildings (offices and stores). Also, because the SES industry will be in a different stage of the product life cycle, and thus will experience a different rate of market acceptance over a given set of conditions in each of the three decades, we have designed separate curves for each decade.

To actually design the curves, we define two market capture rates (based on results of discussions with consumers and key decision-makers) along the given set of conditions, and from these two points are able to calculate the mean and standard deviation of each normal curve, and thus the shape of the curve. The actual performance of the system (defined by the same set of conditions) is then measured against the mean, and the corresponding Z value* defines the actual market penetration rate. An example of this procedure for multi-family apartments is presented in Table 3-3. A brief discussion of the rationale for each curve follows.

In the SFR market, the developer is the key decision-maker, and SES industry efforts must focus there (in the custom market, the owner also can play a direct role in the purchase decision). However, the developer will make purchase decisions based on assessments of market demands. Thus performance criteria is defined in terms of consumer requirements.

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* Z equals the system performance minus the mean of the distribution divided by the standard deviation of the distribution. It measures the area under the curve between the mean and the system performance coordinate. Since half of the area under the curve lies between the mean and the lowest point on the curve, we subtract the area between the mean and the system performance from .5 to determine the cumulative capture up to and including the system performance coordinate.

Table 3-3 Capture Potential Methodology -- Example

1. Assume

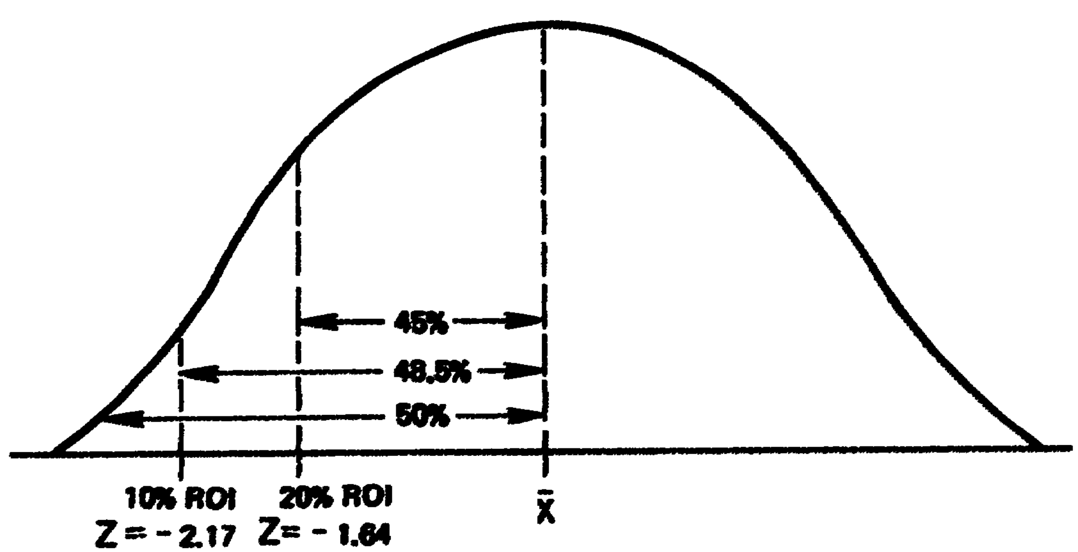
   Lower Bound: 1.5% of Market at 10% discounted ROI

   Second Bound: 5% of Market at 20% discounted ROI

   Actual System ROI = 15%

2. Calculations

   a. Determine mean ($\bar{x}$) and standard deviation ($\sigma_{\bar{x}}$) of the curve:




For any normal curve,

$$\frac{\text{Actual Value} - \bar{x}}{\sigma_{\bar{x}}} = Z$$

Thus, in this example

$$\frac{10\%\ \text{ROI} - \bar{x}\ \text{ROI}}{\sigma_{\bar{x}}\ \text{ROI}} = -2.17$$

$$\frac{20\%\ \text{ROI} - \bar{x}\ \text{ROI}}{\sigma_{\bar{x}}} = -1.64$$

Solving the two equations gives

$\bar{x}$ = 51% ROI

$\sigma_{\bar{x}}$ = 18.9% ROI

This means that a 51% ROI will result in a 50% market capture.

   b. Determine actual system capture

$$\frac{\text{Actual Value} - \bar{x}}{\sigma_{\bar{x}}} = Z$$

OR

$$\frac{15\%\ \text{ROI} - 51\%\ \text{ROI}}{18.9\%\ \text{ROI}} = -1.9$$

A Z value of -1.9 equates to 2.87% market capture. Note that this would reflect a reasonable capture for a new, unproved product. For a proved product, a 15% discounted ROI is considered an excellent return. Thus, penetration curves for 1990 and 2000 assume different capture criteria for defining the shape of the curve.

The consumer is relatively unsophisticated regarding financial analysis, and primarily will be interested in fuel savings resulting from SES purchase, compared to the incremental SES mortgage and maintenance cost. Present value, life cycle, and Return on Investment (ROI) considerations will not occur to the average consumer. Thus, the performance criteria reflects the relationship between incremental SES cost and fuel savings.

In 1980, given essentially an unproved product, the consumer will not consider a pay-back period as a relevant consideration, but will demand that in the first year of system operation, savings generated by the SES equal the incremental payments (mortgage plus maintenance) resulting from SES installation. This condition defines our minimum capture coordinate on the curve.

In 1990 and 2000, SES's will be a proved product with proved performance. Thus the consumer can reasonably consider an operating cost payback period in defining a minimum purchase decision. We assert that the consumer will be interested only in a pay-back period of less than five years, reflecting the fact that the average consumer moves once every five years, and thus would not be interested in a system that did not pay back within that time period. Thus, given fuel savings and projected fuel price increases, we calculate the maintenance and annuity payment (and thus consider present value) that would result in a five-year operating cost payback of the system, and define this amount as the lower bound on market capture.

Decision-makers in multi-family and commercial markets are more sophisticated than SFR consumers, and are demonstrating increased usage of cash flow and ROI as financial evaluation techniques and final decision criteria. Thus, we consider discounted ROI to be the most indicative and relevant economic performance measure for these market sectors.

We calculate the ROI by assuming a 25% down payment as an outflow in the first year, and define the income (or deficit) stream by fuel savings minus the annual incremental SES mortgage and maintenance cost. We measure the ROI over a five-year period, and thus calculate the discount rate which equates this income stream to zero over the five-year period.

Depending on the specific market sector (multi-family sector by investor- or owner-operated, versus commercial sector) we then define a discounted ROI rate which would generate a minimum market, and define a second market capture ROI, and thus define the normal curve in the same manner as mentioned for the SFR market.

School building decision-makers have the highest awareness of life-cycle costing requirements and definitely consider pay-back implications in making purchase decisions. Thus we define economic performance and criteria in terms of total system cost pay-back, and define the normal curve in a manner similar to the SFR, MF, and commercial markets.

Optimum System Definition

Actual system performance and relative competitiveness vary depending on regional factors of total building load, percent solar utilization, fuel price, and other quantitative factors (Tables 3-1 and 3-2). Thus different regions reflect different optimum system performance, and it is important to determine the optimum system for each SMSA and region.

This optimum system performance point is determined by inputting varying collector sizes for each SMSA study case, calculating resultant market capture rates and total dollar markets, and selecting that system generating the highest dollar market. Through this procedure, optimum collector size and optimum solar utilization for each SMSA and thus for each region is determined.

Fuel Availability

Since fuel prices determine the relative competitiveness of SES to conventional systems, we measure SES market performance under each energy source fuel price. Solar competes most favorably against electricity, and is hardly competitive against gas until about 1995. Thus, relative market size for each region and SMSA will depend on the relative usage of electricity compared to gas, and to a lesser extent oil. Our program calculates the market capture rate, and then adjusts the unit market depending on percent usage of each fuel type. Thus, market capture of 10% with electricity would, for example, result in an overall market capture of 5% if 50% of the market were supplied with electricity, and 1% if only 10% of the market were supplied with electricity. Thus the importance of relative fuel type usage is apparent. Our final penetration rates reflect overall market capture.

Solar Energy System Market

The output of the entire capture potential analysis is a regional and U.S. market for SES by units, dollars, total square feet, and percentage market capture, as well as a definition of major qualitative and quantitative forcing functions which can affect this market. These results form the basis for the social, environmental, and economic impact assessment, and for determining the Proof of Concept Experiments and market strategy or implementation planning.

## 3.2 CASE ASSUMPTIONS

We selected four alternate cases to illustrate relative SES market performance, given varying economic and government role assumptions. These assumptions reflect our determination of economic factors which will have a strong influence on SES market performance: capital cost, fuel price and availability, and potential government financial participation.

Case I, the base case, is the most conservative estimate of possible SES market performance. It is based on our detailed cost estimates and on relatively conservative estimates of fuel price escalation (see Table 3-4). These fuel price estimates are based on a model embodying the important cost parameters of the electric and gas utility industry. The base case also assumes the current electric utility practice of preferential rates for single-family homes and a slight moderation of the recent increasing trend toward electric heating. No direct government incentives to encourage SES purchase are assumed. The SES industry is presumed to be in essentially a market introduction stage. Furthermore, no cost credit is given for the fact that the collector will be integrated into the roof in new construction, resulting in a portion of the cost actually being new construction cost and not incremental SES cost.

Case II assumes the same cost and fuel price escalation as the base case, but also assumes direct government incentives of a 25% tax credit on the SES incremental mortgage payment to SFR consumers, and an investment tax credit of 7% for MF and commercial markets.

Case III assumes the same system cost, fuel availability, rate structure, and government role as the base case, but assumes a 1980 system cost reduction of 25%. This case would reflect a large government- or industry-initiated R&D effort, and a more advanced SES industry "state of the art".

## Table 3-4. Forecasted Change in Energy Rate Levels

### Electric Rate Level

| Region | 1973 | 1980 | 1985 | 1990 | 2000 |
|---|---|---|---|---|---|
| East | 1.00 | 1.37 | 1.55 | 1.7 | 2.2 |
| South East | 1.00 | 1.61 | 1.87 | 2.1 | 2.8 |
| East Central | 1.00 | 1.34 | 1.55 | 2.0 | 2.4 |
| South Central | 1.00 | 1.66 | 2.07 | 2.4 | 3.1 |
| West Central | 1.00 | 1.35 | 1.65 | 2.0 | 2.7 |
| West | 1.00 | 1.43 | 1.68 | 1.9 | 2.6 |

### Residential Gas Rate Level

| Region | 1973 | 1980 | 1985 | 1990 | 2000 |
|---|---|---|---|---|---|
| East | 1.00 | 1.57 | 2.11 | 2.21 | 2.50 |
| South East | 1.00 | 1.50 | 1.99 | 2.33 | 3.20 |
| East Central | 1.00 | 1.67 | 2.39 | 2.67 | 3.50 |
| South Central | 1.00 | 2.03 | 3.06 | 3.45 | 4.20 |
| West Central | 1.00 | 1.66 | 2.31 | 2.50 | 2.90 |
| West | 1.00 | 1.67 | 2.34 | 2.62 | 3.40 |

### Commercial Gas Rate Level

| Region | 1973 | 1980 | 1985 | 1990 | 2000 |
|---|---|---|---|---|---|
| East | 1.00 | 1.66 | 2.31 | 2.50 | 2.70 |
| South East | 1.00 | 1.86 | 2.71 | 3.00 | 3.61 |
| East Central | 1.00 | 1.80 | 2.66 | 2.95 | 3.60 |
| South Central | 1.00 | 2.22 | 3.44 | 3.69 | 4.10 |
| West Central | 1.00 | 1.85 | 2.69 | 3.10 | 4.03 |
| West | 1.00 | 1.86 | 2.72 | 3.15 | 3.55 |

### Oil Rate Level

| Region | 4Q 1973 | 1980 | 1985 | 1990 | 2000 |
|---|---|---|---|---|---|
| East | 1.00 | 1.70 | 1.87 | 2.06 | 2.40 |
| South East | 1.00 | 2.00 | 2.20 | 2.42 | 2.84 |
| East Central | 1.00 | 1.85 | 2.05 | 2.25 | 2.63 |
| South Central | 1.00 | 2.00 | 2.20 | 2.42 | 2.84 |
| West Central | 1.00 | 1.85 | 2.05 | 2.25 | 2.63 |
| West | 1.00 | 1.85 | ..05 | 2.25 | 2.63 |

It also could relect part of the SES cost being absorbed into the construction cost of the building. This case illustrates SES relative market sensitivity to capital cost.

Case IV assumes the same system cost, fuel escalation, and government role as the base case, but also assumes that the preferential rate structure for single-family residences is abolished and re-established at multifamily rates. This case illustrates the sensitivity of SES market penetration to fuel cost or rate changes, and will given an indication of probable effects of fuel price escalations above our estimates.

## 3.3 ENERGY SUPPLY/DEMAND

Figure 3-2 compares four energy demand scenarios with the available domestic supply. If a stabilized energy economy can be developed as shown in Case D, there will be no shortage or need for imported fuels after 1990. Case C is perhaps the most realistic of the scenarios. Under this scenario the difference between the supply and demand remains relatively constant after 1985.

The potential for solar energy to contribute to the supply/demand gap is illustrated in Tables 3-5 and 3-6. The figures reflect 80% solar utilization for hot water heating, space heating, and space cooling requirements.

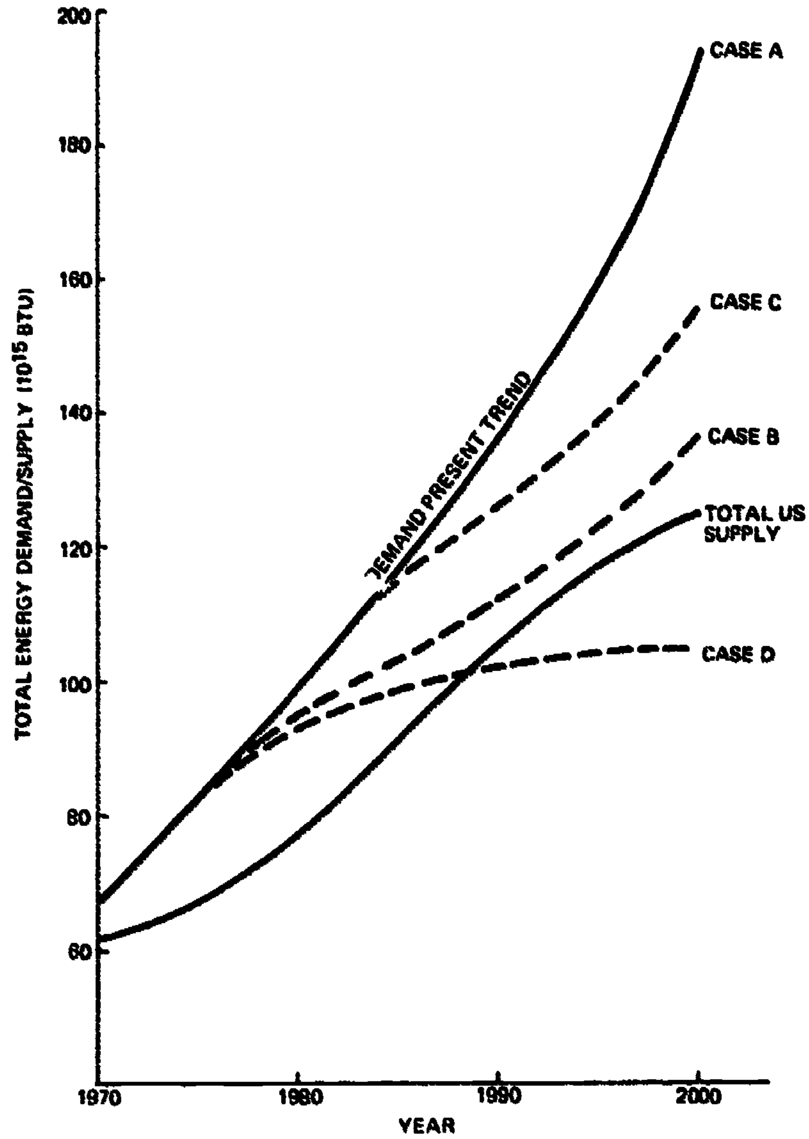
Table 3-5 Percent of Total Energy Displaced by SES for Residential and Commercial Buildings

Millions of Barrels of Oil Displaced Annually (Solar Capture Potential in Parenthesis)

| | | | | | | |
|---|---|---|---|---|---|---|
| 1980 | 3.7 | (0.1) | 38.6 | ( 1) | 190.3 | (5) |
| 1990 | 56 | (1) | 283.8 | ( 5) | 567.5 | (10) |
| 2000 | 412.6 | (5) | 827.3 | (10) | 1652.5 | (20) |

Table 3-6 Equivalent Barrels of Oil Displaced by Solar Energy

| Year | Total Energy pr. Case C $10^{15}$ Btu | Percent of Energy Displaced per Year (Solar Capture Potential Percent in Parenthesis) | | | | | |
|---|---|---|---|---|---|---|---|
| 1980 | 100 | .022 | (0.1) | .22 | ( 1) | 1.1 | ( 5) |
| 1990 | 127 | .26 | (1) | 1.3 | ( 5) | 2.6 | (10) |
| 2000 | 155 | 1.5 | (5) | 3.1 | (10) | 6.2 | (20) |




Assumptions underlying each scenario are as follows:

Case A -- Continuation of present population, energy consumption, and GNP growth rates. Fuel costs will rise with the general price level.

Case B -- The annual population growth rate will decline to zero by 2050, growth in real GNP will decline to 2.5 percent by 2000, conservation techniques will increase energy savings 18 percent by 2000, and the price of energy will increase by a factor of 3.2 by the year 2000, but will not affect consumption.

Case C -- Same as Case B except impact cannot start until 1985. Due to long range planning, electric power generation will be capable of meeting demand incorporated into Case A using nuclear energy.

Case D -- Same as Case B except the price of energy will increase by a factor of 4 above the 1970 base in the year 2000, and will reduce consumption by 25 percent.

Figure 3-2 Projec[illegible] U.S. Demand Scenarios Compared with U.S. [illegible] Supply from Conventional Sources

Tables 3-5 and 3-6 suggest that if by the year 2000, ten percent of residential and commercial buildings are equipped with SES's supplying 80% of the heating and cooling requirements, this would reduce the required imported oil (Case C) by 16 percent, and would reduce total energy requirements by 3.1%.

## 3.4 CAPTURE POTENTIAL FORECAST

Base Case Results - United States

Detailed results of our base case analysis are presented in Table 3-7. Major summary points are as follows:

- Hot water systems are substantially more competitive than space heating systems for all building types and all regions. This reflects the lower costs for hot water systems, as well as the stability of the hot water load over the year.

- The multi-family, low-rise apartment market is the most advantageous market for SES. Fairly large capture (12% for hot water heating) occurs as early as 1980. Major reasons for the feasibility of this market are summarized in Table 2 and include high electric fuel prices, moderate internal/external heat load, relatively low unit cost (compared to costs for other building types), low heat loss (fewer walls exposed to the outdoors), high hot water and heating load as a percent of total load, and economies of scale (eight units as opposed to a single unit in a SFR, for example). Furthermore, the number of building starts and the percent electric fuel penetration are relatively high. Schools have approximately the same performance advantages that apartments do, but because fuel costs are less, and building starts and electric fuel penetration are low, schools do not generate so large a total market.

Initial penetrations for apartments are high, but do realistically reflect performance in relationship to performance requirements. Return on Investment is as high as 40% in 1980 when SES's are compared to electric usage, and in some cases rises to as high as 75% by 2000.

- Commercial buildings do not represent large markets for SES's. Reasons are summarized in Table 3-2 and include low heating and hot water loads, relatively low fuel prices and high system costs, high internal to external load, and low electricity usage percent penetrations. Furthermore, builders/developers are first-cost sensitive, are not highly concerned with operating costs and life-cycle costing, and are generally resistant to technological innovation.

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Table 3-7. Total Solar Energy System Market by Building Type and Reference System, Base Case, 1990-2000

| | | 1980 | | | | 1990 | | | | 2000 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Building Type | System | Units | % Market Capture | $ (000) | Sq.Ft (000) | Units | % Market Capture | $ (000) | Sq.Ft (000) | Units | % Market Capture | $ (000) | Sq.Ft (000) |
| Single-Family Residence | HW | 11,240 | .98 | 19,470 | 875 | 36,435 | 3.4 | 50,698 | 2,760 | 49,585 | 4.5 | 67,128 | 3,835 |
| | Space | 1,430 | .12 | 7,641 | 274 | 3,775 | .35 | 17,631 | 711 | 6,700 | .61 | 29,138 | 1,291 |
| Multi-Family Low-Rise | HW | 14,490* | 12.0 | 59,461 | 3,694 | 26,230 | 22.5 | 93,422 | 6,613 | 31,670 | 25.6 | 103,458 | 8,000 |
| | Space | 6,520 | 5.4 | 64,829 | 3,095 | 15,270 | 13.2 | 132,840 | 7,256 | 19,530 | 15.8 | 154,488 | 9,232 |
| Schools | HW | 540* | 7.4 | 1,929 | 102 | 1,000 | 14.3 | 3,057 | 184 | 1,540 | 22.0 | 4,344 | 287 |
| | Space | 225 | 3.1 | 2,260 | 105 | 525 | 7.6 | 4,457 | 236 | 895 | 12.5 | 6,938 | 402 |
| Commercial | HW | 650 | .87 | 1,481 | 68 | 1,140 | 1.6 | 2,305 | 120 | 1,790 | 2.4 | 3,316 | 188 |
| Total New Construction | | 35,095 | - | 157,072 | 8,213 | 84,375 | - | 304,410 | 17,800 | 111,710 | - | 368,808 | 23,235 |
| Retrofit | | | | | | | | | | | | | |
| Single-Family Residence | HW | 5,650 | - | 14,700 | 441 | 23,000 | - | 48,817 | 1,794 | 34,500 | - | 65,546 | 2,691 |
| Multi-Family Low-Rise | HW | 3,900 | - | 24,000 | 995 | 14,000 | - | 71,869 | 3,570 | 21,000 | - | 94,325 | 5,355 |
| | Space | 2,000 | - | 29,850 | 950 | 3,500 | - | 43,857 | 1,663 | 6,500 | - | 70,821 | 3,088 |
| Schools | HW | 1,000 | - | 5,358 | 189 | 4,700 | - | 20,524 | 888 | 9,500 | - | 37,160 | 1,796 |
| | Space | 320 | - | 4,824 | 150 | 1,600 | - | 19,658 | 747 | 3,200 | - | 35,195 | 1,494 |
| TOTAL | | 47,965 | - | 235,804 | 10,938 | 131,175 | - | 509,135 | 26,542 | 186,410 | - | 671,855 | 37,659 |

* Units actually refers to number of installation. Since our building type is an 8-unit apartment, each installation reflects capture of 8 apartment units.

- Markets increase fairly rapidly between 1980-1990, but experience a steadying growth between 1990 and 2000. Reasons reflect marketing consideration regarding product life-cycle, and relative fuel price/system cost escalations. The increased capture between 1990 and 2000 is due to increased gas market penetration (by 2000, gas prices in many SMSA's are equal to electric prices) and to marketing factors reflecting higher acceptance of SES.
- By the year 2000, approximately 20% of the new residential construction market can be captured by SES. Notice that about 85% of this market will be in multi-family low-rise structures.
- The retrofit market reflects substantially lower capture rates than the new construction market, but because the base is so high, generates a significant additional market. Retrofit market feasibility is low because financing charges are higher, system cost is generally 50-100% higher, and system efficiency is lower than for new construction.

Base Case Results - Regions

The regional markets for SES are summarized in Table 3-8. The SES industry will be a local market and not a regional market, but comparisons among regions do indicate areas of relative potential. The Southern region represents the largest market in all decades, with the Western region the second largest in 1990 and 2000. The decline in market share for the Northeast region reflects decreased building construction and the lowest rate of fuel price escalation. The high initial market reflects the high fuel prices in the Northeast region, and the relatively high usage of oil rather than gas as an alternate to electricity. This high market in the Northwest region illustrates the importance of fuel price variations compared to climatological variations among regions. The Western and Southern regions have climate as well as fuel price advantages.

Table 3-8 Solar Energy System New Construction Market by Region, Base Case, 1980-2000

| | 1980 | | | 1990 | | | 2000 | | |
|---|---|---|---|---|---|---|---|---|---|
| | $ (000) | Sq.Feet (000) | Sq. Ft. % of Total | $ (000) | Sq.Feet (000) | Sq.Ft. % of Total | $ (000) | Sq.Feet (000) | Sq.Ft. % of Total |
| West | 32,744 | 1,631 | 20% | 97,465 | 5,454 | 30% | 115,395 | 6,943 | 30% |
| North East | 42,806 | 2,098 | 26% | 59,510 | 3,277 | 19% | 74,755 | 4,426 | 19% |
| South | 60,874 | 3,495 | 42% | 113,695 | 7,335 | 41% | 133,330 | 9,246 | 40% |
| Central | 20,648 | 989 | 12% | 33,740 | 1,814 | 10% | 45,330 | 2,620 | 11% |
| Total U.S. | 157,072 | 8,213 | 100% | 304,410 | 17,880 | 100% | 368,810 | 23,235 | 100% |

## Alternate Case Results

SES market potential under the alternate cases is summarized in Figures 3-3 and 3-4.

Case III (25% system cost reduction) results in the largest potential unit market. A reduction of 25% in the cost increases the total unit market by approximately 50%. The percentage increase in the market, given a specific cost reduction, will depend on the building type current position on the market penetration curve, reflected in existing market share. For example, the SFR market will be on the relatively flat part of the normal curve in 1980 (only 0.98% penetration), and thus will increase more slowly, given the same cost reduction, than the apartment market which is in the steeper section of the curve (12% penetration in 1980).

The largest dollar market is generated by Case II (incentives case). Case IV (SFR rate structure change) actually results in the largest direct dollar and unit increase, but because it applies only to SFR, the effect on total market growth is not so large as in the other cases. However, this case resulted in the largest increase for the SFR market. For example, a system cost reduction of 25% (Case III) resulted in a hot water heating system penetration of 1.67% in 1980 (compared to 0.98% in the base case), but the rate structure change resulted in a capture of 2.05%. Results were similar for all decades and both reference systems. In fact, by the year 2000, this case resulted in an 11.2% market capture for hot water systems (compared to 4.5% in the base case) in the SFR market. This is a significant increase, and one that has a fairly good probability of actually occurring.

Energy Savings Implications

Yearly energy savings by the year 2000 under each case assumption are summarized in Table 3-9

Table 3-9 SES Market Capture Potential and Energy Savings for the Year 2000

| Case | Area (Million) (sq-ft/yr) | Cumulative Area (Million) (sq-ft) | Market ($Million/yr) | Yearly Energy Savings ($10^{14}$ Btu) |
|---|---|---|---|---|
| I | 38 | 447 | 680 | 1.29 |
| II | 60 | 720 | 1010 | 2.09 |
| III | 65 | 812 | 900 | 2.36 |
| IV | 54 | 635 | 940 | 1.84 |

For solar to satisfy 1% of the total nation's energy requirements under energy demand scenario C (total demand of 155 quads by the year 2000), the following situation would have to occur. The probabilities listed assume our fuel rate projections are correct. More rapid fuel price escalation would greatly increase the probability of this situation occurring, and would permit an increase in the required dollars per square foot.

| Requirement | Comments | Probability of Occurrence |
|---|---|---|
| Capture rate for SFR new construction would be about 55% for space heating systems. | Requires a system cost reduction to approximately $2.00 per square foot installed. This would require a massive R and D effort and government incentives. | Possible |

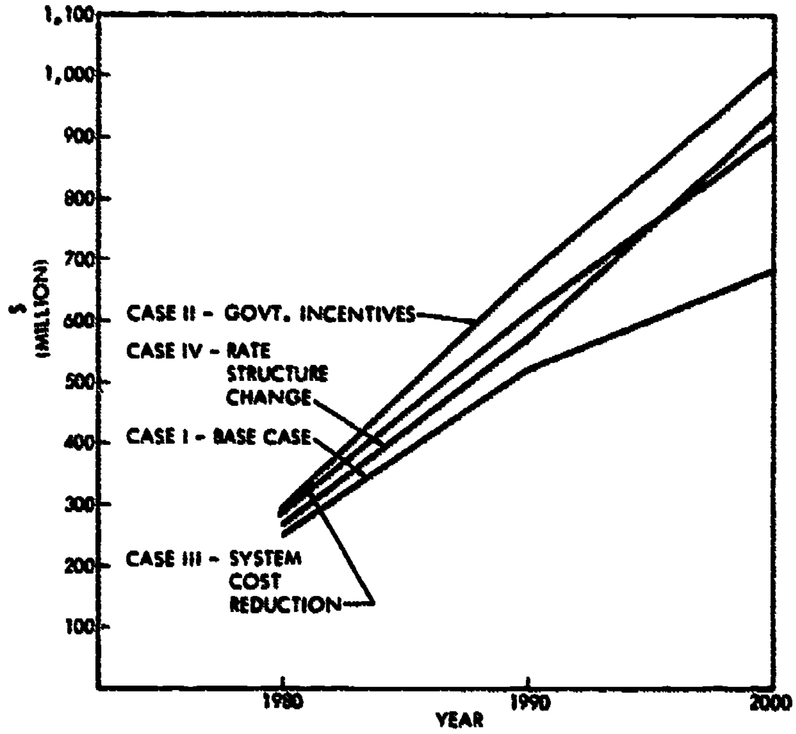


Figure 3-3. Solar Energy System Market in Dollars, by Case, 1980-2000

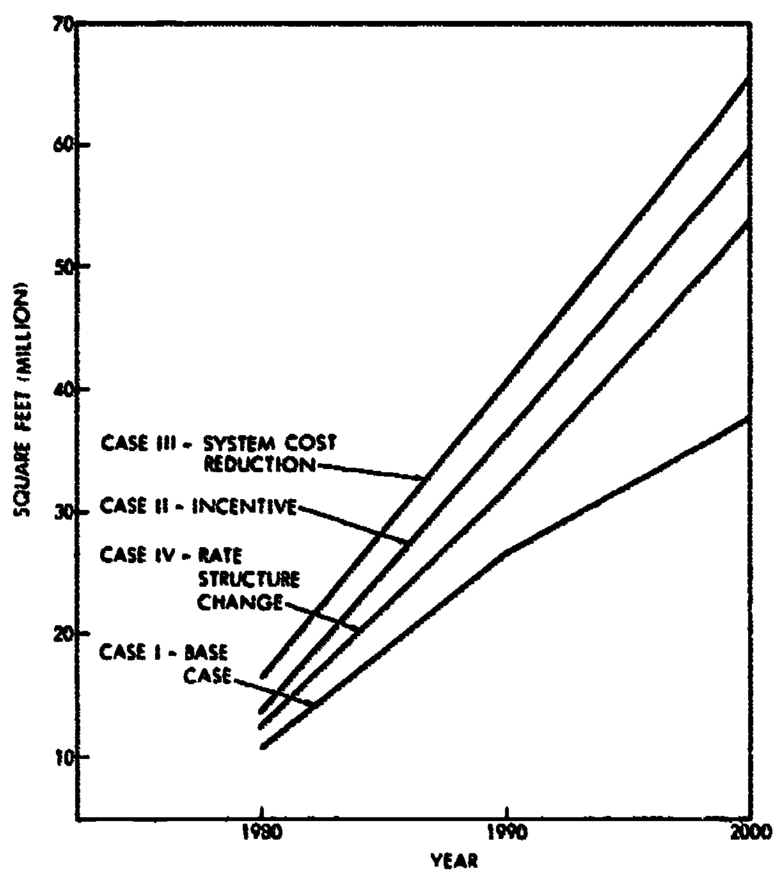


Figure 3-4. Solar Energy System Market in Square Feet, by Case, 1980-2000

| | | |
|---|---|---|
| Capture rate for MF new construction would be about 55% for space heating systems. | Requires a system cost reduction to approximately $3.50 per square foot installed. This would require massive R and D and government incentives. | Possible |
| Retrofit applications would be about 40% of the total square footage. This would require about a 1% capture of the total retrofit market (uniform 1% - can be higher for some building types and lower for others). | Current projections show retrofit applications at 40% of the total. However, percent capture is low. At required cost reductions, higher penetrations are possible. | Probable |
| Capture rate for commercial new construction would be about 10%. | Case III (25% system cost reduction) reflects 4.1% capture for hot water heating only. Lower system costs will make space heating feasible, thus increasing capture. | Highly Probable |
| Capture rate for institutional new construction would be about 50% for space heating systems. | Case III reflects a capture of 22% for space heating. Required cost reductions would result in 50% capture, but because of the low number of starts, the overall impact is not so great. | Highly Probable |

Notice that the above scenario reflects solar utilization for hot water heating and space heating only. If solar can be made competitive for cooling, the required capture rates would decrease by about one-third, since overall energy savings for each building type would be greater.

Reference to Tables 3-5 and 3-6 indicate the larger energy savings potential for SES, given a competitive system for hot water heating, space heating and space cooling.

# 4. SOCIAL, ENVIRONMENTAL, AND ECONOMIC IMPACT

## 4.1 PUBLIC ATTITUDES TOWARD SOLAR ENERGY

To assess the public's attitude toward solar energy use, a random telephone survey was conducted in Minneapolis, Phoenix, and Kansas City in late February and early March 1974. These three locations were chosen for their different climatological conditions and the local level of solar research. Two demonstration projects (solar heating of a school and a mobile testing station) were being conducted by a Minneapolis-based firm. The TRW/ASU team was receiving considerable attention in Phoenix because of its involvement with this study. In Kansas City there was no apparent major involvement. Several key questions were examined which were assumed to have an impact on future utilization of solar energy products. Among the major findings were that the public expects rapid development of solar energy. Of those who expressed an opinion, almost half (46%) expected solar energy to be in general use in less than 10 years. Another 44% expected widespread use of solar energy within 20 years, and only 10% felt that it would never be in general use.

The public seems quite willing to investigate the use of solar units even if they cost more than conventional ones initially. Only a small minority seem unwilling to ever use solar energy. Of those expressing an opinion, 53% said they would seriously consider buying solar energy units even if they cost more than conventional ones. When the cost was made identical, 78% said they would seriously consider buying solar units. About 13% said they would not buy solar units even if there were no cost differential.

Of particular interest was the fact that residents of cities in which research projects were being conducted (Minneapolis and Phoenix) were more knowledgeable about solar energy use and were most positive in their attitudes toward its use. Somewhat surprising was the fact that the under-25 age group was the least knowledgeable about solar energy systems, while the age groups 26-41 and 42 and over were roughly comparable.

Over 68% of the respondents favored tax incentives to encourage development and use of solar energy.

Low operating cost, availability, saving of fossil fuels, and no pollution were the most attractive features of solar energy use to our respondents. High initial cost and a combination of climate and storage problems were the main negative features of solar energy mentioned. However, 13% of the respondents felt there were no negative features of solar energy.

Generally speaking, the public has favorable attitudes toward solar energy use, they expect it to be implemented fairly soon, and they expect Government and public to cooperate in its development for practical use. In general, the extent of the public's optimism concerning solar energy utilization and their willingness to use it personally were influenced by the degree to which they perceived the energy crisis as being "real". However, the public often pictures solar energy as a means of producing electricity which will then be fed into our existing electrical transmission systems with little or no impact on them personally . Attention may have to be shifted from glamour uses of solar energy, such as "solar cells," and directed toward thermal systems such as solar water heaters.

## 4.2 ENERGY AND MATERIAL RESOURCE REQUIREMENTS

The energy resources required to produce solar energy systems were evaluated and found to be on the order of 92 to 127 x $10^3$ Btu per square foot of collector area. Therefore, SES's can be expected to repay their energy investment in less than one year of operation. If the energy investment in creating energy-producing devices is compared to the energy return expected over the equipment lifetime, solar heating and cooling devices show a larger return on energy investment than any alternate conversion system, including nuclear reactors. In terms of capital costs per unit of installed energy capacity, solar energy systems are found to be competitive with alternate energy generating and conversion systems.

Solar collector raw material requirements were compared to 1972 consumption rates. For a production rate of 100 million square feet of collector per year, the following percentages of 1972 consumption would be required for a solar collector with an aluminum absorber plate: float glass (8.2%), steel (0.05%) and aluminum (1.0%). For alternate absorber plate materials the percentage of 1972 consumption rates would be 3.6% for copper and 0.09% (additional) for steel.

## 4.3 UTILITY COMPANY IMPACT

Because the total energy contribution from SES's will be small and gradually implemented, it is unlikely that there will be any negative impact on the utilities. The SES contribution will at best result in a slowing of the conventional energy supply growth rate rather than an actual reduction. A possible long-term concern of the utilities is the capital implication of maintaining a standby energy production capability for assuming the SES increment during long-term periods of inclement weather.

## 4.4 ECONOMIC IMPACT

The SES industry will approach or even exceed a multi-billion dollar-a-year industry by the year 2000, even with our conservative market capture analyses and use of 1974 dollars as a yardstick. As such, it will begin to approach the size of the present air conditioning and refrigeration equipment industry. Again, because of the anticipated gradual growth of the SES industry, no capital, manpower, or material shortage or displacement problems are anticipated.

## 4.5 KEY DECISION-MAKERS

The developer is the key decision-maker in single- and multi-family buildings. Decisions are heavily influenced by cost within the confines of certain market constraints such as operational quality, appearance and, in some cases, size. When system types are identified that meet the quality standards appropriate for the price range of the housing units (or apartments) being built, effort will be made to find the least expensive system.

Single-family developers will be interested in purchasing higher first-cost systems only if the market is demanding SES's. Multi-family developers generally will be less first-cost sensitive (especially condominium builders), and more concerned with operating costs. Primary considerations for investor-owned apartment builders will be return on investment and capitalized value.

In the multi-family market, central systems will be installed. Thus, design will be done primarily by a professional engineer rather than by the developer's engineering staff. SES industry efforts, therefore, should focus on both developers and engineers.

The equipment selection for general-purpose office buildings is usually the result of a joint decision between the mechanical engineer and the builder, who is often the owner. If the building is being built for speculation or near-term sale, prime factors considered will include performance, initial cost and ease of installation. Little concern will be given to the longevity of the equipment. However, if the builder is going to retain ownership of the building, he will spend more on the first cost of the equipment in return for substantially lower maintenance costs and increased length of service. Other considerations include ease of access for maintenance and repairs and standardized components which are interchangeable in the event of a breakdown.

The equipment selection process for shopping centers is virtually identical to that for the owner-built office building, except that a secondary influence may come from the lessees. The major considerations here are reliability, length of service, and ease of maintenanc , with a secondary emphasis on the first cost of the system.

The primary decisions on equipment selection in the school buildings is made by the mechanical engineer, with a secondary influence coming from the architect. In recent years the trend has shifted to the use of packaged systems designed specifically for the requirements of school buildings. The prime factors considered in the selection process are reliability, ease of maintenance, long lifetime, and the ready availability of repair parts and services. The major emphasis is on quality rather than price. Life cycle costing for public buildings has become more important in evaluation and selection of building components, and can often be the deciding factor in the award of bids.

## 4.6 INFRASTRUCTURE ACCEPTANCE

Builders, developers, design engineers and other key decision-makers will pl. ' a large role in influencing SES acceptance. However, for decision makers to react favorably to SES, the infrastructure problems relating to building codes, product quality, labor conflicts, and financial and insurance institution philosophies regarding innovative systems will have to be identified and overcome. However, we do not see infrastructure acceptance as being a serious impediment, since our projections reflect low initial market capture.

## Building Codes

Codes in general do not present any basic obstacle to the utilization of solar energy. On the other hand, they do not provide incentives, advantages, or opportunities for the use of solar energy in most building construction. An essential market ingredient for solar energy systems would be the existence of performance-oriented codes that specifically establish, for example, maximum heat losses through the building envelope or which encourage innovative energy-conserving designs. Traditionally, however, codes have been prescriptive in nature, simply because they are more readily interpreted by the people who use them. Performance-oriented codes would not place conventional environmental comfort systems at any competitive disadvantage, but it would be easier and less expensive for solar energy systems to satisfy reduced energy consumption requirements. As pressure is brought to bear on the code-writing authorities to improve the semantics of model codes - and there is no doubt this will happen in time as States adopt model codes that are performance-oriented and mandatory or preemptive in nature - the better chance there is for entry of solar energy systems into the building construction market.

## Financial and Insurance Institution Standards

Any opposition to SES's by the insurance industry will be largely overcome if adequate quality assurance measures are adopted by the manufacturers. The insurance industry will require extensive testing and certification by an agency such as "Underwriters Laboratory" prior to adopting underwriting policies and fee structures equivalent to conventional products and systems.

SES operational characteristics which differ from conventional system characteristics will be the prime areas of concern to the insurance companies. The insurance industry also will be concerned with the ability and willingness of the solar manufacturers and installers to guarantee their products in the event of failure.

If the standards established by the insurance industry and the agencies concerned with public safety and product liability are realized, favorable acceptance by the financial community should follow. Our discussions with lenders have not identified any long-range major obstacles to overcome, pending the requirement for an established solar industry which is producing reliable products.

Before the SES industry is developed, however, near-term financing problems may arise. In the start-up phase of the industry, the incremental SES cost for single family residences may not initially receive mortgage approval. If a lending institution considers that a SES would make a house difficult to sell in the event of foreclosure, it will refuse to grant a mortgage. Also, the lending institution must be willing to accept the life-cycle costing concept, and the capital/operating cost trade-off involved. This acceptance will require some change in conventional financial institution philosophies regarding definition of mortgage commitments in terms of a fixed percentage (25%) of the homeowner's monthly income. If the financial institutions do not consider operating costs as an integral part of the monthly housing expenses, the incremental SES mortgage payment could disqualify a large number of families from obtaining the mortgage. The government can play a major role in minimizing this problem.

In the commercial market, the financial constraint is not so great, since financing methods differ. However, an effort should be made to establish credible operating cost comparisons, particularly for income-producing properties. If it can be demonstrated that solar systems can reduce the cost of operating such buildings, it may be possible to prove that they are worth more than non-solar buildings because of the higher capitalized value of the net income stream generated. If this could result in more favorable financing or a slightly higher ratio of debt to equity, the market acceptance of SES for income-producing properties would be greatly enhanced.

## Labor Considerations

The primary labor consideration is the potential overlap of trade responsibility and a possible lack of single-point product responsibility. The problem arises when the collector is both part of the roof and an integral part of the HVAC system. With solar systems, numerous trades could be involved or affected with the system installation, thereby making it difficult, if not impossible, to place the responsibility with a single subcontractor. This problem is of particular significance in view of the probability that in the near future, builders/develoners will be required to warranty their products for an undetermined period of time.

## 5. PROOF-OF-CONCEPT EXPERIMENTS

### 5.1 REFERENCE SYSTEM SUMMARY

The initial Phase 0 study resulted in the selection of three Reference Systems. These were designated System A (Hot Water System), System B (Hot Water and Space Heating), and System C (Hot Water, Space Heating and Cooling) and were used to establish capture potential for solar energy systems. While these Reference Systems were cost-effective for many building types and cities, it was apparent that new, innovative designs should also be evaluated to further improve their cost-effectiveness, particularly for the overall combined hot water, space heating and cooling systems. The results of these evaluations led to the selection of three solar augmented heat pump systems as a means of reducing both initial costs as well as operating costs. The three solar augmented heat pump systems were designated Reference Systems (D), (E), and (F). Their general characteristics are given in Table 5-1. All three systems were designed to provide the combined building functions of service for hot water, space heating, and space cooling. The thermal models and system diagrams for Reference Systems (D) and (E) are shown in Figures 5-1, 5-2, 5-3, and 5-4.

Systems (D) and (E) utilize a combination of solar augmentation and a variable pressure ratio heat pump to achieve significantly higher coefficients of performance than that achievable with a conventional heat pump. System (D), which is essentially an all-air system (except for the hot water function), uses crushed rock for both the hot and cold energy storage. System (E) circulates water through the collector loop but permits the option of using water or air in the building distribution loop. Both systems utilize heat pumps which are capable of operating with either "reverse-refrigerant" or "reverse-air or water" loops.

In order to accommodate one of the Phase 1 recommended POCE's, a System (F) was also defined. This system, shown in Figure 5-5, is essentially a state-of-the-art modification of System (E). It includes a rock-bed regenerator to provide cooling and regenerative heating of circulation air and a conventional heat pump rather than a variable pressure ratio unit which is to be developed concurrently in Phase 1.

Table 5-1. General Characteristics of Solar Augmented Heat Pump Systems

| Reference System Designation | Major System Component | System Operation |
|---|---|---|
| (D) | • Flat-Plate Solar Collector<br>• Crushed Rock Energy Storage (Hot and Cold)<br>• Variable Pressure Ratio Heat Pump<br>• Auxiliary Hot Water Heater<br>• Collector Air Circulation Fan | • All air circulating system (collector and distribution loops)<br>• Heat pumps with "reverse-air" or "reverse-refrigerant" options available |
| (E) | • Flat-Plate Solar Collector<br>• Water Storage Tanks (Hot and Cold)<br>• Variable Pressure Ratio Heat Pump<br>• Auxiliary Hot Water Heater<br>• Collector Water Circulation Pump | • Water circulating system (collector loop)<br>• Water or air circulating system (distribution loop)<br>• Heat pump with "reverse-refrigerant" on "reverse water" loop options available |
| (F) | • Flat-Plate Solar Collector<br>• Water Storage Tanks (Hot and Cold)<br>• Conventional Heat Pump (with Evaporative Water-Cooled Condenser)<br>• Rock-Bed Regenerator<br>• Auxiliary Hot Water Heater<br>• Collector Water Circulation Pump<br>• RBR Air Circulation Fan | • Water circulating system (collector loop)<br>• Water and air circulating systems (distribution loop)<br>• Heat pump with "reverse-water" loop only<br>• RBR used to cool or regeneratively heat air for gym space<br>• Collector loop used to heat office space<br>• Heat pump loop used to cool or heat office space |

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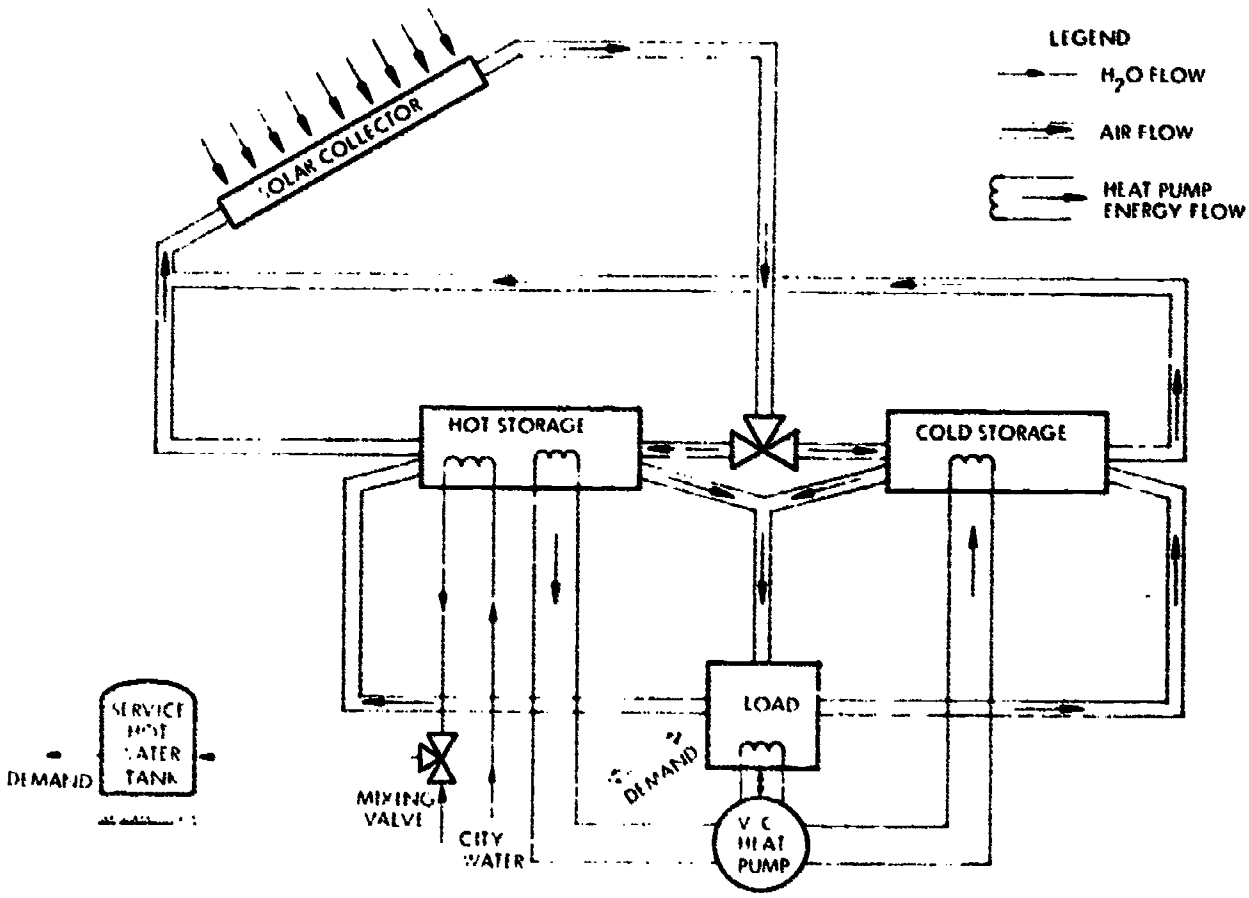


Figure 5-1. Schematic Diagram of Reference System (D) Thermal Model

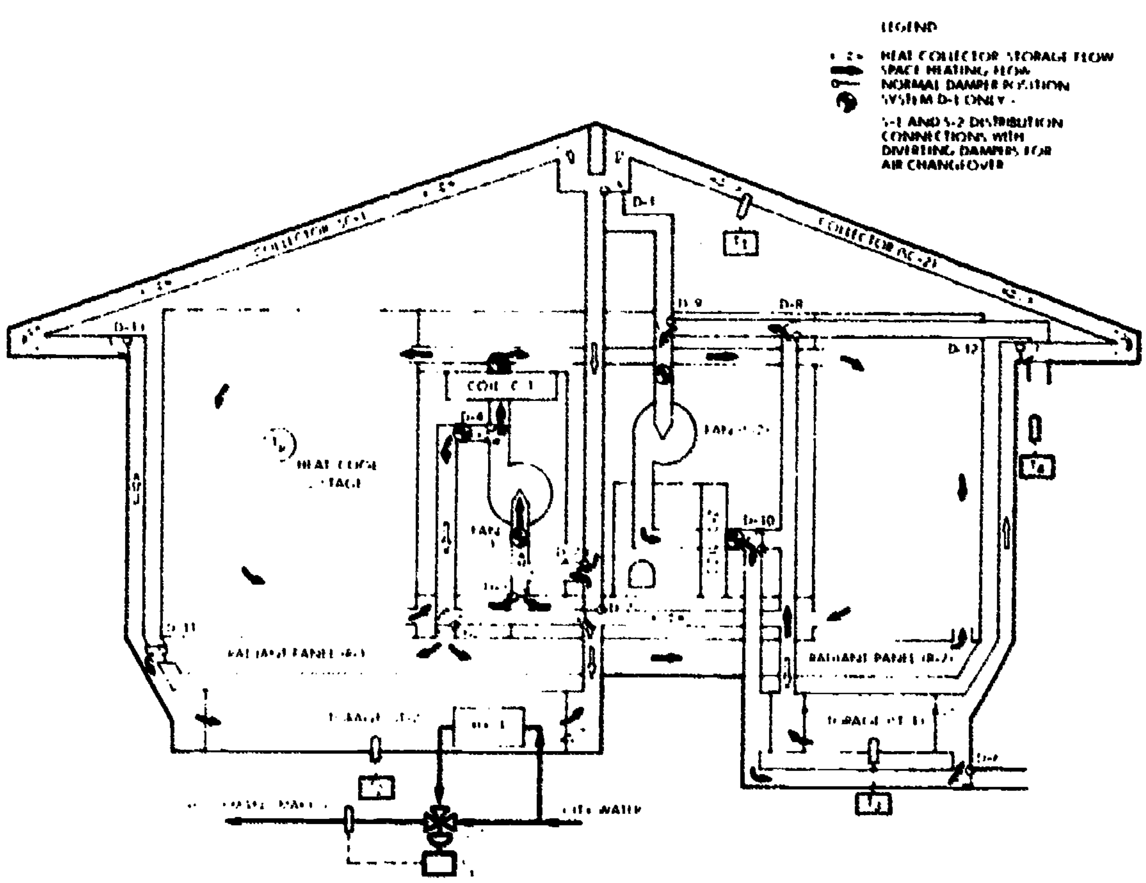

Figure 5-2. Reference System (D) Solar Heat Pump System (Air Transfer-Refrigerant Changeover)

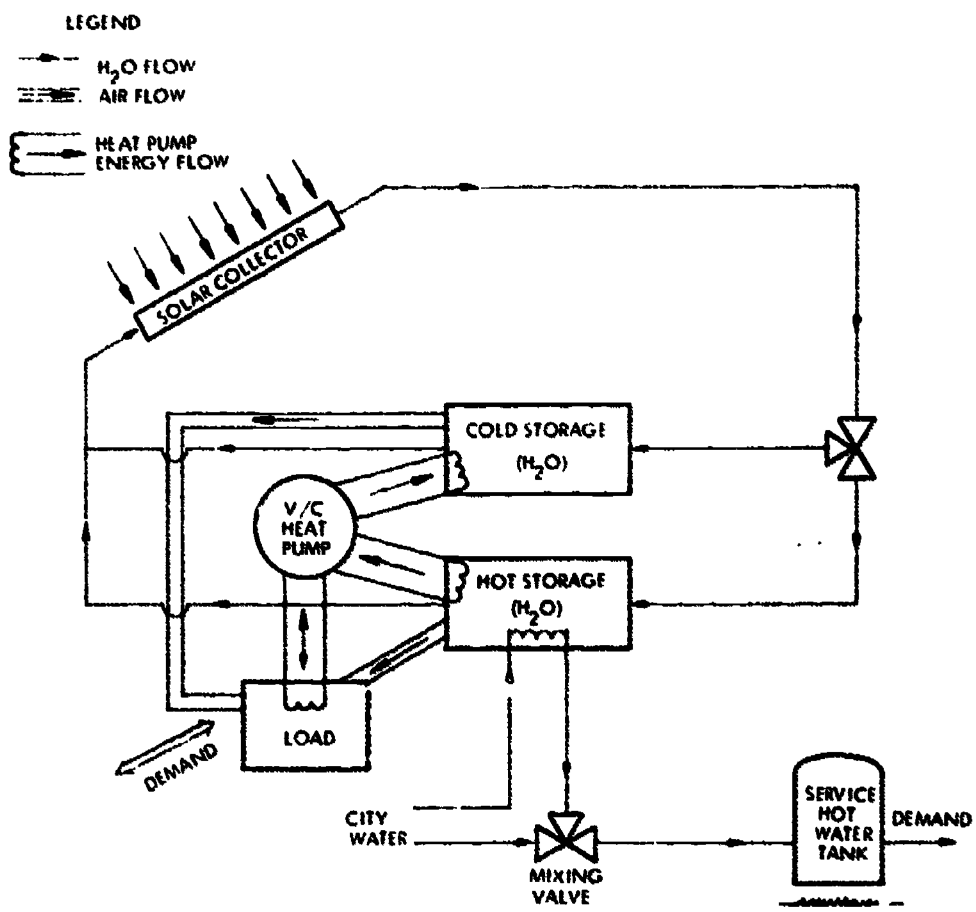


Figure 5-3. Schematic Diagram of Reference System (E) Thermal Model

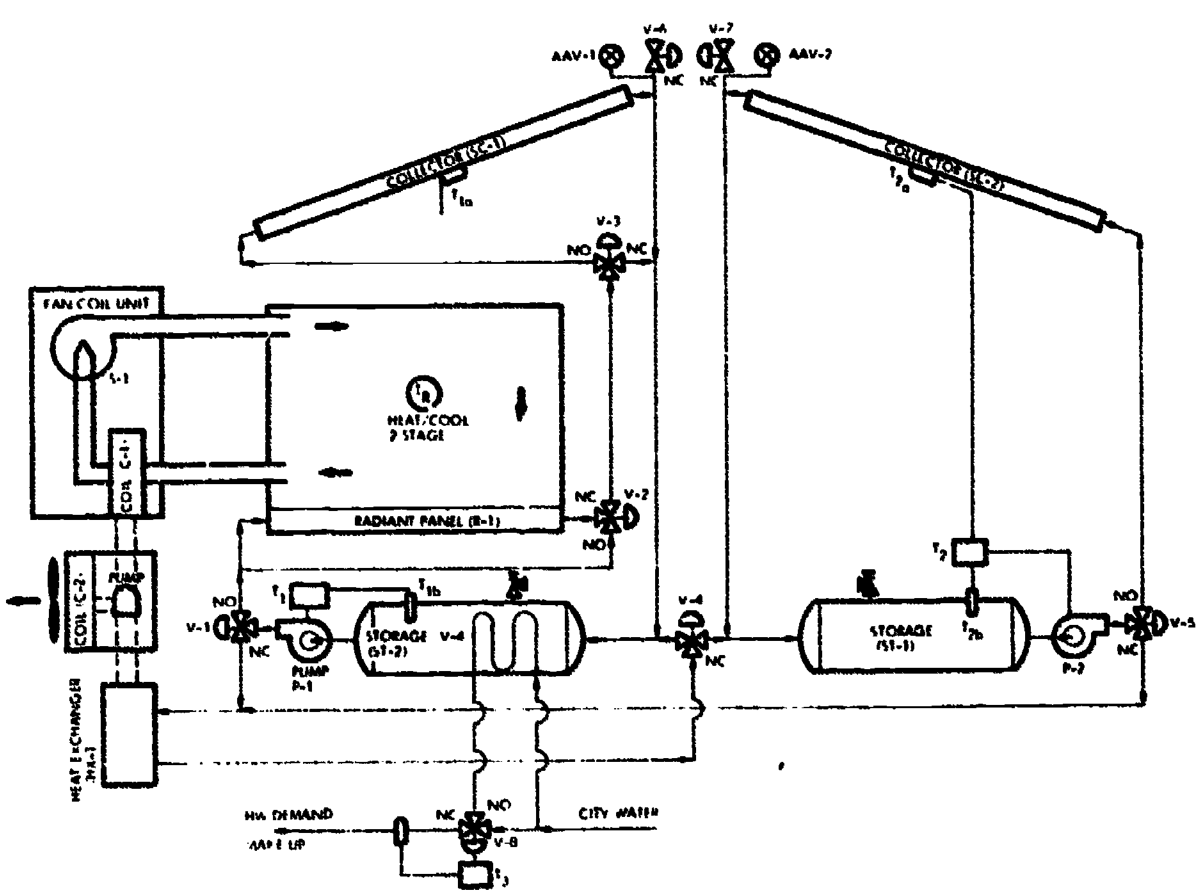


Figure 5-4. Schematic Operational Diagram-Reference System (F)

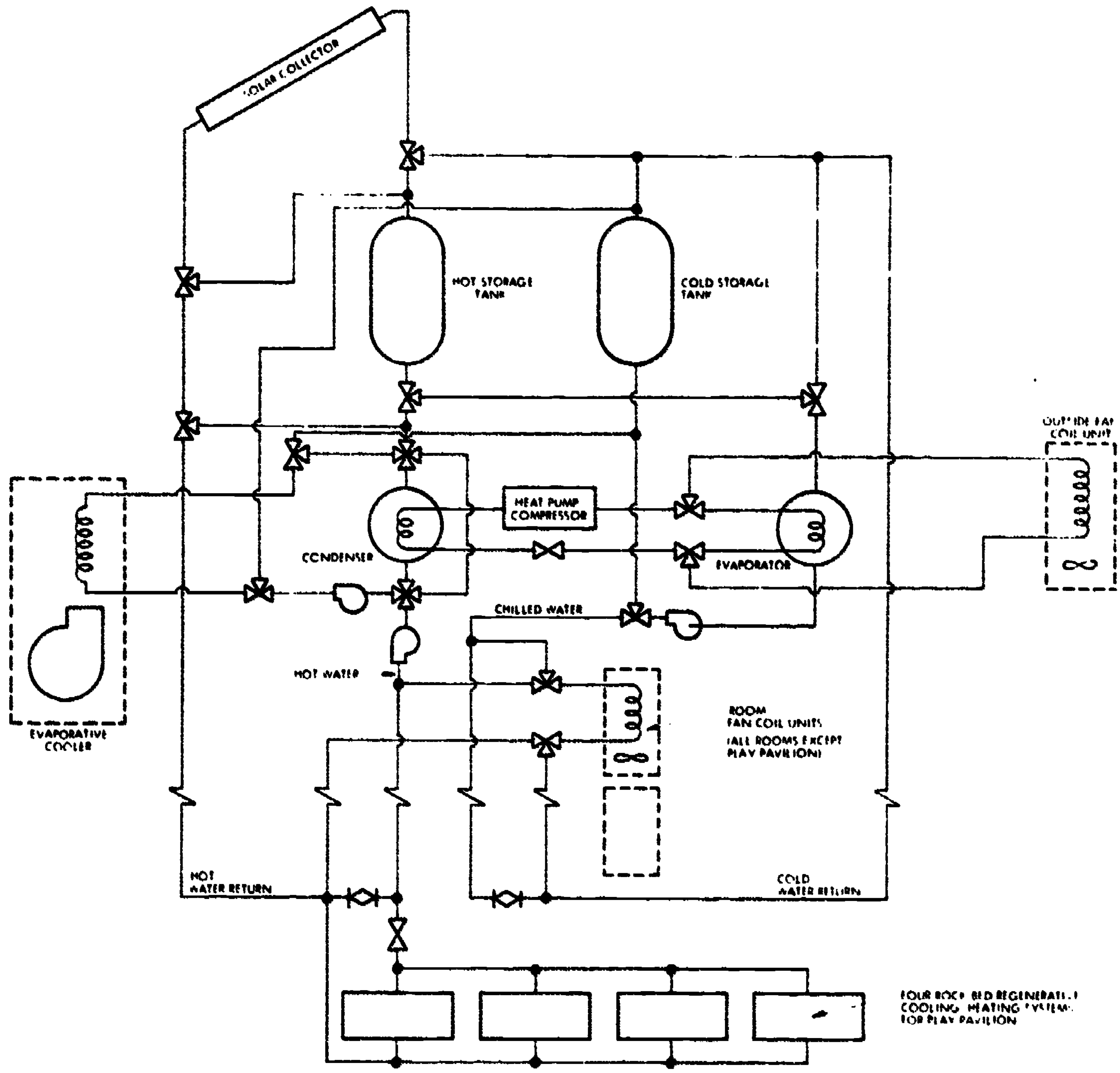


Figure 5-5. Schematic Diagram of Reference System (F)
(Rock-Bed Regenerator & Evaporative Cooler)

# 6. PHASE 1 DEVELOPMENT PLAN

The Phase 1 program consists of three separate tasks or near-term POCE's. Two of these tasks are designed to gather data applicable to reduced-cost solar collector systems using existing large buildings. The third task is to develop a variable pressure ratio heat pump to permit: 1) the cost-effective use of lower temperature solar heat during the heating season, and 2) reduced conventional energy consumption during the cooling season.

The Phase 1 development effort for the Solar Heating and Cooling of Buildings will be carried out over a twelve (12) month period. The emphasis during this phase will be to prepare the preliminary designs and conduct the development tests for the NSF approved POCE's. Cost estimates for these Phase 1 development efforts are provided in "Volume IV - Cost Summary" of this Phase 0 Final Report.

## 6.1 SCOTTSDALE GIRLS' CLUB BUILDING (POCE NO. 1) -PROGRAM PLAN

### 6.1.1 Program Summary

The Scottsdale, Arizona Girls' Club is planning to construct a new building of moderate size (i.e., First Floor - 12,600 $ft^2$, Second Floor - 2,700 $ft^2$). This building is being funded by contributions from the citizens of Scottsdale. Plans have been completed and construction will be initiated in September 1974. Discussions with the board members of this public building have resulted in their enthusiastic support for the possibility of providing both solar heating and cooling for this facility.

Both Reference Systems (D) and (E) were investigated for their applicability to this building. However, Reference System (D), which uses air circulation in both the collector and distribution system loop must be architecturally integrated into the building. Since the plans for the Scottsdale Girls' Club building have been completed and approved, the Reference System (D) was eliminated from consideration. Reference System (E), which uses water circulation in the collector loop and either water or air in the distribution system loop, was determined to be more compatible for incorporation into the existing building plans. However, several factors contributed toward requiring that some modifications be made to Reference System (E). These were:

- Since the variable pressure ratio heat pump would not be available in time to meet the construction schedule, a conventional heat pump employing "reverse-water" operation was substituted.

- The climatic conditions in Scottsdale permit the use of an evaporatively cooled condenser, and, since this will enhance the COP obtainable from the heat pump, it was substituted for the ambient air-cooled condenser.

- The Girls' Club recreational area requires 2000 CFM of outside make-up air to meet ASHRAE standards but dehumidification is not essential, so a rock-bed regenerator to provide summer cooling and regeneration of the make-up air for winter heating was included to reduce the heat pump loads and conserve on the use of electrical energy.

This modified system, designated Reference System (F), is shown on Figure 5-5. The system design characteristics are given in Table 6-1.

<u>Building Description</u>

The plan and one elevation of the Scottsdale Girls' Club South, located in Scottsdale, Arizona, are shown in Figures 6-1 and 6-2. The ground floor is approximately 12,600 square feet and includes a play pavilion of 5,400 square feet, a cooking area of 2,400 square feet, a crafts room of 1,500 square feet, and an office, foyer, and living suite of 2,700 square feet. A second story of 2,700 square feet above the office area will be left unfinished. The major axis of the building runs from southeast to northwest. The entire flat roof area of the play pavilion and two-story office section adjacent to it will be built initially, and the two one-story sections of the crafts room and cooking area will be completed at a later date. This two-story section has a total roof area of 8,100 square feet with a low parapet at the perimeter. It is intended that the solar collectors, tilted 32 to 42 degrees to the horizontal and oriented southward would be placed on the two-story section of the building. The unfinished space above the office area would be used as an interim crafts room until funds become available to build the one-story sections. A mechanical equipment room would be located on the second floor above the foyer and hot and cold water storage tanks will be burried under the courtyard adjacent to the foyer.

Table 6-1. Scottsdale Girls' Club Building (POCE No. 1)- Overall Solar/Heat Pump System Design Characteristics

| Quantity | Subsystem Description | Design Characteristics |
|---|---|---|
| 1 | Solar Collector (and Circulating Water Pump) | 1000 sq. ft.<br>Single-Glaze<br>Fluid-Water<br>Flow Rate-5000 gals/hr |
| 1 | Energy Storage Tank (Hot) | 2000 Gallons<br>Fluid-Water |
| 1 | Energy Storage Tank (Cold) | 2000 Gallons<br>Fluid-Water |
| 1 | Heat Pump | 20 Ton Capacity<br>"Reverse-Water" Operation<br>Evaporative Water-Cooled Condenser |
| 4 | Rock-Bed Regenerator | 2000 CFM Ventilation Flow<br>Cool & Ventilate Recreational Area Only<br>Pre-heat Ventilation Air for Heating Mode |
| 4 | Air Circulation Fan | 2000 CFM<br>0.65 in. $H_2O$, Gage |
| 1 | Auxiliary Hot Water Tank (and Circulating Water Pump) | 100 Gallons<br>Electrically Heated |

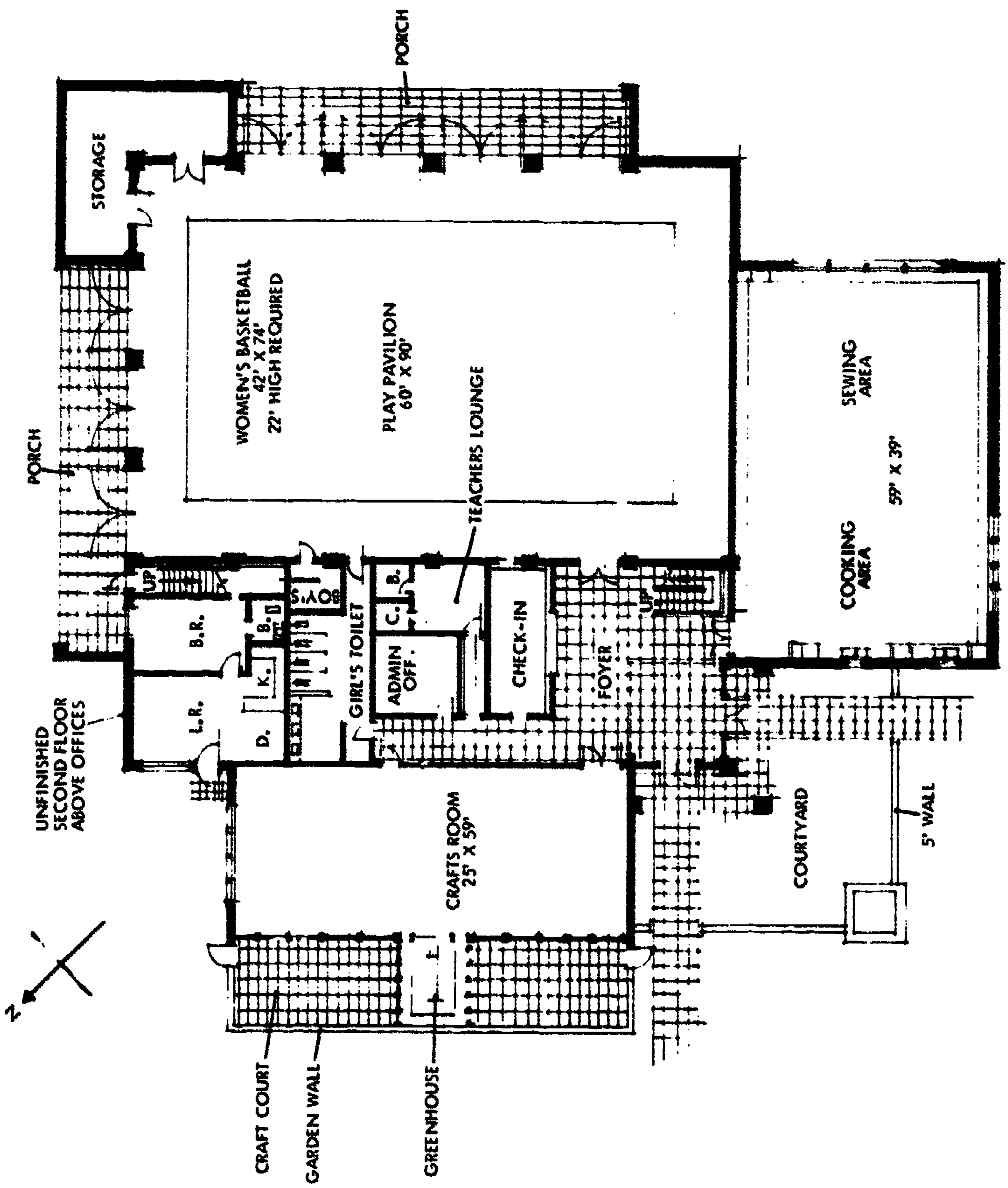


Figure 6-1. Floor Plan of Scottsdale Girls' Club South

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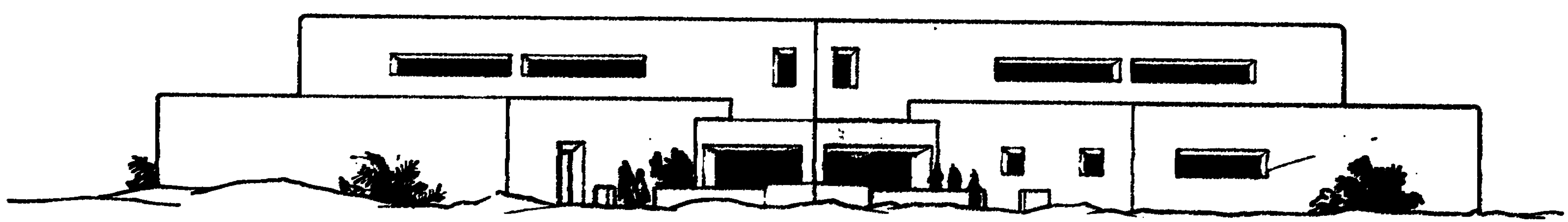

Figure 6-2. East Elevation of Scottsdale Girls' Club South

### 6.1.2 Rationale for Selection

The Scottsdale Girls' Club building was selected because it was compatible with Phase 1 Development Plan groundrules. The funds for the building will be obtained by public contributions. Ownership of the solar-augmented heat pump heating and cooling system would ultimately be transferred to the Club's board of trustees and/or the municipality of Scottsdale after installation and completion of performance evaluation of the solar heating and cooling system. Construction of the Scottsdale Girls' Club will be initiated in September, 1974, and the building is estimated to be completed by December, 1974.

The Reference System (F) design was selected since it permits utilization of currently available subsystems and components. This is an important factor if a 12 month Phase 1 Development Program schedule is utilized. In addition, the Reference System (F) will act as a precursor to the development of Reference System (E), since it incorporates many of the design features of the latter system. Furthermore, upon completion of the variable pressure ratio heat pump development work (see Section 6.2), the Reference (F) system can be retrofitted with this more advanced heat pump concept. This should further increase the cost effectiveness of the Girls' Club building by providing increased annual electrical cost savings. Finally, the southwest area of the United States is one of the most attractive climatic regions for the utilization of solar energy. Hence, it is one of the areas which could lead to the early commercialization of solar heating and cooling systems. The major milestones and schedule for POCE No. 1 are shown in Figure 6-3.

## 6.2 VARIABLE PRESSURE RATIO HEAT PUMP (POCE NO. 2) - PROGRAM PLAN

### 6.2.1 Program Summary

The solar augmented variable pressure ratio heat pump (see Figures 6-4 and 6-5) will be analyzed, designed, fabricated and tested. Two (2) prototype units will be built. The first unit will be built and tested at the Airesearch Division of the Garrett Corporation who will be a major subcontractor to TRW for this development effort. They will perform component tests on the motor, centrifugal compressor, fan coil and sink/source coil, coil fans, and controls. The performance of all

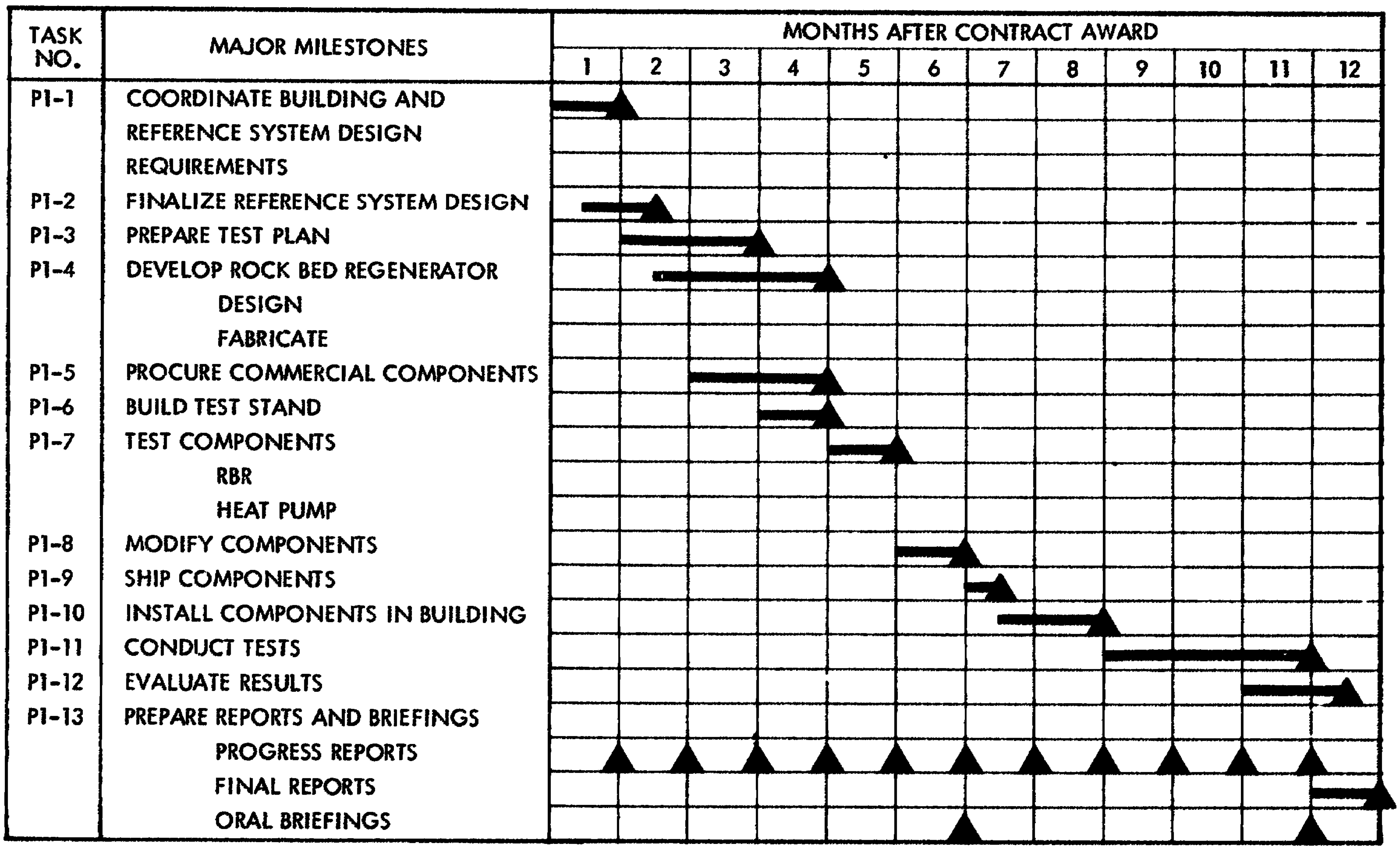


Figure 6-3. POCE No. 1 Major Milestone Schedule

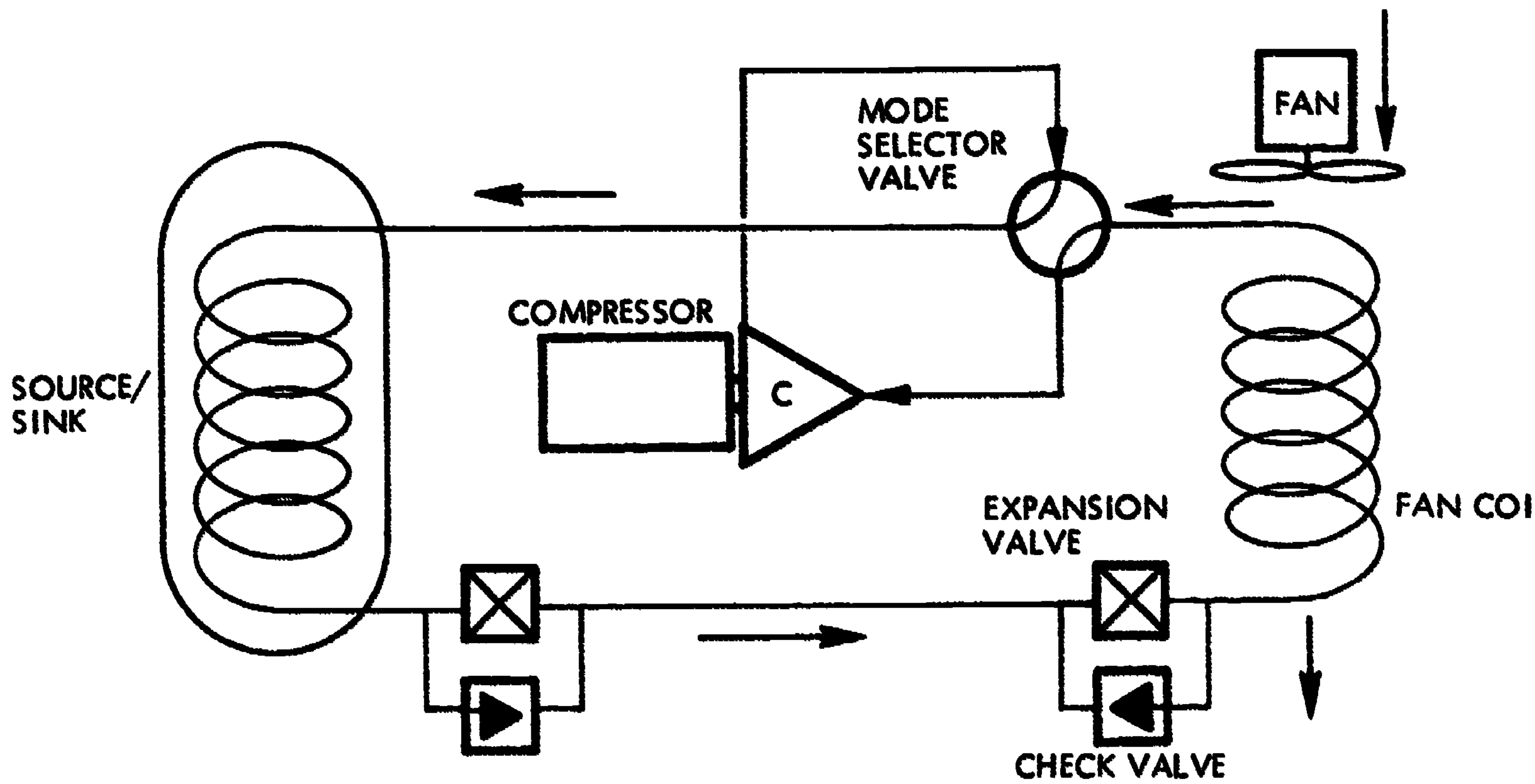


Figure 6-4. Heat Pump-Cooling Mode

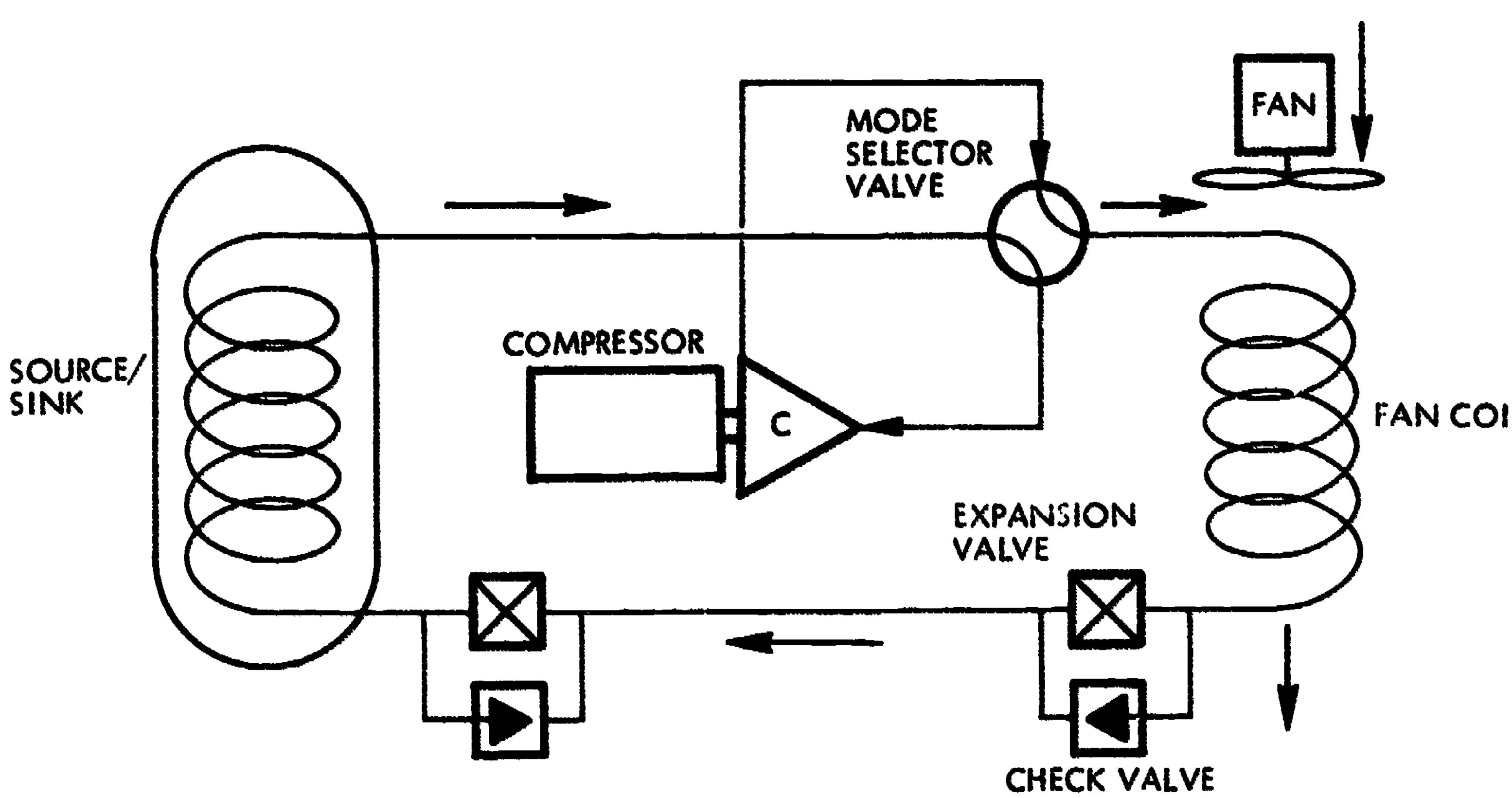


Figure 6-5. Heat Pump-Heating Mode

individual components will be determined. A second completely assembled unit will be shipped to TRW where the overall performance of the heat pump will be evaluated in the TRW Systems Solar Laboratory. Simulated heating and cooling loads (including the effects of solar augmentation) will be used to evaluate the performance of the overall variable pressure ratio heat pump. A final report will be prepared providing all the results of the Phase 1 - POCE No. 2 development effort.

Description

The Reference Systems (D) and (E) utilize two techniques for increasing their overall performance (i.e., solar collector loop augmentation and variable pressure ratio compression). In the heating mode the solar collector loop provides input energy to the hot storage so that the source coil of the heat pump is operating at temperatures greater than ambient. This results in increasing the heating mode COP from a conventional value of 2 to values potentially as high as 5 to 6 depending upon the climatic region involved. Similarly, in the cooling mode by using an unglazed collector to permit night sky radiation, the cold storage can be reduced to temperature values considerably below those available during daytime ambient conditions. This permits the sink coil (i.e., condenser) of the heat pump to operate at temperatures much lower than could be achieved by a ambient air, fan-cooled condenser. This results in increasing the cooling mode COP from values of 1 to 2 to as high as 4 to 5. Since the amount of electrical energy a heat pump uses is directly related to the COP, a significant saving in electrical energy costs results.

The second technique that can be employed to reduce heat pump electrical energy requirements is to operate with a variable pressure ratio heat pump. Since during many portions of the year the climate is sufficiently moderate, it is possible to operate the heat pump at reduced capacity in order to meet the building loads. Conventional heat pumps or air conditioners utilize a fixed pressure ratio compressor. Thus, at part load the compressors operate at off-design-load conditions which results in reduced compressor efficiency. This results in little or no electrical energy savings despite the fact that the heat pump is operating at reduced capacity. To offset this, it is proposed to develop a variable pressure ratio heat pump. This work would be carried out by TRW, with the Airesearch Division of the Garrett Corp. acting as a subcontractor. Upon the successful completion of this system, consideration will be given towards its retrofit and/or integration into the POCE No. 1 and POCE No. 3 configurations during the Phase 2 implementation and commercialization portion of the overall solar heating and cooling of buildings program.

The system consists of a variable speed centrifugal refrigerant compressor, a fan coil heat exchanger of standard tube-fin construction, a source/sink heat exchanger constructed from copper tubing, a mode selector valve, two expansion valves, and two check valves.

In the cooling mode (Figure 6-4), refrigerant gas from the fan coil heat exchanger, which is acting as an evaporator, is compressed by the centrifugal compressor and delivered through the mode selector valve to the source/sink coil where the gas is condensed. The high pressure liquid then flows through the check valve at the source/sink coil and expands through the expansion valve at the fan coil heat exchanger. The liquid is then evaporated in the fan coil heat exchanger and sent through the mode selector valve to the refrigerant compressor. In this manner, heat is pumped from the fan coil to the source/sink coil.

In the heating mode (Figure 6-5), refrigerant gas from the source/sink heat exchanger, which is acting as an evaporator, is compressed by the centrifugal compressor and delivered through the mode selector valve to the fan coil heat exchanger where the gas is condensed. The high pressure liquid flows through the check valve at the fan coil heat exchanger and expands through the expansion valve at the source/sink coil. The liquid is then evaporated in the source/sink heat exchanger and sent through the mode selector valve to the refrigerant compressor. In this manner, heat is pumped from the source/sink to the fan coil heat exchanger.

Three types of refrigerant compressors have been considered for this application. Two of these are positive displacement type (i.e., piston and screw) compressors. The other is a high speed centrifugal type. Based upon performance and cost tradeoffs the centrifugal compressor was selected.

The centrifugal compressor can provide both variable pressure ratio and good efficiency over a large range of flow rates. This can be accomplished primarily by varying the speed of the compressor. The centrifugal compressor undoubtably best suits the requirements of the heat pump system. However, a suitable variable speed drive must be developed at a reasonable factory cost to make this solution practical.

For this application, the centrifugal compressor impeller will rotate at approximately 70,000 rpm at its maximum design point and at 50,000 rpm at its minimum pressure ratio requirement. Over this range of speeds the compressor can provide essentially constant efficiency. The problem is to produce a low cost variable speed drive for the impeller.

A 2-pole, 60 Hz motor, will produce a maximum rotational speed of only 3,600 rpm and therefore a speed ratio device of 19.4 to 1 is required. This could be accomplished through a gear box similar to those used for jet engine starters. However, a variable ratio is still required. Motor speed controls of this size would be too costly. A mechanical solution with the potential of meeting a reasonable cost goal is the variable ratio traction drive. This type of drive uses rotating cones which can be positioned to vary the effective gear ratio. The traction drive operates similar to a friction drive except that the elements do not make contact and transfer torque through an oil film. An electronic approach to the variable speed drive appears to be the most cost competitive at this time. This approach consists of a frequency converter and high speed motor. In this manner a two pole motor with a frequency of approximately 1200 Hz will produce the 70,000 rpm required and by varying the frequency over the range of 800-1200 Hz the complete operating range can be obtained. The reason that the frequency converter offers a cost competitive solution, is that the high speed motor can be made extremely small thereby minimizing its cost. The compressor impeller and housing is also very small and can be manufactured at much less cost than the typical piston elements. This leaves a reasonable budget for the frequency converter. At this time it is felt that a reasonable factory cost target of $100.00 can be obtained in large quantity production.

Figure 6-6 shows typical characteristics of a centrifugal refrigerant compressor. This map indicates the use of R114. This refrigerant was selected to be compatible with the centrifugal compressor requirements and also maintain positive loop pressure over the operating range.

### 6.2.2 Rationale for Selection

The potential savings in electrical energy by use of a solar augmented heat pump can be of considerable magnitude. By narrowing the overall temperature difference between the sink/source coil and the fan coil of the heat pump a considerable increase in COP can be achieved. In addition, by operating the solar collector at modest temperature increases above ambient, high solar collector efficiencies can be obtained. This latter operating mode can permit the use of unglazed collectors or smaller area glazed collectors. This will result in reduced system costs and enhance tne market potential for both Reference Systems (D) and (E). Finally, the improved performance achievable with a variable pressure ratio heat pump can also be used with conventional systems thus resulting in a large electrical energy saving for the entire country and opening up a broad new market for retrofitting existing buildings using conventional, low performance heating and cooling systems. The major milestones and schedule for this POCE No. 2 task is shown in Figure 6-7.

## 6.3 WEST LOS ANGELES CITY HALL (POCE NO. 3) - PROGRAM PLAN

### 6.3.1 Program Summary

The Reference System (B) (see Figure 2-4) configuration will be analyzed, designed, fabricated, tested, and then installed and integrated into the existing West Los Angeles City Hall Building. The solar collector will be based upon a TRW unglazed, low cost configuration but will be adaptable to the installation of a single glaze design if required. The circulating fluid will be water and a hot water energy storage tank will be specified and procurred for use with this system. The auxiliary hot water heater, pumps, heating coils and controls will all be specified and obtained from commercial sources. The system components will be checked out and tested in the TRW Systems Solar Laboratory. The overall system will be shipped to West Los Angeles and installed on the WLA-City Hall building. Performance tests to evaluate solar collector efficiency for both the unglazed and glazed designs will be conducted. In addition, percent solar energy utilization will be determined for both these configurations. A final report will be prepared summarizing the results of these development tests.

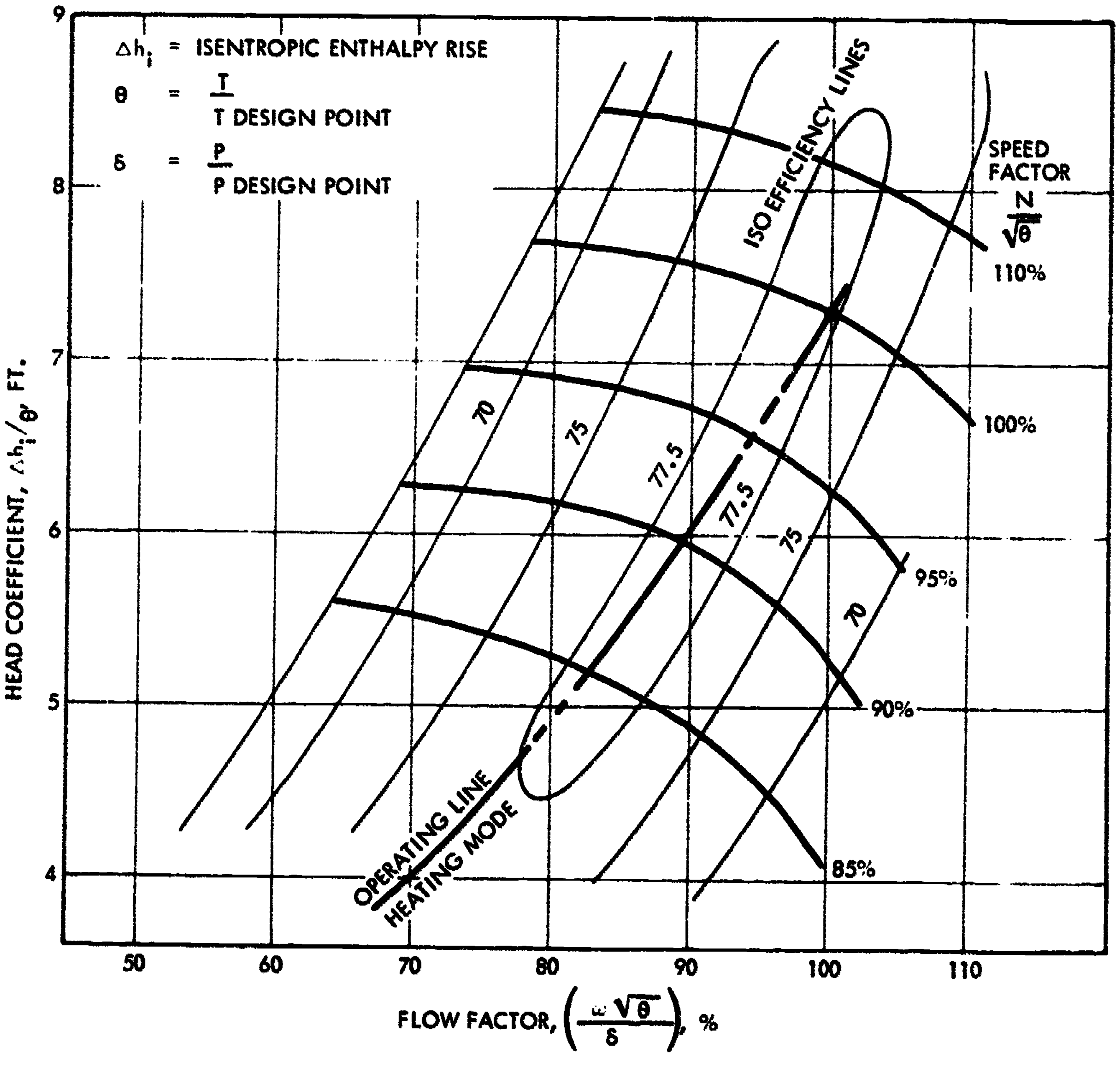


Figure 6-6. Characteristics of Centrifugal Compressor

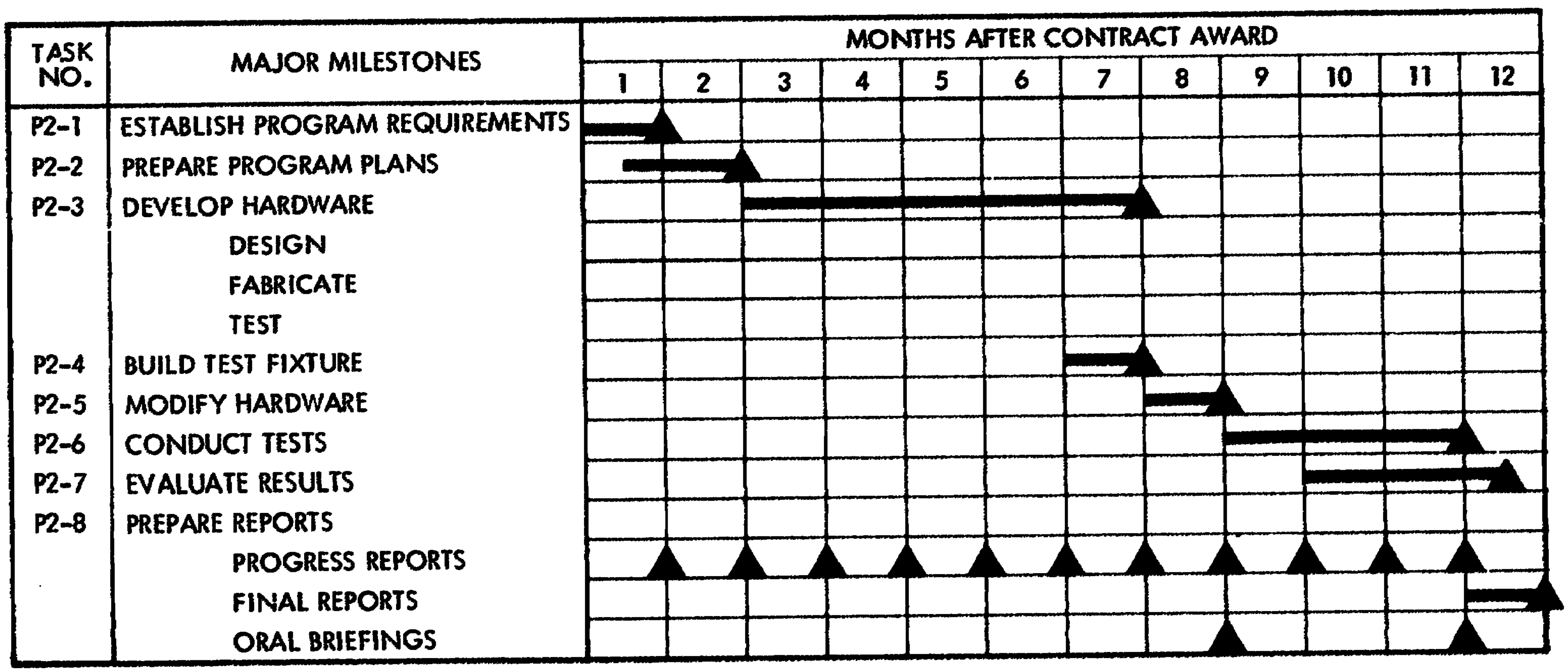


Figure 6-7. POCE No. 2 Major Milestone Schedule

In addition to the above effort. as part of POCE No. 3, an analysis and design of a Reference (D) or (E) type system (see Figures 5-2 and 5-4) will be carried out for integration into the Los Angeles Bureau of Standards Building addition. The test data available from the development work of POCE No.'s 1 and 2 as well as the data from this POCE No. 3 will be used to iterate the analysis and design in order to arrive at a maximum performance, minimum cost configuration. A final report will be prepared for this Phase 1 - POCE No. 3 analytical and design effort and a baseline system will be configured for consideration for integration into the Los Angeles Bureau of Standards building. This baseline system would be implemented after review and approval by NSF.

Building Description

Figure 6-8 illustrates the site plan and location of the existing West Los Angeles Municipal Building at Corinth and Iowa Avenues. The building is approximately 72 feet wide by 257 feet long and two stories above grade. The building is heated and cooled by air handling equipment located in a partial basement and a penthouse 32' x 112' on the roof. The balance of the roof area above the second floor and the roof over the penthouse are available for locating the solar collectors. The mechanical equipment room is adequate for location of hot water storage tanks, while the four multi-zone two deck air handling units can be readily modified to incorporate heating (pre-heat) coils (heat exchangers) which would be part of the SES. The building is ideally suited for retrofitting Reference System (B) with glazed or unglazed collectors and offers a high potential for demonstrating Reference System (E) where a heat pump would be employed. The peak heating load is about 750,000 Btu/hr. The data obtained from the retrofit of the systems employed will be used to arrive at the final design for a system (D) type configuration for the Bureau of Standards Building addition. This new building will be located north of Dodger Stadium, on the banks of the Los Angeles River in the 2300 block of Dorris Place. The City of Los Angeles Bureau of Standards currently has a facility in which materials and assemblies are tested for compliance with the Los Angeles City Building Code. Discussions with the Department of Public Works indicate that the preliminary

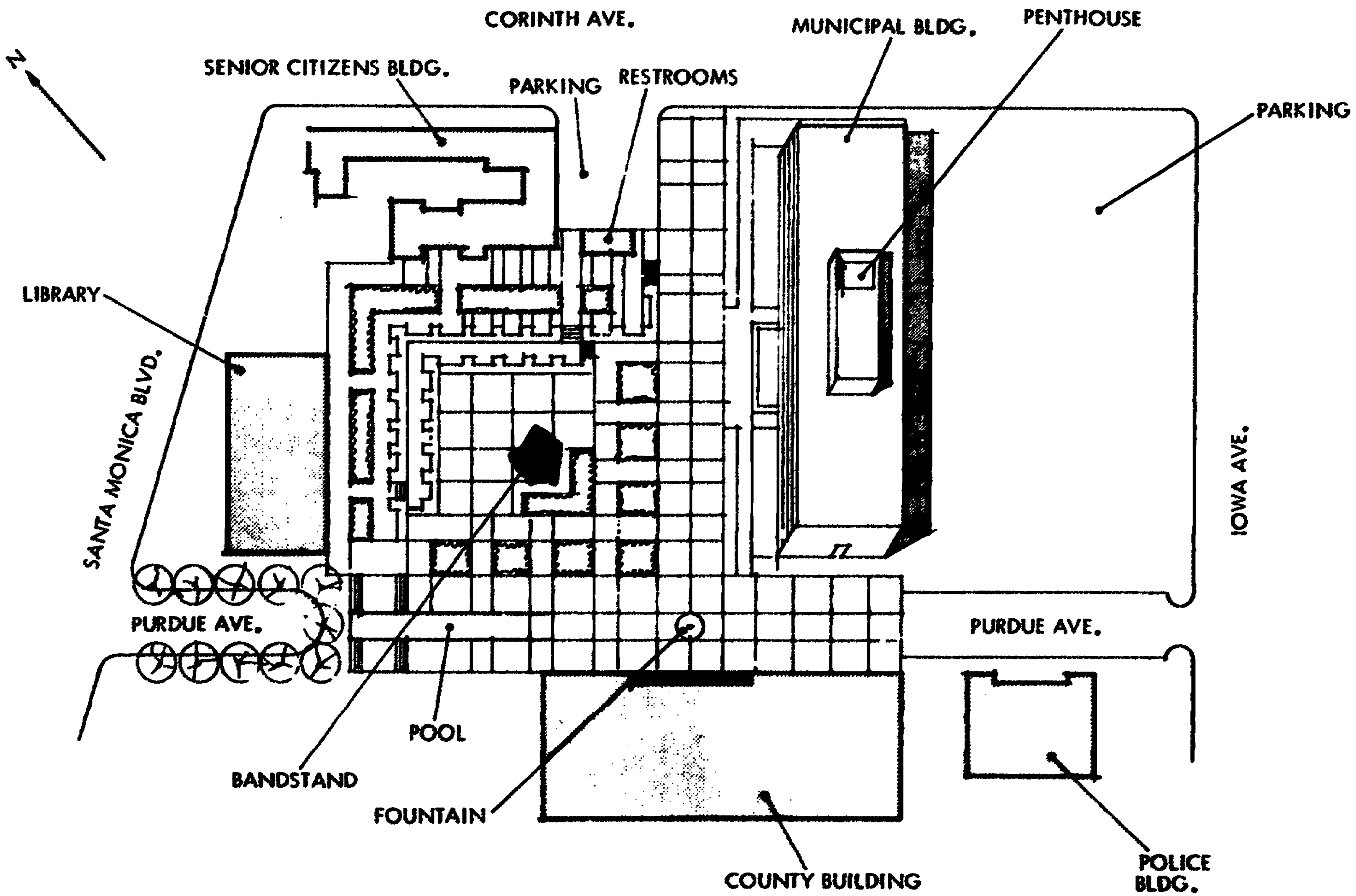


Figure 6-8. Plot Plan for West Los Angeles Municipal Building

planning for an office and laboratory addition will begin in July 1974. The program calls for a three story, 11,250 square foot structure about 50' x 75' in plan with two stories above grade and one below. Since the orientation, framing, fenestration, and building envelope have not been determined at this point in time, it is not feasible to estimate space heating and cooling loads. Air make-up requirements in the laboratory areas would have to be determined on an individual basis. A more detailed analysis will be performed to determine the size of the system components and to make other appropriate tradeoffs in the designs of the building envelope itself. By working with the city architects and engineers, the design of this building will be successfully integrated with an SES similar to Reference System (D) of Figures 5-1 and 5-2.

### 6.3.2 Rationale for Selection

The West Los Angeles City Hall will be made available for retrofit with a solar hot water and space heating system based upon the Reference System (B). This building meets several important criteria for its acceptability for a Phase 1 POCE. It is a government owned building and transfer of ownership of the solar hot water and heating system to the West Los Angeles municipality (after installation and completion of performance evaluation) is anticipated. The building is located in a climatic region that is ideally suited for solar energy system use. In addition, the region also possesses a high market capture potential based upon both new construction and demographic considerations.

The implementation of a Reference System (B) type configuration will provide important performance data for both unglazed and single glazed collectors as well as energy storage subsystem characteristics, which will be used to establish a minimum cost design of Reference System (D) for use with the future planned Los Angeles National Bureau of Standards building addition. These data, together with the data obtained from the variable pressure ratio heat pump (POCE No. 2) program, should prove invaluable in designing a cost effective Reference System (D) for implementation in Phase 2, with minimum business and development risks. The emphasis in arriving at this design configuration will be to minimize the initial cost of the system and to maximize the savings in electrical energy consumption. The major milestones and schedule for POCE No. 3 are shown in Figure 6-9.

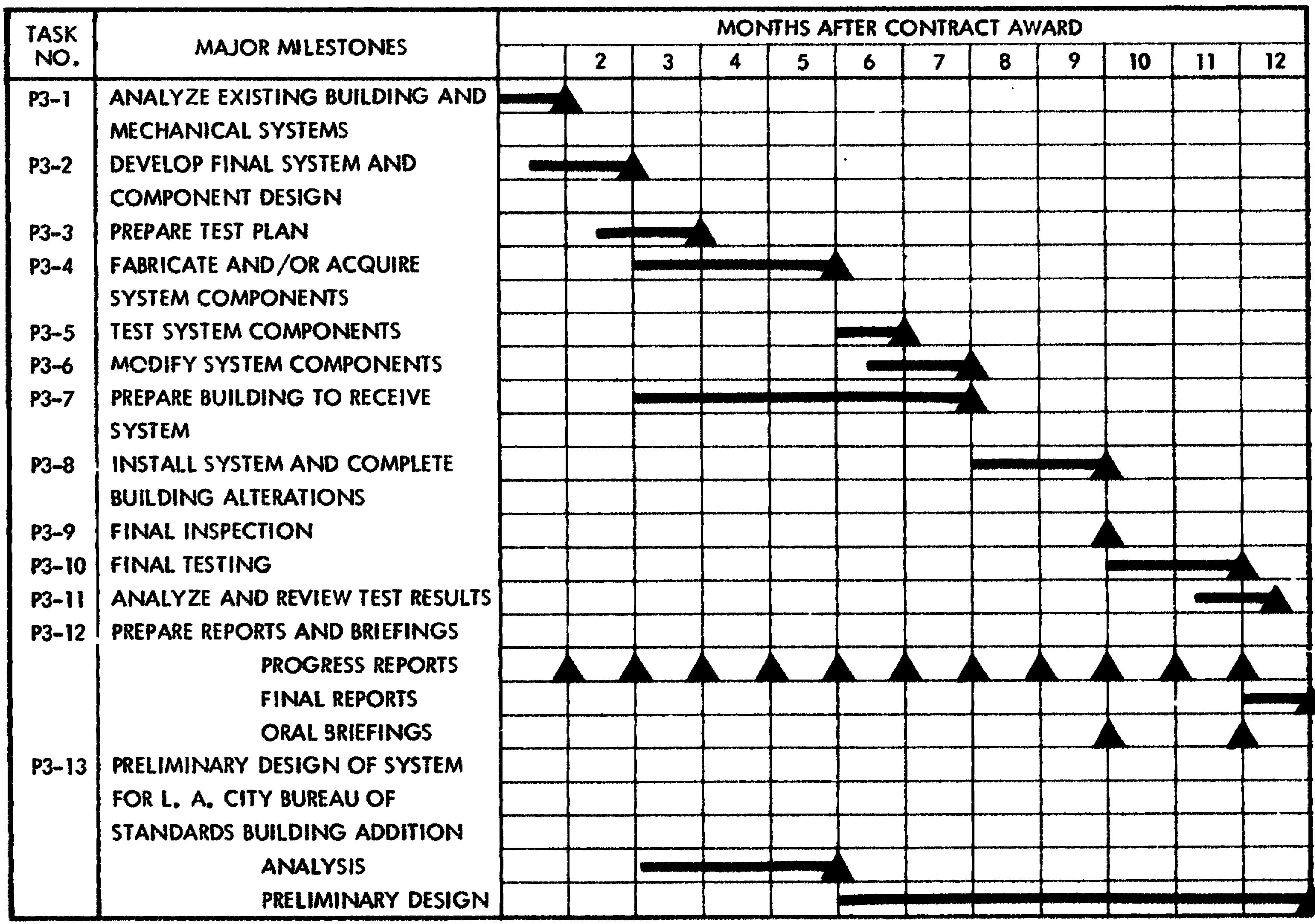


Figure 6-9. PULL No. 3 Major Milestone Schedule

## 7. PHASE 2 DEVELOPMENT PLAN

From among the fourteen cities selected during our Phase 0 Study, six were chosen for nation-wide implementation of the system designs developed during Phase 1. The cities are:

- Los Angeles
- Phoenix
- Boston
- New York
- Dallas
- Denver

The six cities were selected on the basis of market capture potential, which in turn was based on climatic conditions, conventional energy types and uses, projections of future building starts and conventional energy costs. Four of our five original building types were selected and a total of nine buildings are recommended for each city as follows:

- Multi-family low-rise apartment buildings (2)
- Single family residences (5)
- Schools (1)
- Commercial buildings (1)

The residential units were emphasized since this segment must demonstrate a high market capture potential if significant total energy savings are to be realized. The multiple family residence is already one of the better markets, but the single family residence has one of the lowest capture rates of our five building types. As mentioned elsewhere, this is somewhat of an artificial situation since a major reason for the difference in capture potential between the two types of residences is the preferred electric utility rate given to single family units. Schools have been selected because they, too, have high capture potential. Although the total market is relatively small because of the number of schools and anticipated new starts is small, the exposure value in terms of a stimulating public awareness and acceptance of solar energy systems is high. Office buildings have been included even though the market capture potential is expected to be less than 10 percent. However, most government buildings (including federal, state, and local) fall into this category and are prime candidates for solar energy systems, both with regard to life-cycle cost considerations and public exposure value.

The design, construction, and operation of these 54 buildings should provide the performance data and public exposure required to successfully initiate widespread utilization of solar energy systems for the heating and cooling of buildings. The total duration of Phase 2 is expected to be 30 months. The planning and preliminary design aspects of Phase 2 can be initiated prior to the completion of Phase 1.

## 8. UTILIZATION PLANNING

In order to stimulate the introduction of SES's on a significant scale, the following concurrent activities should be carried out.

The government must play a strong role in SES industry development. Specific focus should be on R & D funding oriented towards reducing SES costs and on funding for demonstration projects. Our public opinion survey clearly showed that consumers in cities with solar demonstration projects are significantly more aware of the concept of solar heating and cooling and are more likely to accept their utilization. Thus, demonstration projects should be planned for buildings that have high public exposure, such as schools, government buildings, etc.

Additional government participartion must focus on implementing building code modifications requiring increased energy conservation, and performance rather than prescriptive building code criteria. Government assistance in establishing standards and performance criteria for SES would reduce insurance industry opposition. Government can also play a large role in minimizing financial institution resistance. The Federal Home Loan Bank Board can use its influence to encourage member financial institutions to grant mortgages on SES homes. Furthermore, the government can insure the SES incremental mortgage amount, thus diminishing financial institution reluctance to finance this increment.

A major impact on both consumers and developers could be generated through the government requiring SES installations on government-funded projects, especially housing projects. SES installation on government housing would generate consumer awareness, but more importantly, would also demonstrate the direct practicality of SES for residences.

A further role of the government can play is in offering incentives to consumers and/or to SES manufacturers. Possible incentives include tax credits, low-interest financing, and tax deductions. It will also be important to assure that state and local property taxes on the incremental costs of SES's are not applied in a manner that produces a negative incentive.

An important role must also be assumed by industry organizations such as NAHB, ASME, AND ASHRAE. These organizations have a large direct effect on developer and other decision maker acceptance of SES.

The housing market can be approached most advantageously by eliciting SES usage by the large tract developers such as Kaufman and Broad, Levitt, and Sons, etc. Most new construction is done on a volume basis, and necessarily provides the largest markets. Equally important, small builders tend to follow the lead of large builders, but will generally be more conservative initially. However, the custom home market should not be overlooked because the buyer is generally less first-cost sensitive. Also SES is more financially feasible for luxury condominium apartments than for investor-owned and operated apartments.

Another important participant in any implementation plan is the utility industry, particularly the gas companies. Since the supply of natural gas is limited and some regions now have moratoriums on new hookups, the use of solar energy is an ideal approach for permitting the expansion of the customer base without increasing the consumption of natural gas.

The involvement of professional builder/owners of industrial and commercial buildings could be very beneficial for the implementation of solar energy systems. Since this group is very sensitive to life-cycle costs, they could be expected to be among the most likely early users of these systems.

## 9. CONCLUSIONS AND RECOMMENDATIONS

Solar heating and cooling of buildings provides a potential market approaching a billion dollars per year by the year 2000, even under the conservative assumptions of our capture analysis and measured in terms of 1974 dollars. However, it is important to keep in mind the primary objective of this study, which is not to maximize the utilization of solar energy, but to minimize the consumption of fossil fuels. Using that yardstick, the current single-and double-glazed collectors and lithium bromide gas absorption refrigeration systems reduce the projected total national energy consumption in the year 2000 by only a few tenths of a percent. This is primarily because of the high incremental equipment costs for these conventional designs. This limits their capture potential largely to hot water heating, with space heating being only selectively competitive and space cooling essentially non-competitive for most building types and climatic regions.

We feel that solar-energy-augmented systems can be designed to permit a one percent reduction in total national conventional energy consumption by the year 2000. However, this requires the development of construction-integrated solar energy collection systems (to lower the incremental capital costs) in conjunction with variable pressure ratio heat pumps (to provide improved coefficients of performance and thereby reduce conventional fuel consumption and operating costs). Our recommended Phase 1 program is directed towards determining the system and subsystem designs most likely to meet the objective of attaining significant conventional energy savings in the heating and cooling of buildings. Our Phase 2 effort is oriented towards implementing these system designs on a nationwide scale.