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ABSTRACT

After the Westinghouse Electric Corporation made a comprehensive analysis of the technical, economic, social, environmental, and institutional factors affecting the feasibility of utilizing solar energy for heating and cooling buildings, it determined that solar heating and cooling systems can become competitive in most regions of the country in the 1985-90 period. Heating-only systems can be competitive in the 1975-80 period in limited regions of the country. Impressive progress has recently been made in solar collectors, but further reduction in costs is necessary to capture a large market. Five regions of the country containing more than 75 percent of the country's population have been identified as the market for solar systems. Retrofit of solar systems to existing structures is not economically attractive for residential buildings but can be applied to larger buildings. The amount of fossil fuel that can be saved by use of solar energy will build up slowly and could reach 50 million barrels of oil per year by 1990. In the next century, sales of solar systems could approach $10 billion. A proof-of-concept experiment spanning a 3-year period involving 300 single-family residences and 25 large buildings, and requiring $26 million is recommended. (Author)

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Solar Heating and Cooling of Buildings

Phase O

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16. Abstract

A comprehensive analysis was made of technical, economic, social, environmental and institutional factors affecting the feasibility of utilizing solar energy for heating and cooling buildings.

Solar heating and cooling systems can become competitive in most regions of the country in the 1985-1990 period. Heating-only systems can be competitive in the 1975-1980 period in limited regions of the country.

Impressive progress has recently been made in solar collectors but further reduction in costs is necessary to capture a large market.

Five regions of the country containing more than 75 percent of the population have been identified as the market for solar systems. Retrofit of solar systems to existing structures is not economically attractive for residential buildings but can be applied to larger buildings.

The amount of fossil fuel that can be saved by use of solar energy will build up slowly and could reach 50 million barrels of oil per year by 1990. In the next century, sales of solar systems could approach $10 billion.

A proof-of-concept-experiment spanning a 3-year period, and involving 300 single-family residences and 25 large buildings at a budget estimate of $26 million, is recommended.

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FOREWORD

This Executive Summary of the Final Report is submitted to the National Science Foundation in partial fulfillment of the requirements of Contract NSF-C854, Solar Heating and Cooling of Buildings. This report was prepared by the prime contractor, Westinghouse Special Systems. Also participating in the project were the following:

- Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.
- Westinghouse Georesearch Laboratories, Boulder, Colorado.
- Colorado State University, Boulder, Colorado.
- Carnegie-Mellon University, Pittsburgh, Pennsylvania.
- Burt, Hill and Associates (Architects), Butler, Pennsylvania.
- NAHB Research Foundation, Inc., Rockville, Maryland.
- PPG Industries, Inc., Pittsburgh, Pennsylvania.

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INTRODUCTION

1.0 INTRODUCTION

More than twenty-five percent of the total energy used in the United States is consumed by the heating and cooling of buildings and by providing hot water. To date, fossil fuels have been the primary source of that energy.

On a broad scale and long-term basis, the sun, a medium size star, is an abundant source of electromagnetic energy. That energy could be collected and converted to thermal form to heat and cool many of the buildings in the Nation. On a local geographic basis, the day/night and seasonal cycles, plus cloud cover variation, inject uncertainties that have frustrated many previous efforts to design systems that could economically capture, transform, and utilize that energy.

Over the past several decades, more than twenty experimental or custom-made solar heating and cooling systems have been built. Although they have contributed much to the fund of knowledge and techniques, none has resulted in systems that were produced in volume. Other forms of energy, including gas and oil, appeared to be sufficiently available to serve the purpose more simply and at lower costs. Solar systems could not compete economically with fossil fuels, and there was little incentive to develop or market them commercially. Recent dramatic events have driven the cost of gas and oil upward and raised serious questions as to their long-term availability. Thus, the potential for solar energy heating and cooling systems has become a matter of intense national interest, and there is now a sense of urgency to develop such systems.

Under National Science Foundation Contract C854, Westinghouse Electric Corporation and its associates have conducted a comprehensive study of the "Feasibility of Solar Heating and Cooling of Buildings". This Executive Summary, together with the main report and appendices, presents the results of the study.

The feasibility analysis is considered the initial phase of a three-phase program planned by the National Science Foundation and was designated as Phase 0. Phase 1, for the design of systems, and Phase 2, for the construction test and evaluation of systems for a Proof-Of-Concept-Experiment (POCE), are expected to follow.

The term feasibility is intended to include all factors that would affect and determine the eventual commercial viability of utilizing solar energy for the heating (space heating and domestic hot water) and cooling of buildings. In particular these factors are:

- Technical.
- Economic.
- Social and Environmental.
- Institutional (building codes, etc.).

It is further important to recall that the fundamental purpose of this effort is to conserve scarce forms of energy, particularly oil and gas, and contribute to easing the projected pinch of the energy crisis. Despite the urgency, it is realistic to recognize that substantial savings will not occur until solar systems are adapted in a significant number of buildings of all types on a national basis.

Although the average ownership of a house is less than 10 years, a house is generally purchased with the view that it should last forty years and more.

Innovations in building designs are adopted slowly. Since single-family residences represent the largest investment that a family normally makes, it is quite understandable that a conservative clinging to tried techniques and designs tends to prevail. Building innovations that increase initial costs are also normally introduced at the narrow top of the economic ladder or in commercial buildings first, and "trickle down" to a broader base over a protracted period of time.

Central air-conditioning for homes is a pertinent example of these conclusions. It was available in the early 1930's but incorporated in only a relatively few high-priced homes. Not until the 1960's did costs decrease sufficiently and middle-income-family aspirations rise to create a volume demand for central air-conditioning. Today, in many sections of the country.

few homes are built without it. Residential heating and air-conditioning systems are considered to have a useful life of about 15 years. Therefore, the solar and conventional systems considered in this study have been analyzed on a 15-year-life-cycle basis.

Feasibility of solar systems is strongly dependent on present and future costs of equipment and conventional forms of energy. Solar system equipment costs can be expected to come down as technology improves and production volume increases. Concurrently, fossil fuel prices can be expected to increase over the long term. In this analysis, future costs are projected on a normal, rational growth basis. However, sudden changes can occur, particularly in gas and oil prices, that could create a more urgent demand for solar systems.

Left to the interaction of the free market, solar systems will become competitive with conventional heating and cooling when the equipment, operation, maintenance, and fuel cost of the one are similar to those of the other over their projected useful life. It is the conclusion of this study that, in general, a parity will be reached about 1985, and that general acceptance and widespread use will follow in two to three decades.

To shorten the time span required to achieve widespread use of solar systems, it is important that a broad effort in research, development, and demonstration be supported. In the national interest, the Government has employed a variety of incentives to foster infant industries. A similar stimulus is needed to launch the solar heating and cooling industry. This would ensure the timely availability and early acceptance of proven, practical solar systems when the demand occurs. Such a vigorous program by the Government would serve as a catalyst to accelerate the process of achieving widespread acceptability of solar systems. One important purpose of this study has been to help point the way for the Government to assume this role.

The Phase 0 feasibility analysis has involved ten specified tasks, starting with a delineation of requirements and culminating with plans for utilizing the results. The tasks are:

- Task 1--Development of Requirements.
- Task 2--Systems Definition.
- Task 3--Assessment of Capture Potential.

- Task 4--Social and Environmental Study.
- Task 5--Preliminary Cost Study.
- Task 6--Recommendations for Proof-Of-Concept-Experiments.
- Task 7--Recommendation for a Special Project.
- Task 8--Development Plans for Phase 1.
- Task 9--Development Plans for Phase 2.
- Task 10--Preliminary Utilization Plans.

In the full report and appendices, the results of each task are presented in detail. This Executive Summary highlights the major results.

The analysis has been conducted by several Westinghouse divisions and associates as listed below:

- Westinghouse Special Systems, Baltimore, Maryland (Prime).
- Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.
- Westinghouse Georesearch Laboratories, Boulder, Colorado.
- Colorado State University, Boulder, Colorado.
- Carnegie-Mellon University, Pittsburgh, Pennsylvania.
- Burt, Hill and Associates (Architects), Butler, Pennsylvania.
- NAHB Research Foundation, Inc., Rockville, Maryland.
- PPG Industries, Inc., Pittsburgh, Pennsylvania.

PRINCIPAL FINDINGS

2.0 PRINCIPAL FINDINGS

2.1 REGIONAL REQUIREMENTS

The principal potential market in the United States for solar systems can be divided into five distinct regions which differ importantly in climatic conditions. They constitute the primary market because more than seventy-five percent of the population live in these regions. These regions are:

- Northeast.
- Southeast.
- Gulf Coast.
- Great Lakes.
- West.

2.2 BUILDING TYPES

Three classes of residential buildings (single-family residences, multifamily dwellings or apartments, and mobile homes) and three classes of commercial buildings (offices, schools, and stores) comprise the major demand for heating and cooling and hot water.

2.3 TECHNICAL CONSIDERATIONS

The three solar systems that would best meet the needs of a potential broad market of the identified building types on a national basis are:

- Solar Heating Only.
- Solar-Assisted Heat Pump.
- Solar Heating and Cooling (Absorption).

The technology for Solar Heating Only systems is well understood, and solar collectors are the only unusual components in the system.

Impressive progress has been made in the design of solar collectors, but the manufacture of suitable collectors has not exceeded several thousand square feet in quantity.

Solar energy can be utilized to increase the amount of heat delivered by heat pumps during the heating mode.

Absorption systems using water as the refrigerent in a lithium-bromide solution are the most immediately promising method of utilizing solar energy for cooling. Other techniques, including Rankine cycle absorption systems or night radiation, have not been developed to the same stage of manufacturability.

Solar-energized absorption cooling systems using available components have low efficiencies and reliability compared to conventional systems.

Although solar systems are not scientifically sophisticated, they are complex and do require careful design. The capability to carry out such designs is currently limited. Education and training, starting at architectural and engineering school levels, will be essential.

Reliability and maintainability are of crucial importance. Solar collectors are not easily accessible after installation and must be designed to perform for many years. Performance and reliability of absorption cooling components are promising but require improvement.

Water or rocks, as appropriate, are currently the only dependable heat storage mediums. Eutectic salts, although promising, have not established a capability for extensive cycling without losing their required characteristics.

Photovoltaic systems are not currently competitive with thermal systems, although recent research suggests significant potential. To become economically attractive for application to buildings, the cost of cells must be reduced from the present commercial price of $20 per peak watt to $.20 per peak watt.

2.4 ECONOMIC CONSIDERATIONS

At this time, none of the solar systems indicated above is economically competitive with oil or gas systems on a significant scale. The initial investment is appreciably greater for solar heating and cooling systems than for conventional systems in all regions.

Solar heating-only systems can first become competitive for residences in the California region in the 1975-1980 period. By 1980, these systems can become competitive, primarily for commercial and institutional structures, in several regions.

There can be a renewal of a market for solar systems for hot water only in appropriate regions of the country. This would contribute to creating a volume demand for solar collectors of acceptable performance and cost.

Solar heating and cooling can become competitive in most regions of the country in the 1985-90 time period.

Solar collector costs versus gas and oil prices are the dominant factors in the equation of solar energy economic feasibility.

On the average, it will cost several thousand dollars more to equip a single-family residence with a solar system than with a conventional system. To be most economical and aesthetically attractive, the house should be specifically designed for a solar system. Retrofitting single-family residences is not likely to be economically feasible on a significant scale.

Retrofitting solar systems on larger buildings, such as public buildings, is approaching economic feasibility from a life-cycle cost basis, and can provide a desired impetus to accelerate the use of solar systems over a much broader spectrum of building types.

The determination of the proper size of solar collectors greatly affects costs as well as performance. Whereas oversizing a conventional furnace by 100% would result in additional cost of less than $200, a similar overdesign for solar collectors would result in an additional cost of several thousand dollars.

There is a gap between the near-term costs for solar systems and the additional cost that consumers would be willing to pay. Government programs and incentives will be necessary to close that gap.

The planned Proof-Of-Concept-Experiment and demonstration programs by the Government can help significantly to establish the credibility of solar systems and accelerate their use in the near term. They can also serve to more accurately assess the extent that further Government assistance will be necessary. Other Government incentives related to financing, regulating, and controlling the construction of buildings will also be required to encourage commercial exploitation during the initial period of marginal benefits to the building industry and to users.

Once the solar systems becomes competitive, their impact will increase due to both increasing fuel prices for competitive systems and the gradual accumulation of structures using solar energy.

2.5 SOCIAL AND ENVIRONMENTAL CONSIDERATIONS

Seven population groups--architects, builders, labor, manufacturers, energy suppliers, financiers, and potential consumers--were surveyed in regard to solar systems. Results indicated a broad spectrum of reaction, ranging from interest and acceptance to skepticism. The respondents appear to like the idea of solar heating and cooling, but their enthusiasm drops off sharply as the system becomes more expensive.

Reactions of builders to the proposed solar heating and cooling system ranged from skepticism to qualified acceptance. None appears anxious to pioneer with an untried and unproven system.

Of the seven groups canvassed, energy suppliers are the least enthusiastic about the proposed solar model and the benefits of currently feasible solar energy systems in general. Their objections center on high cost, technological complexity, constantly fluctuating demand on their services, and general skepticism with respect to consumer acceptance.

The manufacturers interviewed reacted quite favorably. Several said that their firms were already engaged peripherally in assessments of the feasibility of solar energy usage.

Consumers indicate a decreasing acceptability with increasing costs and decreasing fuel cost reductions, as would be expected. The potential consumer finds an additional cost (over conventional system cost) for solar systems of $1,000 to $2,500 very acceptable in all cases. An additional cost of $2,500 to $5,000 would be on the borderline between acceptability and unacceptability. (Higher costs are more acceptable for newly built homes). Any additional costs over $5,000, regardless of fuel cost reduction, were rated very unacceptable.

Architects favor emphasizing all types of buildings in introducing solar heating and cooling.

Financiers believe that a solar supplement would have no direct adverse effect on financing and could possibly improve it.

Environmentalists endorse solar systems with some reservations concerning aesthetics.

2.6 INSTITUTIONAL CONSIDERATIONS

Existing building and safety codes do not appear to require major changes. It will be necessary to provide designers, builders, and code officials with adequate information to ensure that code and safety requirements are met and to enable officials to make the necessary interpretations of codes.

Existing channels of marketing, distribution, and servicing can be adapted to the requirements of solar designs.

Involvement and action by land-use and zoning planners in local governments will be necessary to establish the zoning and protection of sun-rights precedents that will stimulate utilization.

Nonresidential building contractors have the necessary technical resources which can be adapted to the installation and servicing of solar systems.

Residential building contractors will require more substantial technical support and/or more "factory-packaged" system designs to be able to utilize solar systems.

Federal, State, and local government programs and incentives will be required to stimulate and encourage investment in solar systems.

Adoption by financial institutions of eligibility standards and feasibility evaluation methods which recognize life-cycle operating cost benefits would be an important step in making available financing for higher initial costs.

TECHNICAL CONSIDERATIONS

TASK 1 -- REQUIREMENTS

TASK 2 -- SYSTEM DEFINITION

3.0 TECHNICAL CONSIDERATIONS

3.1 REQUIREMENTS

The best opportunities for the greatest savings of energy are to be found in those situations where most of the energy is consumed. Consumption of energy for space heating and cooling is determined by population and climate. Population establishes the requirement for buildings, while the climate determines the heating and cooling characteristics of buildings and the heating and cooling load. Thus, an analysis of demographic and climatic relationships would suggest the best opportunities for energy savings.

3.2 ENERGY CONSUMPTION

Table 1 summarizes the annual energy consumption for space heating, space cooling, and domestic hot water in the United States, and compares it to the total energy demands (including transportation, power, etc.) of the Nation. It is significant that heating and cooling requirements of buildings constitute more than a quarter of the total annual energy consumption of the Nation. It is not surprising that most of the energy for space heating is used in the North while that for space cooling is used in the South, and hot water demand is fairly uniform throughout the United States. The table shows that space heating dominates the demand for energy now and that space cooling demand is expected to rise sharply.

TABLE 1. ANNUAL ENERGY CONSUMPTION OF THE UNITED STATES

	1968		1980	
	10^{12} Btu	Percent of Total	10^{12} Btu	Percent of Total
Space Heat	12,105	20.0	19,161	18.4
Hot Water	2,416	4.0	4,110	3.9
Space Cooling	1,540	2.5	5,320	5.2
Subtotal	15,961	26.5	28,591	27.5
National Total	60,529	100.0	104,000	100.0

3.3 REGIONS

A demographic analysis identified the regions of the country where the population densities are greatest. Taken together with the climatic conditions that determine the type of demand for heating and cooling systems, these areas would constitute the principal potential commercial market for solar systems. The remainder of the area represents a less densely populated secondary market.

Five regions were selected which differ in terms of total heating and cooling loads, and the balance between them. The populations of these regions are shown in millions in Figure 1 and Figure 2 for the years 1969 and 2000, respectively. The population distribution for the year 2000 is similar to the year 1969 except that the densities for all regions are increased. It should be noted that the greatest growth is expected in the Southeast and West.

For each region, a city for which climatic data is available was selected as representative of that region. The regions and representative cities are:

Region	Representative City
Gulf Coast	Mobile, Alabama
Southeast	Atlanta, Georgia
Northeast	Wilmington, Delaware
Great Lakes	Madison, Wisconsin
West	Santa Maria, California

Table 2 indicates the population and the seasonal heating and cooling degree-days for the above regions and representative cities. For single-family residence requirements, they are characterized by:

- Gulf Coast - Heating is modest and cooling requirements dominate.
- Southeast - Heating and cooling requirements are equal.
- Northeast - Total heating and cooling requirements are high, with heating being about three times greater than cooling.

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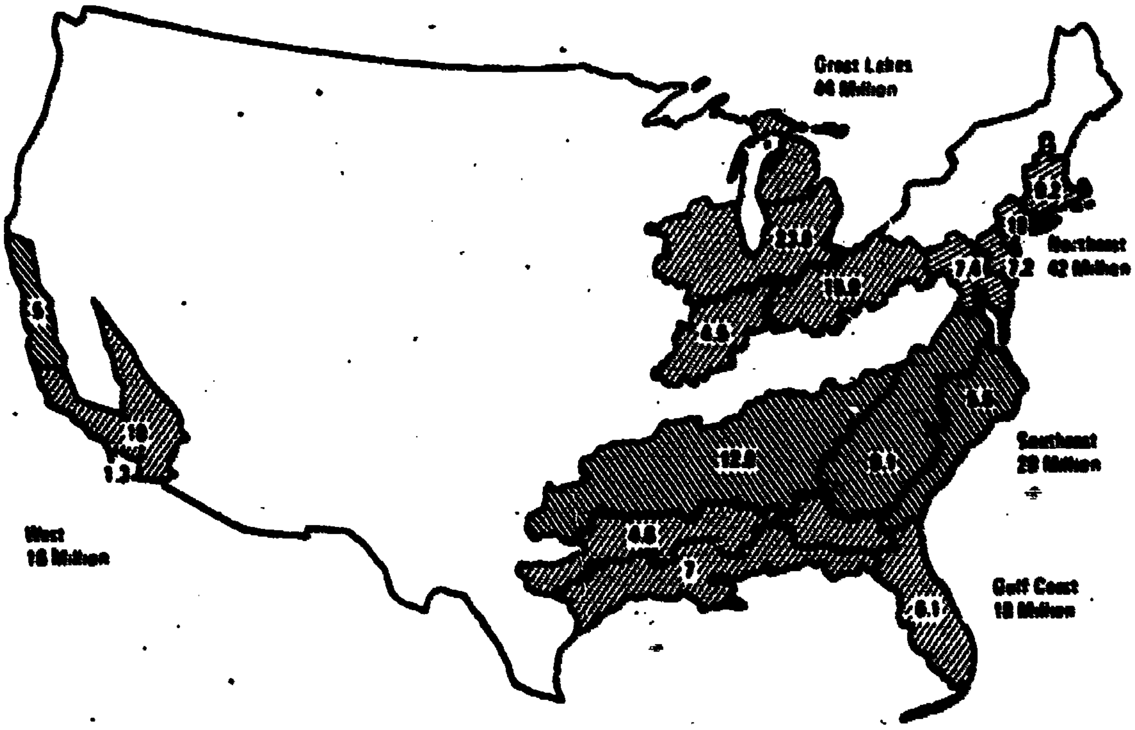

Figure 1. 1969 Demographic Analysis for POCE Sites

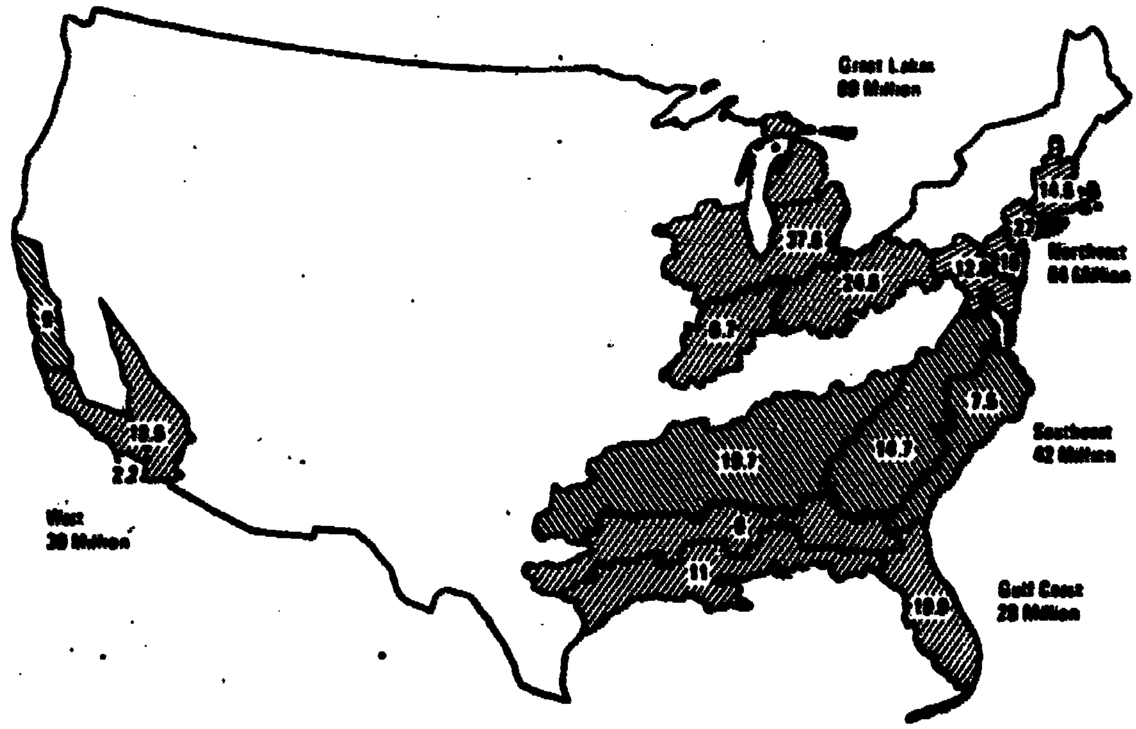

Figure 2. 2000 Demographic Analysis for POCE Sites

- Great Lakes - Heating requirement is about six times that of cooling.
- West - Heating requirement is about the same as that for the Southeast, but the cooling need is very low.

For most buildings other than single-family residences, the cooling load tends to dominate.

TABLE 2. REGIONAL DATA

Regional City	Population, Millions 1969/2000 yr	Seasonal Heating Degree-Days	Seasonal Cooling Degree-Days
Gulf Coast Mobile, Alabama	18/28	2000-1000 1612	3500-2700 3000
Southeast Atlanta, Georgia	28/42	4000-2000 2826	2500-1800 2250
Northeast Wilmington, Delaware	42/64	7000-4000 4910	2000-1000 1500
Great Lakes Madison, Wisconsin	44/69	8000-5000 7417	2000-1000 1250
West Santa Maria, Calif.	16/30	4000-2000 2934	1500-500 500

3.4 BUILDINGS

The U.S. Department of Commerce (USDC) Construction Review groups buildings into 12 classes and provides statistics on the number of annual starts for each. An analysis of the data disclosed that a very high percentage of all buildings would be encompassed if considerations were limited to the six classes indicated in Table 3.

There are 1 to 2 million building starts annually, and each building differs from the others in some way. To make the analysis tractable, a "typical" design and construction for each of the above building types in each of the five selected regions was determined. The characteristics included usage, total floor area, wall and roof dimensions, windows,

TABLE 3. PERCENTAGE OF BUILDING STARTS BY CLASS

USDC Class	Type	Percent
	Residential	
001	One Family Homes[1]	37
004	Five or More Family Buildings[2] (Low Rise Apartments)	37
300	Mobile Homes	21
	Total of Residential Construction	95
	Commercial	
015	Offices, Banks, Professional Buildings[3]	30
017	Schools/Educational Buildings[4]	4
018	Stores/Mercantile Buildings[5]	30
	Total of Commercial Construction	64

Notes:

1. Includes semidetached, row, and townhouses or townhouse apartments.
2. Each building contains five or more housing units having a common basement, heating plant, stairs, water supply and sewage disposal facilities, or entrance.
3. Includes post offices, court houses, etc.
4. Includes schools, colleges, libraries, gymnasiums, etc.
5. Includes stores, restaurants, laundry and dry cleaning shops, animal hospitals, etc.

ventilation, and insulation. It was recognized that future insulation practice for residential and commercial buildings would probably be improved over existing and past practices. Therefore, the heat gain/loss computations accounted for the anticipated insulation improvement. The required thermal loads for space heating and cooling and hot water heating were calculated on an hour-by-hour basis for the 8760-hour year, utilizing detailed weather data for each of the representative cities. The calculated annual and peak hourly heating and cooling load for each of the typical buildings in the five regions is presented in Table 4.

3.5 SOLAR SYSTEMS, SUBSYSTEMS, AND COMPONENTS

3.5.1 Operational Requirements

It is economically impractical to design solar systems to provide 100 percent of the heating and cooling requirements of buildings by solar energy alone. The required size of solar collector to absorb, and storage subsystem to hold, enough energy to carry the building through protracted periods of cloudy days would be so great that the costs would be prohibitive. Solar systems will, therefore, incorporate conventional components such as gas- or oil-burning furnaces as auxiliary systems. The requirements and costs for solar systems which would provide 50 percent or 80 percent of the total annual energy needs were analyzed in this program, on the basis that a conventional auxiliary system would provide the balance.

Solar systems are more sophisticated that the conventional heating, ventilating, and air-conditioning (HVAC) systems; and strong attention to system reliability and maintenance is essential. To provide a baseline and competitive goal for operation of solar systems, reliability data for conventional subsystems was obtained. The details are summarized in Table 5. It should be noted that a gas furnace has the best reliability, but that gas-fired absorption air-conditioners have the poorest.

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TABLE 4. BUILDING TYPES, PLAN AREAS, AND LOADS

	Building Plan Area Sq.ft.	Annual Heat Load 10^6 Btu	Annual Cooling Load 10^6Btu	Annual Water Heating 10^6 Btu	Peak Hrly Htg. 10^3Btu	Peak Hrly Cool 10^3 Btu
Atlanta,Ga. 1956						
Office	10,000	282	1912	91	815	1578
S.F. Home	1,560	36	45	26	35	36
Mobile Home	845	22	35	20	23	25
M.F. Apt.	7,424	129	508	205	230	301
School	130,000	1928	2978	1810	3942	5012
Store	1,400	26	101	1	107	95
Mobile, Ala.1963						
Office	10,000	176	1489	91	647	1197
S.F. Home	1,600	10	60	26	29	33
Mobile Home	845	11	47	20	24	24
M.F. Apt.	7,488	68	690	205	272	372
School	130,000	1012	4414	1810	3824	5607
Store	1,400	13	131	1	110	119
Santa Maria,Cal.1957						
Office	10,000	144	2423	91	938	1751
S.F. Home	1,632	21	14	26	19	25
Mobile Home	845	15	13	20	14	18
M.F.Apt.	7,680	114	302	205	145	279
School	130,000	1303	1237	1810	2860	2559
Store	1,400	9	87	1	41	35
Wilmington,Del.1959						
Office	10,000	479	1463	91	1070	1680
S.F. Home	1,144	58	41	26	54	32
Mobile Home	845	34	25	20	29	24
M.F. Apt.	7,680	209	385	307	340	288
School	130,000	3032	2039	1810	4356	5995
Store	1,400	31	82	1	145	104
Madison, Wis.1956						
Office	10,000	775	1234	91	1344	1783
S.F. Home	1,612	108	26	26	71	29
Mobile Home	845	48	21	20	50	26
M.F. Apt.	7,200	197	306	205	262	284
School	130,000	4517	1589	1810	5509	4869
Store	1,400	47	70	1	227	121

TABLE 5. RELIABILITY DATA FOR RESIDENTIAL HEATING AND COOLING SYSTEM COMPONENTS

Type	Yearly Service Call Rate Calls/Unit/Year
Gas Furnace	.42
Oil Furnace	1.16 - 1.80
Gas Air-Conditioning (Ammonia Absorption)	2.91 1.89*
Electric Air-Conditioning (Vapor Compression)	1.08
Heat Pump	1.38

*Based on a smaller sample for first-year operation

A thorough review was made of existing literature on solar systems, components, and techniques for heating and cooling of buildings. Those systems that could satisfy the requirements for a Proof-Of-Concept-Experiment and could be manufactured in volume quantities to meet the needs for the developing market were selected for detailed analysis and evaluation:

- Solar Heating Only.
- Solar-Assisted Heat Pump.
- Solar Heating and Cooling (Absorption).

Conceptual diagrams of these systems are shown in Figures 3, 4, and 5.

The performance of each of these systems was analyzed to determine the percentage of auxiliary energy required as a function of collector size. Figure 6 shows the annual energy budget for a single-family detached residence in Wilmington, Delaware, and illustrates how the loads and auxiliary inputs differ for the three systems.

3.5.2 Region/Building/Solar System Combinations

The three selected solar systems were analyzed for each of the six building types and five regions, as tabulated in Table 6. Thus, a total of 90 region/building/solar system combinations have been analyzed and evaluated in this program.

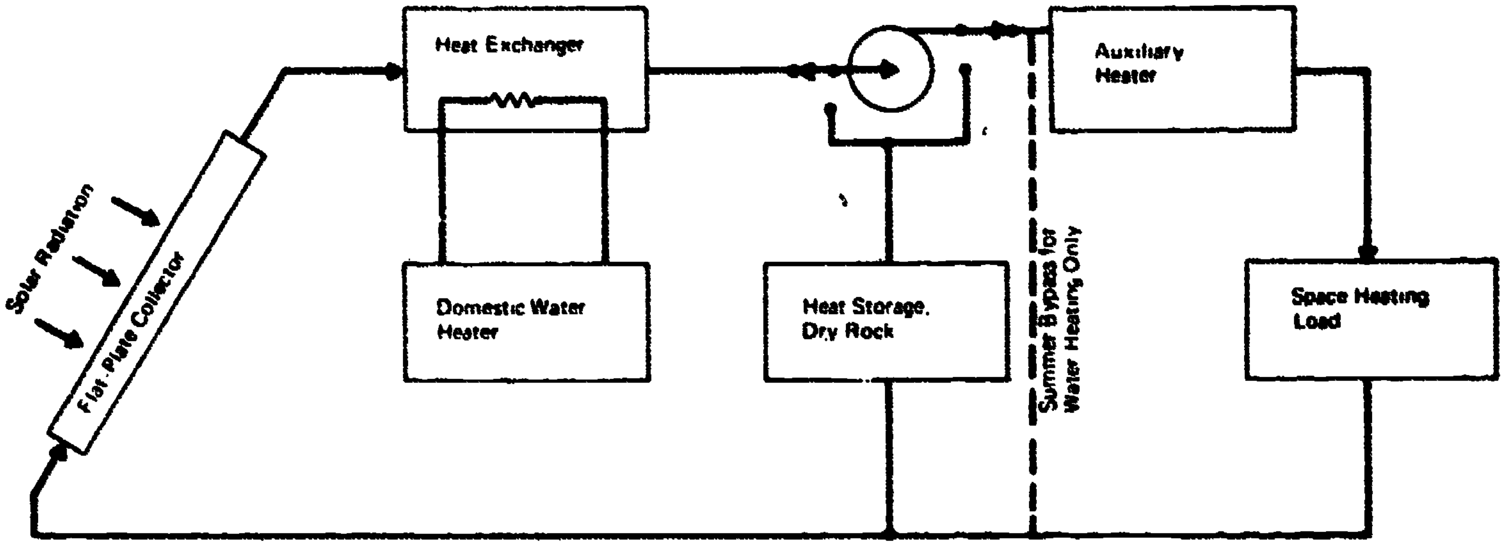


Figure 3. Solar-Powered Heating Only

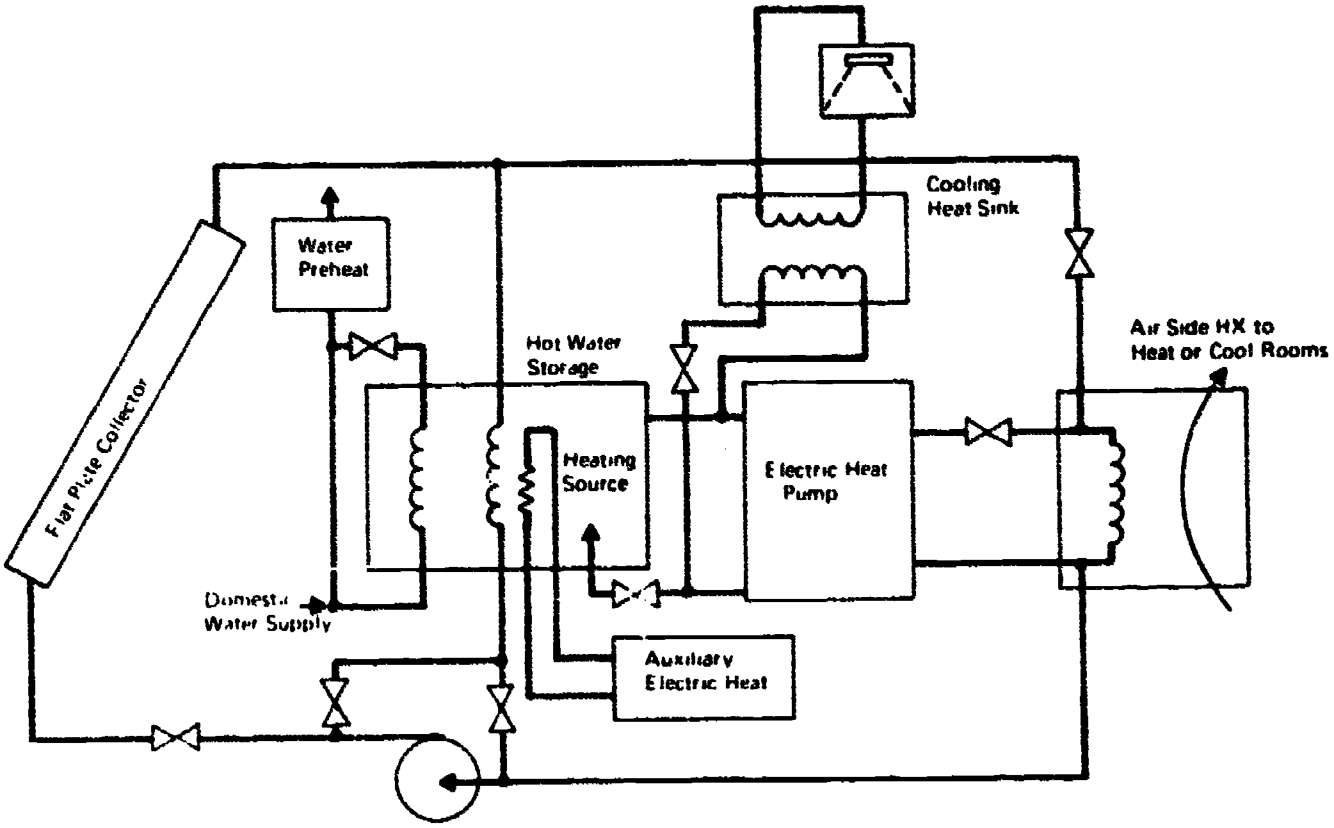


Figure 4. Solar-Assisted Heat Pump

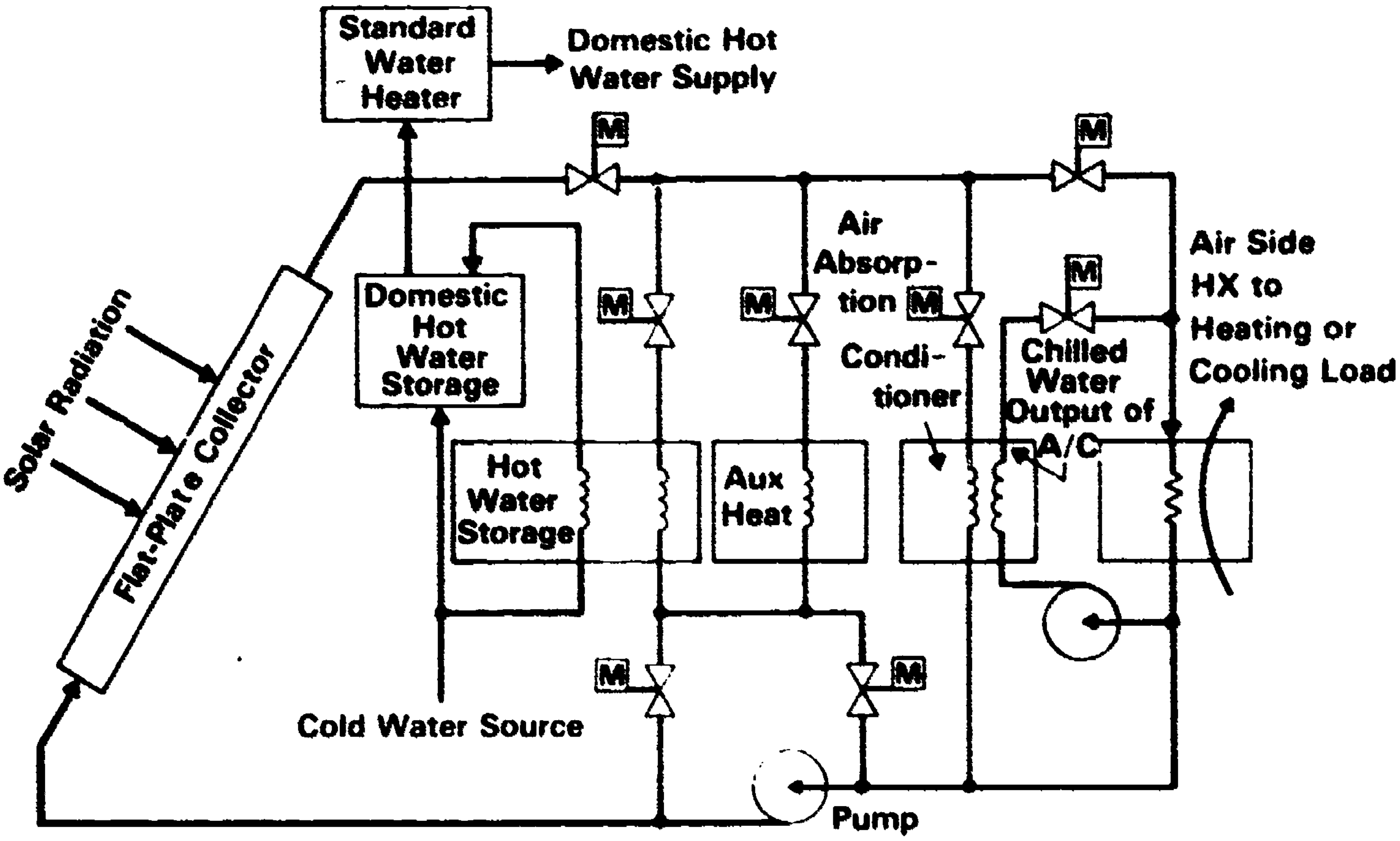
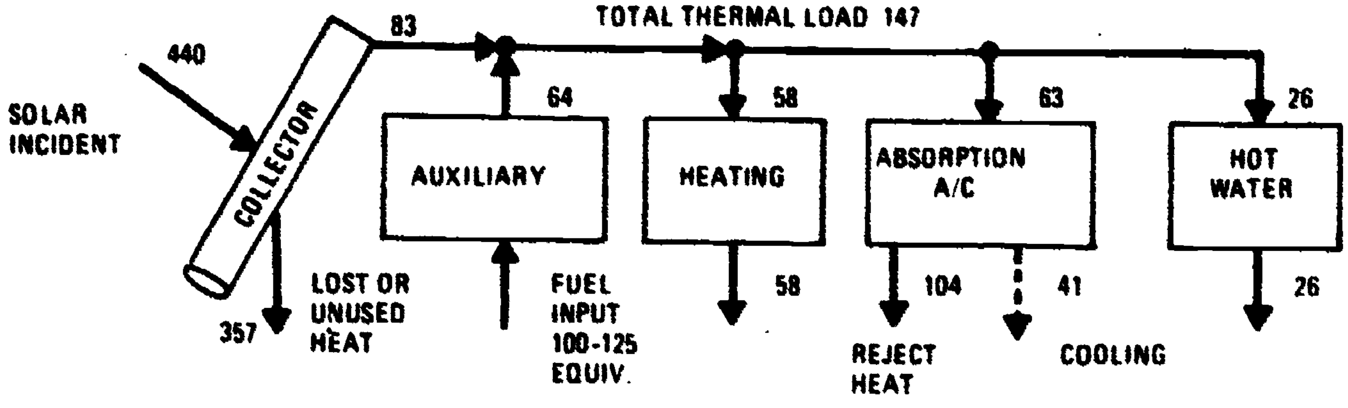


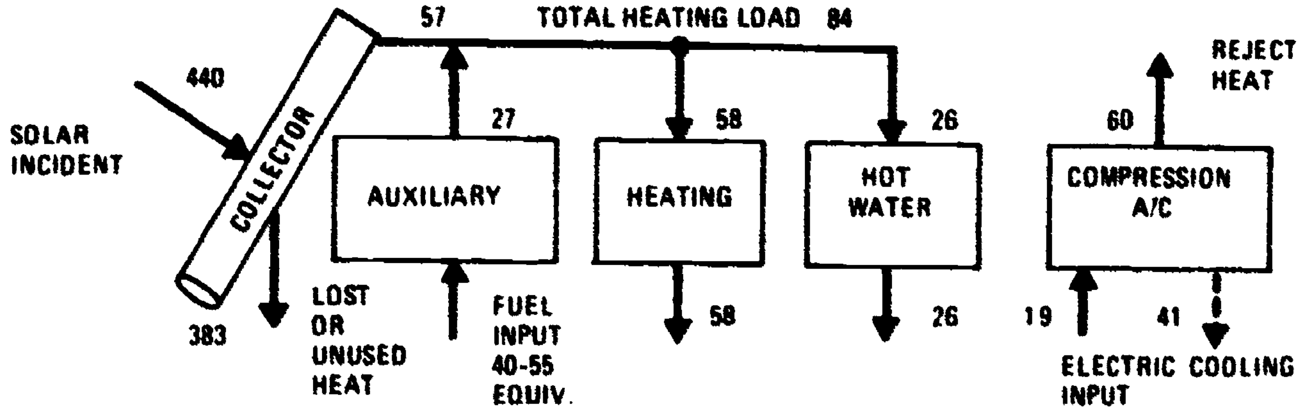
Figure 5. Solar Heating and Cooling with Absorption Air-Conditioner

TABLE 6. REGION/BUILDING/SOLAR SYSTEM COMBINATIONS EVALUATED

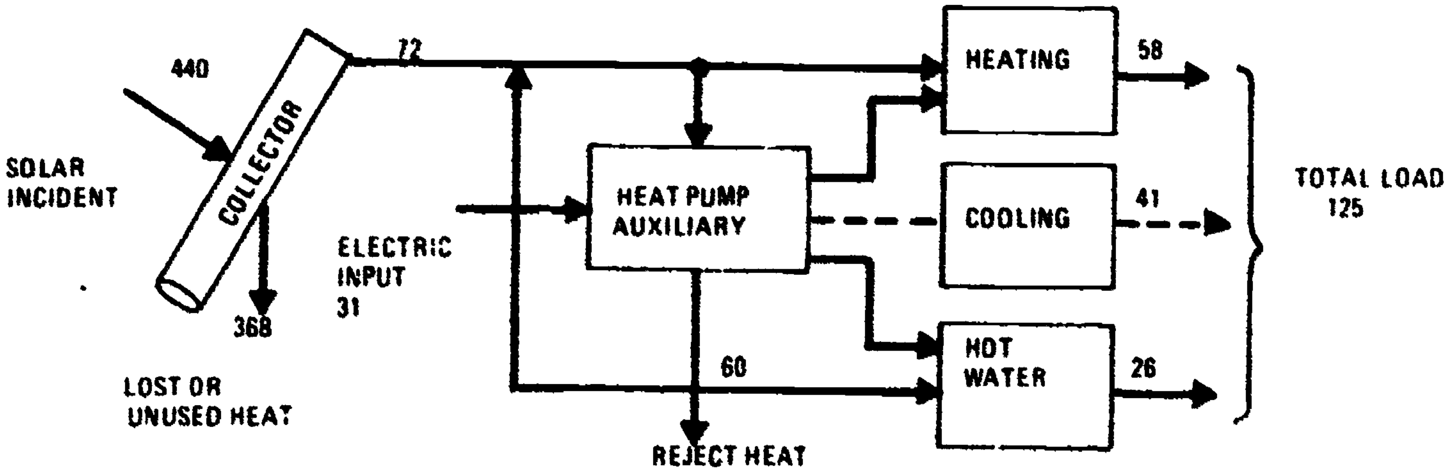
CITIES	BUILDINGS	SELECTED SOLAR SYSTEMS
• Wilmington, Delaware	• Single Family Residences (1600 ft^2)	• Solar Heat Only
• Madison, Wisconsin	• Multifamily Low-Rise Apartments (Five or More Families) (14,400 ft^2)	
• Atlanta, Georgia	• Mobile Homes (832 ft^2)	• Solar-Assisted Heat Pump
• Mobile, Alabama	• Offices (35,000 ft^2)	
• Santa Maria, California	• Schools/Educational Buildings (210,000 ft^2)	• Solar Heat & Cool (Absorption)
	• Stores (1400 ft^2)	



SYSTEM 1. HEATING AND COOLING



SYSTEM 2. SOLAR HEATING ONLY



SYSTEM 3. SOLAR ASSISTED HEAT PUMP

Figure 6. System Comparison, 800 Ft^2 Collector, Wilmington, Single-Family House, (Numbers are Millions of Btu's Annually--1959 Data

3.5.3 Collectors

The unique and essential component of all solar systems is the collector. Focusing collectors do not absorb any more energy than flat plate, nonfocusing configurations but, by concentrating the energy into a smaller area, can achieve temperatures as high as several hundred degrees Fahrenheit. In contrast, flat plate collectors absorb and utilize both the direct and diffuse components of solar radiation whereas focusing collectors function only with direct radiation. For heating-only requirements, flat plate collectors using liquid as the working fluid can generate temperatures of about 150° F without difficulty and with good efficiencies. Careful system design can also enable flat plate collectors to generate the temperatures of 180-200° F required to drive absorption cooling systems, although at reduced collector efficiencies. Flat plate, nonfocusing collectors were chosen from considerations of performance requirements, costs, and simplicity.

The collector types evaluated included those using liquid and air as working fluids. Table 7 summarizes the calculated performance and efficiencies of alternative collector designs using water as the working fluid. Designs involving one to four glass covers and both selective and non-selective absorbing surfaces were considered. Heat losses from the collector were determined for typical winter operation (30° F ambient temperature and 140° F collector temperature) and typical summer operations (90° F ambient and 200° F collector temperature). A level of 317 Btu/hr Ft^2 insolation was used in determining collector efficiencies.

In view of uncertainties in the production processes and in the long-term stability of selective surfaces, a collector based on a non-selective surface with two glass covers was chosen for the heating-only system. Figure 7 illustrates the detail of such a design. When higher temperature operation for cooling is required, the use of a selective surface or a more complex physical design may be economically justified.

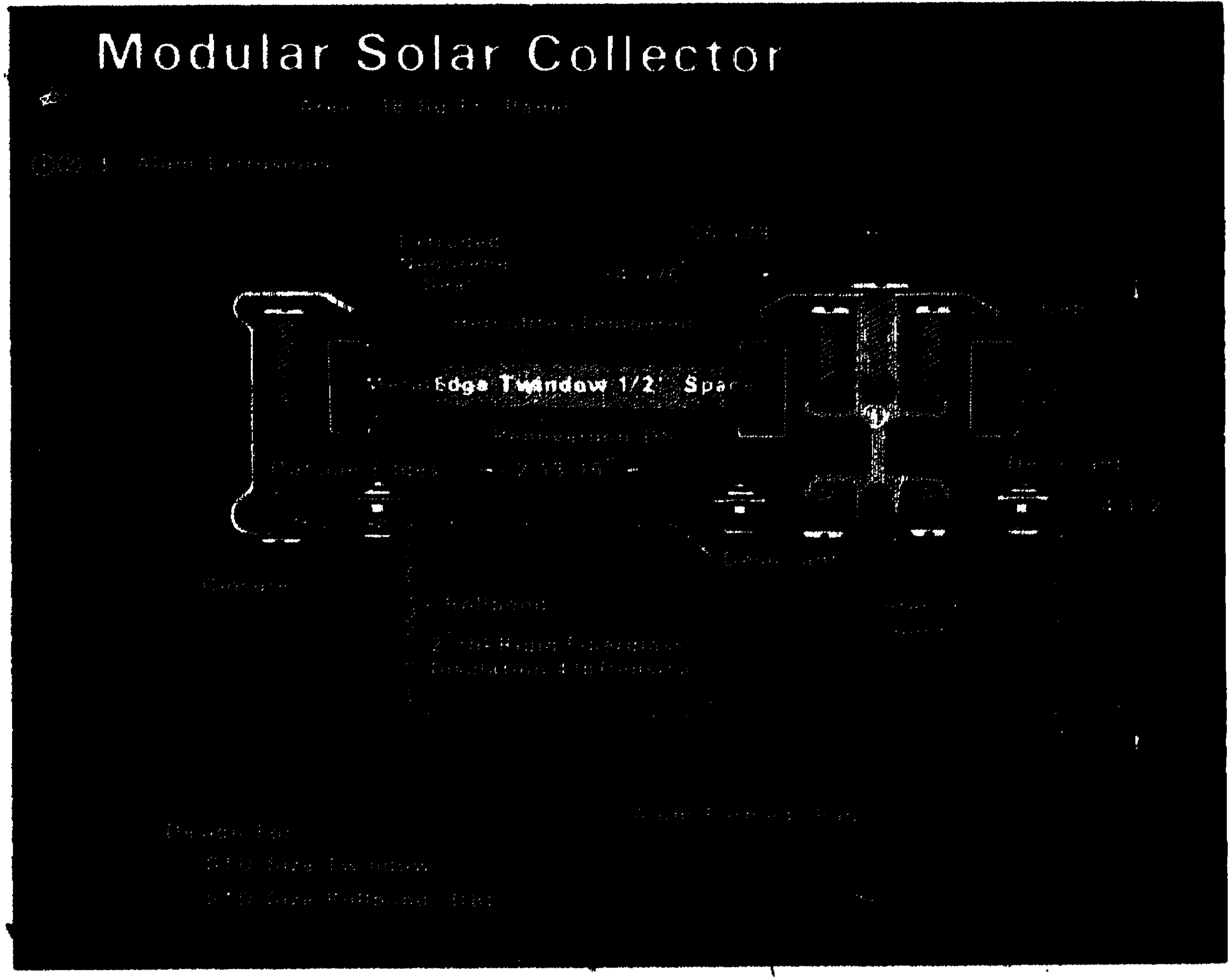
Determining the collector size necessary to provide the desired amount of solar energy must be carefully computed. Whereas the sizes of conventional heating and cooling equipment systems are calculated for maximum

TABLE 7. COLLECTOR PERFORMANCE PARAMETERS

COLLECTOR TYPE		Absorptivity α	Emissivity ϵ	No. of Glass Covers	F_e	U_L $(W/m^2\ °C)$			
						T_a=20°F(0°C) T_c=140°F(60°C)		90° F (32° C) 200° F (93° C)	
							Eff.%		Eff.%
Water Heating									
0	W Tube-Plate	0.95	0.95	1	0.86	7.8	39	9.2	30
1	W	0.9	0.2	1	0.81	4.6	53	5.2	49
2	W	0.95	0.95	2	0.79	4.1	54	5.1	48
3	W	0.9	0.2	2	0.74	2.9	57	3.3	54
4	W	0.95	0.95	3	0.72	2.7	56	3.4	51
5	W	0.9	0.2	3	0.68	2.1	55	2.4	53
6	W	0.95	0.95	3*	0.83	2.8	66	3.4	62
7	W	0.95	0.95	4	0.72	2.0	60	2.5	57
8	W	0.95	0.95	4*	0.81	2.0	69	2.5	66
9	W Honeycomb	0.95	0.95	1	0.81**	2.0	69	2.5	66
10	W Evac. Tube	0.85	0.1	1*	0.76	1.0	70	1.4	67
11	W Evac. Tube	0.90	0.2	1*	0.82	2.1	69	3.0	64

* Low Reflectivity Glass (0.02)

** Effective Absorptivity Reduced for Honeycomb



Modular Solar Collector

Figure 7. Modular Solar Collector

peak hourly demand, a solar system is calculated on an annual basis. The latter calculations involve annual solar insolation data for the locality, as well as the heating and cooling load of the specific building. An error in determining the proper collector size would not only cause poor performance but would be very costly. Table 8 illustrates that an error of 100 percent in sizing a conventional furnace results in a cost differential of only $175, but that a similar error in sizing of the collectors (assuming a collector price of only $4 per square foot) costs $2000.

TABLE 8 ECONOMICS OF SIZING

Oil Furnace		Solar Collector (At $\$4/\text{ft}^2$)	
Btu (10^3)	$*	Ft^2	$
210	504	1,000	4,000
105	329	500	2,000
Differential	$175	Differential	$2,000

*Sears, Roebuck and Co., 1973 Catalog

Utilizing insolation and weather tape data for the selected five regions and the structural and use characteristics of the five classes of buildings, the collector size required for various levels of solar dependence or auxiliary fuel use was determined with the assistance of a computer. Table 9 summarizes the results for 50- and 80-percent solar dependency (50- and 20-percent auxiliary fuel). It should be noted that, to provide 50-percent solar heating only for a single-family residence in the West (Santa Maria), only 160 square feet of collector is required, whereas 1200 square feet is necessary in the Great Lakes (Madison, Wisconsin) region.

3.5.4 Storage Subsystems

Techniques which utilize latent heat of fusion (such as in eutectic salts) continue to show promise of reducing the volume required for energy storage. However, none of these techniques has proven dependable or consistent in performance over many cycles of heating and cooling and extended

TABLE 9. COLLECTOR AREA REQUIRED FOR SINGLE-FAMILY RESIDENCES

Region	50% Solar Dependency			80% Solar Dependency		
	HO	HP	HC	HO	HP	HC
Northeast (Wilmington)	440	400	680	1,120	1,120	1,380
Southeast (Atlanta)	240	160	560	820	(2,000)	1,260
Gulf Coast (Mobile)	120	100*	580	240	(---)	1,200
Great Lakes (Madison)	1,200	480	860	(---)	(---)	(---)
West (Santa Maria)	160	100*	100*	220	120	160

Key: Solar collector area (ft^2) required for:

HO - Heating Only

HP - Solar-Assisted Heat Pump

HC - Heating and Cooling (Absorption)

* - Required for domestic hot water only

( ) - Collector area exceeds available roof area periods of time. Sensible heat storage is the most reliable technique for near-term application.

Dry rock is considered the most practical heat storage medium for air-heating collectors, and water is the choice for liquid systems. These were selected on the basis of simplicity, availability, reliability, and maintainability, as well as economics.

3.5.5 Cooling

Utilizing solar energy to perform the cooling function is much more difficult than for heating. Six systems were evaluated:

- Absorption Systems.
- Adsorption Systems.
- Jet Ejector Systems.
- Rankine Cycle - Inverse Brayton Cycle.
- Rankine Cycle - Vapor Compressions.
- Night Radiation Schemes.

These evaluations disclosed that much more extensive operating and manufacturing experience has been obtained with lithium bromide-water and ammonia-water absorption air-conditioners having capacities over the complete range of interest than with any other complete system alternative. Adsorption systems involving drying and subsequent evaporative cooling will require extensive development before they can be applied with confidence.

Night radiation schemes were found to be dependent on local humidity and ambient temperature conditions, and their application is geographically constrained to an undesirable extent.

3.5.6 Solar-Assisted Heat Pump

A heat pump is basically a modified air-conditioning system that has the flexibility to interchange functions between the evaporator and the condenser, allowing it to either heat or cool the desired space. Figure 8 represents an example of a heat pump in the heating mode. During the summer, it operates as a conventional cooling system. Cool air is delivered to the conditioned space, and the heated air from the condenser is exhausted outdoors. In the heating mode, during the winter, the evaporator cools the outdoor air by absorbing heat at the low ambient temperatures. The compressor then pumps the heat to a higher temperature which is delivered to the space to be warmed. The heat delivered is several times the electric resistance heat equivalent of the input power.

The coefficient of performance (COP) of the heat pump varies with operating conditions. The variable with the greatest effect on the COP is the temperature of the outside air (or the water) to which heat is rejected in the summer, and from which heat is drawn in the winter. During the winter, solar energy can be employed to maintain higher input temperatures to the heat pump, resulting in a higher coefficient of performance. During the summer, solar energy is not utilized, and the system functions as a conventional air-conditioner.

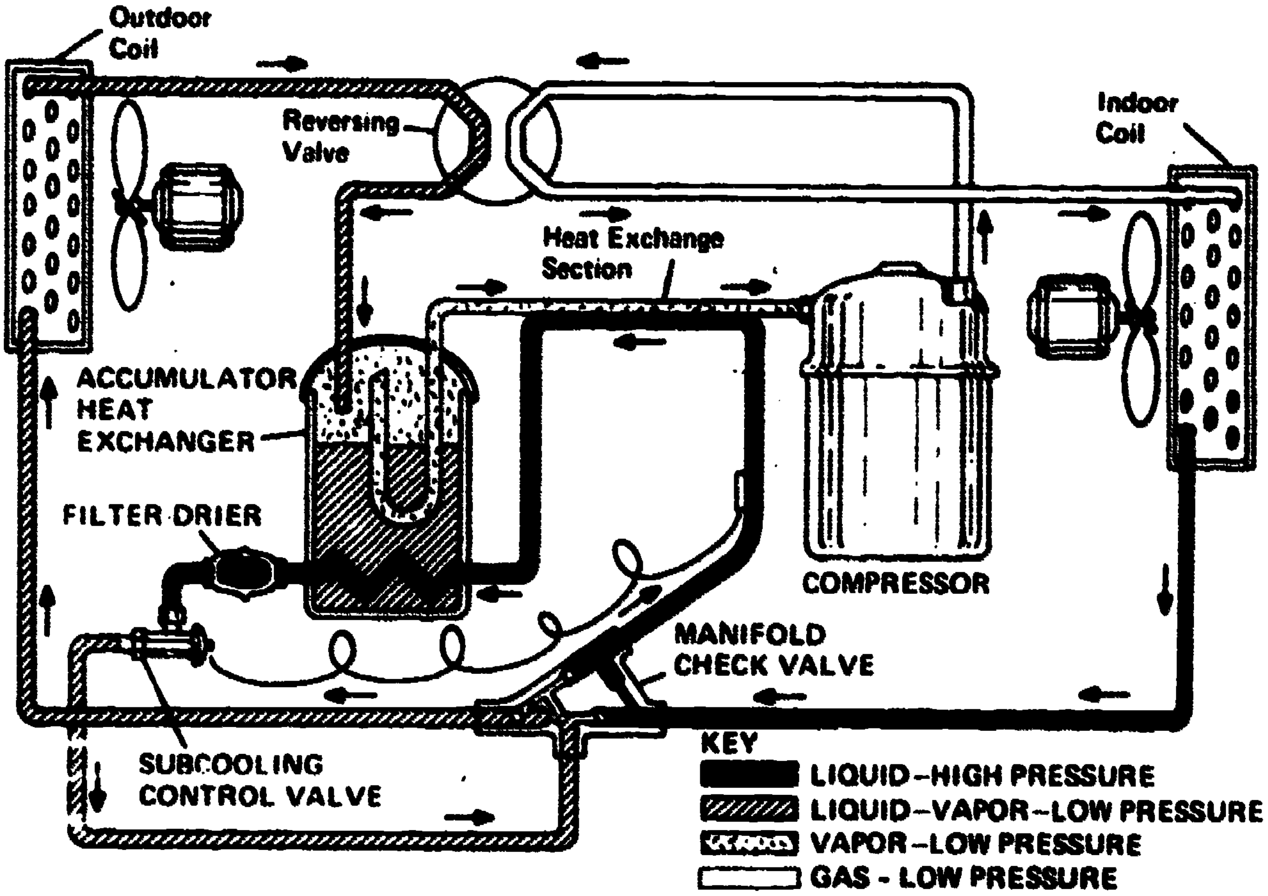


Figure 8. Westinghouse HI/RE/LI Heat Pump

ECONOMIC CONSIDERATIONS

TASK 5 -- PRELIMINARY COST STUDY

TASK 3 -- CAPTURE POTENTIAL

4.0 ECONOMIC CONSIDERATIONS

4.1 PRELIMINARY COST STUDY

The life-cycle costs of candidate solar systems were estimated and compared among themselves and with conventional systems to identify those having the greatest potential on a cost-effective basis. To determine costs, the three candidate systems were designed in sufficient detail to identify and define all of the hardware, subsystems, transportation, labor, and markup to permit an estimate of the installed system cost. Concurrently, investment costs of comparable conventional systems were established, and operating and maintenance costs were determined for all systems.

Since solar systems are not designed for 100-percent solar dependency, they require supplementary conventional equipment and fuels to ensure 100-percent performance during extremely cold or hot periods and during prolonged cloudy weather. The costs of the supplemental equipment and fossil fuel, as well as the fuel cost for conventional systems, were determined.

Using the investment, operating and maintenance, and fuel costs, the 15-year life-cycle costs were calculated for solar and conventional systems. The life-cycle cost was determined for solar systems designed to provide one-half of the heating and cooling load from solar energy and one-half from conventional fuel (i.e., 50-percent solar dependency). The life-cycle costs were also calculated for systems designed for 80-percent solar dependency. In addition, calculations were made for each of two dates, 1975 and 1985, using constant 1973 dollars. Future costs were discounted 8 percent, but included an annual inflation factor of 5 percent on equipment and maintenance costs, and a fuel escalation cost of 7 percent per year. Thus, the life-cycle cost for each system, each degree of solar dependency, and each date is equal to the investment cost plus the sum of the discounted annual charges.

Examples of these cost estimates are shown in Table 10. This table contains the estimated investment and life-cycle costs of each of the three 50-percent-solar-dependent heating and cooling systems and two comparable conventional systems, in a single-family residence, in each of two regions for both 1975 and 1985.

Life-cycle costs are useful in comparing dissimilar equipment performing similar tasks. Systems having the lowest life-cycle cost are the

TABLE 10. SINGLE-FAMILY RESIDENCE, INVESTMENT AND LIFE-CYCLE COST ($)
50% SOLAR DEPENDENCY

Heating/Cooling Region and System	1975		1985	
	Investment	15-Year Life-Cycle	Investment	15-Year Life-Cycle
West Coast Santa Maria, Calif.				
Solar Heating and Cooling	3650	5820	2840	6640
Solar Heat Pump	-	-	-	-
Solar Heating Only	2540	3500	1970	3730
Conventional Heating and Cooling	2220	5020	2850	8100
Conventional Heating Only	1110	2530	1420	4110
Northeast Wilmington, Del.				
Solar Heating and Cooling	8810	12700	6850	13800
Solar Heat Pump	4800	9930	3740	13400
Solar Heating Only	4220	5860	3290	6300
Conventional Heating and Cooling	2220	7600	2850	13200
Conventional Heating Only	1140	3420	1460	5870

most economic. For example, in Table 10 it is seen that, in 1975, for a single-family residence in the northeast region, the life-cycle cost of a solar-assisted heat pump providing 50-percent solar dependency is $2,330 more expensive than a conventional HVAC system. But, by 1985, the solar-assisted heat pump is within $200 of the conventional HVAC. Thus, given an annual expectation of 5-percent wage inflation, a 7-percent growth in the cost of energy, and a 2.5-percent reduction in the cost of solar systems (characteristic of many new industries), solar heating and cooling systems should become generally competitive in many regions of the United States by 1985. Analysis of the life-cycle costs calculated in this study discloses that very few solar system cases compare favorably with conventional systems in 1975. But, again by 1985, many solar system cases are more cost-effective than conventional systems.

4.2 CAPTURE POTENTIAL

The amount of conventional fuel that can be conserved through substitution of solar energy is directly dependent on the number and energy demand of buildings of various classes that would adopt solar systems. The fundamental question is, How much of the heating and cooling market can solar systems capture?

The willingness of a home buyer or commercial building developer to choose solar over conventional systems is greatly influenced by economic considerations. In view of the increased initial investment required for solar systems over conventional systems, a decision to install a solar heating and cooling system would be motivated by the expectation of reducing future operating costs by an amount at least equal to that of the increased investment. The maximum amount a rational consumer might be willing to invest in a solar system should be repaid by the reduction in fuel bills he would experience in combination with any tax incentives. Other factors may influence the selection of solar systems but, in the final analysis, economics should dominate the majority of decisions on a long-term basis.

In determining the competitive equivalent of solar versus conventional systems, the principal factors involved for each building in the selected geographical regions include:

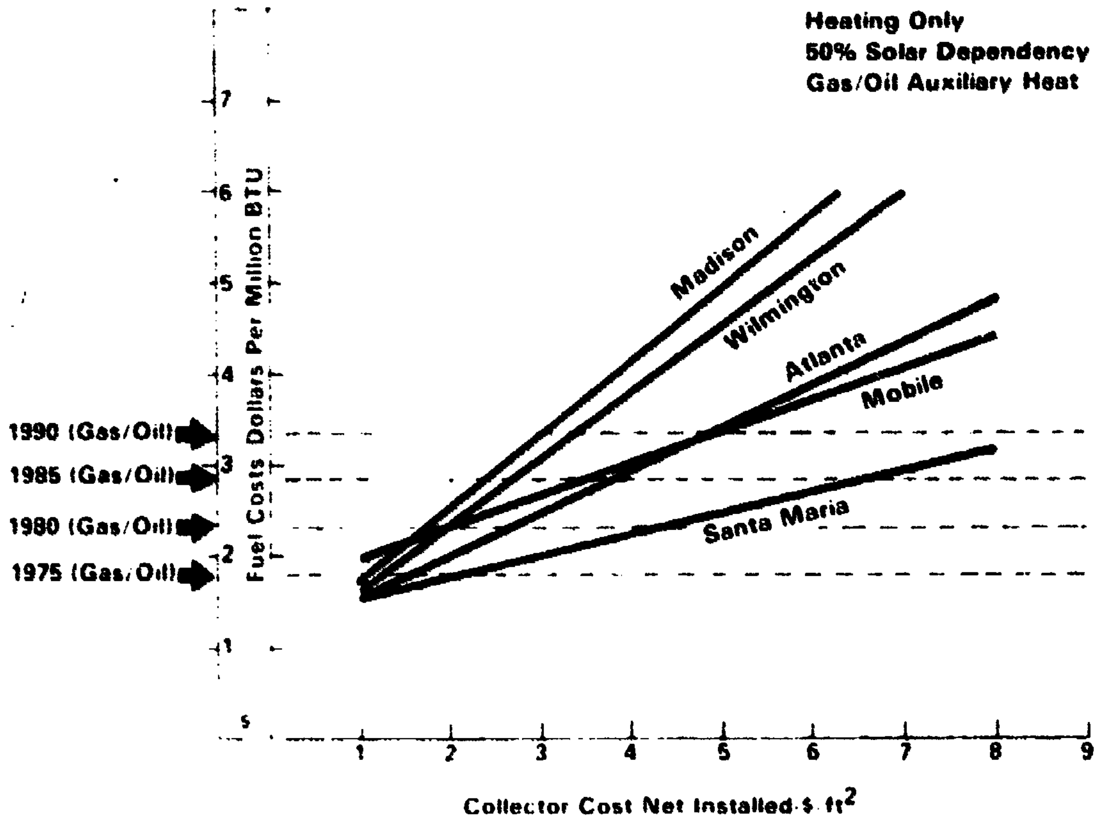
- Heating, Hot Water, and Cooling Requirement (Btu/Yr).

- Annual Solar Insolation (Btu/Yr).
- Solar Collector Size (Ft^2).
- Solar Collector Installation Costs ($\$/Ft^2$).
- Competitive Fuel (Gas/Oil/Electricity) Prices for Specific Time Periods ($/Million Btu).
- Cost of Conventional System ($).

Of the above, the solar collector installed costs versus the price of competitive fuels dominate the equation of solar energy economic feasibility. These prices are time dependent. It is expected that, in the next several years, solar collector costs will decrease as a result of design and manufacturing improvements and that electricity, gas, and oil prices will increase. The downward push of solar collector costs and upward pull of conventional energy prices will result in solar systems reaching a competitive position in respect to conventional systems. This trend may be accelerated by the application of tax incentives and other government stimuli to improve the economic advantages of solar systems.

Impressive progress has been made recently in the design improvement and cost reduction of the several solar collectors that are being manufactured. The collector manufactured by PPG Industries is particularly attractive. It uses two tempered glass covers and Roll-Bond as the absorber plate. In quantities of 10,000, the quoted price is $5.80 per square foot. For new construction, collectors can become a part of the structural walls or roof. The credit in labor and materials for that portion of the buildings replaced by solar collectors could substantially offset the collector installation costs in most cases. Thus, the installed collector cost is essentially equivalent to the cost of the collector itself.

The year in which economic feasibility will be attained will vary, depending on the region of the country, the level of solar dependency, and the type of solar systems, as well as all the factors listed above. Figure 9 is an example for a solar heating-only system providing 50 percent of the heat from solar energy and 50 percent from gas or oil. For this chart, as a simplification, current and projected national fuel price averages are indicated on the ordinate. Figure 10 is a similar chart for heating and cooling.



igure 9. Economic Feasibility of Solar Systems - Heating Only

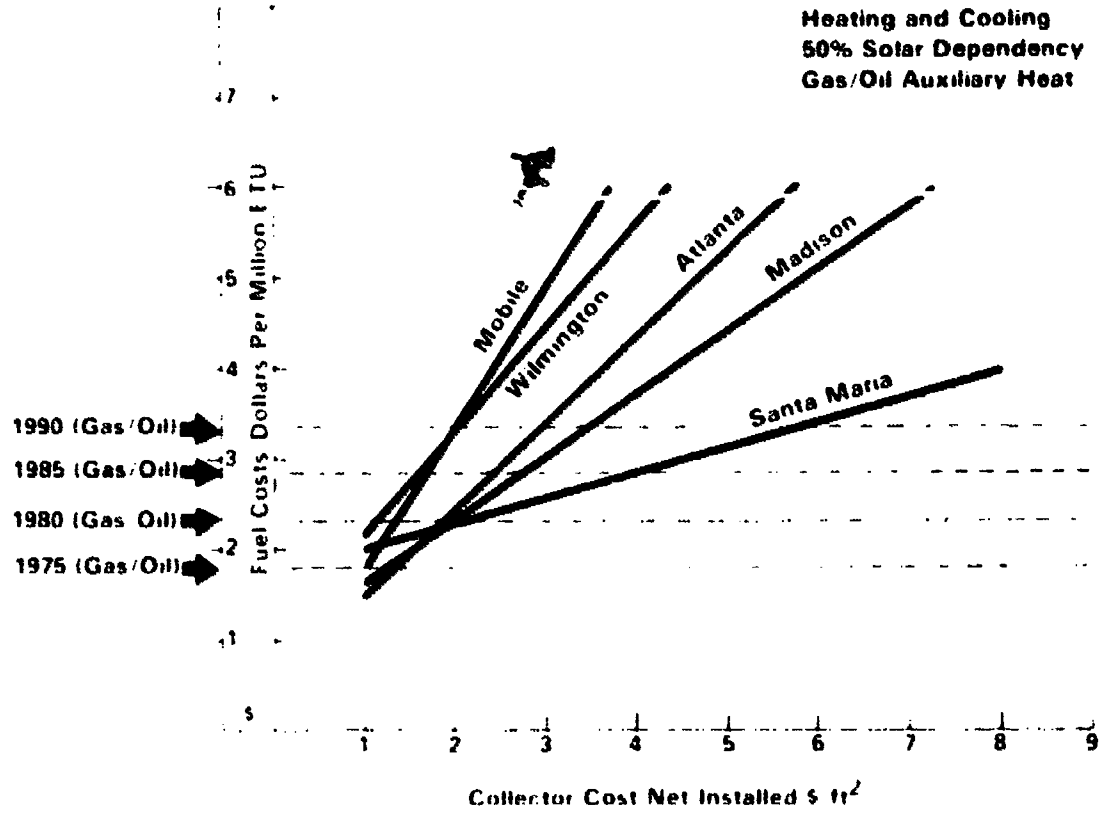


Figure 10. Economic Feasibility of Solar Systems - Heating and Cooling

The curves, a simplification of a more complex set of conditions, represent the crossover from noneconomic to economic feasibility for the indicated systems. Points below the curves are conditions of nonfeasibility and those above represent conditions of economic feasibility. It can be expected that collector costs will be reduced as a consequence of product improvement and production rate. The following are considered reasonable projections for the indicated time periods:

Period	Collector Cost/Square Foot
1975-1980	$5.50
1980-1985	3.00
1985-2000	2.00

On the basis of these anticipated collector costs, the time periods during which the selected solar systems reach economic feasibility in the various regions have been computed and the results indicated in Table 11. For the purpose of this table, regional energy prices rather than national averages were utilized.

The annual total capture potential for buildings, solar equipment sales, and amount of fuel saved in 1980, 1985, and 1990 for the combined regions was computed and is summarized in Table 12.

The amount of conventional energy, expressed as equivalent barrels of oil, that could be saved by the use of solar energy deployed as a function of time is shown in Figure 11. The near-term detail indicates a slow rise reaching 50 million barrels of oil per year by 1990. The initial slow increase is in part a consequence of the normal limited construction rate of new buildings compared to the large inventory and long life of existing buildings. Saturation in terms of energy saved per year would occur in about 50 years. When that point is reached, the amount saved will be very large. In fact, it will be greater than the present automobile consumption in equivalent barrels of oil, and the dollar market will approach ten billion 1973 dollars.

TABLE 11. TIME OF REACHING ECONOMIC FEASIBILITY -- SINGLE-FAMILY RESIDENCES

System	Region	Competing Fuel/System		
		Fossil	Elec/Res	Elec/HP
Solar Heat	Madison	1985-90	1985-90	2000
	Wilmington	1985-90	1980-85	1990
	Atlanta	1985-90	1980-85	1980-85
	Mobile	1980-85	1980-85	1975-80
	Santa Maria	1975-80	1975-80	1975-80
Solar Assisted Heat Pump	Madison	1985-90	(1)	2000
	Wilmington	1985-90		2000
	Atlanta	1985-90		1990
	Mobile	1985-90		1995
	Santa Maria	1980-85		1985-90
Solar Heat and Cool	Madison	1985-90	1980-85	2010
	Wilmington	1990	1995	2020
	Atlanta	1990	1990	2015
	Mobile	1995	2015	2020
	Santa Maria	1980-85	1980-85	1985-90

Note: (1) Not applicable

(2) Collector costs are:
1975 - \$5.50/ft^2
1980 - \$3.00/ft^2
1985 - \$2.00/ft^2

(3) Energy costs are those projected for the region and year indicated

TABLE 12. SUMMARY OF CAPTURE POTENTIAL

	1980	1985	1990
Buildings			
Single-Family Residences (units)	16,000	129,000	174,000
Multifamily Residences (dwelling units)	227,000	344,000	308,000
Nonresidential (square feet)	98,000,000	278,000,000	410,000,000
Solar Equipment Sales (In addition to conventional HVAC Components)			
Single-Family Residences	$22,000,000	$226,000,000	$357,000,000
Multifamily Residences	$67,000,000	$205,000,000	$238,000,000
Nonresidential	$79,000,000	$339,000,000	$580,000,000
Fuel Saved	1,040,000	4,820,000	6,990,000
(Annual increment-bbls/oil/year)			

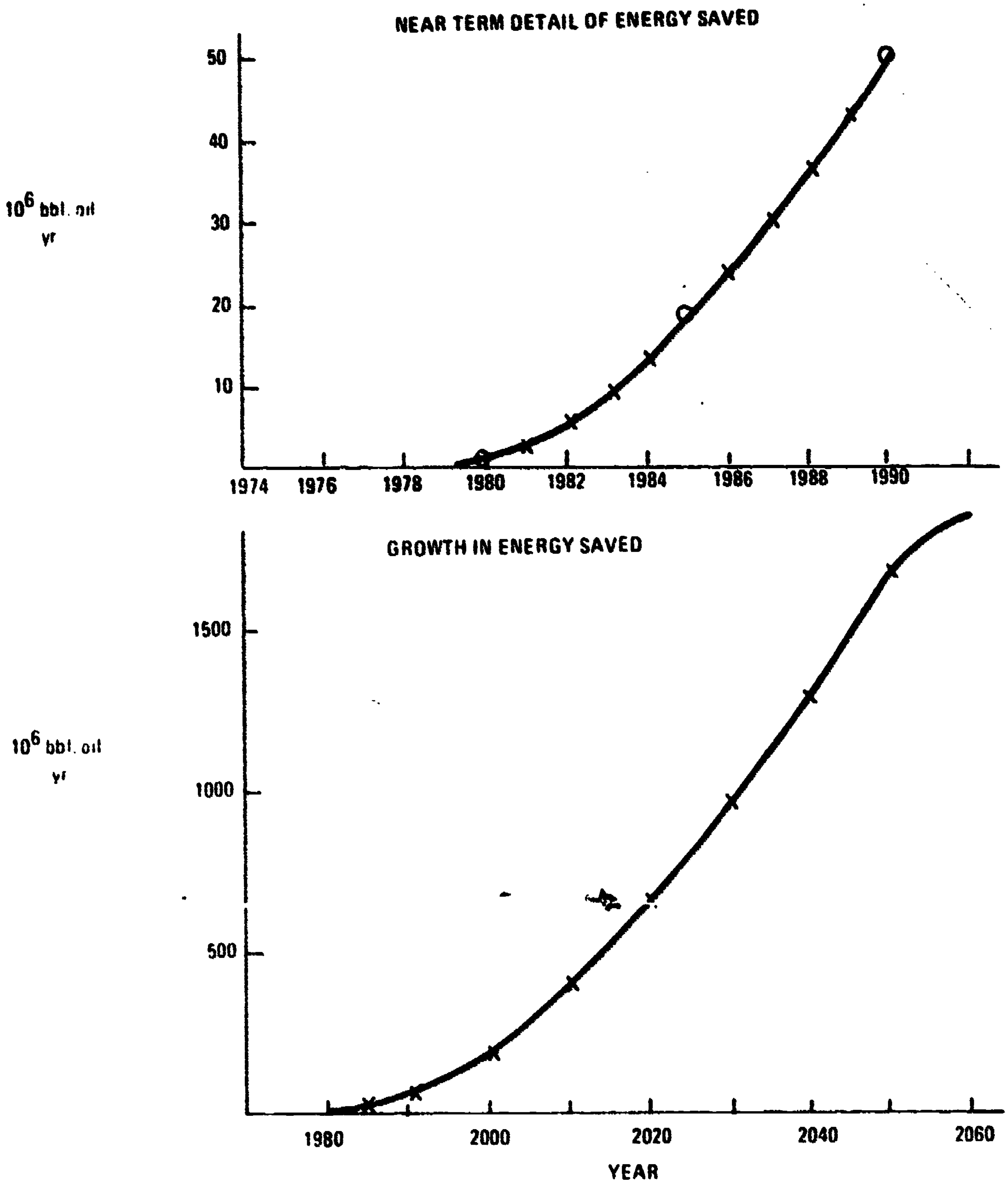


Figure 11. Growth in Energy Saved per Year as Solar-Equipped Structures Accumulate

SOCIAL, ENVIRONMENTAL, AND INSTITUTIONAL CONSIDERATIONS

TASK 4 -- SOCIAL AND ENVIRONMENTAL
TASK 10 -- UTILIZATION

5.0 SOCIAL, ENVIRONMENTAL, AND INSTITUTIONAL CONSIDERATIONS

5.1 SOCIAL AND ENVIRONMENTAL

An assessment of the social and environmental acceptability of solar energy systems was conducted in specific problem areas, including:

- The social acceptability at the user level of solar heating and cooling of buildings, including the effects of cost, appearance, and financing.
- The environmental acceptability of the use of solar energy for heating and cooling of buildings, including polution, noise, and aesthetics.
- The impact of solar heating and cooling of buildings upon heating, ventilating, and air-conditioning manufacturers and upon the labor force associated with them.
- The wide-scale application of solar heating and cooling of buildings through a building systems approach, using both architectural and engineering inputs.

The effort was divided into two major parts:

- Delineation of constraints.
- Acceptability of systems.

The survey technique was employed to assemble basic data. Seven relevant population groups were surveyed: Architects, builders, labor groups, manufacturers, energy suppliers, financiers, and potential consumers. First, questionnaires were sent to 1,714 individuals deemed most qualified to make judgements about solar heating and cooling in their respective fields. After the data produced by the surveys were analyzed, in-depth "one-on-one" interviews were utilized to assess the acceptability of solar heating and cooling systems. The findings of these efforts are generalized in the following paragraphs.

Surveys of seven population groups in regard to solar systems indicated a broad spectrum of reaction, ranging from interest and acceptance to skepticism. The respondents favor the idea of solar heating and cooling, but their enthusiasm drops off sharply as the system becomes more expensive.

Architects favor emphasizing all types of buildings in introducing solar heating and cooling. Schools, commercial buildings, and office or professional buildings were singled out, however, as requiring special emphasis. Architects clearly prefer fitting systems to newly designed buildings as opposed to retrofitting existing buildings.

Reactions of builders to the proposed solar heating and cooling system range from skepticism to qualified acceptance. None appears anxious to pioneer with an untried and unproven system. There is general concern that, without extensive merchandizing backed up by documented success of solar systems, buyers would tend to stick with traditional systems. Costs, aesthetics of the solar collector, and location of the storage tanks are major concerns.

Labor groups are in general agreement with other populations. Increased construction time required for installation of a solar system is marginally acceptable, and they perceive the need for a modest amount of special training.

The manufacturers interviewed are generally quite favorable. Several said that their firms are peripherally engaged in assessments of the feasibility of solar energy usage.

Of the seven groups canvassed, energy suppliers are the least enthusiastic about the proposed solar model and the benefits of currently feasible solar energy systems in general. Their objections centered on high cost, technological complexity, constantly fluctuating demand on their services, and general skepticism with respect to consumer acceptance.

Financiers believe that a solar supplement would have no direct adverse effect on financing and could possibly improve it. It is felt that solar heating and cooling systems will enhance the salability of a building, and that solar unit sales should experience a strong growth rate of between 10 percent and 50 percent per year once these systems are in use. Salability of buildings with solar units would be affected by cost considerations, just as conventional systems are, but the novelty of the concept is not considered likely to impair the market and, in fact, would probably enhance it.

Consumers indicate a decreasing acceptability with increasing costs and decreasing fuel cost reductions, as would be expected. The potential consumer finds an additional cost (over conventional system cost) for solar systems of $1,000 to $2,500 very acceptable in all cases. An additional cost of $2,500 to $5,000 would be on the border line between unacceptability and acceptability. Any additional costs over $5,000, regardless of fuel cost reduction, are rated very unacceptable.

High costs for solar heating and cooling systems were found to be more acceptable in new buildings.

The cost of solar heating for large buildings such as schools should not exceed 15 percent of the total building cost.

A solar collector site on the roof of the building is judged to be acceptable by almost all populations. An off-site center location also receives quite acceptable ratings, especially from consumers.

5.2 UTILIZATION PLANNING CONSIDERATIONS

The effective utilization of the results of the NSF Solar Heating and Cooling of Buildings Program is dependent on a comprehensive, active plan for that purpose.

5.2.1 Architects and Engineers

The Utilization Plan would include a program to develop, refine, and disseminate standardized design procedures and data, working through the architects and engineers involved with the POCE designs and through organizations such as the American Institute of Architects (AIA) Research Foundation, Inc. and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. (ASHRAE)

As the key technical resources utilized in the planning and design of buildings, architects and engineers represent a fundamental resource in institutionalizing both the technical capacity to incorporate solar systems into building designs, and a knowledgeable source that can promulgate utilization through recommendations to owners and investors.

Recognizing the important interaction between land-use planning and architectural design, a parallel program to address the development of model land-use planning guidelines should be conducted with organizations such as the American Institute of Planners (AIP) and the American Society of Planning Officials (ASPO).

5.2.2 Building Contractors

Many building contractors have the capacity, but inadequate information, to respond to solar construction and installation requirements in nonresidential buildings. An information program to assist these contractors and subcontractors to adapt their procedures to these requirements should be initiated through national contractor organizations, such as the Associated General Contractors (AGC).

A program of builder education and involvement in specifying design refinement objectives would be initiated with the assistance of the residential POCE builders and the NAHB Research Foundation, Inc.

5.2.3 Code and Safety Requirements

Existing equipment, building, and safety codes do not appear to require changes for the introduction of solar systems. However, the experience in the construction industry amply demonstrates that the absence of the negative prohibitions does not necessarily equate to the presence of positive interpretations by the various local code bodies involved in the review and approval of construction projects.

The Utilization Plan includes an intensive effort to ensure that designers are provided adequate information to avoid creating problems, and that code officials are provided adequate information from qualified and reliable sources to enable them to interpret codes applicable to solar system designs. This program would be conducted in conjunction with the various national model codes groups, professional and trade standards groups, and insurance and safety standards groups.

5.2.4 Channels of Distribution

Analysis of the manufacturing, distribution, and installation requirements of solar systems indicates that the existing channels of distribution of heating and cooling equipment offer clear advantages over any other alternative for at least an initial period. The preliminary plan is based upon making the investments necessary to utilize these channels in ways that minimize the need for external investment. At the same time, it would maximize the flexibility for achieving the evolution from early generations of equipment to more completely packaged systems in the longer range.

Recognizing the need for more incentive in adaptation by the residential channels of distribution, a proportionately larger investment in providing external resources and packaging designs will be required.

5.2.5 Customer Service

The importance to buyers of adequate service and parts availability will be a significant factor in decisions to utilize solar systems. Customer servicing requirement plans follow closely the distribution channel plans. The plan gives recognition to the need for in-place servicing capabilities and replacement parts at the time initial systems are deployed. It also recognizes the probability that the need for servicing will be greater on initial systems, and that the costs of establishing and maintaining this state of readiness will be greater than for conventional systems.

The objective of the plan would be to ensure that both in-warranty and out-of-warranty service would be locally available at costs competitive with conventional systems from sources that normally provide similar kinds of service to conventional systems.

5.2.6 Government Policies and Incentives

A major element of the utilization plan is the establishment of a coordinated set of Government policies and incentives that would create an initial market and foster the subsequent private investment to establish a viable industry. Since widespread economic competitiveness will depend upon both significant reductions in installed collector costs and increases in conventional fuel costs, external investment will be required if early and widespread utilization is to be realized.

A summary of the alternative areas in which Federal, State, and local governments can take action to accelerate the utilization is shown in Table 13.

5.2.7 Buyers and Homeowners

Before widespread utilization of solar can occur, there must be a broad base of buyer understanding of the consumer benefits of installing solar heating and cooling systems. The proposed program can create that understanding and become the basis for broad public asseptance. The plan is based on working with key buyer-oriented trade and professional groups in nonresidential construction, and key consumer and environmental groups in residential construction. By working with these groups, starting with the POCE and continuing during precommercialization, realistic assessments of readiness and benefits can be established and disseminated. Simultaneously, the spin-off information flowing from the architect/engineering professionals, the builders, and the early users involved with POCE can provide supporting evidence to potential buyers.

TABLE 13. SUMMARY OF POLICY AND INCENTIVE ACTION AREAS

	FEDERAL	STATE	LOCAL
Market Creation and Aggregation	• Public sector (Federal, State, and local) buildings • Private sector buildings • Long-term contracts for production • Performance standards and criteria	• Public sector (State and local buildings)	
Tax Incentives	• Income tax credits/ deductions • Accelerated amortization allowances	• Sales tax exemptions • Income tax credits • Property tax credits	• Property tax exemptions and credits
Financing Incentives	• Low-cost, insured loans and Government-guaranteed loan. • Government ownership of production facilities • Tax-exempt bonds • Government-backed product warranty insurance	• Incentives to State-regulated lending institutions	
Other Actions	• Joint industry/government-funded programs • Favorable data rights and patents policies • Regulatory encouragement to utilities • Adoption of life-cycle costing and solar bonus to energy efficiency budgets for new buildings	• Regulatory encouragement to utilities • Adoption of life-cycle costing and solar bonus to energy efficiency budgets for new buildings	• Adoption of favorable code and zoning provisions and policies

RECOMMENDATIONS

TASK 7 -- A SPECIAL PROJECT

TASK 6 -- PROOF-OF-CONCEPT-EXPERIMENT

TASK 8 -- PRELIMINARY PLANS FOR PHASE 1

TASK 9 -- PRELIMINARY PLANS FOR PHASE 2

6.0 RECOMMENDATIONS

6.1 A SPECIAL PROJECT

The National Science Foundation requested that, during the course of the Phase 0 analysis, a heating and cooling experiment be identified that could be initiated immediately and would make a "substantive contribution to the technology necessary for a successful proof-of-concept-experiment." As a result of the state-of-the-art analysis, it was recommended that such an experiment be directed toward the application of solar energy to the *heating* and *cooling* of a large building, and specifically to design, construct, and install such a system in the southeast region.

Since the mid-1940's, many experiments have been conducted involving the application of solar energy to the heating of small homes and the supply of home hot water needs. Additionally, a few small-scale laboratory experiments have been conducted by university researchers to study the operation of absorption refrigeration systems using solar heat. An experiment which could yield a substantive contribution to the technology should address the system requirements of a large building, as opposed to a small home, and should emphasize the cooling requirements of such a building.

Therefore, it was proposed to design, procure, install, monitor, and analyze the performance of a large-scale solar heating and cooling system of the following characteristics:

- Solar collector area of approximately 10,000 square feet.
- 100-ton absorption cooling capacity.
- Commensurate space heating capability.
- Hot water heating for domestic use.

6.1.1 Research Objectives

The technical objectives of the experiment are:

- To reveal and resolve unanticipated system problems associated with large-scale heating and cooling systems that cannot be completely foreseen in theoretical studies of the design, fabrication, installation, and operation of a large-scale solar heating and cooling system.
- To demonstrate the performance of a well-engineered, low-cost, assembly-line-produced, commercial collector of high performance.

- To operate the above collector at the high fluid temperatures (200° F) necessary for absorption cooling and to store the energy at these temperatures. A collector and storage system designed for operation at such temperatures has not previously been demonstrated.
- To optimize the collector tilt angle for seasonal heating and cooling at a specific site in the Southeast.
- To demonstrate solar heating and cooling of an entire building as distinct from a small section.

6.1.2 Research Plan

The city of Atlanta, Georgia, typifies the climatic and insolation characteristics of the southeastern region of the United States, wherein the seasonal heating and cooling needs are very nearly balanced, and the population of which will double by the year 2000. An elementary school in Atlanta is proposed as the site of this demonstration project. Many Atlanta schools are heated but not cooled. The use of one of these candidates will avoid costly air-conditioning equipment redundancy and the impact of a solar air-conditioning system will be most notable. The Atlanta schools are active throughout the year on a four-semester schedule, and are utilized at night and on weekends for community activities. The use of an Atlanta elementary school would result in a high level of experiment utilization and exposure, and the market potential in this area is large.

A solar system including approximately 10,000 square feet of collector area, water thermal storage of 24,000 gallons, and a 100-ton lithium-bromide absorption chiller was recommended to interface with the forced-air or circulated-hot-water heating system of the selected school. The resulting system should be designed to operate automatically to satisfy the total heating and cooling needs of the building.

6.1.3 System Configuration

The system configuration recommended for this project is that shown in Figure 5. Since the system is to be located where the temperature seldom drops below the freezing point, a design option not requiring the use of anti-freeze in the collector loop should be considered. On the rare occasions when the temperature does approach freezing, hot water from storage can be circulated through the collector at a very low rate to prevent freezing. This can be accomplished by an automatic sensing and control system and a small auxiliary pump. The elimination of a heat exchanger between the collector and hot water storage will permit slightly higher storage temperatures, which are desirable for powering the absorption air-conditioner, and will result in a cost saving.

6.1.4 Collector Design

A collector suitable for adaption to this project is manufactured by PPG Industries, Inc. The collector module consists of a Roll-Bond nonselective collector plate and two layers of tempered glass, mounted in a stainless steel frame. Each collector assembly measures approximately 32 x 74 inches, with 17 square feet of collector area. About 588 of these panels will be required to provide a total collector area of about 10,000 square feet. During a period of approximately three hours centered about noon on a clear day, this collector area will supply about 2.0×10^6 Btu/hr, which is slightly more than the peak thermal energy requirement of a 100-ton absorption air-conditioner.

Incident to the design phase of this experiment, the advantages of orienting the collectors flat on the roof (as opposed to a tilt orientation to maximize insolation) should be thoroughly explored.

6.1.5 Absorption Air-Conditioner

An absorption air-conditioner suitable for this project is the Arkla WF-1200 water-fired unit. It is the only commercially available unit designed to operate directly from hot water at a temperature between 200 and 245° F. The unit is rated at 100 tons of refrigeration, with a coefficient of performance of 0.71.

6.1.6 Thermal Energy Storage

For a solar heating and cooling system, where the load is to be predominantly cooling, energy usage is closely correlated with insolation; therefore, relatively short-term (on the order of a few hours) storage is usually provided. It is recommended that 24,000 gallons of water storage be provided and additional heat made up, when required, from the building's water heater.

6.1.7 Performance Analysis

The performance of the solar heating and cooling system should be monitored and analyzed through at least one year of operation. From this analysis, design optimizations and design and performance extrapolations to other-size solar systems should be performed. System and component reliability and maintainability data should be analyzed to apply lessons learned to the Proof-of-Concept-Experiments to follow.

6.1.8 Schedule and Cost

The tasks, and the estimated time schedule for each, are shown in Figure 12. The estimated cost for this project is $500,000.

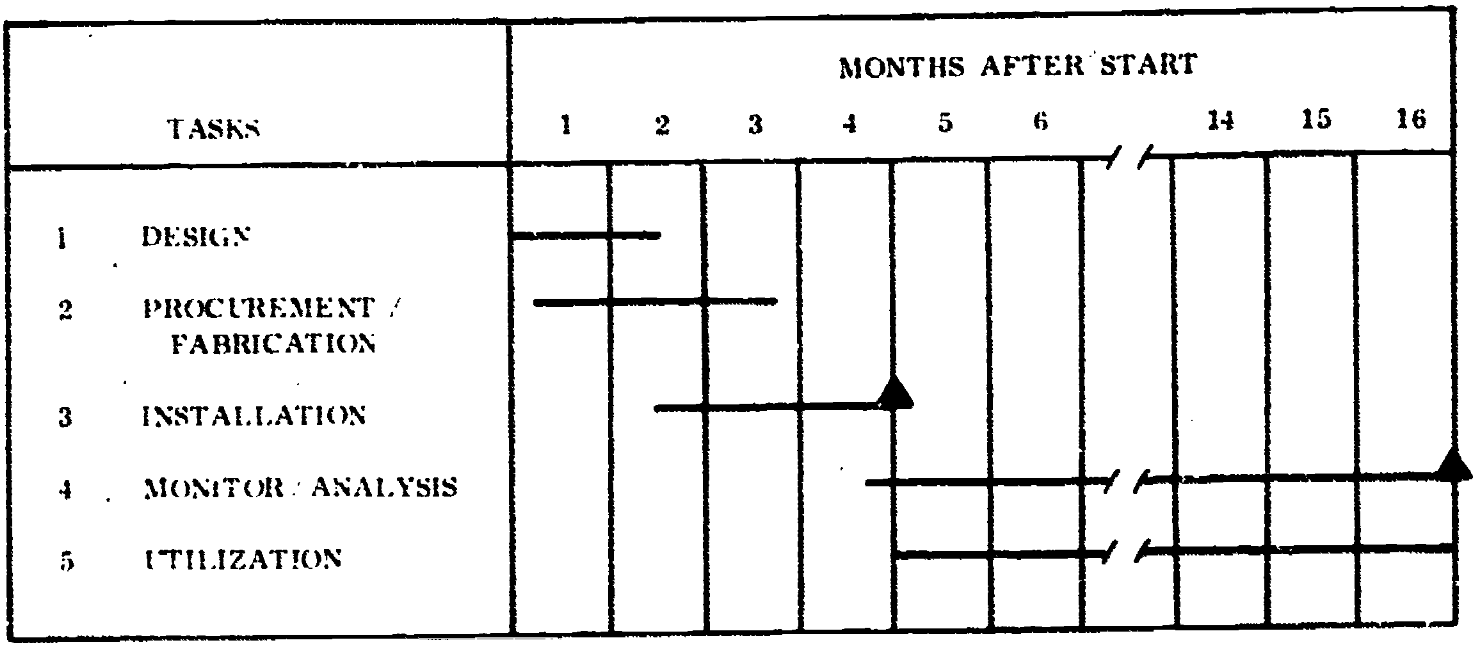


Figure 12. Proposed Project Schedule

6.2 PROOF-OF-CONCEPT-EXPERIMENTS

A task effort was undertaken to identify system/building/region combinations that could be recommended for the Proof-of-Concept-Experiments (POCE's) which would be representative of regional requirements and which would allow generalization of the results to regions of significant size. How large the experiments should be is a matter of balance between national urgency and technical reality.

To serve as a stimulant and have a significant impact, the POCE should be more coherent and at least an order of magnitude greater than previous efforts. It should involve testing each of the selected solar systems for the six classes of buildings in all of the regions. Above all, it must be carefully designed, taking future conditions into consideration, and carefully carried out if the results are to be productive.

Not only performance but potential maintenance and reliability problems must strongly influence considerations of the scale of the experiments. The concept of solar systems could be seriously set back if a very large number of systems were constructed without having ensured an acceptable level of reliability. Comparatively small problems could become major, and the bright image of solar systems would be darkened.

With these considerations in mind, it was judged that an experiment involving three hundred single-family residences and twenty-five larger buildings would be of the proper magnitude. A budget requirement for this size experiment is estimated to be about $26 million, as discussed in the following paragraphs.

The total number of combinations studied was 90 (three systems times six buildings times five regions). The POCE matrix recommended was based upon the following factors:

- Present Area Population.
- Year 2000 Population.
- Heating Degree-Days.
- Cooling Degree-Days.
- Assumed Minimum Viable Experiment for Single-Family Residences.
- Assumption that nonsingle-family residential experiments should be approximately equal in dollar expenditure to single-family residential.

The first four items above are shown in Table 14.

The incremental population times the sum of both heating and cooling degree-days is an indicator of the maximum potential heating and cooling load. Multiplying these by the average solar dependency (for heating only, heating and cooling, and heat pumping at a collector area equal to 50% of plan area), the resulting number will roughly indicate the relative maximum capture potential. The results of this calculation is shown in Table 15.

On a purely judgmental basis, the size of each experiment in the respective cities (and their environs) was rounded to 10 percent, 20 percent, 30 percent, 30 percent and 10 percent. The initial assumption was further made that a minimum viable experiment in any one city should be 30 residences to allow for system variation, residential design variation, and location variation (rural versus urban). Furthermore, consideration was given to the

TABLE 14. DEMOGRAPHIC AND THERMAL LOAD FACTORS RELATIVE TO POCE'S

Region (City)	1969 Population	2000 Population	Heating Degree Days	Cooling Degree Days
Gulf Coast (Mobile)	18 Million	28 Million	1612	4280
Southeast (Atlanta)	28 Million	42 Million	2826	3210
North East (Wilmington)	42 Million	64 Million	4910	2140
Great Lakes (Madison)	44 Million	69 Million	7417	1790
West (Santa Maria)	16 Million	30 Million	3934	715

* Increased 43 percent over sensible degree-days to account for dehumidification requirements.

TABLE 15. RELATIVE MAXIMUM CAPTURE POTENTIAL

(1) Region (City)	(2) Population Increment	(3) Total Degree Days	(4) Ave. Solar Dependency	Product (2)x(3)x(4)	Relative Capture
Gulf Coast (Mobile)	10 Million	5872	.68	40,070	11.1%
Southeast (Atlanta)	14 Million	6036	.74	62,530	17.3%
Northeast (Wilmington)	22 Million	7050	.59	91,510	25.4%
Great Lakes (Madison)	25 Million	9207	.51	117,390	32.6%
West (Santa Maria)	14 Million	3649	.96	49,040	13.6%
				Total	100.0%

character of the loads (heating versus cooling). An additional judgement was made as to the experimental mix for each city. For example, since the load in Mobile is primarily cooling, no heating-only experiments are recommended there. The preliminary single-family residential recommendations are shown in Table 16.

Also included in Table 16 are recommendations with regard to mobile homes. Preliminary cost analyses have shown that, in all locations except Santa Maria, the incremental system cost for mobile homes is too high to make such systems acceptable since the purchase of mobile homes is strongly influenced by comparatively low initial cost. However, in Santa Maria the incremental cost appears to be in the range of $1000 to $1500 and, therefore, ten heating-only experiments in mobile homes for the Santa Maria region are recommended.

TABLE 16 SINGLE-FAMILY RESIDENTIAL POCE'S

Region (City)	Mobile Homes (HO)	Other Single-Family Residences			
		Heating Only	Heating and Cooling	Heat Pump	Total
Gulf Coast (Mobile)	0	0	15	15	30
Southeast (Atlanta)	0	10	25	25	60
Northeast (Wilmington)	0	35	35	20	90
Great Lakes (Madison)	0	25	40	25	90
West (Santa Maria)	10	10	15	5	30
				Total	300

With regard to nonresidential structures, it was decided that there should be at least one POCE experiment for each building type in each city. For schools, two in each city have been recommended because they represent excellent candidates for retrofitting and because of their public ownership. The capture potential results stressed the importance of air-conditioning for large buildings. Therefore, the POCE recommendations for large buildings include only heat pumps and heating and cooling experiments, with a 1.5-to-1 ratio between the two as being representative of the estimated degree of technical feasibility.

Additional factors employed in determining the mix of building types were economic feasibility, capture potential, effectiveness, reliability, availability, maintainability, manufacturability, and acceptability. The final tabulation is shown in Table 17.

6.3 DEVELOPMENT OF PLANS FOR PHASES 1 AND 2

The Proof-of-Concept-Experiments recommended would consist of 300 single-family residences and 25 larger buildings. Plans for preliminary system design, critical component design, fabrication, and test have been made for Phase 1. These plans will provide the base for detailed design, implementation, and operation of the POCE's as well as indicate critical subsystem research and development. Plans for system construction and test for Phase 2 have also been developed.

It is recognized that NSF either has, or will have in the near future, research programs in innovative approaches to 10 technical areas. Also, it is recognized that various manufacturers are conducting in-house research and development on components and subsystems. The planning indicated in this section describes a totally integrated approach to system design and component development for POCE. Where other programs already in existence can contribute substantively to this program, the proposed program element can be deleted in favor of the existing program.

6.3.1 Critical Component/Subsystem Research and Development

A solar heating and cooling system will, in general, consist of a large number of components and subsystems which must operate in a very sophisticated integrated system under a control system which presents options of the utmost simplicity to the operator while, at the same time, providing

TABLE 17. RECOMMENDED PROOF-OF-CONCEPT-EXPERIMENT DISTRIBUTION FOR SOLAR HEATING AND COOLING OF BUILDINGS

	(300) Mobile Home	(001) Single Family Residence	(004) Multi-Family Residence	(015) Office Building	(018) Store	(017) School
Atlanta, Georgia (Location 1)	0	20 HO 26 HP 20 HC 66	1 HP	1 HP	1 HC	2 HC
Mobile, Alabama (Location 2)	0	8 HO 18 HP 14 HC 40	1 HC	1 HC	1 HC	2 HC
Santa, Maria, California (Location 3)	10 HP	16 HO 24 HP 16 HC 56	1 HC	1 HP	1 HC	1 HP 1 HC
Wilmington, Delaware (Location 4)	0	16 HO 18 HP 14 HC 48	1 HP	1 HP	1 HP	1 HP 1 HC
Madison, Wisconsin (Location 5)	0	30 HO 30 HP 30 HC 90	1 HC	1 HP	1 HC	1 HP 1 HC
System Totals	10 HP	90 HO 116 HP 94 HC	2 HP 3 HC	4 HP 1 HC	1 HP 4 HC	3 HP 7 HC
Total Experiments	10	300	5	5	5	10

Note: HO = Heating only

HP = Solar-assisted heat pump

HC = Heating + absorption air-conditioning comfort, performance, safety, and fail-safe protection of the system apparatus. These components and subsystems can be characterized as follows:

- Available off-the-shelf.
- Requiring straight-forward engineering design and manufacture.
- Requiring further research and development as to design and/or manufacture.

Table 18 lists system components and subsystems in accordance with the foregoing classification.

Absorption refrigeration in particular requires strong development effort. The successful application of absorption refrigeration in single-family residential application will require the development of machinery that is more reliable and less costly than that presently available for that purpose. There is considerable room for improvement of the nonrefrigeration portion of the system, as well. The absorption refrigeration system problems include:

- Pump Failures.
- System Leaks (Purge and Refill).
- Corrosion.
- Hydrogen Generation (Purge and Refill).
- Valving Failures.
- Condenser Fouling.
- Crystallization of LiBr.

In addition to these problems, which are sensitive to design and materials selection, problems peculiar to solar system operation will arise because of the wider variability of generator temperature available.

6.3.2 System Design, Construction, and Test

System design has been divided into three major categories:

- Single-Family Residences -- Heat Pumping and Heating Only.
- Single-Family Residences -- Heating and Cooling.
- Large Buildings -- Heating and Cooling.

TABLE 18. COMPONENT AND SUBSYSTEM CHARACTERIZATION

Off-the-Shelf	Straight-Forward Engineering & Design	Requiring Further Development
Air-Handling Equipment	Plumbing Systems	Control Systems
Cooling Towers	Heat Pumps	Collectors
Hydronic Units	Storage Systems	Absorption Refrigeration
Furnaces	Heat Exchangers	Integrated Packaged Units
Pumps		
Valves		

Figure 13 is a master plan for the design, construction, and test of single-family residences. The plan is subdivided into three principle sections in which the individual elements overlap in scheduling. These are:

- Phase 1 - System Design.
- Phase 2A - POCE Precursor.
- Phase 2B - POCE.

Phase 1 would begin with a detailed determination of the design requirements at the component level and critical component development (some of which may have been undertaken as part of independent projects). The designs for solar heating only and solar-assisted heat pumps for the first group of single-family residences (Santa Maria) would be completed about 10 months after program start, and 5 months later for the last group (Madison). For solar heating and cooling, the designs would be completed in 17 and 20 months, respectively. On this basis, the construction of the first group of single-family residences would begin 18 months after start of Phase 1.

To obtain experience with single-family residences earlier than indicated in the above schedule, a POCE Precursor, designated Phase 2A is proposed. The precursor program would consist of a total of 12 single-family residences (6 in each of two locations) using solar-assisted heat pumping for heating purposes and the inverted operation of the heat pump in the summer for cooling. It is believed that systems of this type could be constructed and made ready for occupancy within a 14-month period. These systems would not meet all of the objectives of the POCE but would provide an early

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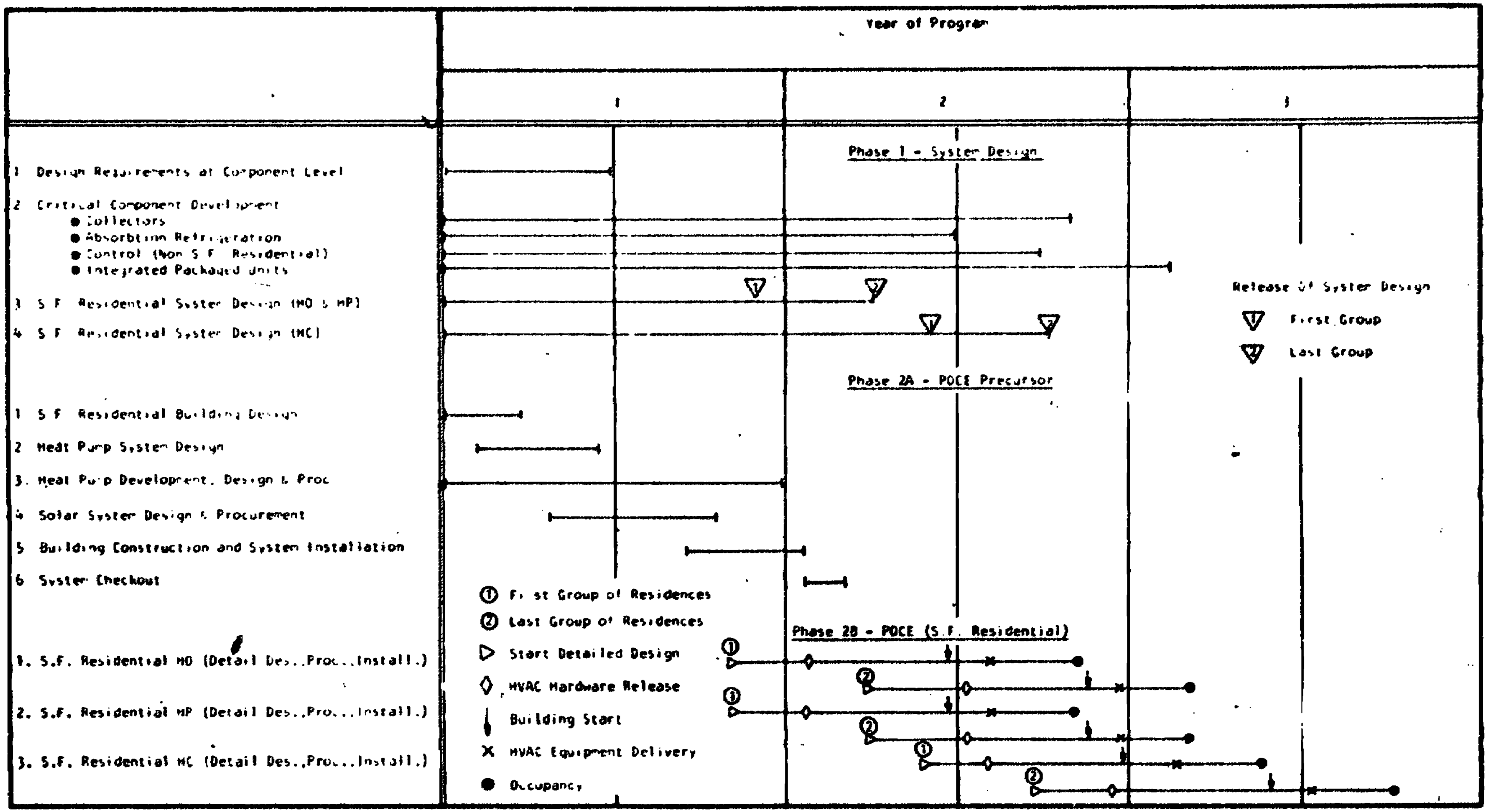

Figure 13. Phase 1 and Phase 2 Master Plan

experience with special component development and medium-scale construction problems. The systems would not be optimized for cost benefit nor would they necessarily have the reliability nor maintainability of the later POCE's. The major development effort in the precursor program would be devoted to heat pumps suitable for use in solar systems.

6.3.3 Large Buildings

The POCE recommendations call for installation of 25 systems in large buildings including apartments, offices, stores, and schools. All of these would employ either a heat pump or an absorption air-conditioner. An unspecified number would be retrofitted to existing buildings. Since each project will be custom designed, and separately and explicitly costed and scheduled, to satisfy the requirements of the specific project, it is not practicable to prepare preliminary schedules for them. It is envisioned that each project will entail a separate procurement. The purpose of the Phase 1 effort (with regard to these larger custom-designed buildings) will be to provide modular component specifications and designs that will be acceptable to architects and engineers responsible for both the building design and its HVAC system.

6.3.4 Costs

The estimated costs for Phase 1 (design), Phase 2A (Precursor), and Phase 2B (POCE) are summarized in Table 19.

TABLE 19. SUMMARY OF COSTS OF SOLAR EQUIPMENTS AND SYSTEMS

Phase 1	
Single-Family Residence Design	$ 1,120,200
Large Building Design	1,087,500
Critical Component Development	1,632,000
Phase 1 Subtotal	$ 3,839,700
Phase 2A (Single-Family Precursor)	
12 Single-Family Residential Systems	$ 903,200
Phase 2B (POCE)	
Includes	
300 Single-Family Residential Systems 10 Mobile Home Systems 25 Large Buildings	12,275,000
Monitoring, Data Collection, Etc.	5,540,000
Maintenance (5 years)	1,502,000
Contingencies	2,500,000
Phase 2B Subtotal	$21,800,000
Total	$26,542,900