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ABSTRACT

This report presents the Energy Research and Development Administration (ERDA) program plan for solar heating and cooling of buildings and for agricultural and industrial process applications. An overview of the program plan is followed by a description of the ten paths to the solar heating and cooling of buildings and a brief discussion of the agricultural and industrial process applications. The appendices present detailed information on the tasks, including flow diagrams for the heating and cooling tasks, brief descriptions of these tasks and of the nonengineering tasks, and an indication of the importance of each nonengineering task to the overall research and development program. (Author/MLF)

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ERDA 76-144

Interim Report
National Program Plan
for Research and Development
in Solar Heating and Cooling

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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Division of Solar Energy
Washington, D.C.

November 1976

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National Program Plan for Research and Development in Solar Heating and Cooling

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Washington, D.C.

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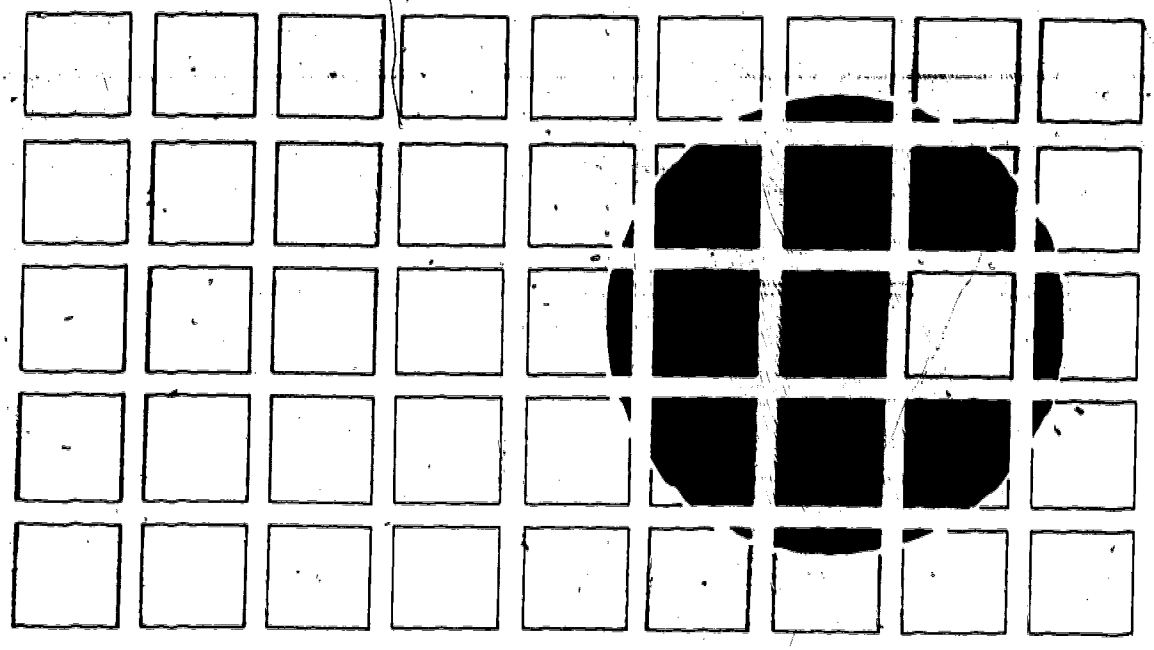

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FOREWORD

This interim report on a National Program Plan for Research and Development in Solar Heating and Cooling was prepared by the Research and Development Branch of the Division of Solar Energy of the Energy Research and Development Administration (ERDA). The report was first drafted by the Solar Energy Group of the Los Alamos Scientific Laboratory. It is based on a thorough assessment of the present status of solar heating and cooling technology and presented with the confidence that the emerging solar energy industry will continue to conduct a broad range of R&D activities. This plan describes the Federal R&D program plan for solar heating and cooling, including those activities to be funded in whole or in part by the Federal Government. The program plan is compatible with, but more detailed than, that described in the *National Plan for Solar Heating and Cooling*, ERDA 23A. It is intended that this interim report be circulated widely for review and comment by all those concerned with the R&D aspects of solar heating and cooling. It is also planned that several groups, such as ASHRAE, ASME, and SEIA, will conduct formal reviews of this plan and provide ERDA with their recommendations. Comments received by March 1, 1977 will be considered in the preparation of the final report on the Program Plan for Research and Development in Solar Heating and Cooling. Comments should be sent to:

Dr. Frederick H. Morse, Chief
Research and Development Branch
Division of Solar Energy
Energy Research and Development Administration
Washington, D.C. 20545

As with most planning documents, it is anticipated that this R&D program plan will be revised and improved as results from the current research, development, and demonstration projects, both Federally and privately supported, become available. Comments received after March 1 will be considered for incorporation in future revisions of this plan.

CONTENTS

Section		Page
Foreword		iii
Table of Contents		v
Executive Summary		ix
Part I. PLAN		
I.	Introduction	3
	Solar Heating and Cooling Program	3
	Technology Status	4
	Directed R&D Plan	4
	Structure of the R&D Program	4
	Structure of the R&D Plan	6
	Implementation	10
II.	Program Objective and Emphasis	11
	Objective	11
	Emphasis	11
Part II. PATHS		
III:	R&D Program Structure: Heating and Cooling of Buildings	17
	Liquid-Heating Collectors for Service Hot Water: Path W1	22
	Air-Heating Collectors for Service Hot Water: Path W2	26
	Solar-Assisted Heat Pumps for Space Heating: Path H1	29
	Direct Solar Heating of Space or Structure: Path H2	33
	Air-Heating Collectors for Space Heating: Path H3	36
	Liquid-Heating Collectors for Space Heating: Path H4	39
	Concentrating Collectors with Absorption or Rankine Cycle Chiller for Space Cooling: Path C1	42
	Advanced Non-Concentrating Collectors with Absorption or Rankine Cycle Chiller for Space Cooling: Path C2	46
	Flat Plate Collectors with Desiccant Chiller for Space Cooling: Path C3	50
	Evaporative and Night-Effect Cooling: Path C4	53
IV.	Agricultural and Industrial Processes	57
	Path Characteristics	57
	Path Requirements	57
Part III. TASKS		
Appendix A.	Task Flow Charts	63
Appendix B.	R&D Program Tasks for the Solar Heating and Cooling of Buildings	75
I.	Solar Collectors	79

Section — Page

II. Thermal Storage and Heat Exchange ... 113
III. Solar Air Conditioning and Heat Pumps ... 131
IV. Systems and Controls ... 147
V. Non-Engineering Aspects ... 163

Appendix C. Importance Numbers for Engineering Tasks ... 167

Appendix D. Priorities of Non-Engineering Tasks ... 183

FIGURES

Figure — Page

I–1 Path Diagram Examples ... 5
II–1 System Analysis Interaction ... 13
III–1 Paths to Solar Heating of Service Hot Water ... 19
III–2 Paths to Solar Space Heating ... 20
III–3 Paths to Solar Space Cooling ... 21
III–4 Liquid-Heating Collectors for Service Hot Water: Path W1 Activity Schedule ... 24
III–5 Liquid-Heating Collectors for Service Hot Water: Path W1 Flow Chart ... 25
III–6 Air-Heating Collectors for Service Hot Water: Path W2 Activity Schedule ... 27
III–7 Air-Heating Collectors for Service Hot Water: Path W2 Flow Chart ... 28
III–8 Solar-Assisted Heat Pump for Space Heating: Path H1 Activity Schedule ... 31
III–9 Solar-Assisted Heat Pump for Space Heating: Path H1 Flow Chart ... 32
III–10 Direct Solar Heating of Space or Structure: Path H2 Activity Schedule ... 34
III–11 Direct Solar Heating of Space or Structure: Path H2 Flow Chart ... 35
III–12 Air-Heating Collectors for Space Heating: Path H3 Activity Schedule ... 37
III–13 Air-Heating Collectors for Space Heating: Path H3 Flow Chart ... 38
III–14 Liquid-Heating Collectors for Space Heating: Path H4 Activity Schedule ... 40
III–15 Liquid-Heating Collectors for Space Heating: Path H4 Flow Chart ... 41
III–16 Concentrating Collectors with Absorption or Rankine Cycle Chiller for Space Cooling: Path C1 Activity Schedule ... 44
III–17 Concentrating Collectors with Absorption or Rankine Cycle Chiller for Space Cooling: Path C2 Flow Chart ... 45
III–18 Advanced Non-Concentrating Collectors with Absorption or Rankine Cycle Chiller for Space Cooling: Path C2 Activity Schedule ... 48
III–19 Advanced Non-Concentrating Collectors with Absorption or Rankine Cycle Chiller for Space Cooling: Path C1 Flow Chart ... 49
III–20 Flat Plate Collectors with Desiccant Chiller for Space Cooling: Path C3 Activity Schedule ... 51
III–21 Flat Plate Collectors with Desiccant Chiller for Space Cooling: Path C3 Flow Chart ... 52
III–22 Evaporative and Night-Effect Cooling: Path C4 Activity Schedule ... 55
III–23 Evaporative and Night-Effect Cooling: Path C4 Flow Chart ... 56

A–1 Liquid-Heating Collectors for Service Hot Water: Path W1 Task Flow Chart ... 65
A–2 Air-Heating Collectors for Service Hot Water: Path W2 Task Flow Chart ... 66
A–3 Solar-Assisted Heat Pump for Space Heating: Path H1 Task Flow Chart ... 67
A–4 Direct Solar Heating of Space or Structure: Path H2 Task Flow Chart ... 68
A–5 Air-Heating Collectors for Space Heating: Path H3 Task Flow Chart ... 69
A–6 Liquid-Heating Collectors for Space Heating: Path H4 Task Flow Chart ... 70
A–7 Concentrating Collectors with Absorption or Rankine Cycle Chiller for Space Cooling: Path C1 Task Flow Chart ... 71

Figure		Page
A–8	Advanced Non-Concentrating Collectors With Absorption or Rankine Cycle Chiller for Space Cooling: Path C2 Task Flow Chart	72
A–9	Flat Plate Collectors with Desiccant Chiller for Space Cooling: Path C3 Task Flow Chart	73
A–10	Evaporative and Night-Effect Cooling: Path C4 Task Flow Chart	74

TABLES

Table		Page
I–1	Path Descriptions for Heating and Cooling of Buildings	7
I–2	Path Descriptions for Agricultural and Industrial Processes	8
I–3	Task Classifications	9
III–1	Paths to Solar Heating and Cooling of Buildings	18
C–1	Importance Numbers for Collector Tasks	169
C–2	Importance Numbers for Thermal Storage and Heat Transfer Tasks	174
C–3	Importance Numbers for Air Conditioning and Heat Pump Tasks	177
C–4	Importance Numbers for System Study Tasks	179
D–1	Priorities for Non-Engineering Tasks	186

EXECUTIVE SUMMARY

R&D PROGRAM PLAN

This report presents the ERDA/Division of Solar Energy (DSE) program plan for research and development in the use of solar energy for heating and cooling buildings and for agricultural and industrial process applications.

The objective of the ERDA solar energy R&D program is to provide the solar energy industry and other users with the means (information, components, etc.) to produce cost-effective solar energy systems. The application of solar energy for heating and cooling involves, to a significant extent, components (such as heat pumps, air conditioning machines, and controls) which are used in conventional HVAC systems. The relatively new and rapidly developing solar energy industry is also producing many of the required components. The ERDA program builds on this technology and attempts to assist the solar energy industry to develop cost-effective components and systems more rapidly.

As part of the preparation of this program plan, meetings were held with representatives from industry, universities, and the Government. The following conclusions were reached:

- The major problem to be addressed is the development of cost-effective components and systems.
- The state of the art varies greatly for different components and applications, with solar cooling technology being generally less developed than that for solar heating.
- Applications and climatic zones are so varied that careful analysis is necessary to determine the most cost-effective approaches.
- Cost-effective retrofit systems are not well developed, and techniques for optimizing retrofit design are not readily available.

As a result of these conclusions, an ERDA-directed, applications-oriented R&D program is being initiated. The plan for this directed R&D program is the subject of the present report. The current R&D program is components-oriented; and, while that approach has made significant contributions to the present state of technology, it can be strengthened by the applications strategy. The directed program, then, is a continuation of the present program, but with a shift in emphasis.

The main feature of the directed program is the focus on several approaches, called paths, to the applications of solar energy. Ten such paths are identified for buildings applications and eleven for agricultural and industrial process applications. A path is simply the linking of a method of energy collection or rejection with a particular application.

The ten paths identified in the report for the solar heating and cooling of buildings are as follows:

- Service hot water (2 paths): flat plate liquid-heating collectors and flat plate air-heating collectors.
- Space heating (4 paths): direct solar heating of space or structure, solar-assisted heat pump with various types of collectors, flat plate air-heating collectors, and flat plate liquid-heating collectors.
- Space cooling (4 paths): evaporative cooling, night sky radiation, or cool night air without additional energy conditioning equipment; concentrating collectors with absorption or Rankine vapor compression chiller; advanced non-concentrating collectors with absorption or Rankine vapor compression chiller (operating at moderate temperatures); and flat plate collectors with desiccant machines for air conditioning or dehumidification.

The report lists the eleven paths for agricultural and industrial process applications but does not describe them in detail.

The ten heating and cooling paths differ in character. Some require an emphasis on materials development, some on system analysis, and some on component development and testing. In order to move along any of the paths, specific tasks must be undertaken, whether in series or in parallel. Approximately 275 tasks have been identified. They occur in five categories: collectors, storage and heat exchange, air conditioning and heat pumps, systems and controls, and non-engineering aspects. Because most of the tasks occur on more than one path, the paths are

interdependent. The importance of each task to a given path is indicated by a number assigned on a 0 (unimportant) to 10 (critical) scale. The tasks for each path are placed in functional categories and arranged in sequence, giving each path a logical development.

Since the directed program is a continuation of the current R&D program, many of the tasks described in this report are already under study, either fully or in part. The other tasks will be initiated as indicated in the plan.

The implementation of the directed program will differ from that for the present program chiefly in being based on competitive solicitations rather than on unsolicited proposals. Industry, universities, small businesses, and Government laboratories are expected to continue to perform R&D tasks, with project support coming from the ERDA laboratories.

Since the R&D program is a part of ERDA's total energy program, it has many points of impact on other ERDA programs and organizations and on other Federal agencies. Implementation of the R&D program is being coordinated with the appropriate groups, with special emphasis being placed on integration with the residential and commercial demonstration program.

The ten solar heating and cooling paths for buildings applications will be cost effective if key problems can be solved. As technology advances and project results are analyzed, the paths will be given periodic evaluations and priorities will be adjusted. Milestone schedules and the emphasis given various tasks will receive corresponding adjustments.

A final point remains to be made concerning the R&D program plan. The plan calls for both information dissemination and component development. While major milestones are indicated for each path, it is expected that new components and systems information will be developed throughout the duration of the program.

R&D PROGRAM REPORT

The present report is divided in three parts: Plan, Paths, and Tasks. The report is organized to allow a reader to gain an overview of the R&D program plan without forcing him to become involved in all of its details.

Part I of the report (the Executive Summary and Sections I and II) gives the overview of the program plan. The second part (Sections III and IV) describes the ten paths to the solar heating and cooling of buildings and briefly discusses the agricultural and industrial process applications. The third part (the appendices) presents detailed information on the tasks. Appendix A gives flow diagrams for the heating and cooling tasks, and Appendix B includes brief descriptions of these tasks and of the non-engineering tasks. Appendix C lists the importance numbers for all of the solar heating and cooling engineering tasks, and Appendix D indicates the importance of each non-engineering task to the overall R&D program.

Part I. PLAN

SECTION I

INTRODUCTION

This report presents the ERDA research and development program plan for solar heating and cooling of buildings and for agricultural and industrial process applications. The plan is written for those familiar with the basics of solar heating and cooling, and it describes in detail the ERDA solar heating and cooling R&D plan. It provides the many users of solar technology with an insight into likely advances in the components and systems for solar heating and cooling.

In this plan, it is recognized that the application of solar energy for heating and cooling involves, to a significant degree, existing components, such as heat pumps, air conditioning machines, controls, etc., which make up today's HVAC systems. Furthermore, since the relatively new and rapidly developing solar energy industry is producing many of the key components for solar energy systems, the plan builds on this existing technology and, by supporting work on a wide range of problems, seeks to assist the solar energy industry in developing the cost-effective components and systems that will be essential for the widespread use of solar energy for solar heating and cooling of buildings and for agricultural and industrial processes.

In addition to ERDA's solar energy activities, many efforts are underway in other Federal agencies, industry, universities, small businesses, and state and local governments. Together these solar energy activities comprise the national solar energy effort. Under the provisions of the Energy Reorganization Act,[1] ERDA has the central responsibility for the Federal Government's solar energy program. The ERDA program, the largest and most heavily funded activity of the solar energy effort, must give that effort substance, shape, and stimulus.

In order to carry out its leadership role as mandated by the Solar Energy Act,[2] ERDA has prepared a National Solar Energy R&D Plan.[3] The primary goal of this plan is to work with industry to develop, demonstrate, and introduce, at the earliest possible time, economically competitive and environmentally acceptable solar energy systems to meet a significant fraction of the nation's energy requirements. ERDA has prepared program plans for the application of solar energy to meet the thermal needs of buildings and for agricultural and industrial processes (ERDA 76-6 and ERDA 76-88 respectively).[4] The present program plan gives details for R&D activities that are only generally outlined in the other two documents.

SOLAR HEATING AND COOLING PROGRAM

The major elements of the ERDA Solar Heating and Cooling Program are:

- Research and development.
- Development in support of building demonstrations.
- Residential building demonstrations.
- Commercial building demonstrations.
- Agricultural and industrial process demonstrations.

The R&D program will provide advanced components and systems that will result in improved performance and lower costs. The development in support of building demonstrations will provide the services necessary to bring these advanced components and systems to the market. The three demonstration programs will indicate ways for available technology to be used to meet the thermal requirements of buildings and of agricultural and industrial processes.

[1] Energy Reorganization Act of 1974, P.L. 93-438, October 11, 1974.

[2] Solar Energy Research, Development and Demonstration Act of 1974, P.L. 93-473, October 26, 1974.

[3] ERDA-48, *National Solar Energy Research and Development Plan*, October 1975.

[4] ERDA 76-6, *National Program for Solar Heating and Cooling, Residential and Commercial Applications*, ERDA (DSE), October 1976. ERDA 76-88, *Program Description, Solar Energy for Agriculture and Industrial Process Heat*, ERDA (DSE), June 1976.

The overall objective of the solar heating and cooling program is to stimulate the development of an industrial, commercial, and professional capability for producing and distributing various solar energy systems, thus reducing the demand on fossil fuel supplies.

TECHNOLOGY STATUS

As part of the preparation of this R&D program plan, several meetings were held with representatives from industry, universities, and Government laboratories and agencies. The objectives of these meetings were to:

- Assess the present state of the art.
- Identify major problems limiting improved performance and/or reduced costs.
- Recommend short- and long-term R&D tasks to solve these problems.

In these meetings and in other discussions, the status of the national solar energy effort was defined. The following points became clear:

- The major problem to be addressed is cost effectiveness.
- The state of the art varies greatly for different components and applications. Solar cooling technology is generally less developed than that for solar heating.
- The applications and climatic zones are so varied that careful analysis is required to determine the most cost-effective approaches.
- Cost-effective retrofit systems are not well developed, nor are techniques readily available to facilitate optimization of retrofit design.

These meetings and discussions also [illegible] many problems that must be solved before the technology can be significantly advanced.

DIRECTED R&D PLAN

ERDA's present [illegible] gram, which has already made [illegible] tions to the present state of technology, will be further strengthened by the initiation of a directed (applications-oriented) R&D program. The specific objective of the directed R&D program is to provide the energy industry and other users with the means (components, information, etc.) to develop cost-effective solar heating and cooling systems. This directed R&D plan defines promising approaches for achieving this objective and outlines a systematic program for providing materials, components, and systems designed to establish the cost effectiveness of each approach as rapidly as possible.

The directed R&D plan described in this report is one of the new initiatives of the ERDA solar heating and cooling program. The other initiatives are:

- A direct market stimulus to aid in creating a large enough market to ensure increasing participation by industry. This stimulus is represented by a major solar service hot water initiative in both the public and private sectors, linked to retrofit applications in commercial and residential buildings.
- A direct manufacturing stimulus, with possible approaches ranging from guarantees to the design or construction of pilot production facilities as incentives for the production of solar energy systems.

STRUCTURE OF THE R&D PROGRAM

This R&D program is based on the development of specific approaches, called paths, to particular solar energy applications. Figure I-1 gives two examples of paths to solar heating and cooling and several examples of building applications. From left to right, this diagram identifies:

- The energy source or sink
- The methods of solar energy collection or heat rejection
- Energy conditioning if required
- The application

[illegible] links a method of energy collection [illegible] with an application.

The program plan calls for ten different paths to the utilization of solar energy for the following specific building applications:

- Service hot water [illegible]
- Space heating [illegible]
- Space cooling [illegible]

[illegible] program plan [illegible] the utilization of solar [illegible] specific agricultural and industrial process applications:

- [illegible]
- Drying [illegible]

[1] The present [illegible] Research and Development [illegible] November 1976, ERDA 76-145. This report may be [illegible] from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

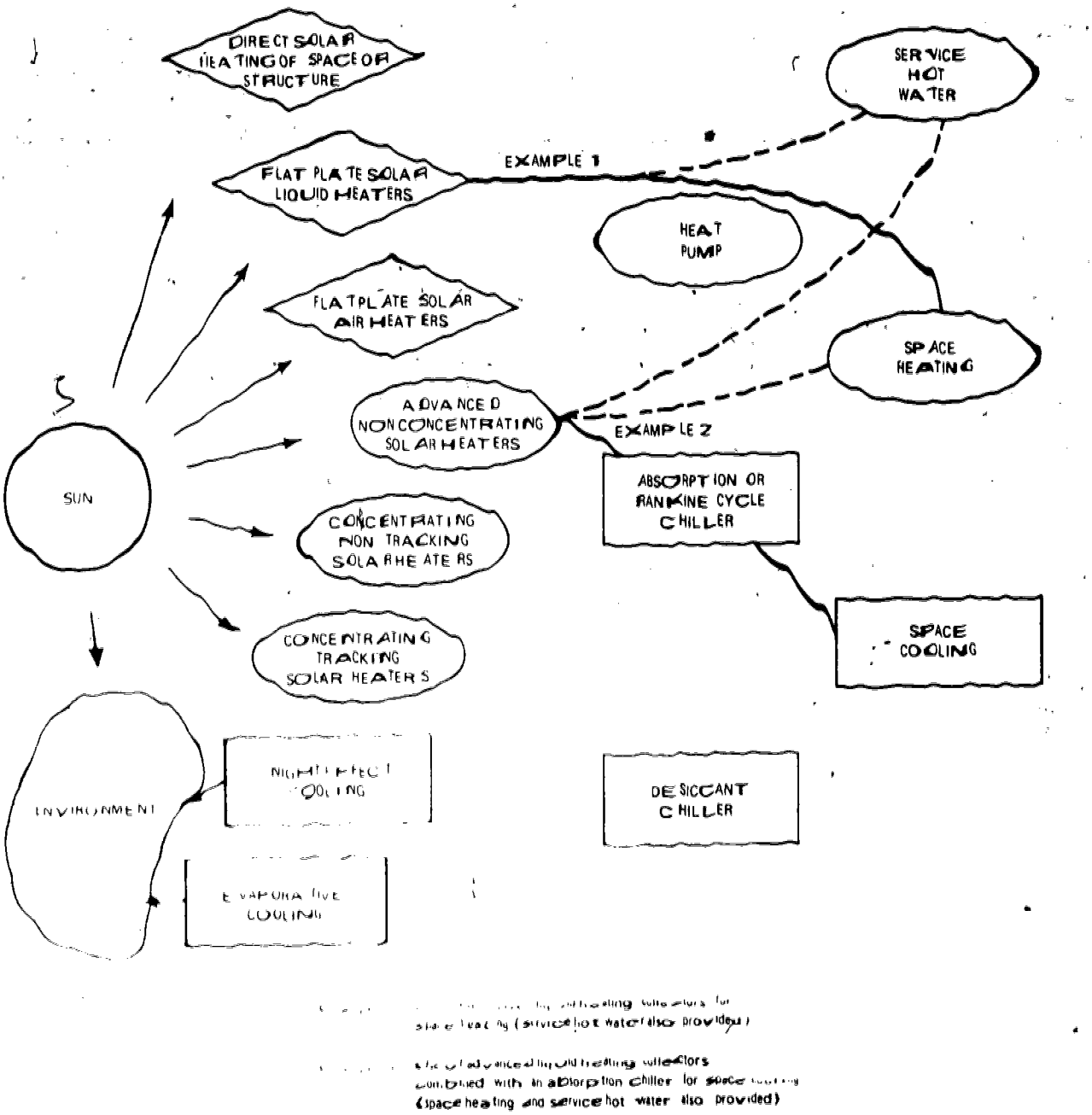


FIGURE 1-1
PATH DIAGRAM EXAMPLES

- Hot water: 2 paths.
- Steam: 2 paths.
- Cooling: 2 paths.

Each path has a single objective: to develop the cost-effective technology to achieve the specific path application as quickly as possible. Paths for the solar heating and cooling of buildings may sometimes lead to more than one application. Space heating paths, for instance, generally involve hot water heating as well; and space cooling generally involves space heating and hot water heating. Agricultural and industrial process applications generally do not involve combinations of paths.

The ten building paths are listed in Table I-1. The designation symbols are as follows:

- Shelter heating: H
- Drying: D
- Cooling: C

The eleven agricultural and industrial process paths are listed in Table I-2. These paths will be designated by two letters to distinguish them from the building paths, the first letter will describe the application

- Shelter Heating: H
- Drying: D
- Hot Water: [illegible]
- Steam: S
- Cooling: [illegible]

The paths [illegible] emphasis on materials [illegible] analysis and others of [illegible] testing. In order to move along any of the paths specific tasks must be undertaken whether in parallel, in series or in combinations of the two. Approximately 275 tasks have been identified and grouped according to the five categories listed in Table I-3. The five are as follows:

- Collector
- [illegible]
- [illegible]
- [illegible]
- Non-engineering [illegible]
- [illegible]

[illegible] detailed [illegible] yet they are [illegible] program [illegible] in solar heating and cooling [illegible] identified tasks are common to several [illegible] and an interdependence therefore exists [illegible]

ious paths. The importance of each task to a given path has been designated by assigning a number on a 0 (unimportant) to 10 (critical) scale.

The tasks pertaining to each path were grouped in functional categories and arranged in sequence. This allows the path to develop in a logical manner.

This R&D program plan concentrates on applications of solar energy to meet the thermal needs of buildings. The paths for the agricultural and industrial process applications are identified, but the only tasks discussed in detail are those relating to the building applications. Results from the building tasks will also frequently apply to the agricultural and industrial process tasks. It is generally agreed, however, that additional agricultural and industrial tasks will eventually be necessary, because of the unique nature of the process paths involved. Identifying these new tasks can begin when the projects and system design studies on which they will be based are completed.

STRUCTURE OF THE R&D PLAN

This R&D program plan consists of three major parts. The first part (the Executive Summary and Sections I and II) gives an overview of the plan. The second part (Sections III and IV) describes the ten paths to solar heating and cooling of buildings and the eleven paths for agricultural and industrial processes. The ten buildings paths are described in Section III where the following information is given for each path.

- A brief description of key features
- The R&D strategy
- The R&D emphasis
- The timing of major [illegible]
- The key milestones

Brief description of the [illegible] industrial process applications is provided in Section [illegible]

[illegible] Appendix A gives [illegible] for the building task groupings and provides information on the timing and arrangement of tasks along a given path. Appendix B contains brief descriptions of the building task including the non-engineering tasks. Where appropriate, the importance of the building task to the path on which it occurs is indicated. Appendix C lists the importance numbers for all of the solar heating and cooling engineering tasks, and Appendix D gives the importance of the non-engineering tasks to the overall R&D program. As previously noted the additional tasks necessary to develop agricultural and industrial process paths are not described in this plan.

TABLE I-1
PATH DESCRIPTIONS FOR HEATING AND COOLING OF BUILDINGS

APPLICATION	DESIGNATION	PATH DESCRIPTION
Service Hot Water	W1	Liquid-Heating Collectors
	W2	Air-Heating Collectors
Space Heating	H1	Solar-Assisted Heat Pump
	H2	Direct Solar Heating of Space or Structure
	H3	Air-Heating Collectors
	H4	Liquid-Heating Collectors
Space Cooling	C1	Concentrating Collectors with Absorption or Rankine Cycle Chiller
	C2	Advanced Non-Concentrating Collectors with Absorption or Rankine Cycle Chiller
	C3	Flat Plate Collectors with Desiccant Chiller
	C4	Evaporative and Night-Effect Cooling

TABLE I-2
PATH DESCRIPTIONS FOR AGRICULTURAL AND INDUSTRIAL PROCESSES

APPLICATION	DESIGNATION	PATH DESCRIPTION
Shelter Heating	HD	Direct Shelter and Greenhouse Heating
	HA	Air-Heating Collector
	HL	Liquid-Heating Collector
Drying	DA	Air-Heating Collector
	DL	Liquid-Heating Collector, Heat Exchanger
Hot Water	WW	Water-Heating Collector
	WA	Air-Heating Collector, Heat Exchanger
Steam (100°C - 200°C)	SL	Advanced Liquid-Heating Collector
	SA	Advanced Air-Heating Collector
Cooling	CO	Passive Cooling
	CH	Collector With a Heat Engine

TABLE I-3
TASK CLASSIFICATIONS

MAJOR CLASSIFICATION	SUB-CLASSIFICATION
I. Solar Collectors	A. System Studies Related to Collectors B. Theory and Basic Phenomena C. Solar Liquid-Heating Collectors D. Solar Air-Heating Collectors E. Advanced Non-Concentrating Collectors a) Evacuated Tube Collectors b) Heat Pipes c) Honeycombs d) Others F. Concentrators G. Reflectors for Flat Plate Collector Augmentation H. Materials a) Selective Surfaces b) Glazing c) Glazing Surface Coatings d) Sealants e) Coolants f) Insulation g) Non-Metallic Films J. Tests and Standards
II. Thermal Energy Storage and Heat Transfer	A. System Studies related to Storage B. Piping, Ducting, Heat Exchangers C. Water Tank Storage D. Rock Bed Storage E Phase Change Storage F Chemical Storage G Tests and Standards
III. Solar Air Conditioning and Heat Pumps	A System Studies related to Air Conditioning, Heat Pumps B Absorption Chillers C Rankine Cycle Vapor Compression Chillers D Evaporative and Night-Effect Chillers E Desiccant Chillers F Other Chillers G Heat-Pumps
IV Systems and Controls	A Integrated Active Solar Systems B System Design Methods C Controllers, Valves, and Actuator Components D Instrumentation and Data Acquisition E Passive and Hybrid Solar Systems F System Studies
V Non-Engineering Aspects of Solar Heating and Cooling	A Economic and Financial Analysis B Consumer Attitudes and Behavior C Marketing, Architecture, and Construction D Energy Utilities E Legal, Regulatory, and Legislative Considerations F Education and Training G Social and Environmental Considerations

With the report organized in this way, the reader can gain an overview of the plan without necessarily becoming involved in its details. Detailed information on tasks and task sequences, however, is available in the appendices.

IMPLEMENTATION

As previously mentioned, the present components-oriented R&D program, which has made significant contributions to the present state of technology, will be replaced by an applications-oriented R&D program. While the presnet R&D program, described in ERDA 76-6, was based on unsolicted proposals, this directed R&D plan will be based on public solicitations, such as the Request for Proposal (RFP) or the Program Research and Development Announcement (PRDA). The involvement of industry, universities, small businesses, and Government organizations in performing the R&D tasks is expected to continue, with project support coming from the national laboratories.

This R&D plan first identifies various paths to major solar heating and cooling applications and then identifies tasks that must be completed for each path to be cost effective. Since the research and development program is a part of ERDA's overall energy program, it has numerous points of contact with other ERDA organizations and with other Federal agencies. The implementation of this R&D program will be coordinated with all appropriate groups. Examples of this coordination include the following:

- All tasks relating to solar radiation will be the responsibility of the Environmental and Resource Studies Branch of DSE.
- Some of the thermal energy storage tasks may become the responsibility of the Thermal Energy Storage Branch of the Division of Conservation. Some tasks may be jointly supported by the Research and Development Branch and the Thermal Energy Storage Branch, and other tasks will be the responsibility of the Research and Development Branch.
- The non-engineering tasks will require more coordination than the engineering tasks, because many of these tasks are at least partially included in the commercial buildings demonstration program and the agricultural and industrial process demonstrations. They therefore involve other Federal agencies, such as HUD, NASA, NBS, GSA, DOD, and USGA. The Barriers and Incentives Branch of DSE will generally be responsible for the non-engineering tasks described in this plan.

Tasks pertaining only to the demonstration program are not included in this R&D plan. Many tasks, however, are the common responsibility of the R&D and demonstration programs. In those instances, advantage will be taken of available services established as part of the demonstration program, with additional activities supported only as needed to meet the special needs of the R&D program.

SECTION II

PROGRAM OBJECTIVE AND EMPHASIS

OBJECTIVE

The objective of the solar heating and cooling research and development program is to assist in creating a viable solar industry. The research and development program is designed to achieve this goal by lowering costs and improving the efficiency of solar energy components and systems. The specific objective of the directed R&D program is to provide the emerging solar energy industry and other users with the materials, components, and information needed for cost-effective solar heating and cooling systems.

EMPHASIS

The R&D plan emphasizes the following program elements:

- Material: characterization and development.
- Components: development of components, including their theory of operation, mathematical modeling, performance testing, and system compatibility.
- Systems: identification of the predicted and actual performance of solar heating and cooling systems for varying climates, building types, competing energy types, and system configurations.
- Information: dissemination of results of all R&D projects, with special attention to system test results. As much information as possible will be put into handbook form.

The R&D program plan is directed at short term objectives and designed to provide maximum support to the developing solar energy industry. Research and development related to long term objectives will continue concurrently. Thus, basic or applied research on new surfaces for solar collection or new thermodynamic cycles for cooling will continue to be supported within the broader R&D program.

The directed R&D program will meet the needs of a developing solar heating and cooling industry by accomplishing the following:

- Supporting the development of components having improved performance and/or lower cost.
- Conducting tests of systems with advanced components to provide the full range of data essential to the development of new solar heating and cooling systems.
- Providing data, information, and computing techniques that the potential users of solar energy may require in order to determine costs and benefits.
- Evaluating various economic, environmental, social, institutional, and legal factors which could influence the manner in which solar thermal energy is used.

In general it is recommended that product development be carried out by the industry that will eventually market the product. This work will be supported by the R&D program where it is desirable to obtain a prototype or pre-prototype for testing. Furthermore, the R&D program will concentrate on providing the technology and information required, so that the industry can develop as quickly and effectively as possible.

The R&D program will have several major areas of emphasis. These are discussed in the following paragraphs.

Materials Characterization and Development

It is often necessary to determine the materials that are necessary for solar heating and cooling components if those components are to function properly. The demands placed on materials are often stringent. They usually include long service life, low initial cost, usefulness in a particular environment (such as a home or factory), compatibility within a system, and

availability. Materials requirements often present complex problems. For instance, the current choice of a liquid coolant is a mixture of ethylene or propylene glycol and water. This mixture, however, forms glycolic acids at temperatures that occur in normal collector operation; and these acids can cause system corrosion and breakdown.

The cost of the R&D necessary to improve component materials generally cannot be borne by any single manufacturer of components or systems, and it seems essential that the Federal program support the necessary research and development and prepare information on characteristics and requirements for materials.

Development of Components

In order to properly evaluate the potential of a particular solar heating system component or configuration, it is necessary to characterize the performance of that component or system mathematically. Such mathematical models must account both for the steady state operation of components and for their dynamic or transient performance. The models must be developed where they do not currently exist and must be calibrated by comparison with steady state and transient tests made on prototypes. The entire operation of a system must then be validated to confirm that the model correctly describes component interaction.

Manufacturers often perform the type of system modeling described above when they plan a new product line. The job of validating the model, however, is often beyond the means of any single manufacturer, and as a result this step is usually omitted or performed in an abbreviated fashion. This can result in components that are inappropriate for the systems for which they were designed. Manufacturers of absorption chillers, for instance, are often familiar with the steady state modeling of these units but unfamiliar with their transient modeling because transient modeling is not often necessary for conventional operation. The transient characterization becomes important though when the chiller is incorporated in a solar heat collection system because the input temperature to the generator in such a system may not be constant. The transient behavior of the chiller and its influence on overall system operation must therefore be understood. The potential manufacturers may also not understand the operation of all other components in the system and may be unable to afford a complete system modeling and validation

System Analysis

Through system
the performance

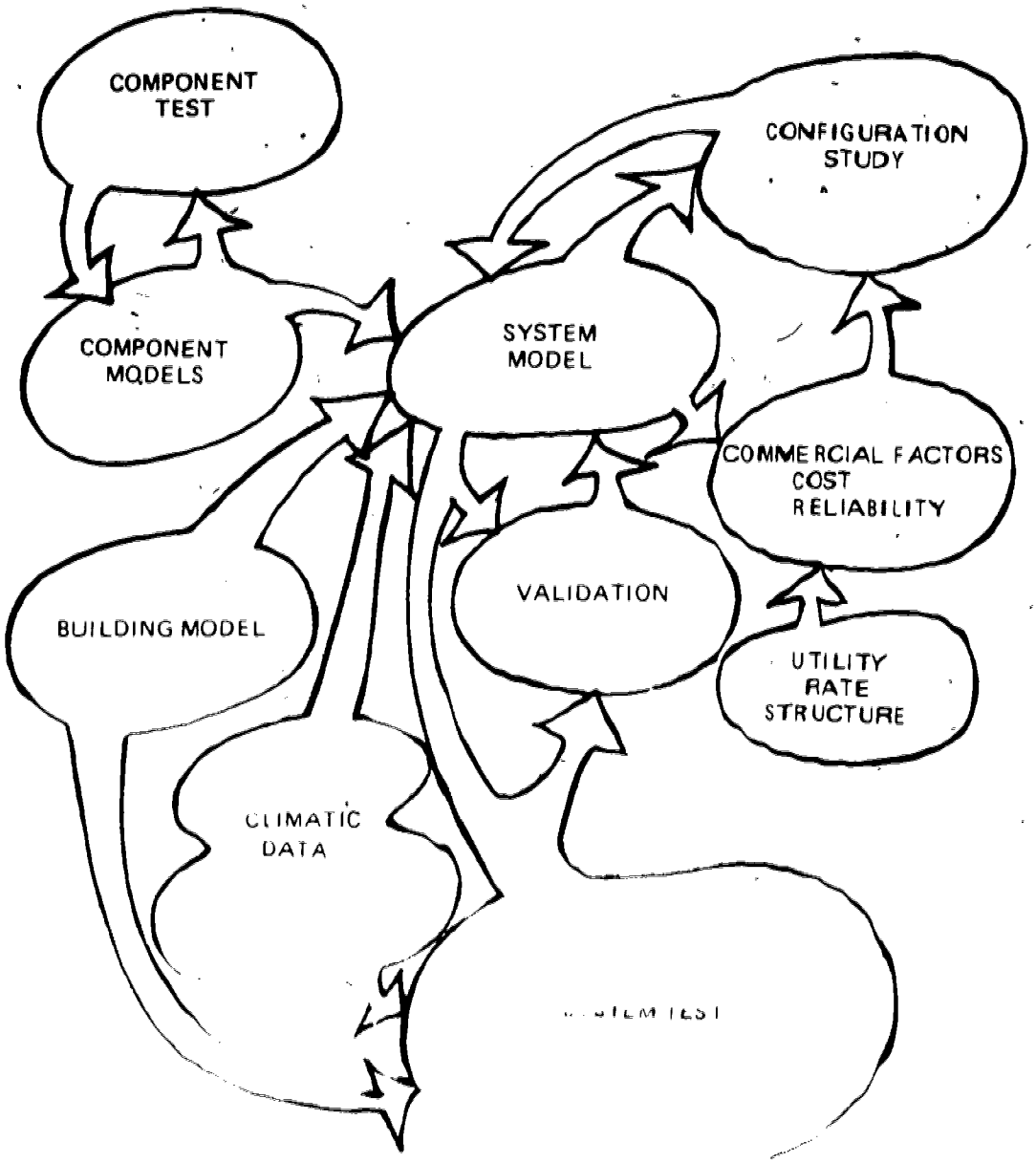
and cooling systems for varying system configurations, climates, building types, and competing energy types. System analysis includes system modeling and testing to validate the performance models and to provide data on system operation. Because building and energy types, climatic zones, and system configurations are all subject to considerable variation, complete system analysis is extremely complex. For example, solar collectors can be combined with heat pumps in dozens of ways to provide net heat output. There are at least 13 different U.S. climatic zones and 5 different building types that must be considered, and fuel types and prices also vary greatly. As a result, the entire set of these possibilities has never been evaluated for even the simplest solar heating system. It is not necessary to evaluate every case, because many are clearly inappropriate, but a comprehensive analysis is necessary for even a first order evaluation of combinations of heat pumps with solar heating and cooling systems.

Dissemination of Information

Component tests and integrated system tests will be carried out under the proposed solar heating and cooling R&D program. These system tests will provide information on actual system operating and maintenance characteristics. They will also provide data for validating the models developed to predict system performance. There will be relatively few system tests, and they will be carefully chosen to provide information on the types of systems most likely to be economically and operationally useful. (Remarkably little information of this type exists at the present time.) Wherever possible, the systems tested will be those already included in the R&D program or in the demonstration program. Where suitable arrangements can be made, systems built privately or by other Government institutions can be used.

A comprehensive parallel plan will be developed to disseminate this information on system testing to the various user groups. This will be done through reports, conference proceedings, and summary material such as design guides, handbooks, and compendia of the results of those tasks which specifically address information collection and system analysis. Care will be taken that the publications are phased to correspond to the R&D plan accomplishments. These data collection and information dissemination activities will be coordinated when possible with the centralized data collection and information dissemination system established under the Solar Heating and Cooling Demonstration Program.

The schematic in Figure 11 illustrates the relationships between component tests, component modeling, system tests, system modeling, and system analysis.



...ystem ... mathematical model. The mathematical model reproduces the data observed during the validation. In a configuration study various components are combined in different configurations each of which is then analyzed for performance and cost effectiveness in different climates.

...ANALYSIS II...

Non-Engineering Aspects

The economic, institutional, and social environment in which solar heating and cooling technology will be applied must be analyzed. All of the following are necessary:

- Collection and dissemination of information on economics, legislation, market structures, consumer attitudes, etc.
- Analysis of policies that may have an impact on the commercialization of solar heating and cooling.
- Research on factors that might affect the acceptance of solar heating and cooling systems and development of acceptance design goals for the R&D program.

The information gathered in these steps will serve several purposes. It can be used in establishing priorities for the R&D program as well as for individual paths in the program. It can also be used to identify possible impediments to the widespread use of solar energy systems. Once the impediments are identified, policies can be designed to overcome them.

Approximately forty non-engineering tasks have been identified and grouped according to the seven classifications in Table I–3. The tasks themselves are described in the fifth section of Appendix B. Because these tasks involve questions common to all solar applications, they are not associated with particular paths. Instead, the importance of each task to the total R&D program (including the building and the agricultural and industrial process applications) is given in Table D–1.

Part II. PATHS

SECTION III

R&D PROGRAM STRUCTURE: HEATING AND COOLING OF BUILDINGS

This section describes in detail the ten different paths to the solar heating and cooling of buildings. Table III–1 lists the paths, their designations, and features. The table is followed by three illustrations (Figures III–1 to III–3). The three figures show the paths to solar heating of hot water, solar heating of buildings, and solar cooling of buildings. Individual descriptions of the paths follow in order. Each description contains a general comment, a discussion of the recommended R&D strategy, a tabulation of the principal R&D task groups, and charts which indicate task sequence and milestones.

TABLE III-1
PATHS TO SOLAR HEATING AND COOLING OF BUILDINGS

APPLICATION	DESIGNATION	ENERGY COLLECTION OR REJECTION	ENERGY CONDITIONING
Service Hot Water	W1	Liquid-Heating Collectors a) Conventional Flat Plate b) Advanced Non-Concentrating	None
	W2	Air-Heating Collectors a) Conventional Flat Plate b) Advanced Non-Concentrating	None
Space Heating	H1	Solar-Assisted Heat Pump a) Environment b) Direct Solar Heating of Space or Structure c) Liquid-Heating Collectors d) Air-Heating Collectors e) Advanced, Non-Concentrating Solar Collectors	Heat Pump Heat Pump Heat Pump Heat Pump Heat Pump
	H2	Direct Solar Heating of Space or Structure	None
	H3	Air-Heating Collectors a) Conventional Flat Plate b) Advanced, Non-Concentrating	None
	H4	Liquid-Heating Collectors a) Conventional Flat Plate b) Advanced Non-Concentrating	None
Space Cooling	C1	Concentrating Collectors	Absorption Chiller Rankine Cycle Chiller
	C2	Advanced, Non-Concentrating Collectors	Absorption Chiller Rankine Cycle Chiller
	C3	Flat Plate Collectors a) Air-Heating Collectors b) Liquid-Heating Collectors	Desiccant Chiller
	C4	Evaporative and Night-Effect Cooling	None

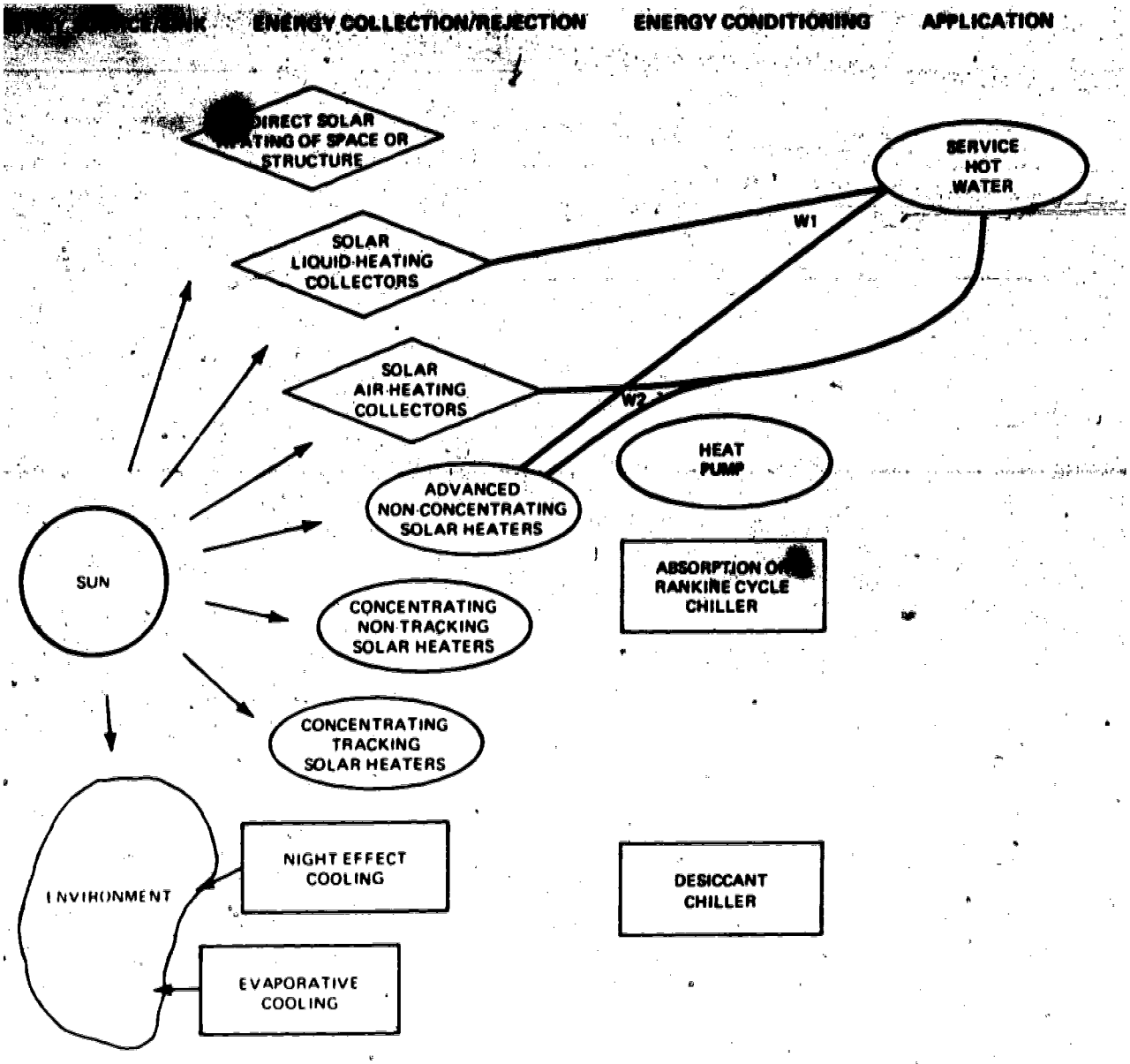


FIGURE III-1
PATHS TO SOLAR HEATING OF SERVICE HOT WATER

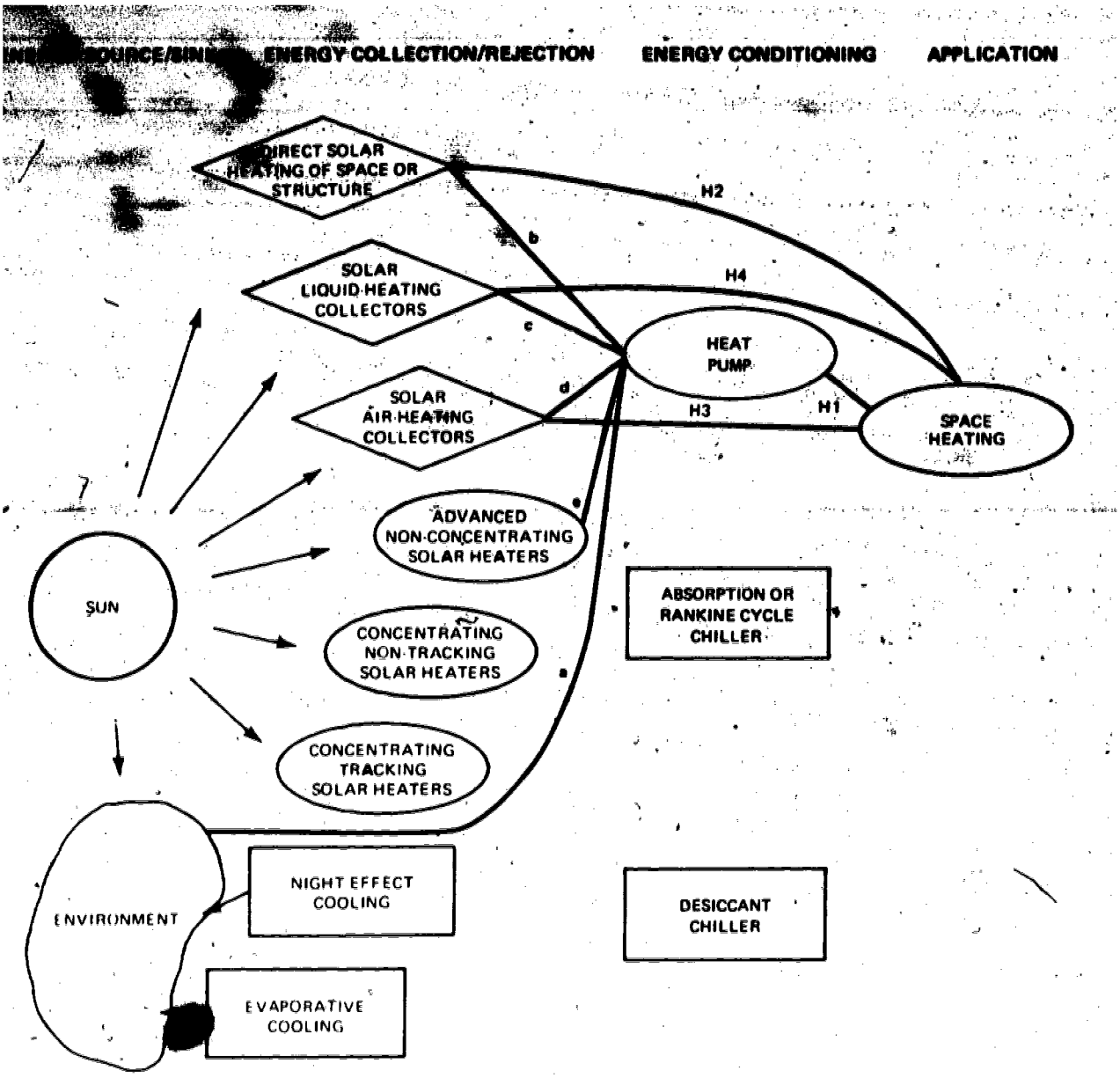


FIGURE III-2
PATHS TO SOLAR SPACE HEATING

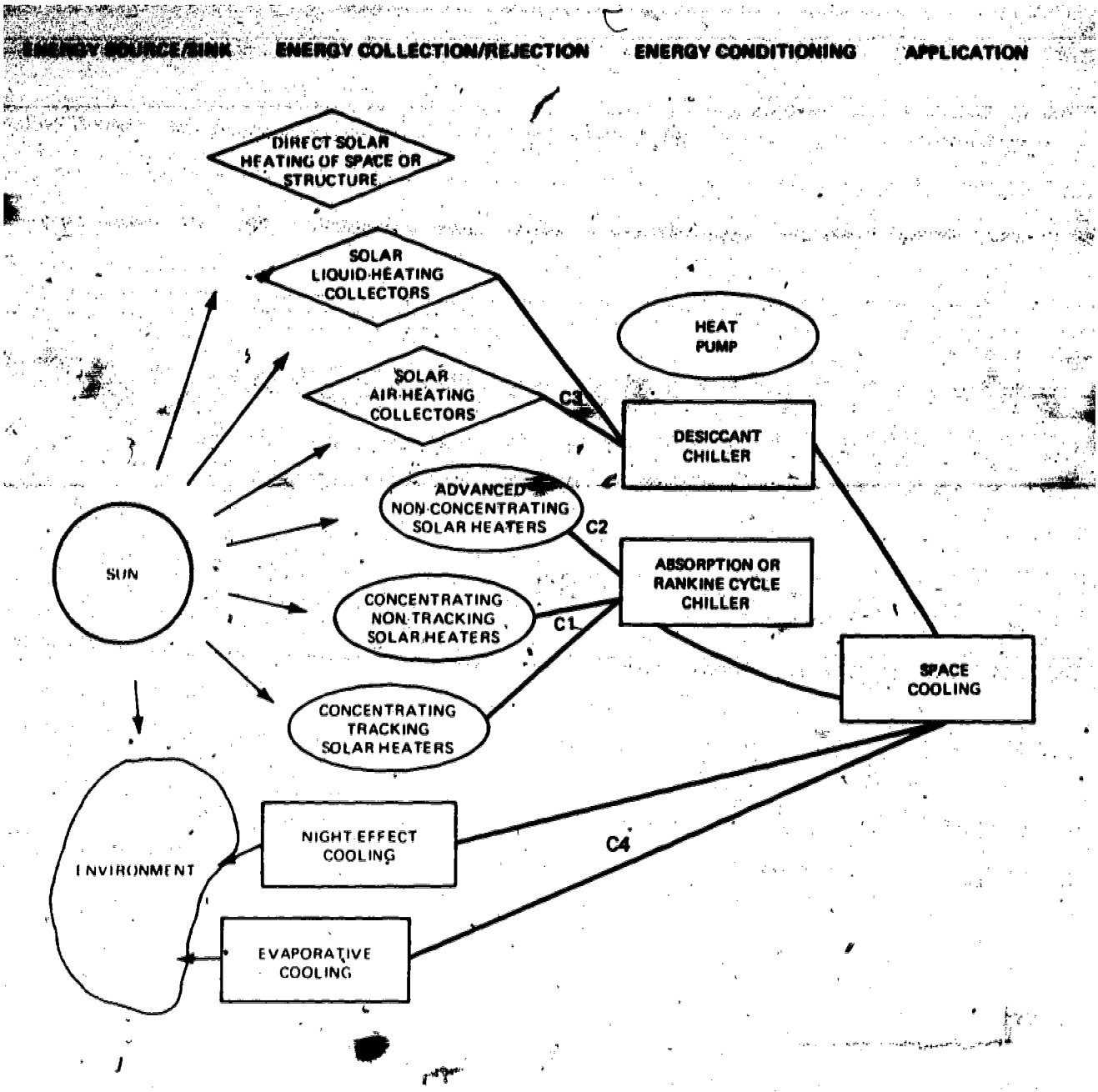


FIGURE III-3
PATHS TO SOLAR SPACE COOLING

LIQUID-HEATING COLLECTORS FOR SERVICE HOT WATER PATH W1

GENERAL

In this system, water or another liquid passes through liquid-heating collectors (flat plate and/or advanced non-concentrating) and transfers heat to a water storage tank, either directly or through a heat exchanger. Thermal storage will usually be in either the normal domestic hot water tank or in a separate preheater tank. Freeze protection is a major design consideration in most climates. Hot water heating is more economical than space heating because the equipment can be used all year, thus achieving a high total energy yield from the collectors. Since the collector area needed is small (from 5 to 200 sq. ft.), ample rooftop space is usually available for mounting the collectors, even in a retrofit situation. Since the investment for hot water heating systems is small, many people are able to install them. A special problem arises in that the system must interact with the potable water supply without danger to the health of the users.

R&D STRATEGY

The objective of this path is to assist a small but viable and developing solar water heater industry. To accomplish this objective, the basic characteristics of the many approaches to service hot water heating will be identified. The emphasis will be on determining basic climate/performance characteristics for these approaches. This will be accompanied by materials characterization, testing, and evaluation. A survey will be made of various approaches to freeze protection, methods of integration with existing hot water systems, and cost-performance characteristics of existing marketed systems. Several points will be emphasized:

- The question of stratification in the storage tank and how stratification is affected by the shape, type, and location of the auxiliary heaters.
- Novel design of appropriate heat exchangers operating at low flow rates and with small temperature drops. Advantage will be taken of the fact that the structural limitations are minimal.
- Finding the appropriate method of connecting collectors.

R&D EMPHASIS

Materials Characterization and Development

- Collectors: glazings, surface coatings, sealants
- Coolants: emphasis on non-toxic coolants
- Heat exchange materials
- Plumbing materials
- Liquid/multi-metallic corrosion effects
- Freeze protection techniques
- Insulation material

Component Development and Testing

- Collectors: including method of connecting
- Storage tanks: including stratification and auxiliary heater configuration
- Heat exchangers: fluid to fluid and direct contact
- Reflectors

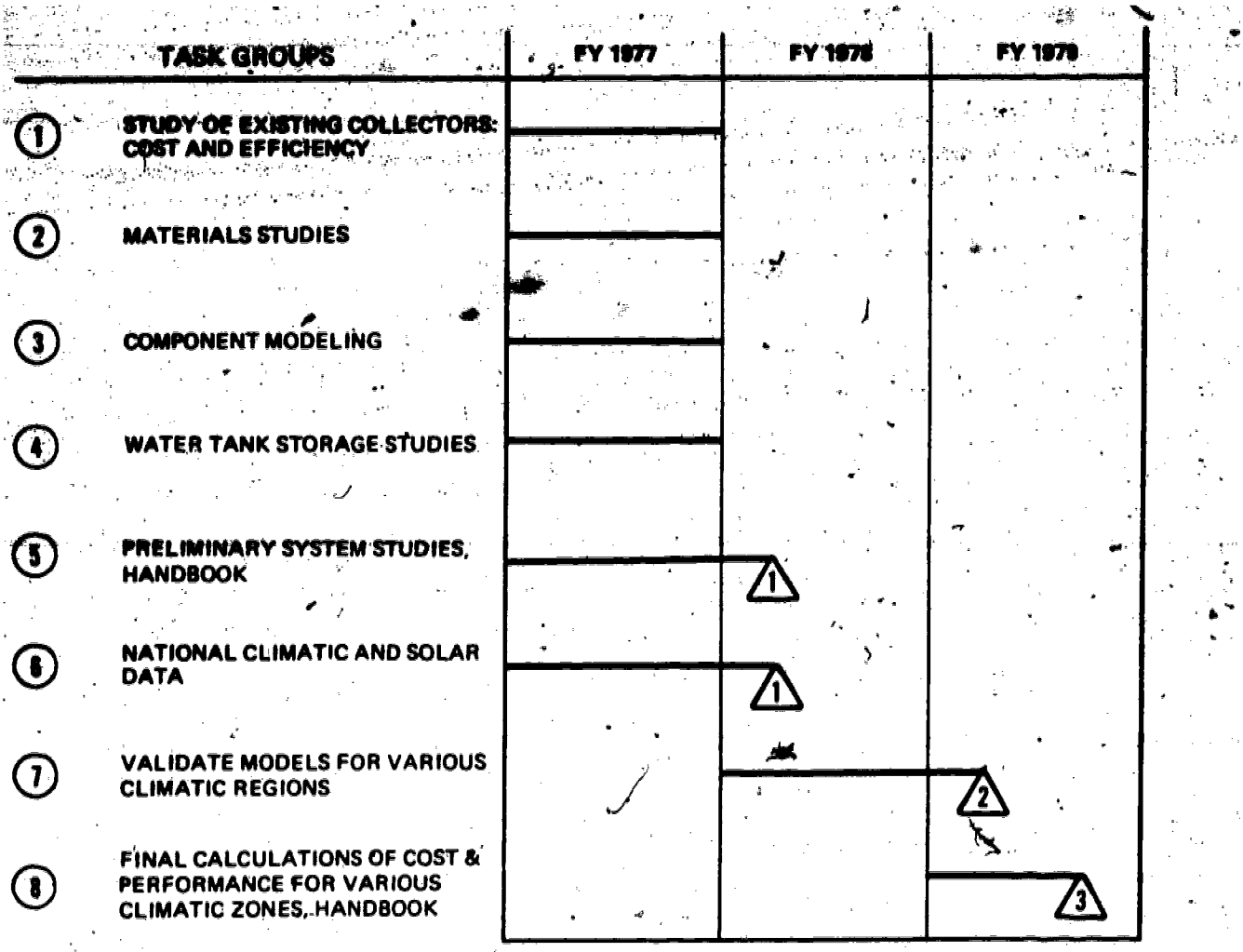
System Analysis

- Market identification
- Performance identification: energy yield as a function of climate, system configuration and design, collector performance characteristics, domestic hot water use pattern and temperature requirement, and collector shading

Cost identification: survey of current system costs
Techniques and implications of retrofitting
Architectural integration
Simplified performance prediction methods
Preparation of handbooks

System Testing

Data gathering on test systems
Model and theory validation



MILESTONE

1/78 (1) Complete system studies identifying performance and cost characteristics for systems chosen for various climatic regions. This will be done assuming validity of current simulation techniques and the characteristics of existing hardware. Publish preliminary handbook.

1/79 (2) Complete a review of system simulation techniques (based on improved system and collectors), validate mathematical models, and certify that the final phase should proceed.

6/79 (3) Repeat above system analysis based on validated models and improved components. Publish revised handbook.

FIGURE III-4
LIQUID-HEATING COLLECTORS FOR SERVICE HOT WATER
PATH WT ACTIVITY SCHEDULE

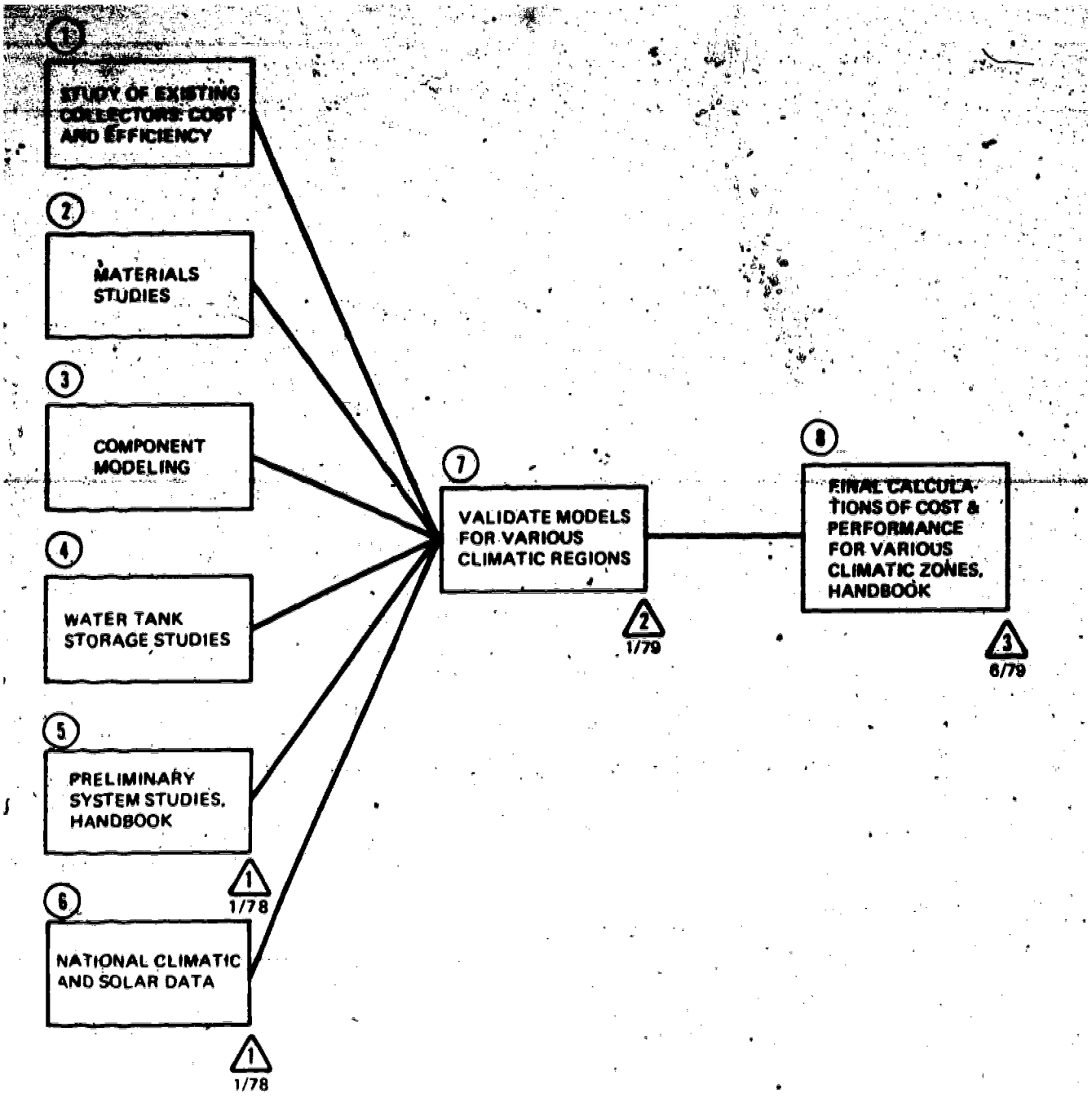


FIGURE III-5
LIQUID-HEATING COLLECTORS FOR SERVICE HOT WATER
PATH W1 FLOW CHART

AIR-HEATING COLLECTORS FOR SERVICE HOT WATER PATH W2

GENERAL

The use of air-heating collectors for service hot water presents two problems: Not enough is known about their method of application, and they are subject to significant heat transfer losses. The heat transfer loss occurs because a heat exchanger is required between the air flowing through the collector and the service water to be heated. The performance of an air-heating system may therefore be lower than that obtained using liquid-heating collectors, but air offers several advantages: It is non-freezing, non-corroding, and non-toxic. Thermal storage for air-heating collectors will generally be either the normal domestic hot water tank or a separate preheater tank.

R&D STRATEGY

The objective of this path is to determine the economic viability of the air-heating approach. The program will emphasize identification of the performance characteristics for various collectors and climates. Materials work will be directed principally toward improved collector durability and performance. Systems will be packaged so as to reduce costs and a few systems will be evaluated. Higher temperature collectors will be emphasized in order to compensate for the heat-exchange temperature drops elsewhere in the system. Storage tanks and auxiliary heaters will be designed to maximize stratification. The best pattern of collector connection will be determined.

R&D EMPHASIS

Materials Characterization and Development

Collector: glazing, surface coatings, sealants

Materials for suppression of collector convection losses

Insulation material

Component Development and Testing

Air-heating collectors

Heat exchangers: air to water and direct contact

Tanks: emphasis on stratification and proper geometry and location of auxiliary heaters

Reflectors

System Analysis

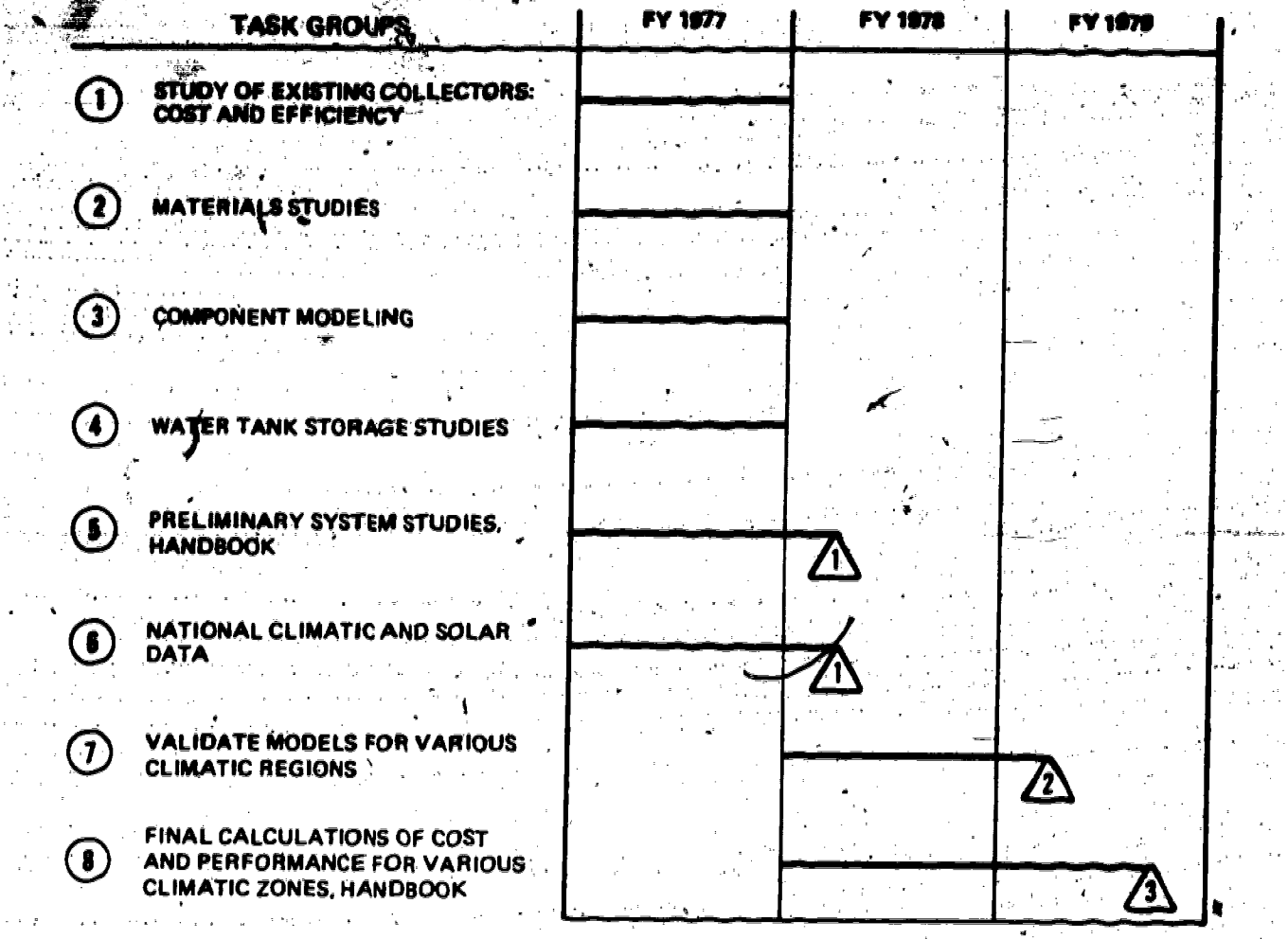
Performance identification: energy yields as a function of collector performance, system design characteristics, climate, storage size and configuration, and water use characteristics

Cost identification: emphasis on existing equipment and pre-packaging

Retrofit installation compatibility

System Testing

Conduct a number of identical system tests in various locations to validate theory and models



MILESTONES

1/78 (1) Complete system studies identifying performance and cost characteristics for systems chosen for various climatic regions. This will be done assuming validity of current simulation techniques and characteristics of existing hardware. Publish preliminary handbook.

1/79 (2) Complete a review of system simulation techniques (based on improved system and collectors), validate mathematical models, and certify that the final phase should proceed.

6/79 (3) Repeat above system analysis based on validated models and improved components. Publish revised handbook.

FIGURE III-6
AIR-HEATING COLLECTORS FOR SERVICE HOT WATER
PATH W2 ACTIVITY SCHEDULE

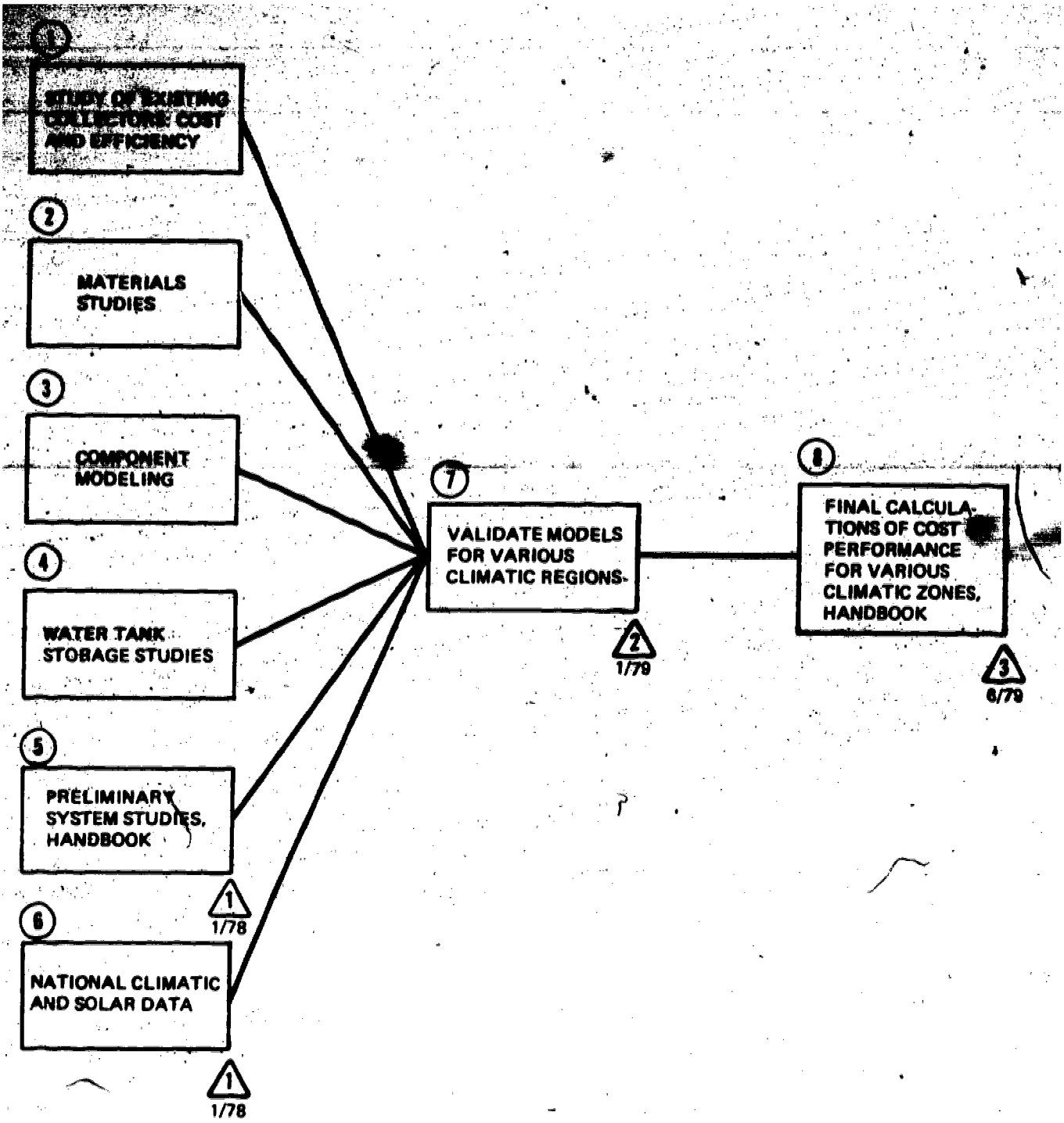


FIGURE III-7
AIR-HEATING COLLECTORS FOR SERVICE HOT WATER
PATH W2 FLOW CHART

SOLAR-ASSISTED HEAT PUMPS FOR SPACE HEATING PATH H1

GENERAL

The objective of this path is the introduction of solar-assisted heat pumps into the market in a cost-effective manner. Auxiliary electrical energy must also be available to drive the heat pumps. A heat pump can use one unit of electrical energy to generate three or more units of thermal energy. Solar-assisted heat pumps make possible the spreading of electrical energy over a longer period of time, thereby decreasing the peaking effect on the electric utility.

The low temperature energy source for the heat pump could be supplemented by various types of collector:

- Direct solar heating of a space or structure (e.g., a solarium or a properly constructed south wall).
- Solar liquid-heating collectors.
- Solar air-heating collectors.
- Advanced non-concentrating collectors.

Extensive system analysis will be necessary to identify those configurations that will be most cost effective in different climatic zones.

Thermal storage can be used on both sides of the heat pump. Low temperature storage smoothes the mismatch between solar input and load demand. High temperature storage can level or even invert the electrical load profile. Low temperature storage devices will vary with the source, while high temperature storage will generally be by means of a water tank.

The economic attractiveness of this approach is increased by the fact that the heat pump can be used for space cooling during the summer, transferring heat from inside the space to the environment.

R&D STRATEGY

A comprehensive analysis of system sensitivity will be made through computer simulation of those configurations that are identified as attractive. This sensitivity analysis will be carried out for various climatic zones and design parameters. Performance predicting will be done both for currently available heat pumps and for improved performance heat pumps. In the second phase, a few operating systems will be built to validate the model and obtain operating experience. Improved performance heat pumps will be developed and cost tradeoffs studied. The technology base for the required collectors, storage, heat pumps, and other subsystems must be established.

The solar heating and cooling R&D program of the Electric Power Research Institute (EPRI) emphasizes the development of solar-assisted heat pumps for space heating with the purpose of providing energy load management flexibility for electric utilities. Cooperation between the EPRI and ERDA programs has been established and will be maintained to avoid unnecessary duplication of effort.

SYSTEM TESTS

The R&D program will probably sponsor several full operating system tests. These will be carefully designed to correspond to configurations which have been identified as optimum for the several different climatic zones. The systems will be thoroughly instrumented, and their performance monitored and evaluated. The primary purpose is to validate the computer models used to choose the optimum systems and to identify appropriate design improvements.

R&D EMPHASIS

Materials Characterization and Development

Since most of the applications are low tempera-

[illegible] (< 120°F), the emphasis will be on characterization of low cost conventional materials. This applies to glazings, sealants, coolants, and insulation.

Component Development and Testing

Collectors: general, emphasis on low temperature, low cost, and integration with structure

Heat pumps: emphasis on transient performance

Solar ponds

System Analysis

Performance identification: energy yield as a function of system configuration and design, collector performance, climate, storage characteristics, and heat pump characteristics

Load profile determination and utility interactions

Cost identification: survey of costs using existing equipment and technology, cost allocation due to summer use of heat pump for cooling

Architectural integration

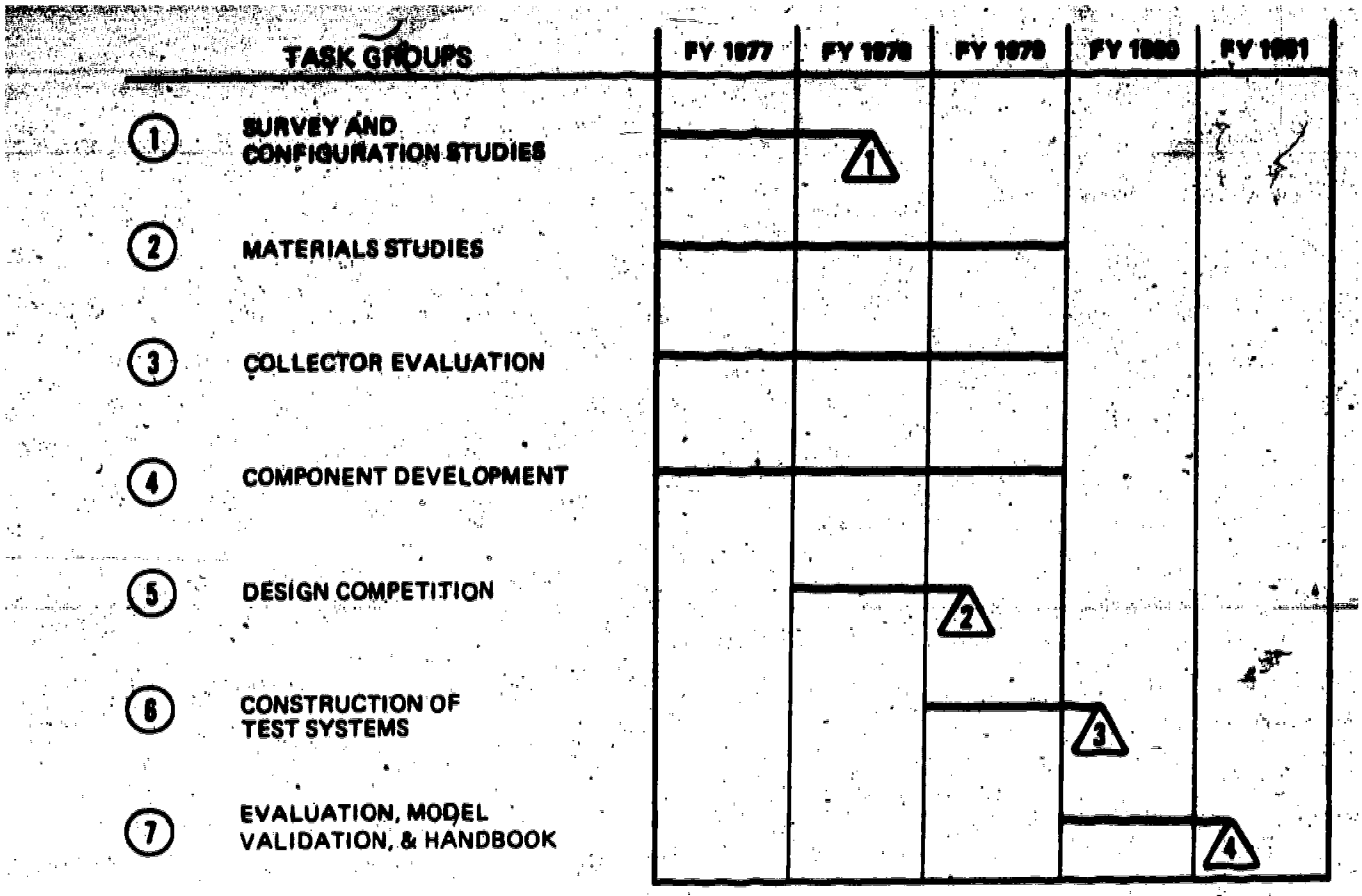
Assessments of domestic hot water add-on and retrofit potential

System Testing

Data gathering on existing systems

New system tests

Model and theory validation



MILESTONES:

4/78 (1) Publication of the results of solar-assisted heat pump configuration studies, identifying the most effective design approaches for each climatic zone.

1/79 (2) Selection of several designs of solar-assisted heat pump systems from among those submitted in response to a design competition. Awarding of contracts for construction.

1/80 (3) Construction of test systems.

1/81 (4) Validation of computer simulation models of solar-assisted heat pump systems. Publication of results in a handbook.

FIGURE III-8
SOLAR-ASSISTED HEAT PUMP FOR SPACE HEATING
PATH H1 ACTIVITY SCHEDULE

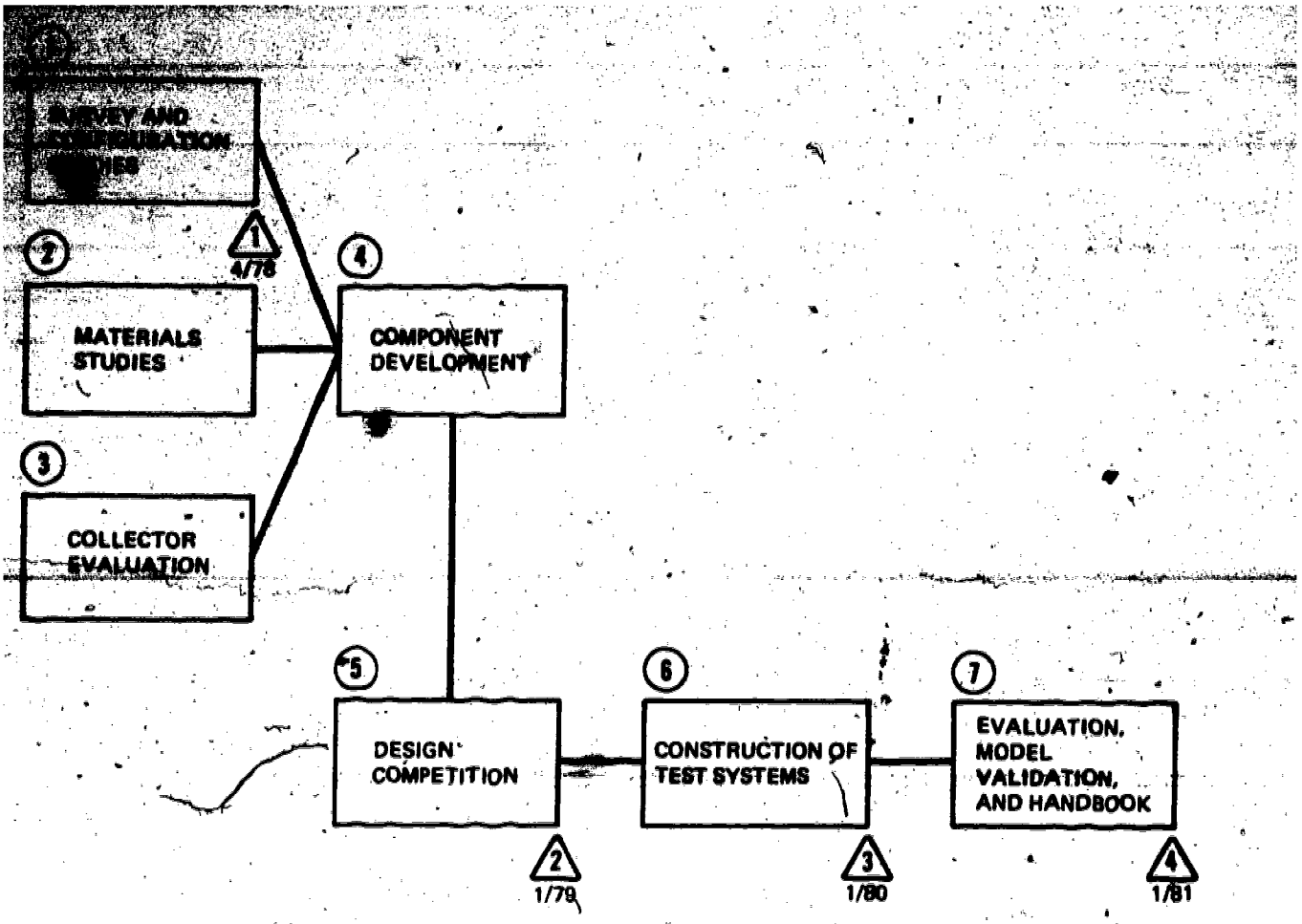


FIGURE III-9
SOLAR-ASSISTED HEAT PUMP FOR SPACE HEATING
PATH H1 FLOW CHART

DIRECT SOLAR HEATING OF SPACE OR STRUCTURE PATH H2

GENERAL

For most buildings, normally incident sunshine provides up to 30 percent of the heat requirement that the building would have without direct solar gains. If the structures are improved, however, that figure can be raised to 50 percent. Design techniques for accomplishing this include improving windows and walls, adding skylights and clerestory windows, and modifying roofing sections.

Thermal storage is usually necessary to obtain solar heating fractions greater than 50 percent. Energy will usually be stored in portions of the structure with large thermal capacities (walls, floor), in specially designed storage units located in or adjacent to the heated space, or in separate thermal storage units coupled to the heated space by forced or natural circulation.

In some building designs movable insulation is used to decrease heat losses at night. Such insulation used with a conventional heating system keeps temperature variations in the building within acceptable limits

R&D STRATEGY

Emphasis will be [illegible] storage, and heat rejection characteristics of [illegible] system designs. Thermal simulation computer models of these systems will be generated, validated, and used to determine system design parameters and effective geographical ranges. The energy yields that can be expected in each climatic zone will also be determined. Architectural integration and cost effectiveness are of paramount concern in the evolution of each design, and information dissemination is perhaps more important for this task than for any other

This category includes [illegible] not restricted to passive solar heating concepts

R&D EMPHASIS

Materials Characterization and Development

Structural or coating materials for storing water in containers in sunlight

Phase-change materials with containers for heat storage at or slightly above room temperature

High transmissivity glazings

Heat transport fluids which expand on cooling, providing a reverse thermosiphon

Component Development and Testing

Thermic diode wall or roof structure

Light and heat flow-control devices

System Modeling

Identify basic characteristics of each type of system

Validate system models

System Analysis

Performance identification: energy yields as a function of system type, solar load ratio, climatic zone, and design parameters

Cost identification: cost characteristics relative to system type

Cost distribution when components have combined functions (a wall, for instance, that has structural and heat storage functions)

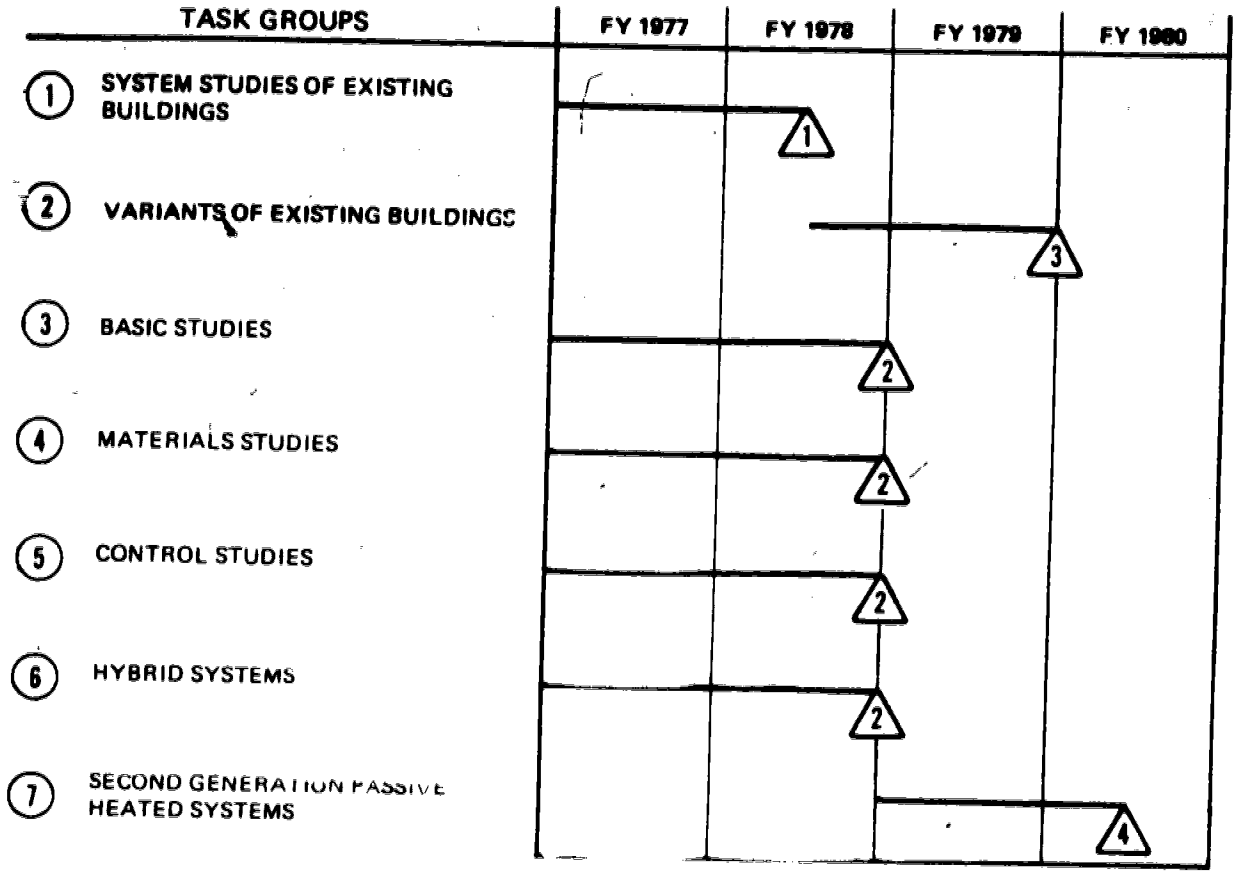
Architectural integration

Retrofit potential

System Testing

Data gathering on [illegible]

Model and theory validation



[illegible]

[illegible] and distri[illegible] a handbook on current designs for buildings [illegible] heated predominantly by direct solar heating of the space or structure.

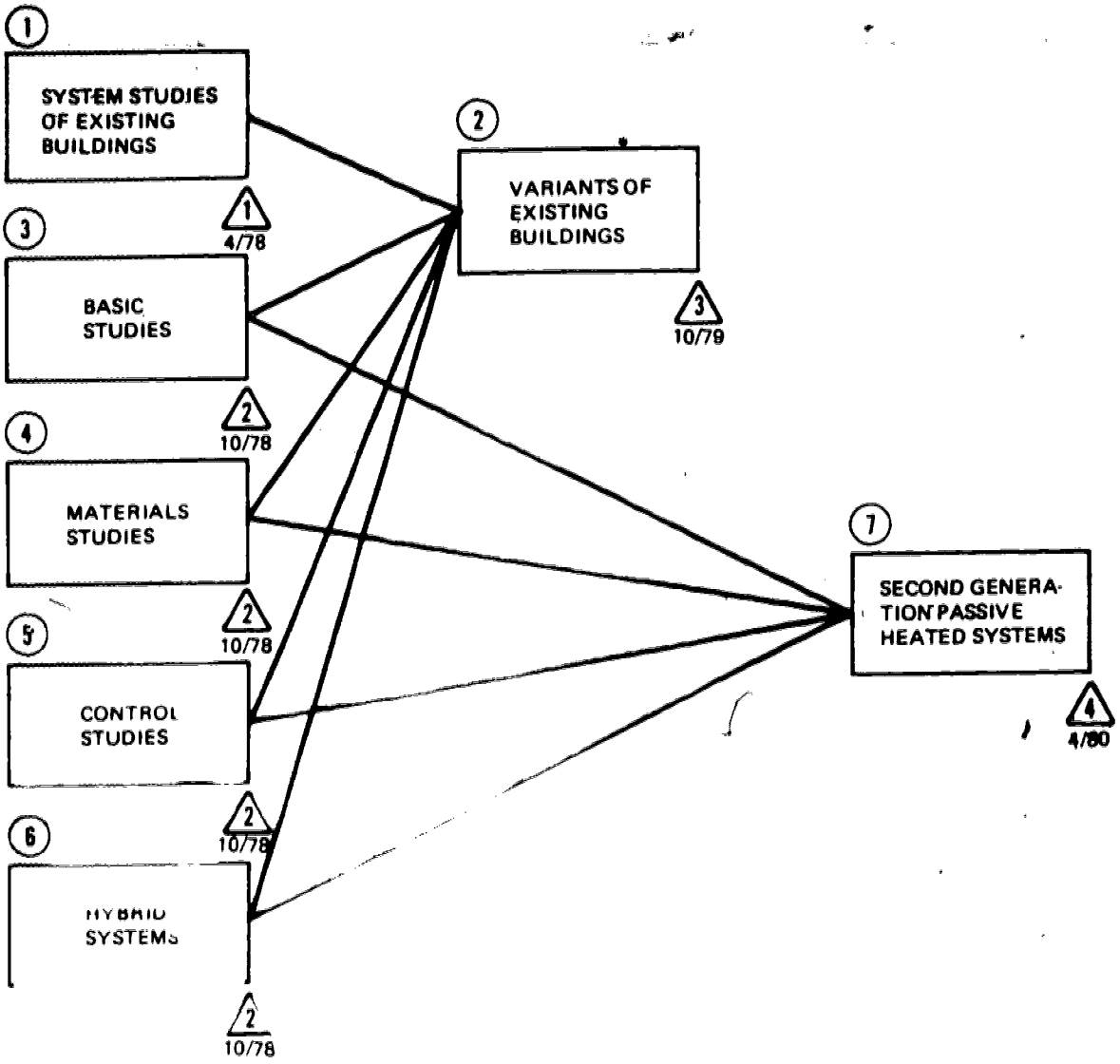
4/78 1 Based [illegible]

10/78 2 Based on results [illegible] materials and control studies [illegible] results with hybrid systems

[illegible] 3 Based on variants and improvement of currently existing buildings.

[illegible] 80 4 Based on results of second generation buildings

[illegible] ACTIVITY SCHEDULE


1
SYSTEM STUDIES OF EXISTING BUILDINGS
1
4/78
2
VARIANTS OF EXISTING BUILDINGS
3
10/79
3
BASIC STUDIES
2
10/78
4
MATERIALS STUDIES
2
10/78
5
CONTROL STUDIES
2
10/78
6
HYBRID SYSTEMS
2
10/78
7
SECOND GENERATION PASSIVE HEATED SYSTEMS
4
4/80

[illegible] FLOW CHART

AIR-HEATING COLLECTORS FOR SPACE HEATING PATH H3

GENERAL

In a space heating system employing an air-heating collector (flat plate or non-concentrating), air passes through channels in the collector and is heated. The heat is transferred to a storage system, usually a bin of rocks under or within the heated space. Where space or weight limitations require it, other storage media, such as containers of water or a phase-change material (paraffin or a hydrated salt), may be considered.

Although air has a low heat transfer coefficient, the system can be designed for performance comparable to that for a system using liquid-heating collectors and water tank storage. In addition, the air system offers potential advantages in cost, ease of installation, maintainability, convenience, and durability. The system lends itself to a combined space heating and domestic hot water heating application. Its primary disadvantage is that the volume required for thermal storage and ductwork may argue against using the concept in retrofit applications.

R&D STRATEGY

Emphasis will be placed on bringing air systems state of the art up to the level achieved for liquid systems. This can be done through collector development stressing performance, cost optimization, materials, and testing and through system development stressing design and layout configurations that minimize system costs. Hybrid systems that use direct solar gains will also be extensively investigated.

R&D EMPHASIS

Materials Characterization and Development

Collectors: glazings, surface coatings, sealants

Phase-change materials for storage

Component Development and Testing

Collectors: general

Improved heat transfer in collectors

Rock beds

Tube bundles: including phase change

Model and theory validation

System Analysis

Performance identification: energy yield as a function of system configuration and design, collector performance, solar load ratio, climate, air leakage, and storage characteristics

Cost identification: survey of costs in existing systems and breakdown of costs by major categories

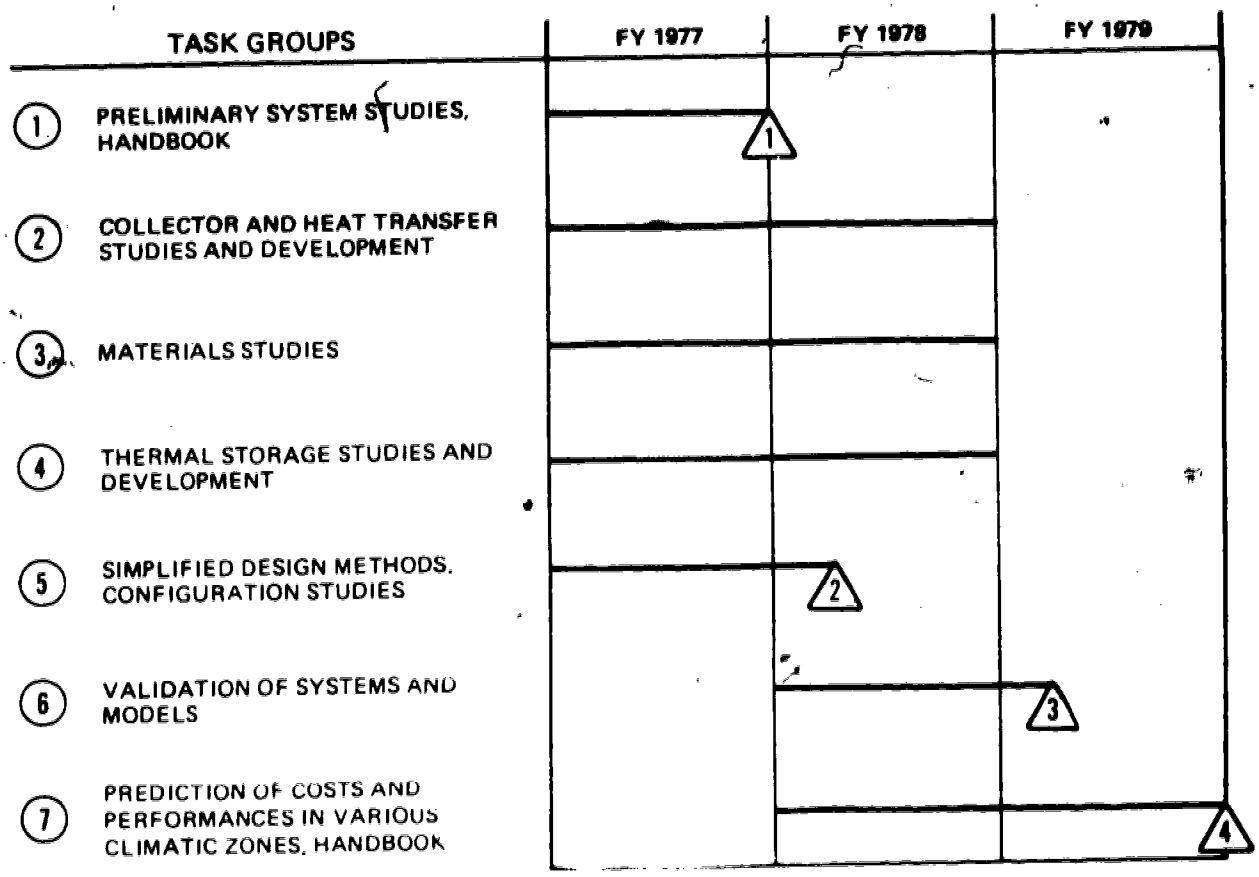
Architectural integration

Assessment of domestic hot water add-on and retrofit potential

System Testing

Data gathering on existing systems

Model and theory validation: emphasis on storage behavior and various energy loss mechanisms



MILESTONES

10/77 1 Preliminary [illegible] of best systems for various climatic zones. Publish handbook

1/78 2 As a result of system studies collector development materials study and construction of final simulations, final systems are confirmed for various climatic zones

1/79 3 Models chosen are assembled and simulations are validated based on data from operating systems. Results are published.

10/79 4 Handbook summarizes system cost and performance characteristics.

DIRECTORS OF SPACE HEATING
THIS ACTIVITY SCHEDULE

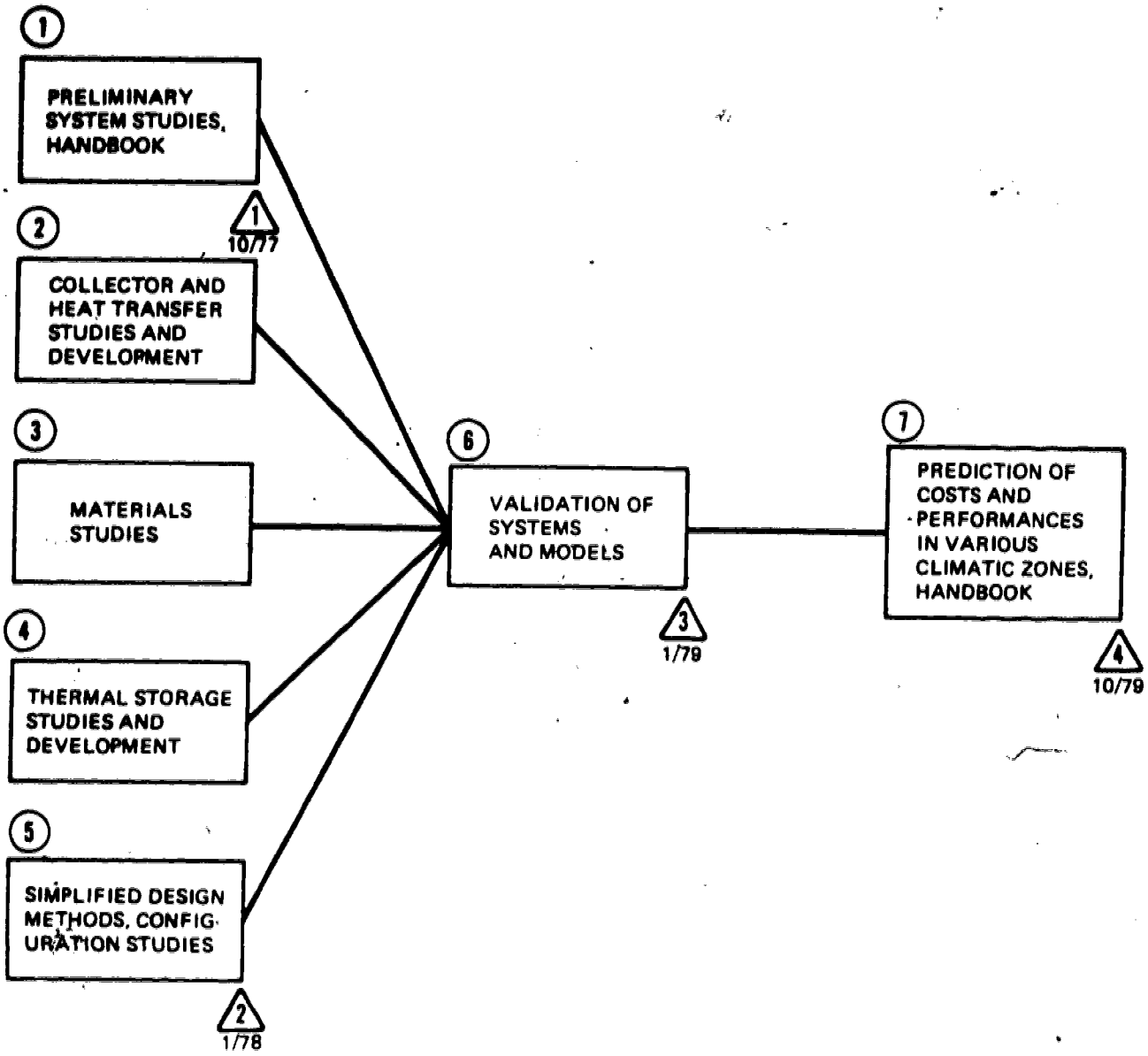


FIGURE III-13
AIR HEATING COLLECTORS FOR SPACE HEATING
PATH H3 FLOW CHART

LIQUID-HEATING COLLECTORS FOR SPACE HEATING PATH H4

GENERAL

This is the most familiar of the solar heating paths. Solar liquid-heating collectors for space heating have received extensive development, but they have proved expensive to purchase and install. Extensive research and development is necessary in order to determine the best techniques for operating them in various climates. For instance, where space heating determines the collector array size or where a net space cooling requirement cannot be met by night-effect or evaporative cooling, a chiller coupled to the liquid system might provide a small cooling capacity. Thermal storage will usually be in an insulated water tank.

This path will likely be developed regardless of the early results from this directed R&D program. It is appropriate to stimulate its development by providing the best possible materials and information.

R&D STRATEGY

The vigorous national industry in this area will be supported by collector R&D that stresses materials characterization and development. Installation costs will be reduced by simplifying manifolding, connections, and thermal storage assemblies. Results of numerous system tests will be made available, computer simulation codes will be validated, and simplified methods of system design will be determined and described.

R&D EMPHASIS

Materials Characterization and Development

Collectors: glazings and coatings, sealants, selective surfaces, coolants, and insulation

Component Development and Testing

Collectors: general

Thermal storage tanks

System Analysis

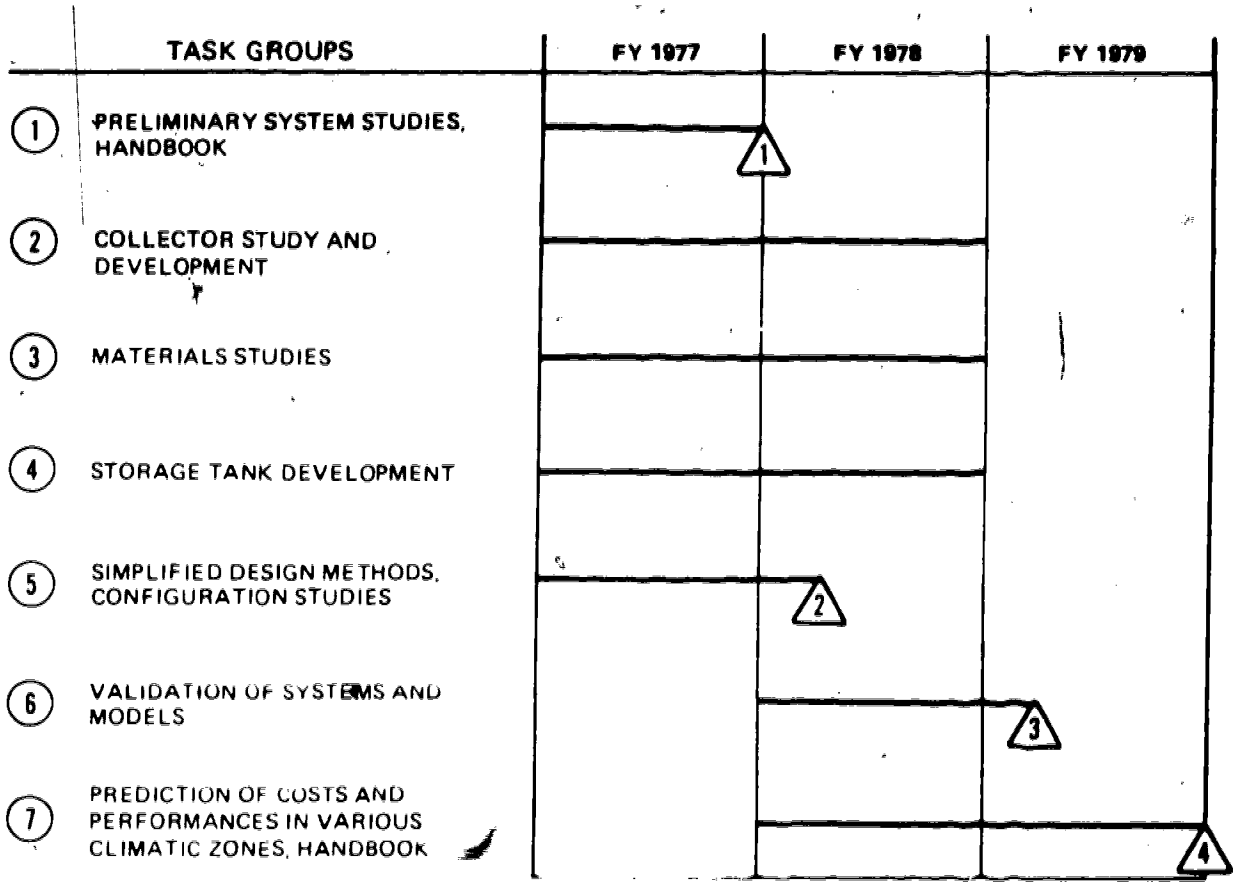
Validation of detailed computer simulation models using test results for existing systems

Evaluation of simplified handbook methods for predicting system performance

Cost identification: survey of costs of existing systems with breakdown of costs as to equipment and labor for the various subsystems

System Testing

Continued compilation of data from adequately instrumented system tests



MILESTONES

10-77 (1) [illegible] of best systems for various climatic zone. Publish handbook

1/78 (2) As a result of system studies, collector development, materials study, and construction of final simulations, final systems are confirmed for various climatic zones.

1/79 (3) Systems are constructed or chosen from Demonstration Program, and codes are validated.

10/79 (4) Publication of results. Handbook summarizes system costs and performances.

ACTIVITY SCHEDULE

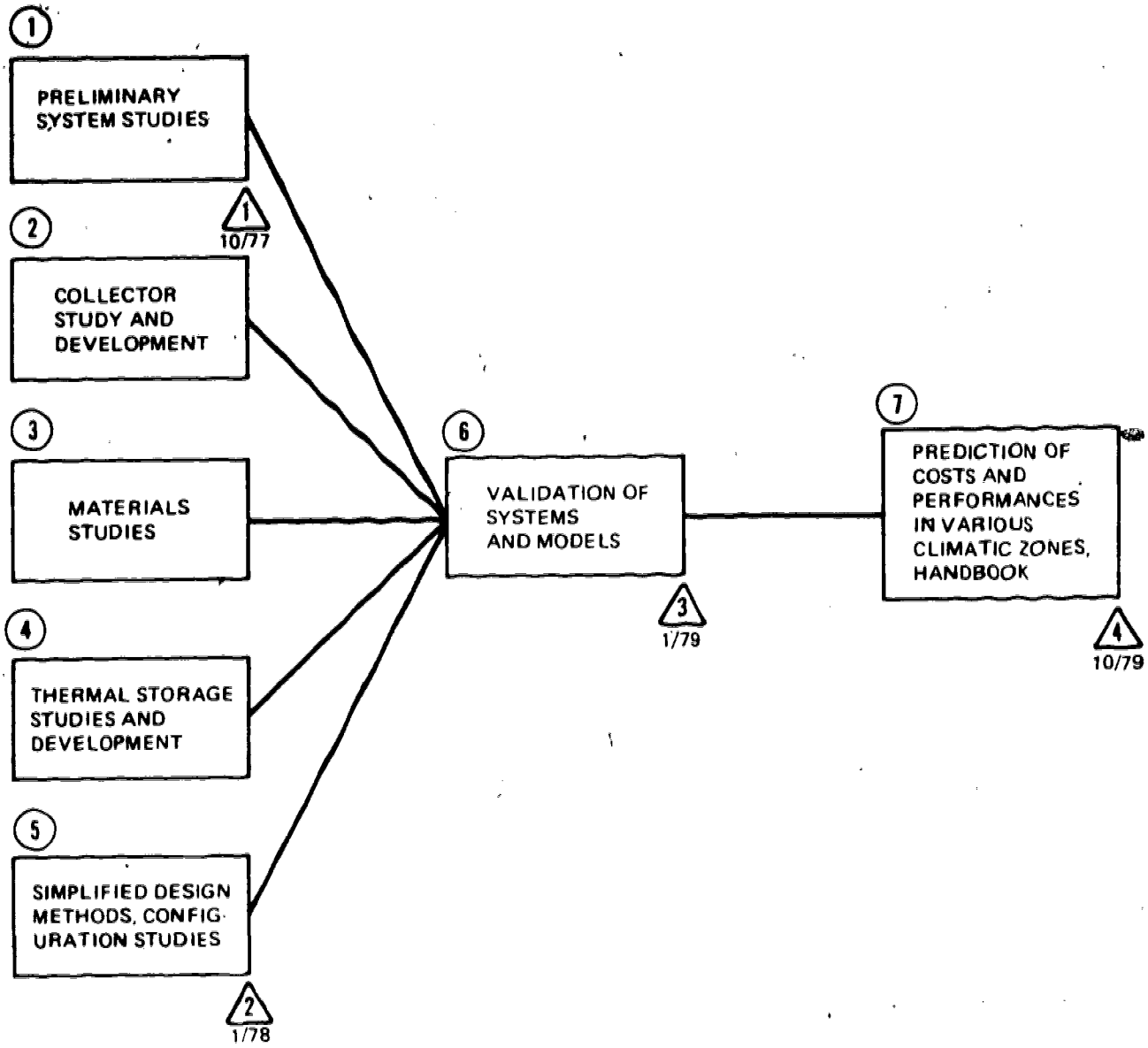


FIGURE III 15
HEATING COLLECTORS FOR SPACE HEATING
PATH H4 FLOW CHART

CONCENTRATING COLLECTORS WITH ABSORPTION OR RANKINE CYCLE CHILLER FOR SPACE COOLING PATH C1

GENERAL

Heat driven chillers can be of various types: absorption, Rankine cycle, desiccant, etc. The performance of these heat engines is markedly influenced by the temperature of the available heat. Their use should be especially considered in those areas of the country where high humidity keeps night-effect and evaporative cooling from being effective.

Absorption chillers normally operate at temperatures over 230° F, though they can be made to operate at lower temperatures. They have been designed to operate in the temperature range required by the air conditioning device. This makes possible the use of an air-cooled condenser. Concentrating collectors are likely to be the most cost-effective types of collector in this temperature range. In high humidity climates, space heating is usually best accomplished by the same collector and storage system that is used for cooling. The collectors operate at very high efficiency at the lower temperatures required for space heating, and the thermal storage capacity will be increased because of the wide temperature range available. Collector concentration ratios will generally be less than 10:1. The area of the absorber will be reduced by the concentration ratio, thereby reducing the heat loss from radiation and convection. Concentrating heaters will generally use either refraction (through a lens such as a Fresnel lens) or reflection (from curved or flat surfaces) to achieve concentration. Concentration will usually be two dimensional, such as is achieved in a cylindrical parabolic trough. However, three dimensional concentration, such as is achieved with a small mirror tower, should also be considered. At a 10:1 concentration ratio, the concentrator must be able to track the sun on a daily basis. Single-axis tracking has not proved as difficult or as costly as was originally anticipated. A 5:1 concentration may be obtained with fixed east-west mounting.

Thermal storage is a major problem at temperatures above the boiling point of water. The use of pressurized water would probably be the most cost-effective solution, but other approaches should also be considered—e.g., the use of collector coolant for storage. Hot storage may be as brief as two or three hours, providing only enough time to smoothe out variations in solar input and to accommodate the load's natural timing lag. Cold water storage will probably be more cost effective for long term thermal storage. Large quantities of cold water will be required, however, because the working ΔT is small. High and low temperature phase-change storage materials may be very desirable.

R&D STRATEGY

Two areas must be emphasized: high temperature collectors and on-off cycling. Simple and reliable concentrating collectors, both tracking and fixed, must be developed. They must be capable of a daily efficiency greater than 50 percent at average fluid temperatures around 260° F. Since the chiller will be a major cost item in the system, it must be operated at nearly maximum output. This will require generator temperatures of approximately 230° F and continuous operation. Current data indicates that the average Coefficient of Performance (COP) may be decreased from a rated value of 0.6 to 0.3 through cyclic operation. The chillers may have to be partially redesigned for the solar application, but manufacturers of absorption units have shown a willingness to do whatever redesigning is necessary so long as market conditions warrant their investment.

The Rankine cycle/vapor compression effort will emphasize the development of models of varying size. These devices offer costs potentially lower than those for absorption chillers, and their efficiency increases with input temperature. R&D systems must also be designed and constructed. These systems can

be used to identify operating characteristics in the field and to validate detailed system models.

R&D EMPHASIS

Materials Characterization and Development

Lens and mirror materials and selective surfaces resistant to exposure must be designed; and liquid coolants must be developed. Questions regarding cost, fabrication, availability, and operation must be settled.

Component Development and Testing

Develop models for heat loss mechanisms for various absorber/container configurations and materials

Validate models and theory of operation in the following areas:

- Fresnel lens concentrators
- Parabolic trough concentrators
- Compound-parabolic concentrators
- Mirror tower reflectors and collectors
- Absorption chillers operating under design, off-design, and transient conditions
- Rankine chillers operating under design, off-design, and transient conditions

System Analysis

Performance identification: net energy yields as a function of system configuration, collector performance, chiller performance, storage size and configuration, and climatic zone

Cost identification: cost characteristics for various collector and system options

Architectural integration: methods of mounting movable hardware on buildings

Integration with service hot water (or process hot water, as in laundries) and space heating

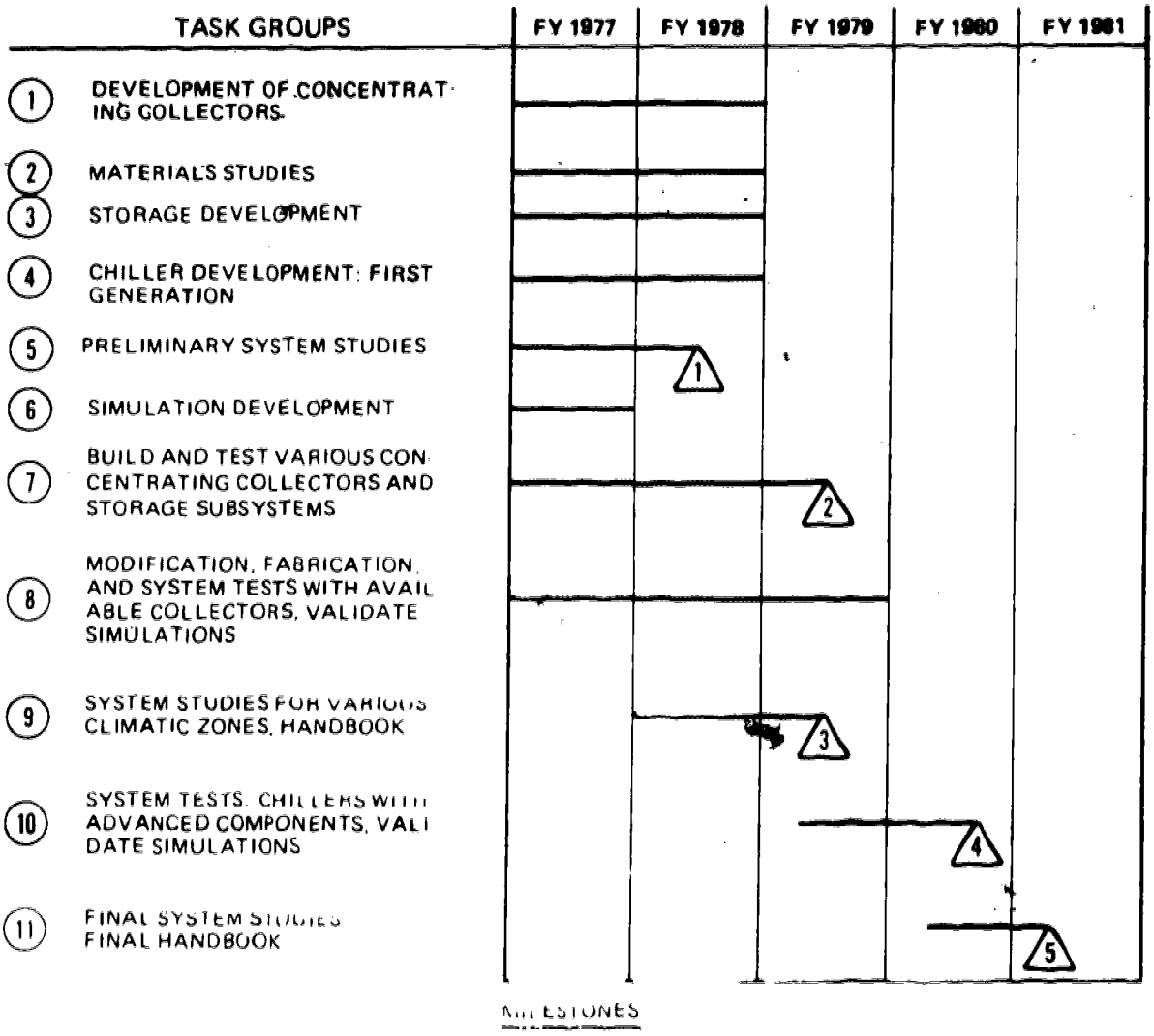
System Testing

Construct one R&D system test for each approach considered attractive in a given climate

Detailed data gathering on above tests

Model and theory validation

Detailed cost and performance calculations in various climatic zones, summarized in a handbook



4/78 1 Preliminary system studies development lead to choices of collectors for first generation absorption tests and various types of most promising concentrating collectors for further development

4/79 2 Advanced concentrating collectors evaluated in simulations and are ready for second generation absorption and/or Rankine tests. Storage systems are evaluated

4/79 3 Currently available absorption and Rankine cycle chillers tested (separately and side by side). System studies performed and preliminary handbooks generated for pertinent climatic zones

4 Tests completed with advanced components and original absorption units of varying sizes. (Second generation tests.)

6/81 5 System studies completed for various climatic ranges for advanced collectors and second generation absorption chillers. Handbook.

...TING COLLECTORS WITH
...ION OR RANKINE CYCLE CHILLER FOR SPACE COOLING
PATH C1 ACTIVITY SCHEDULE

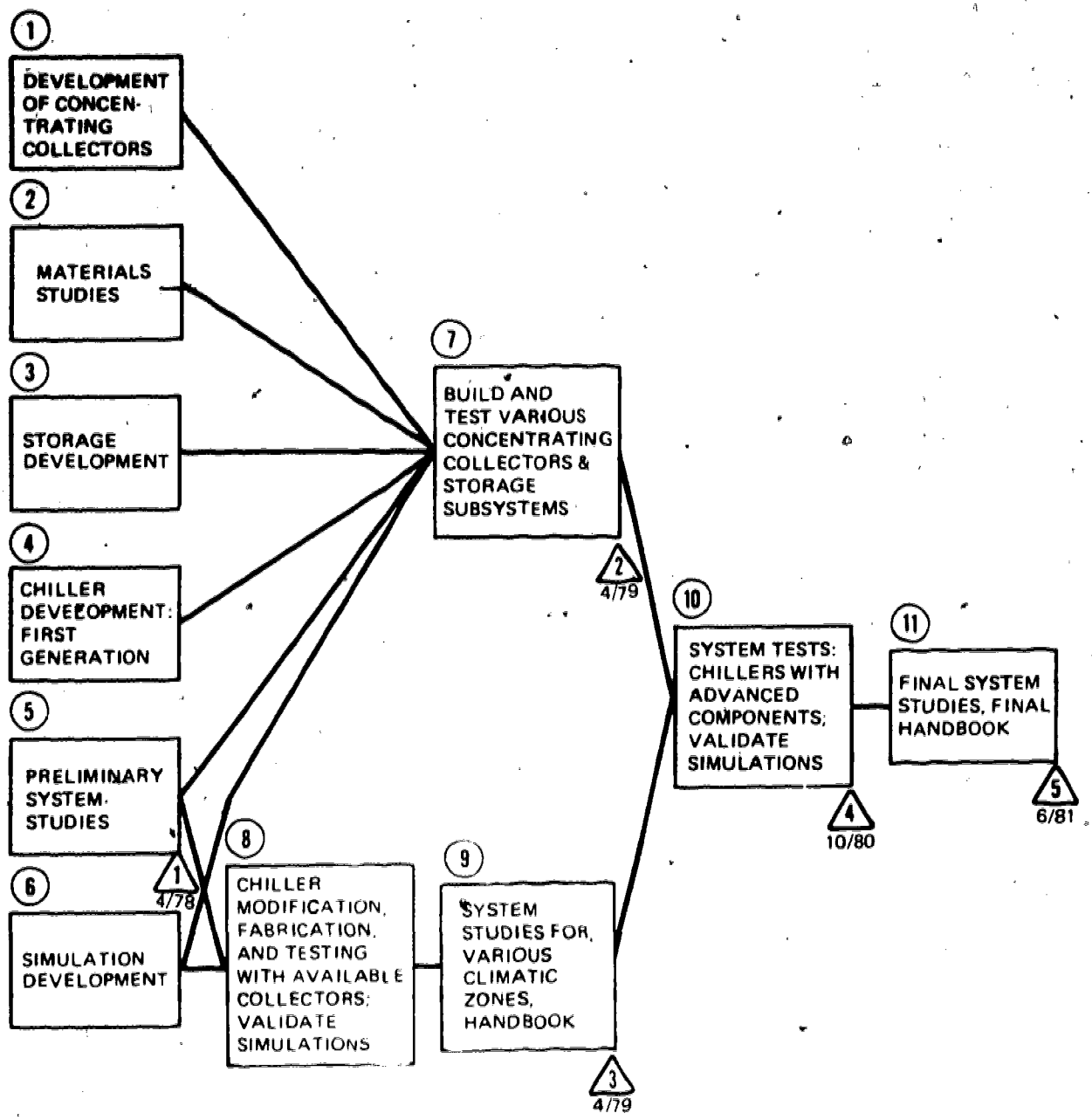


FIGURE III-17
CONCENTRATING COLLECTORS WITH
ABSORPTION OR RANKINE CYCLE CHILLER FOR SPACE COOLING
PATH C2 FLOW CHART

ADVANCED NON-CONCENTRATING COLLECTORS WITH ABSORPTION OR RANKINE CYCLE CHILLER FOR SPACE COOLING PATH C2

GENERAL

Low-loss, fixed-mount, solar liquid-heating collectors will be used to provide suitable inlet temperatures for absorption or Rankine cycle devices. The collectors will include advanced, non-concentrating collectors such as evacuated tubes, honeycomb type collectors, selective surface collectors, heat pipes, and various combinations of these. These collectors have the potential for operating at reasonable (40 percent) efficiencies at temperatures up to 300° F, and they may therefore be suitable heat sources for chillers operating at generator inlet water temperatures up to 230° F. This path will include standard selective-surface collectors suitable for a generator inlet temperature of 195° F. (This path differs from Path C1 in including only those generators with temperatures of 230° F or lower.)

The most cost-effective approach to accomplishing thermal storage above the boiling point of water is probably pressurized water. Other approaches, however, might also be investigated—e.g., using the collector coolant for storage. Hot storage may be used for short periods, perhaps as little as two or three hours. This will be sufficient only to smoothe out variations in solar input and to accommodate the natural time lag of the cooling load. Cold storage of water or phase-change material may be more cost effective for long term thermal storage. Large quantities of cold water or coolant will be required, however, because the working ΔT is small. Phase-change hot storage should be considered, because it is highly desirable that the chillers have a constant temperature source.

R&D STRATEGY

Three areas must be [illegible] ture, high efficiency, non-concentrating collectors, low temperature generators, and on-off cycling. Higher temperatures will be achieved through the use of high performance collectors. Collectors must be developed that are simple, reliable, and capable of daily efficiencies over 30 percent at fluid temperatures averaging near 260° F. Since the absorption chiller will be one of the most expensive items in the system, it must be operated at nearly maximum output.

Advanced systems must be designed and constructed. These systems can be used to identify operating characteristics in the field and to validate detailed system models. Because this path includes generators with temperatures of 230° F or lower, it will be necessary to redesign the absorption generator or Rankine unit to maintain adequate performance. The absorption machines may also require condensers cooled by water towers. (This will be a problem in domestic applications and in areas where make-up water is expensive.)

R&D EMPHASIS

Materials Characterization and Development

Glazing and glazing coatings, sealants, selective surfaces, coolants, insulation, and absorbant/refrigerant pairs

Component Development and Testing

Develop models for heat loss mechanisms for various collector absorber/container configurations and materials

Validate models and develop chillers optimized for solar applications

Study and model transient performance of chillers

System Analysis

Performance identification: net energy yield as a function of system configuration, collector performance, chiller performance, storage size and configuration, and climatic zone

Cost identification: cost characteristics as a function of the various collector and system options

Architectural integration: methods of mounting hardware on buildings

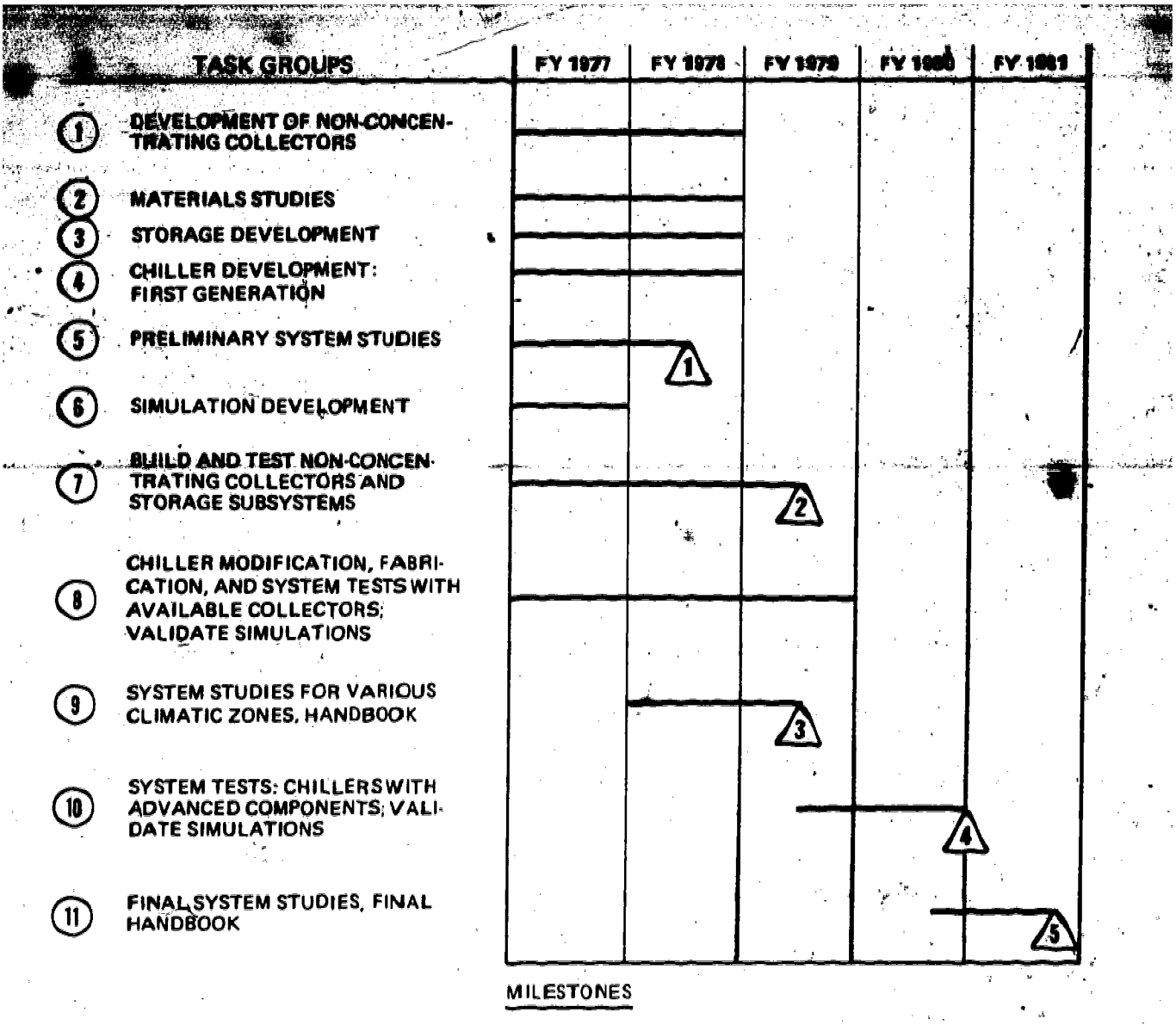
Integration with domestic hot water (or process hot water, as in laundries) and space heating, freeze protection

System Testing

Construct one advanced system test for each approach considered attractive in a given climate

Detailed data gathering on above tests

Model and theory validation



4/78 (1) Preliminary system studies and collector development lead to choices of collectors for first generation absorption tests and various types of most promising collectors for further development.

4/79 (2) Advanced collectors are evaluated in simulations and are ready for second generation absorption test and/or second generation Rankine test. Storage subsystems are evaluated.

4/79 (3) Absorption and Rankine cycle chillers tested with currently available collectors. System studies performed and preliminary handbooks generated for pertinent climatic zones.

10/80 (4) Tests completed with advanced collectors and second generation absorption units of varying size.

6/81 (5) System studies completed for various climatic ranges for advanced collectors and second generation absorption chillers. Handbook.

FIGURE III-18
ADVANCED NON-CONCENTRATING COLLECTORS WITH ABSORPTION OR RANKINE CYCLE CHILLER FOR SPACE COOLING PATH C2 ACTIVITY SCHEDULE

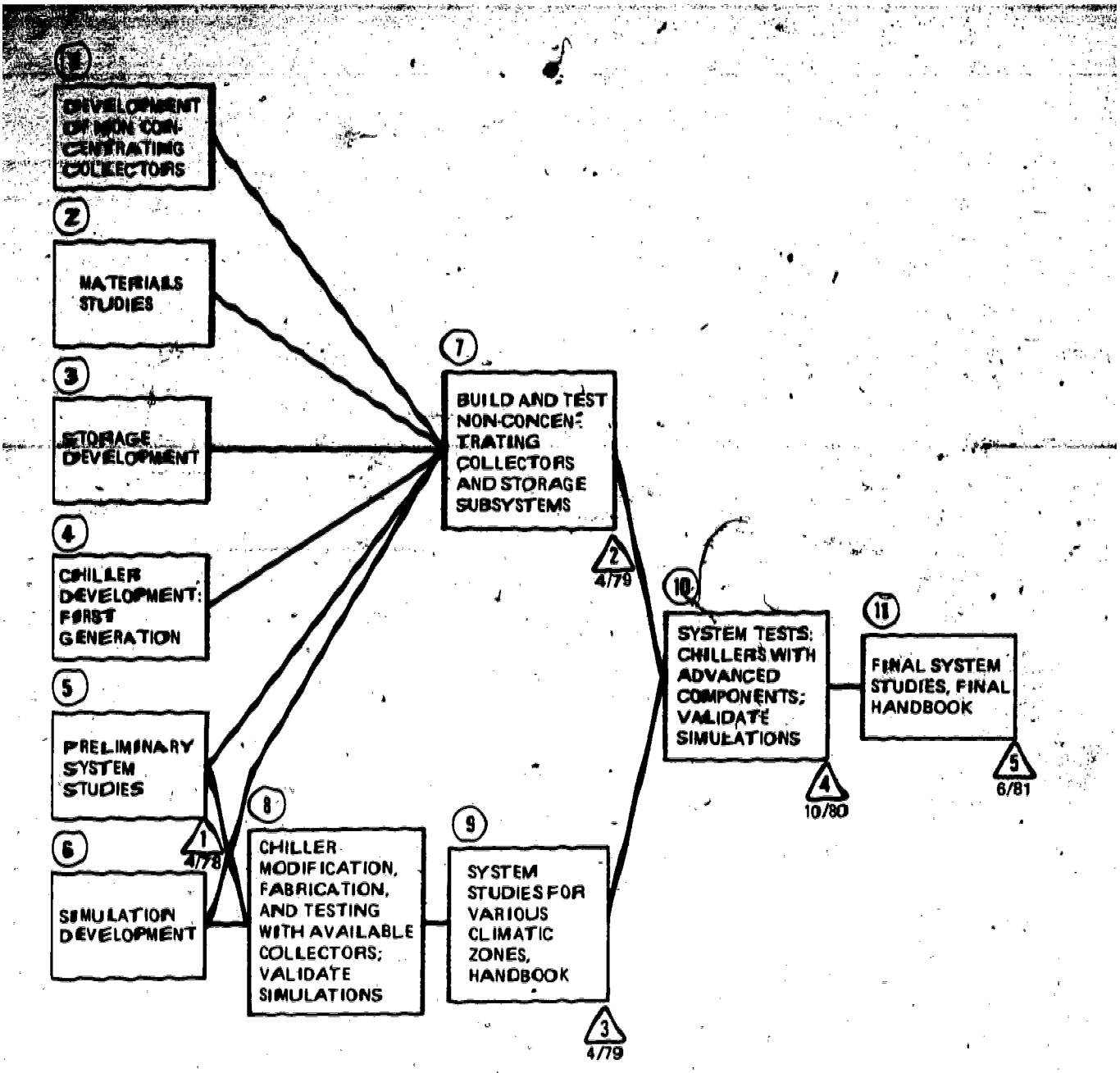


FIGURE III-19
ADVANCED NON-CONCENTRATING COLLECTORS WITH ABSORPTION OR RANKINE CYCLE CHILLER FOR SPACE COOLING PATH C1 FLOW CHART

FLAT PLATE COLLECTORS WITH DESICCANT CHILLER FOR SPACE COOLING PATH C3

GENERAL

Desiccant chilling involves the dehydration of air by contact with a hygroscopic material. The air is either kept at a constant temperature or cooled after dehydration; it is then chilled by the evaporation of water into the air. Solar heat is used to redry the desiccant. This process has a potential advantage in that it can be carried out at temperatures as low as 160° F, though this lowers the performance coefficient significantly. The path is most attractive where the solar collector requirement is governed by the space heating load. This allows the same collectors to be used during the summer for space cooling. Combinations with solar air heaters are effective, because the desiccant is usually most easily reconstituted by contact with hot air (which carries off the moisture). Solar liquid heaters could also be used with a desiccant chiller; but this approach has a lower priority, because it requires more equipment and is therefore likely to be more expensive.

As is normal with this type of collector, thermal storage will be accomplished by means of a rock bed for an air-heating collector and a water tank for a liquid-heating collector.

R&D STRATEGY

This path requires considerable research and development. Solid desiccants capable of being reconstituted at low operating temperatures (130 to 160° F) are needed. Methods of desiccant support and air handling must be developed, with emphasis being placed on subsystems that require a minimum of electrical input energy. These subsystems must be durable, mechanically simple, and suitable for integration into an air-heating collector/rock bed storage space heating system. Methods that use low operating temperatures will be investigated first, but if it becomes advantageous to operate desiccants at higher temperatures, this approach will also be explored.

R&D EMPHASIS

Materials Characterization and Development

Desiccants: thermodynamic properties and operating temperatures

Support structures: simple, rugged matrix structure to support desiccant, with adequate air surface contact and low pressure drop

Component Development and Testing

Humidification/dehumidification process

Desiccant wheels

Model and theory validation

Air handling equipment

Support structures

System Analysis

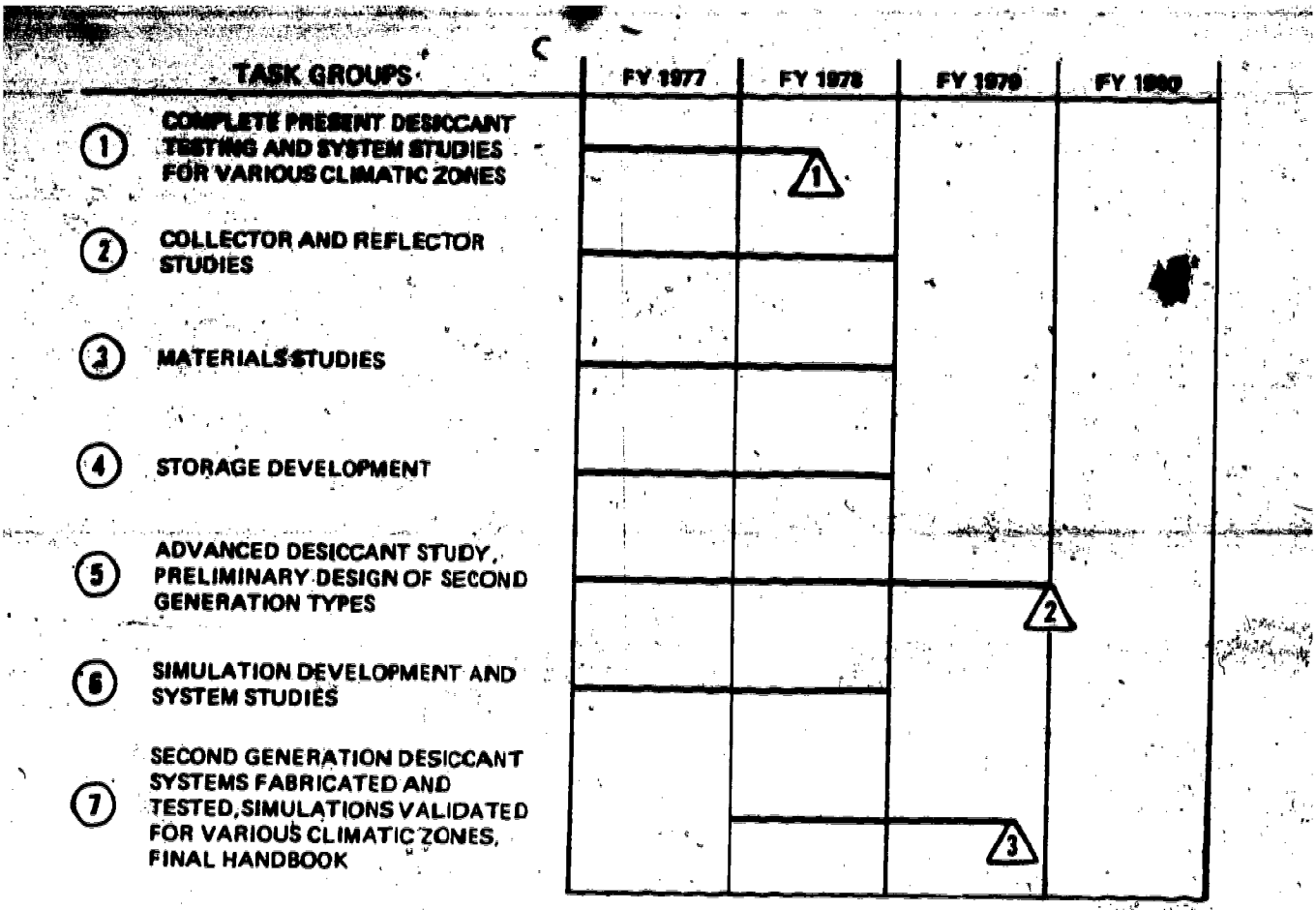
Performance identification: energy yield as a function of collector and desiccant subsystem performance, climate, and system design. Air pumping requirements.

Cost identification: overall evaluation of add-on cost characteristics of desiccant subsystems in an air-heating-only system

System Testing

Construction of suitable system tests in appropriate climatic zones

Model and theory validation



MILESTONES

4/78 (1) Completion of desiccant experiments and system studies, publish preliminary handbook to show cost and performance potential in various national climatic zones.

10/79 (2) Completion of desiccant survey and study of their possibilities, problems, and preliminary designs, construct those second generation systems that show most promise.

6/80 (3) Publish handbook showing applications and potential in various climatic zones.

FIGURE III-20
FLAT PLATE COLLECTORS WITH
DESICCANT CHILLER FOR SPACE COOLING
PATH C3 ACTIVITY SCHEDULE

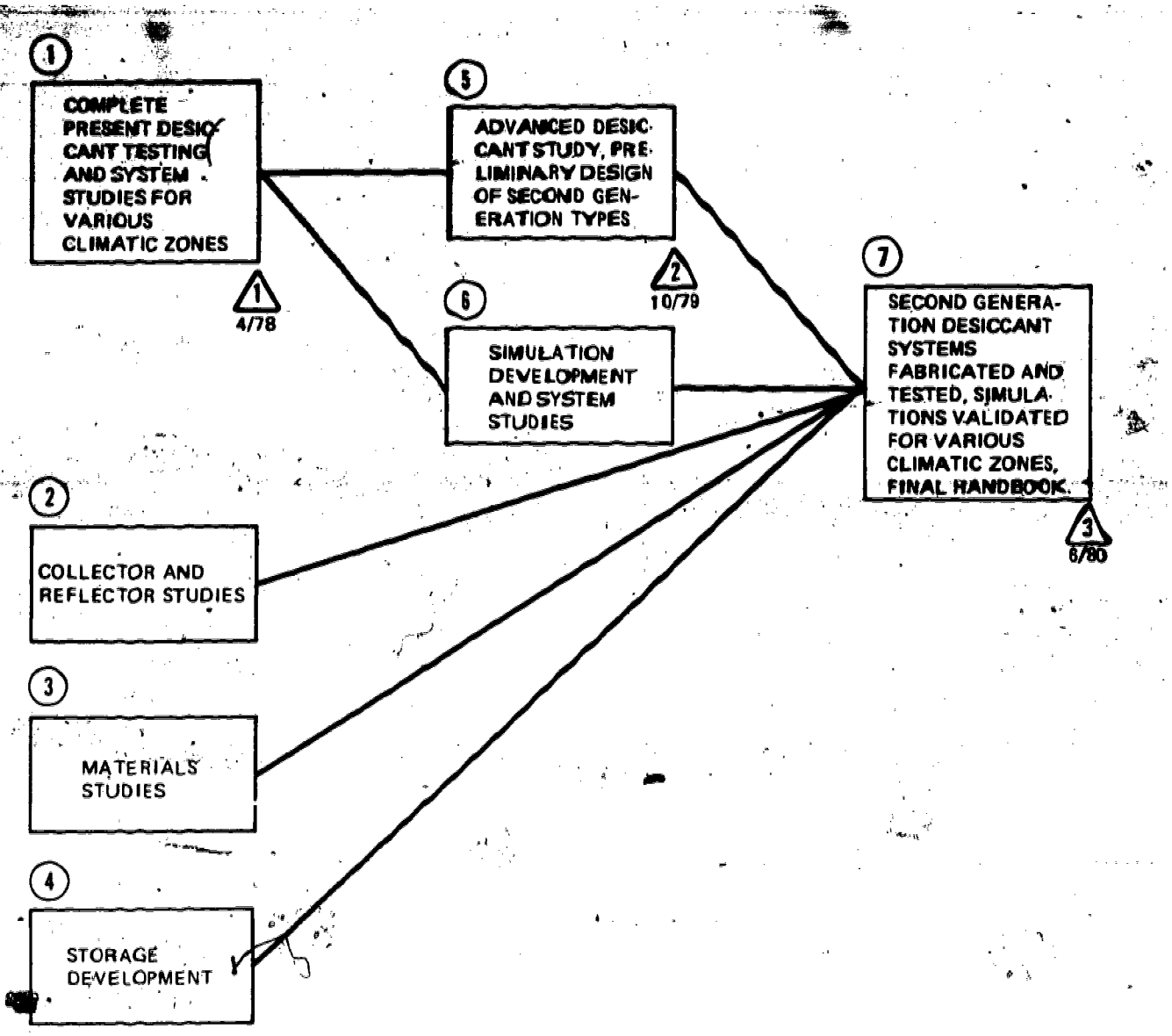


FIGURE III-21
FLAT PLATE COLLECTORS WITH
DESICCANT CHILLER FOR SPACE COOLING
PATH C3 FLOW CHART

EVAPORATIVE AND NIGHT-EFFECT COOLING PATH C4

GENERAL

A building can be cooled through interaction with the environment even when temperatures are high provided the dew point is low enough. Climates where this occurs usually have large diurnal temperature variations. In such climates, evaporation, night-sky radiation, and cool night air can be combined with thermal storage to offset almost completely the need for active cooling. The purpose of R&D in this area is the expansion of the geographic area where this approach is workable.

One method which has already been developed uses passive roof ponds, radiators, and evaporative beds. The ponds act as solar collectors (for heating). Thermal storage is usually in portions of the structure having large thermal capacity (walls, floor), specially designed storage units (roof ponds) that are adjacent to the conditioned space, or separated thermal storage units (rock bins) that are coupled to the space by natural or forced circulation. Movable insulation panels are used to provide control of thermal variations.

A second method uses an active air blower and rock bed thermal storage. The system can store coolness at night, when the dew point is lower, for use during the day. This method works well with solar space heating systems, especially air systems, because the same thermal storage unit can be used for heating and cooling, increasing the cost effectiveness of the storage and blowers.

In some locations, cool night air can be used directly, without evaporative cooling.

R&D STRATEGY

R&D emphasis will be on determining heat rejection, storage, and absorption characteristics of various designs and on generating and validating thermal simulation computer models for designs. The models will be used to determine the most effective parameters for each design, the effective geographical range for each design, and the energy savings that could be expected for each design in various climatic zones. Architectural integration and cost effectiveness will be stressed, and information dissemination is also extremely important for this path. Activities must be closely coordinated with those carried on for paths H1, H2, and H3. In path H1, for instance, cooling may be possible by a heat pump rejecting heat to a rooftop radiator.

R&D EMPHASIS

Materials Characterization and Development

- Structural or coating materials for storing water in containers in sunlight
- Phase-change materials and containers for heat storage at or slightly below room temperature
- High transmissivity infrared glazings

Component Development and Testing

- Thermic diode or roof structures
- Light and heat flow-control devices
- Rock bin thermal storage

System Modeling

- Identify basic characteristics of each type of system
- Validate system models

System Analysis

- Performance identification: energy yield as a function of system type, climatic zone, and design
- Cost identification: cost characteristics relative to system type. Cost distribution when components have combined functions (a wall for instance, that has structural and heat storage functions).

The performance of systems using exterior radiative surfaces (essentially unglazed flat-plate collectors used as night-sky radiators)

Combination with space heating systems

Architectural integration

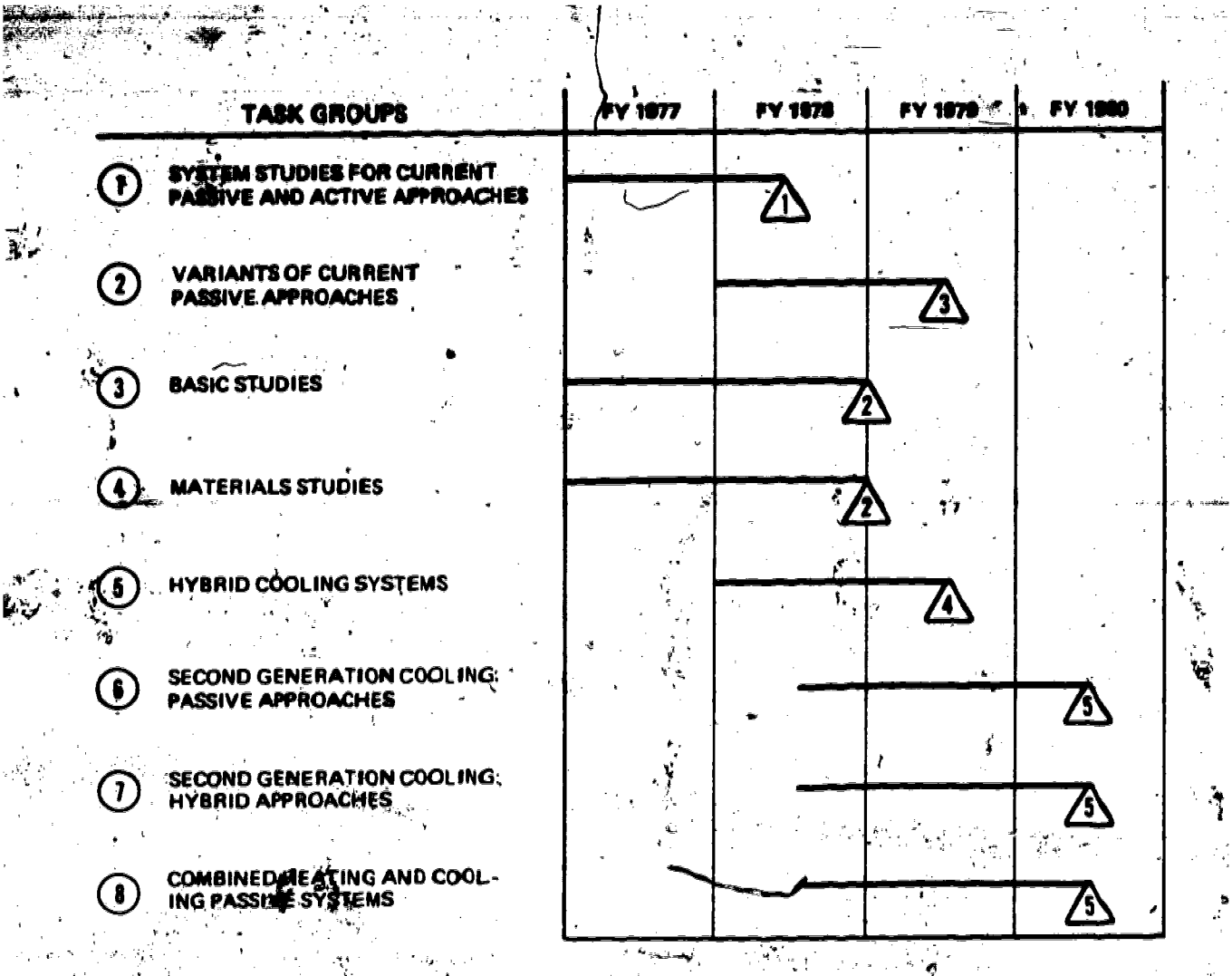
Retrofit potential

System Testing

Data gathering on operating systems

Model validation

Evaluation of the long term effect of humidification on rock bed storage in various climates. If adverse effects are noted, evaluation of fungicides or other remedies.



MILESTONES

Each milestone refers to the preparation and distribution of a handbook on current designs for buildings that will be cooled predominantly by evaporative and night-effect techniques.

4/78 (1) Based on first round system studies of passive and active techniques.

10/78 (2) Based on results from basic and materials studies.

4/79 (3) Based on variants and improvements of correct passive cooling techniques.

4/79 (4) Results from hybrid system tests.

4/80 (5) Based on second generation passive cooling systems, hybrid cooling systems, and combined heating and cooling passive systems.

FIGURE III-22
EVAPORATIVE AND NIGHT-EFFECT COOLING
PATH C4 ACTIVITY SCHEDULE

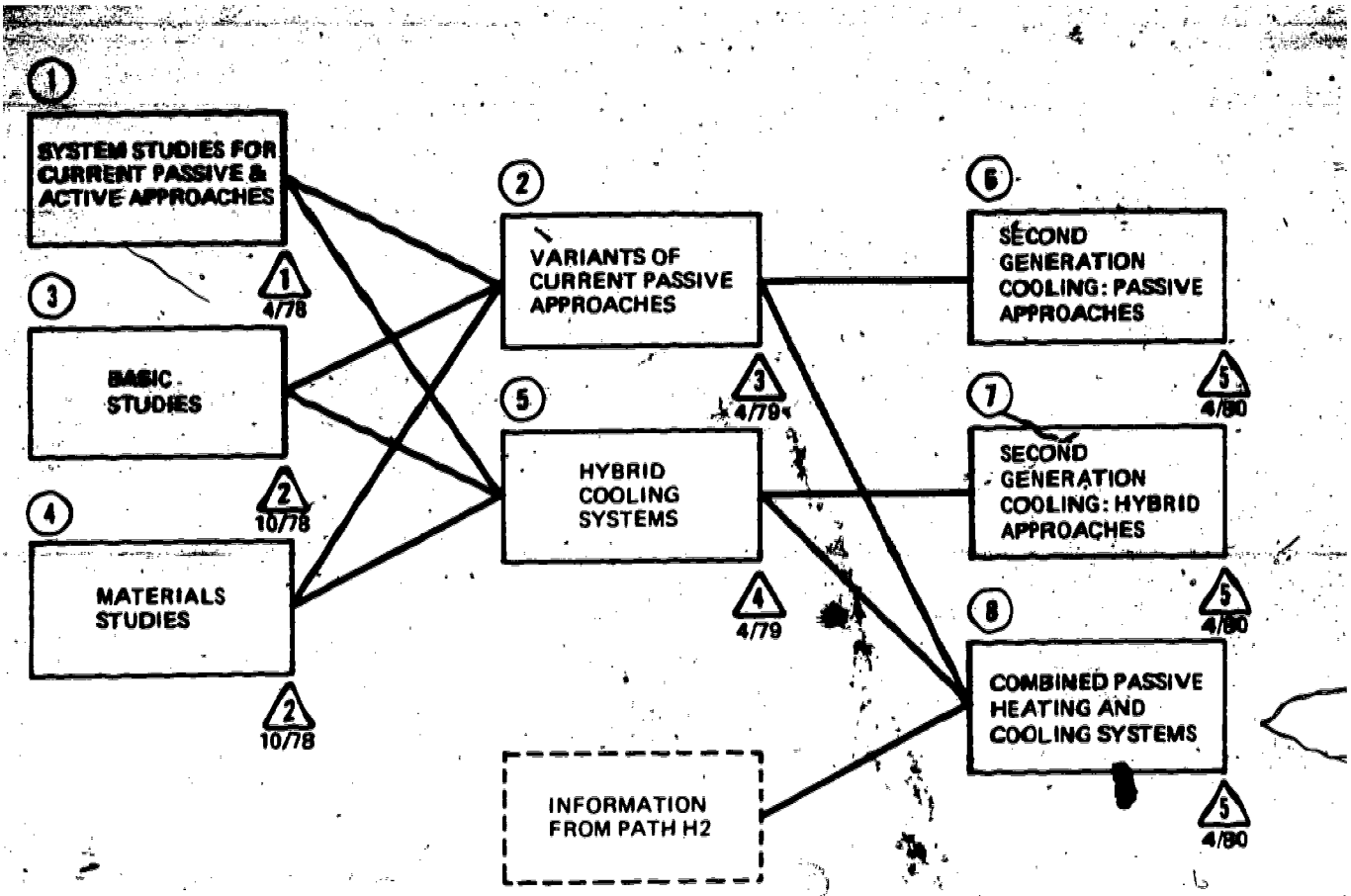


FIGURE III-23
EVAPORATIVE AND NIGHT-EFFECT COOLING
PATH C4 FLOW CHART

SECTION IV

AGRICULTURAL AND INDUSTRIAL PROCESSES

PATH CHARACTERISTICS

The R&D effort required for the agricultural and industrial process paths will be similar to that required for the heating and cooling paths. There are several points, however, which set the agricultural and industrial process paths apart. These points are as follows:

- Agricultural and industrial process systems are usually very large and consume substantial amounts of energy. Energy uses are more varied than in the building applications, and tailoring the systems to meet particular applications is a major challenge. At the same time, industrial process heat loads are usually predictable and constant.
- Industry may need relatively short life cycle costing for the systems, with pay-back periods of less than five years being required for process improvements. Because industrial concerns have trained maintenance personnel available, solar energy systems with lower initial costs but higher maintenance costs might be the most cost-effective approach.
- Since the farmer will probably build and will certainly maintain many agricultural solar energy systems, the systems should consist of materials that are readily obtained and easily worked. The systems should also be relatively portable, so that they can be used for more than one application. This will help amortize the cost of the systems.
- Industrial and agricultural systems should be durable, because they will be required to operate in hostile environments. Systems should be capable of being easily repaired on site.
- Industries connected with agricultural and industrial processes are generally less willing than those connected with heating and cooling to carry on the necessary R&D. As a result, certain crucial tasks may require more ERDA support.

PATH REQUIREMENTS

Additional R&D is necessary for the agricultural and industrial process paths, and it can be carried on in parallel with the building applications R&D program. Systems must be tailored to the needs of individual users. When systems are shown to be cost effective, the principles behind their operation must be made available to other users. Those users can then design similar systems, modifying them to suit their own particular needs.

R&D tasks unique to the agricultural and industrial process paths are currently being identified. They will be described in the revision of this report. Work on such tasks will be coordinated with work on the building applications tasks that pertain to the agricultural and industrial processes.

Part III. TASKS

APPENDIX

The third portion of this report consists of four appendices. Appendix A gives task flow charts for the ten paths; Appendix B contains brief descriptions of the building program tasks; Appendix C lists the importance numbers for the engineering tasks; and Appendix D gives the importance of each of the non-engineering tasks to the total R&D program.

APPENDIX A
Task Flow Charts

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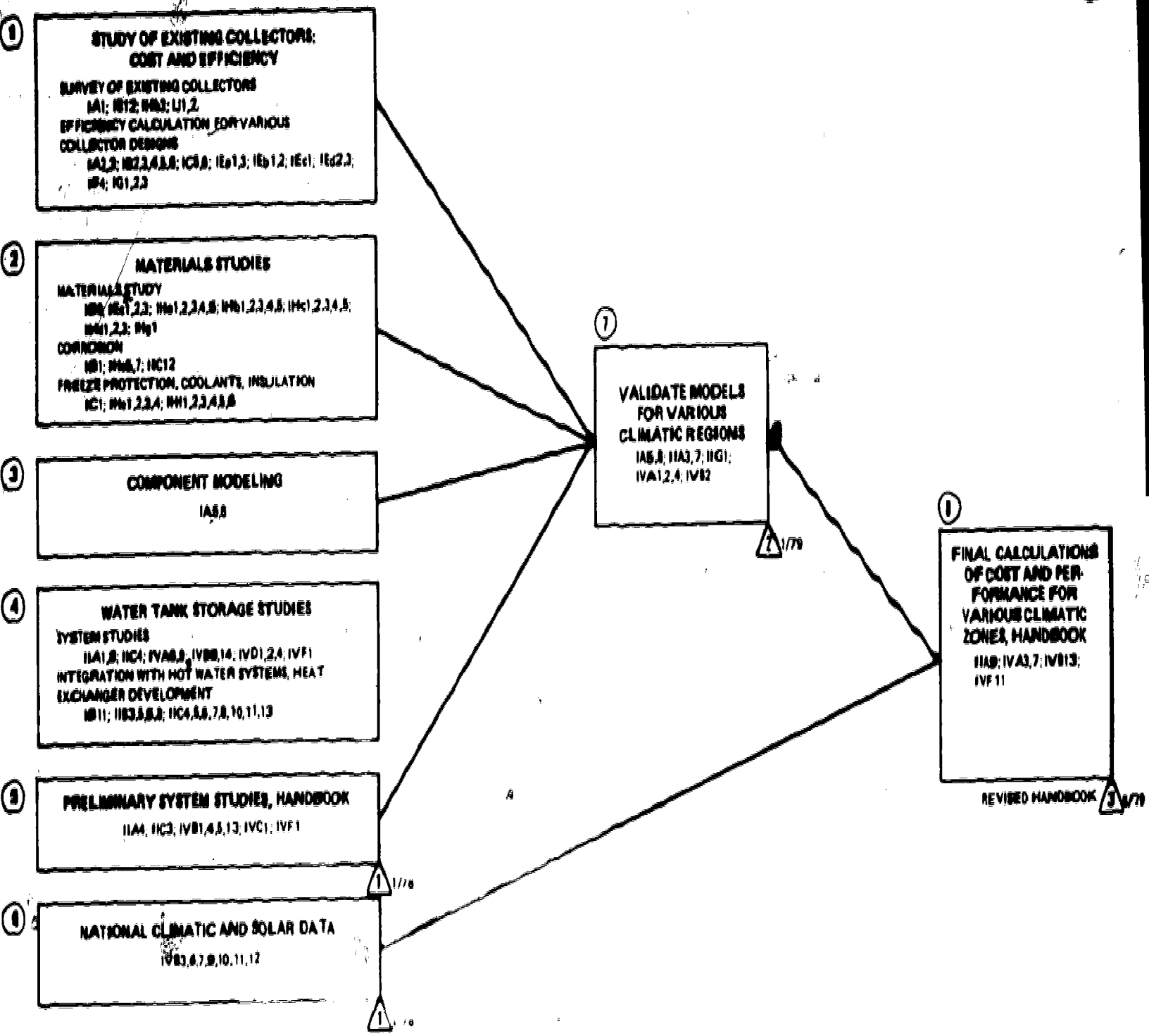
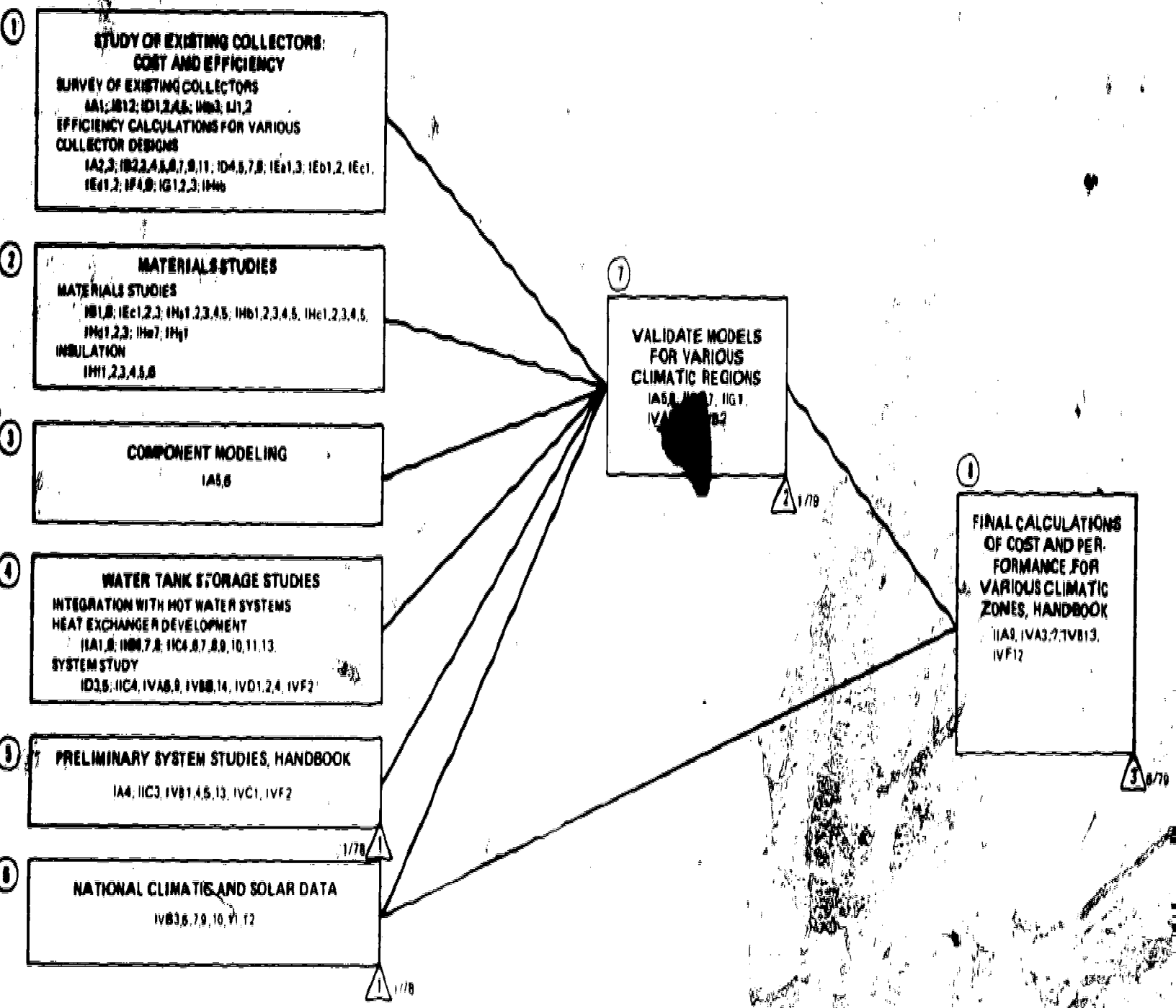


[1] For each climatic zone, a determination must be made of optimum collector type, collector area for nominal load, solar applications for various parameters and locations within each zone, and typical system and life-cycle costs.

FIGURE A 1

LIQUID FLAT-PLATE COLLECTORS FOR SERVICE HOT WATER

PATH W1 TASK FLOW CHART



*For each climatic zone, a determination must be made of optimum collector type, collector area for nominal load solar applications for various parameters and locations within each zone, and typical system and life cycle costs

FIGURE A-2
AIR HEATING COLLECTORS FOR SERVICE HOT WATER
PATH W2 TASK FLOW CHART

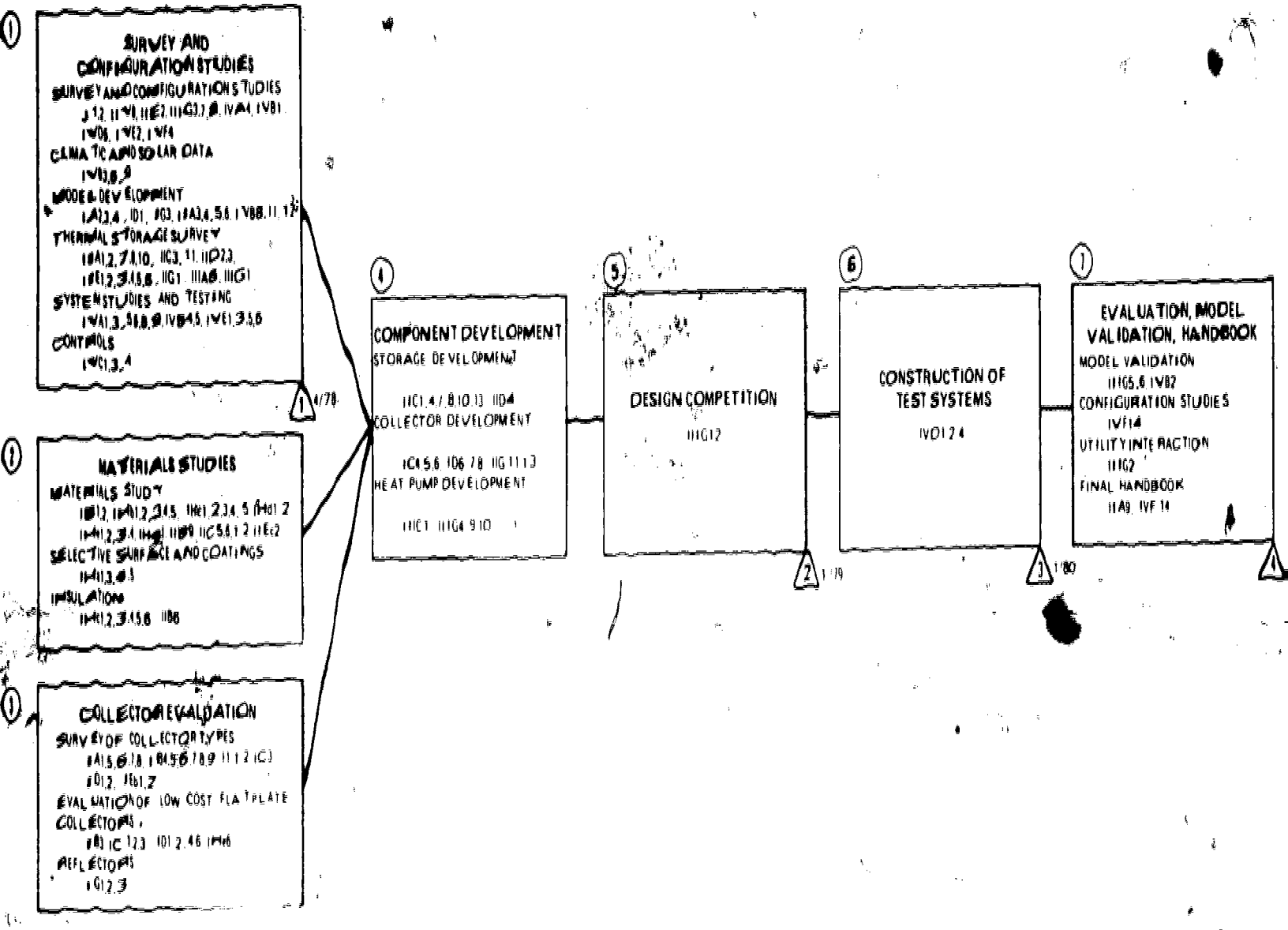


FIGURE A 3
SOLAR-ASSISTED HEAT PUMP FOR SPACE HEATING
PATH H1 TASK FLOW CHART

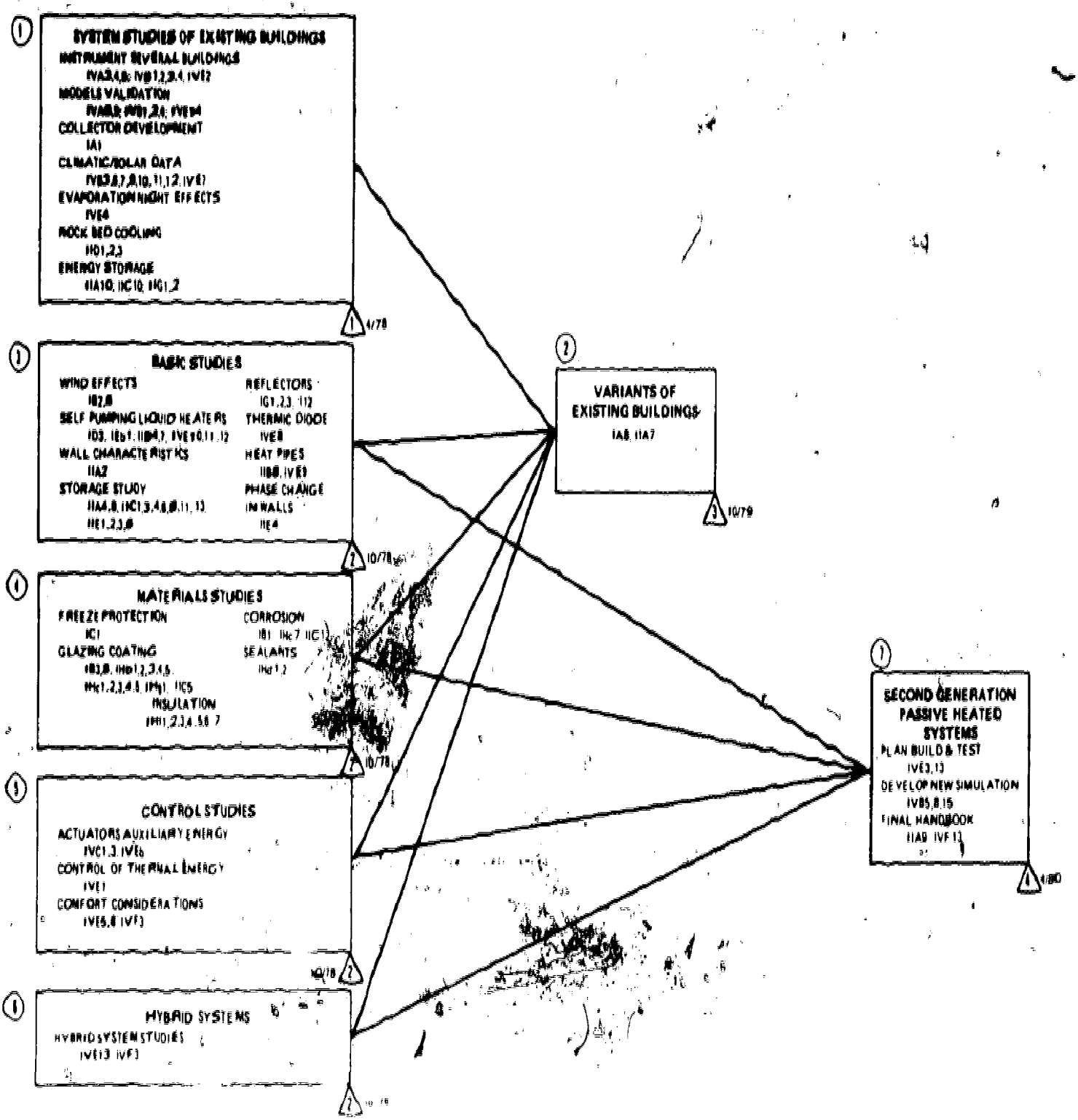


FIGURE A-4
DIRECT SOLAR HEATING OF SPACE OR STRUCTURE
PATH H2 TASK FLOW CHART

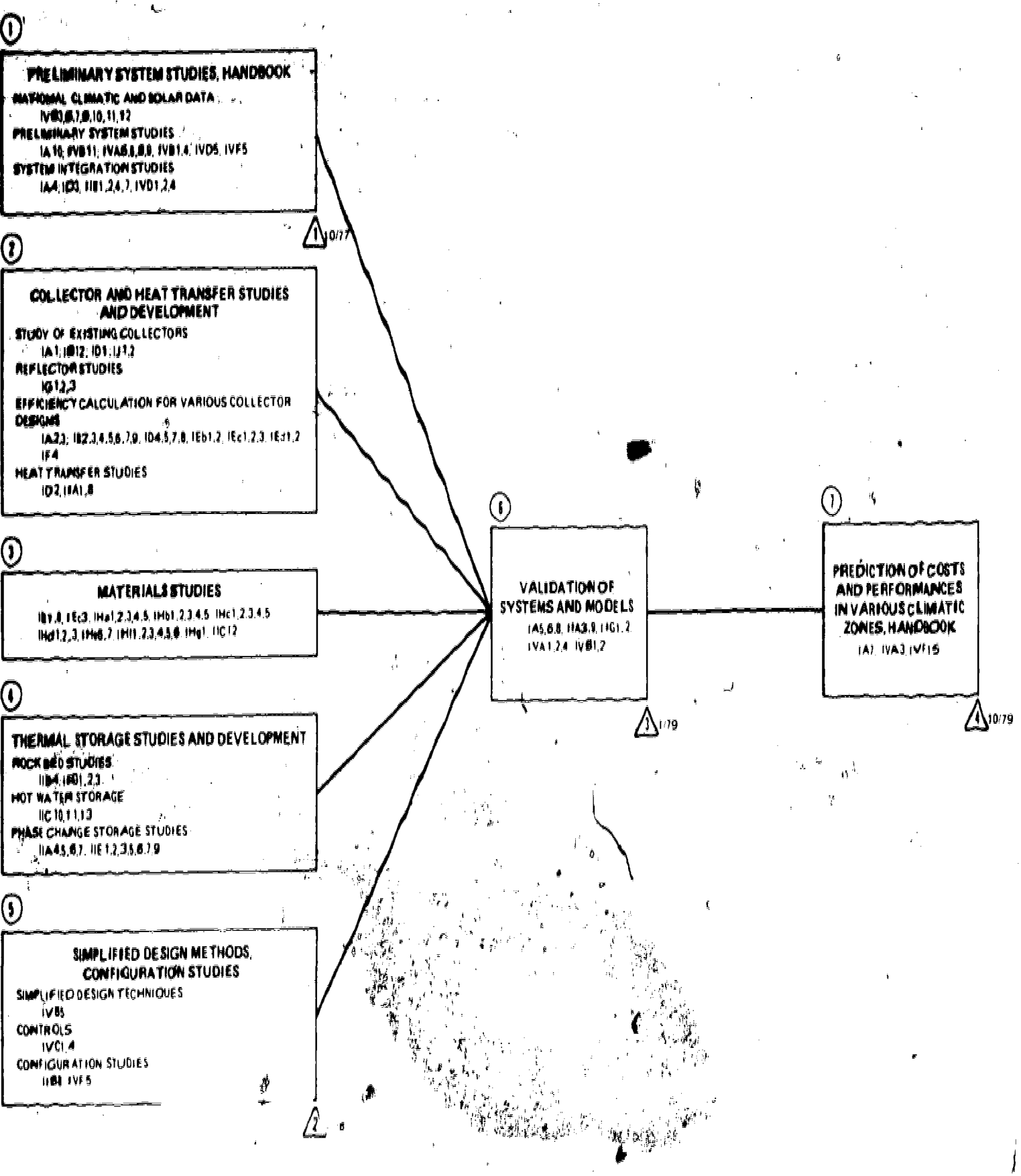


FIGURE A-5
AIR HEATING COLLECTORS FOR SPACE HEATING
PATH H3 TASK FLOW CHART

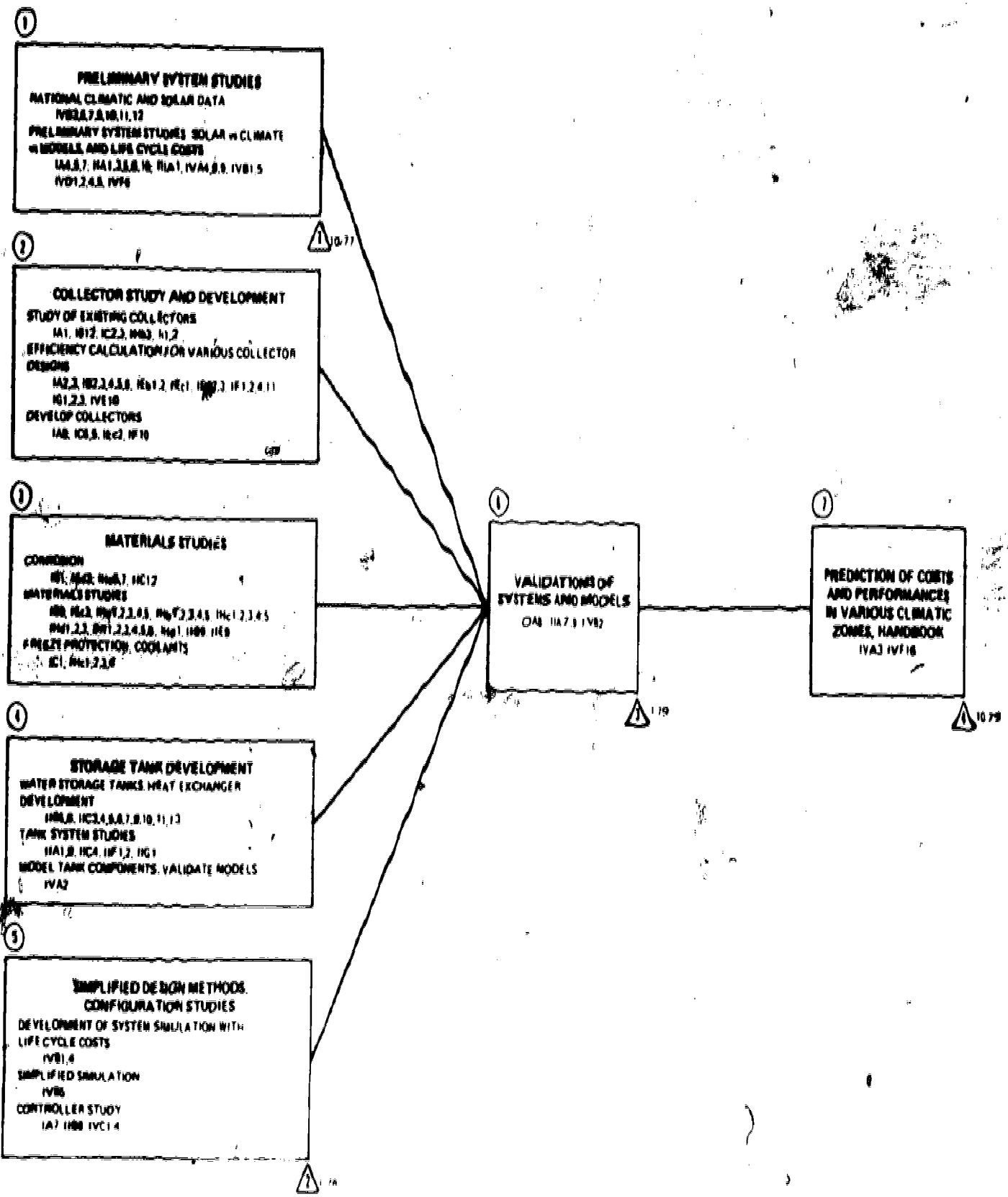


FIGURE A-6
LIQUID HEATING COLLECTORS FOR SPACE HEATING
PATH H4 TASK FLOW CHART

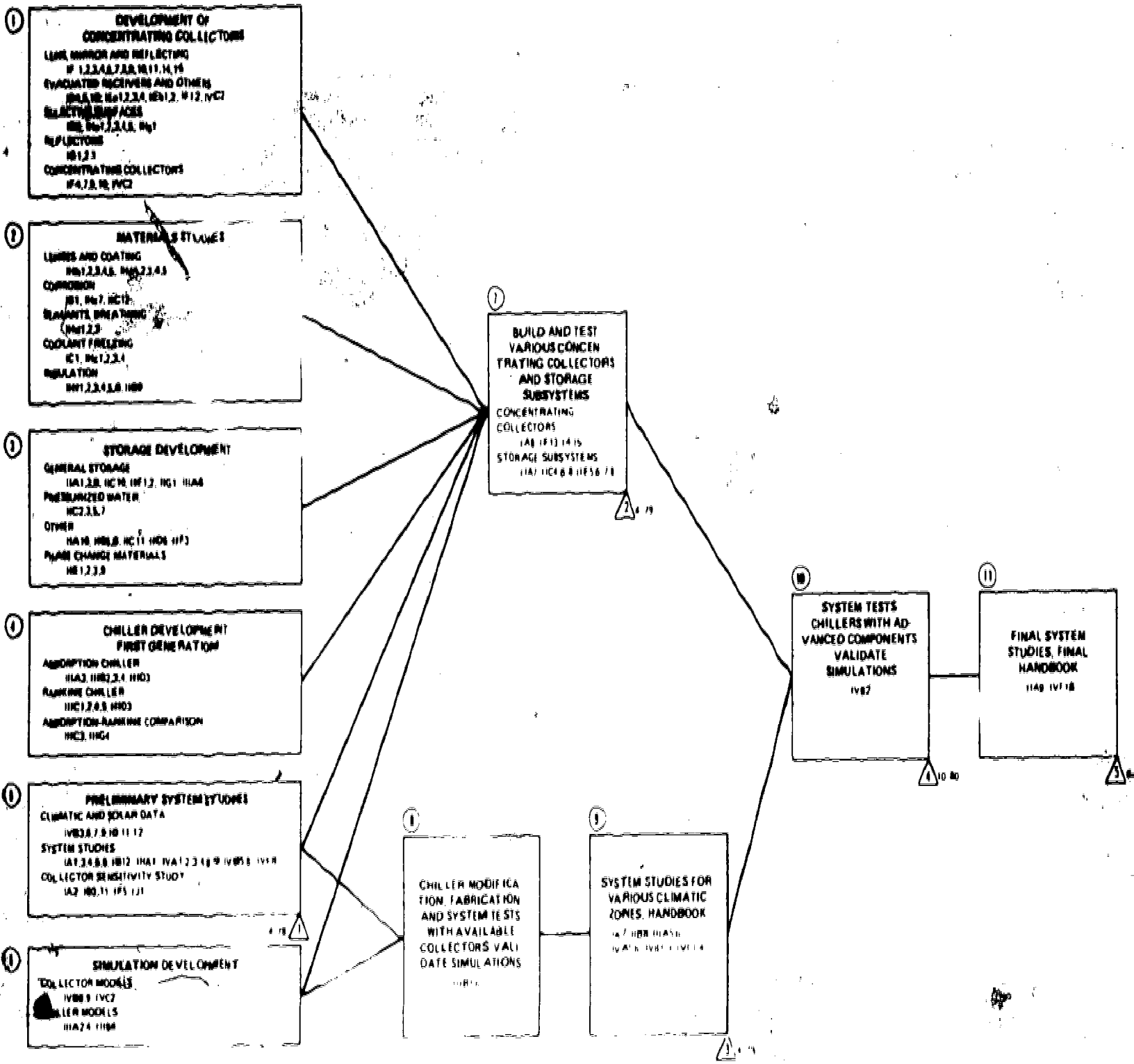


FIGURE A7

CONCENTRATING COLLECTORS WITH
ABSORPTION OR RANKINE CYCLE CHILLER FOR SPACE COOLING
PATH C1 FLOW CHART

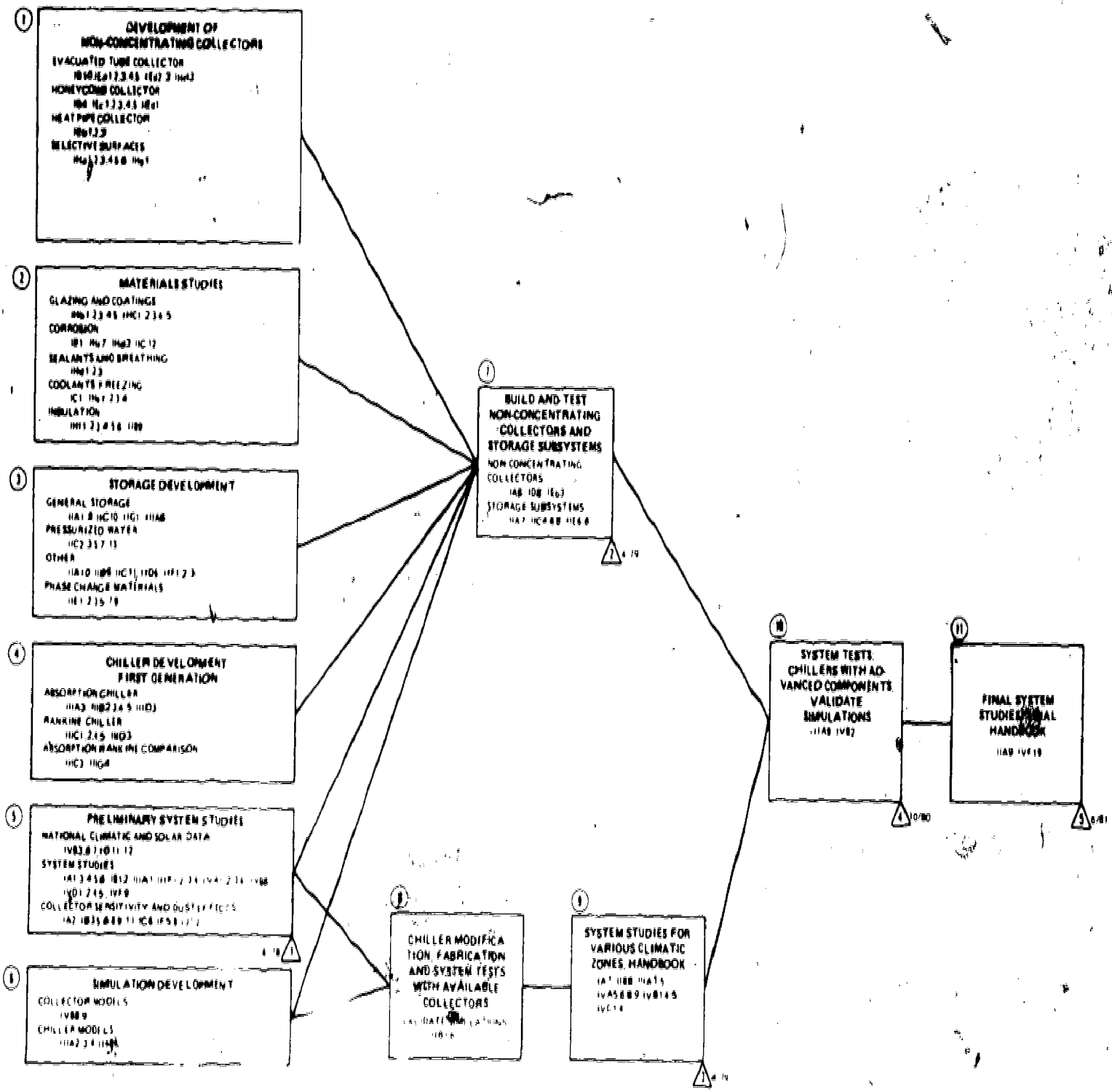
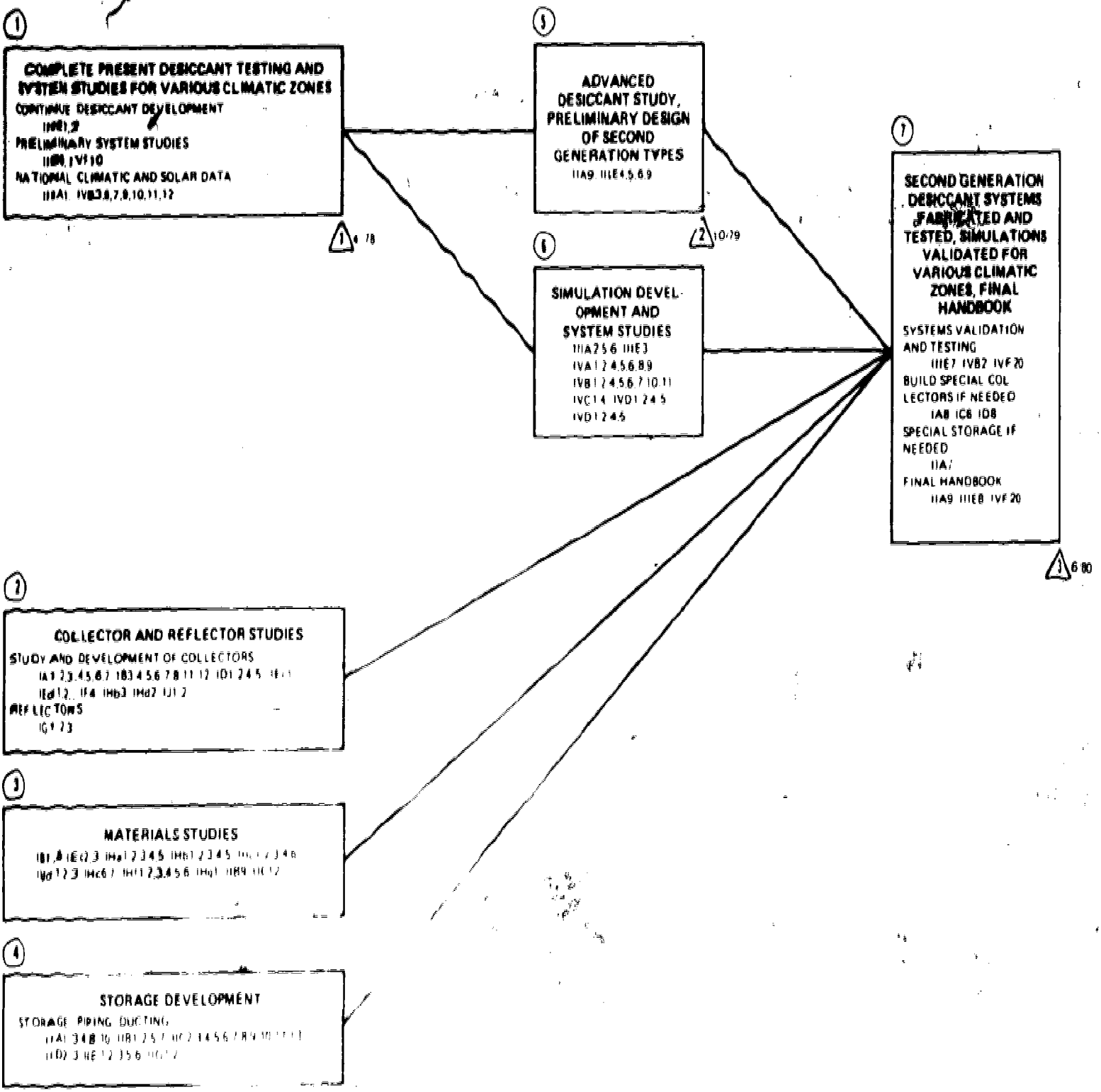


FIGURE A-8
ADVANCED NON CONCENTRATING COLLECTORS WITH ABSORPTION OR RANKINE CYCLE CHILLER FOR SPACE COOLING PATH C2 TASK FLOW CHART



...URE A 5
... TE COLLECTORS WITH
...CANT CHILLER FOR SPACE COOLING
PATH C3 FLOW CHART

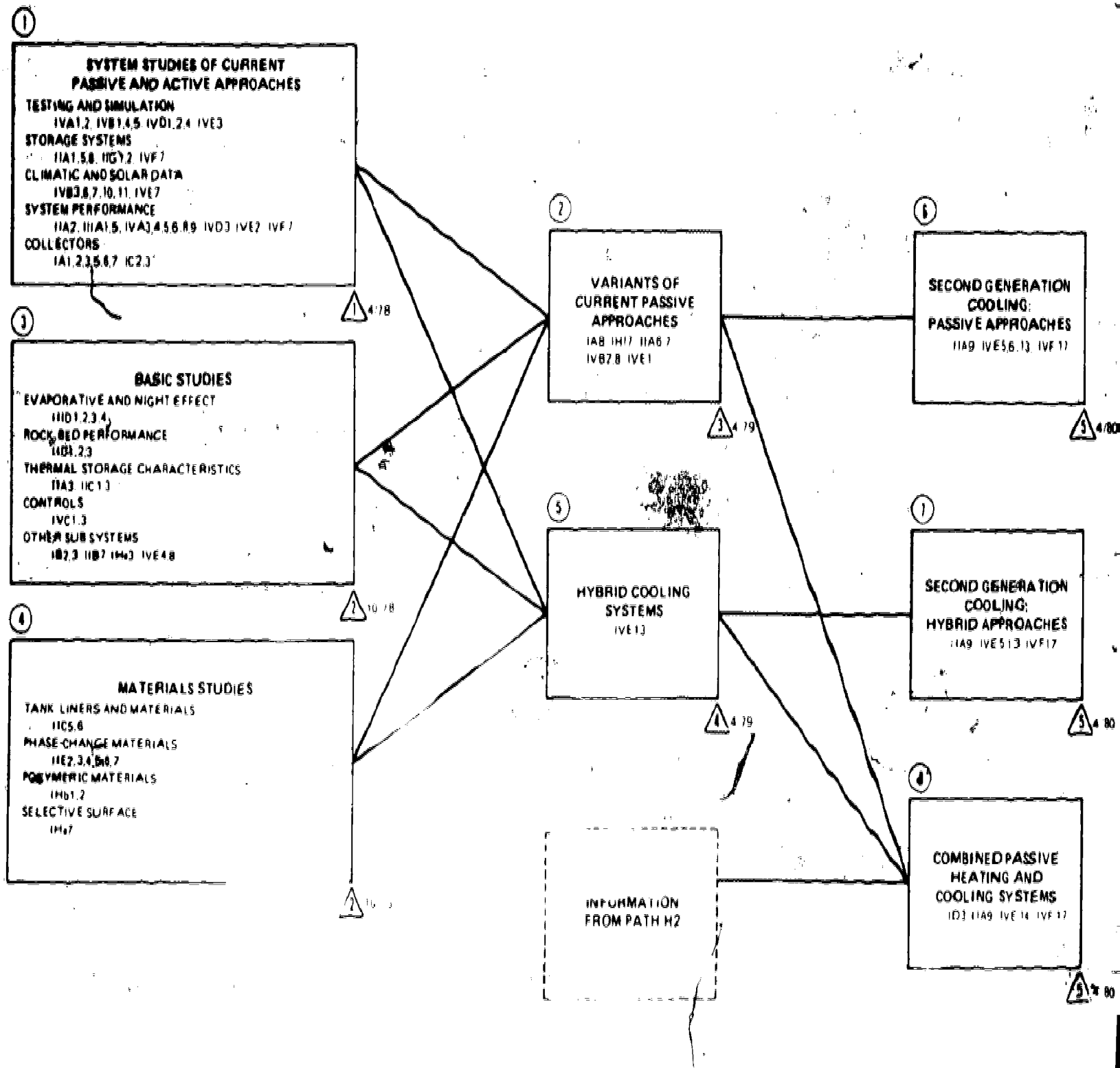


FIGURE A-10
[illegible]IVE AND NIGHT-EFFECT COOLING
PATH C4 TASK FLOW CHART

APPENDIX B
R&D Program Tasks for the Solar Heating and Cooling of Buildings

APPENDIX B
R&D PROGRAM TASKS FOR THE SOLAR HEATING AND COOLING OF BUILDINGS

This appendix describes the tasks that make up the R&D program for the solar heating and cooling of buildings. Both engineering and non-engineering tasks are included. Task descriptions are detailed enough to define the work required but broad enough to make the program flexible and responsive to changes in technology. All engineering tasks are identified according to major category and sub-category. The paths on which the tasks occur develop in parallel, and particular tasks may occur on more than one path. All paths on which each task occurs are listed, however; and the importance of the task to each path is indicated.

The following is an example of a listing of priorities for an engineering task:

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	1	1	9		5	6	6	8	8	3

In this example, the importance number indicates the relative importance of the task to the paths under which the numbers appear. A 0 to 10 scale is used, with a blank indicating no importance, 1 indicating the lowest importance, and 10 indicating the highest importance.

I. Solar Collectors

OBJECTIVE

The objective of the tasks in this category is the development of the technology necessary for a variety of cost-effective air- and liquid-heating solar collectors. The following temperature range classification will be used:

- Low temperature: below 140° F (60° C).
- Medium temperature: 120 to 200° F (49 to 93° C).
- High temperature: 180 to 500° F (82 to 260° C).

EMPHASIS

The solar collector element of the R&D program emphasizes the following points:

- Development of durable materials for glazings, surface coatings, sealants, compatible absorber-plate/coolant combinations, insulation, etc.
- Modeling and testing of various means of increasing solar input (reflectors, tracking) and reducing energy loss (reducing IR emittance, suppressing or eliminating convection, and concentration).
- Optimization of collector design for cost-effective energy collection for each system application.

TASKS

I–A. System Studies for Collectors

I–A–1 Perform a cost breakdown for collectors now being produced or developed. Investigate the following major cost categories: raw materials, parts, labor for assembly, equipment amortization, plant operation and overhead, sales, distribution, and installation. Determine whether the major competing collector types (such as liquid-heating flat plate, air-heating flat plate, evacuated tube, reflecting concentrating, and refracting concentrating) differ significantly in cost and whether regional (geographic) differences will influence collector cost appreciably.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	10	10	2	10	10	10	10	10	10

I–A–2. Study collector sensitivity by determining the effect of changes in collector design on system performance. Use weather data and solar radiation data in a computer simulation of the system, analyzing system performance for all seasons. Study collector sensitivity with varying surfaces, heat transfer characteristics, heat loss mechanisms (such as radiation and convection and the use of honeycombs), and changes in collector heat capacities. Make the sensitivity studies for various system configurations and various climates and applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	10	10		10	10	10	10	10	10

I–A–3. Develop a method for determining which solar collectors are most appropriate in given situations or climatic zones. Determine whether special procedures such as double glazing and the use of selective surfaces are particularly appropriate in certain climatic zones. Evaluate the effect of varying tilt angle, shape, and other collector parameters on collector performance for various climatic zones.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	10	10		10	10	10	10	10	10

I–A–4. Study the performance of collector [illegible] which arrangements of collector rows best balance the effects of shading and limitations on mounting space. This is particularly important for retrofit applications in urban areas. Determine optimum plumbing configurations (series, parallel, and series-parallel) to maximize collected energy for various fluid outlet temperature ranges. Analyze the effects of plumbing and manifolding on flow distribution and fluid pressure drop through the collector arrays.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	8	8		8	8	4	9	8	

I-A-5. Develop a standardized method of recording collector data to reduce the time required for supplying system analysis or test data to manufacturers.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6		10	7	8	8	7	

I-A-6. Evaluate fully instrumented collector or system tests in the field to determine whether or not collector array performance can be predicted with sufficient accuracy from individual collector test data or collector simulation models.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2		H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	6		10	7	8	8	7	5

I-A-7. Conduct control strategy studies, based on system analysis, to determine how collector and system performances are affected by various control strategies and transient parameters.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	2	1	3		4	5	6	7	4	

I-A-8. Design, construct, instrument, and operate those collectors or radiators required for certain improved systems. Develop and validate simulations for these devices. If possible, choose the collector or radiator systems from those available in the demonstration program.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	8	8	8	8	8	8	8	8	8

I–B. Theory and Basic Phenomena

I–B–1. Review the state of the art for collector corrosion processes. Develop a data bank for cataloging basic corrosion information on the various materials and heat-transfer fluids which are used or which might be used in liquid-heating collectors. This data bank will be used to develop corrosion modeling techniques.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING		
	[illegible]	W2	H1	H2	H3	H4	C1	C2	C4
IMPORTANCE NO..	10	10	10	8	5	10	10	10	[illegible]

I–B–2. Determine the effect of wind speed and direction on collector performance for both glazed and unglazed collectors. For unglazed collectors, determine the effect of surface irregularities (such as wind breaks extending from the surface) on collector performance.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	4	8	8	4	4		2	4	7

I–B–3. Determine the effect of condensed water and dust on cover-plate performance.

PATH	SERVICE HOT WATER		SPACE HE[illegible]S				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	4	4	5	4	4	7	6	4	2

I–B–4. Continue to study heat-transfer mechanisms in honeycomb collectors, emphasizing the effect of coupled wall conduction and radiation on natural convection. Investigate the effect of cell shape, properties, and tilt angle on honeycomb designs.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	2		7		6	9	7	

I–B–5. Determine the effect of large scale plate roughness (for example, tubes on the absorber surface, V-corrugations, or cups) on the natural convection heat-transfer loss from the collector. Relate these effects to the performance of various collector types.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	6		7	5	3	3	7	

I–B–6. Study convection heat losses caused by absorber and glazing surfaces that are not individually isothermal. Consider both liquid and air collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	5	5	5	6	5		2	6	

I–B–7. Investigate the relationship between Stanton number (heat transfer), friction factor (flow power requirements), and Reynolds number for forced convection plates with various extended heat-transfer surfaces (V-corrugations, fins, etc.).

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		6	4		7				7	

I–B–8. Investigate the effects on collector performance of reflective coatings on the glazing. Study the optical characteristics of collector glazings and compare the effects of these glazings on direct and diffuse radiation.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	4	3	4	5	5	4	7	6	

I–B–9. Determine the effects of coupled natural and forced convection in transpired surface collectors. Relate these effects to the surface properties.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		6	3		6			7	6	

I–B–10. Determine the theoretical heat-transfer mechanisms in evacuated collectors. Develop an adequate theoretical analysis of gaseous conduction at rarefied pressures for various geometries and tilt angles. The study should include the effect of diffusion of helium into the collectors and an estimate of the pressure required to eliminate significant conduction effects.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							6	9		

I–B–11. Investigate the aero-elastic effects of wind on collectors and collector mounts.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	3	3		3		3	3	3	

I–B–12. Compile a record of the performance of liquid-heating and air-heating solar collectors. Include information on all of the following: collector design and construction problems; the corrosion of collector materials with different coolants and environments; the performance of collector coverings, insulations, and sealants; the effects of mechanical expansion and contraction; the effects of condensation or dirt accumulation inside the cover assembly; collector connections; flow distribution problems; and the integration of collector systems into buildings. The performance record should emphasize problems encountered with these types of collector and should describe methods that have proved effective for dealing with those problems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	10	10		10	10	10	10	10	

I–C. Solar Liquid-Heating Collectors

I–C–1. Investigate the effectiveness and cost of various methods of freeze protection, including draining, chemical anti-freezes, designs for withstanding freeze-thaw cycles, low-loss coefficients, and supplying additional heat.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10		10	10		10	10	10		

I–C–2. Evaluate trickle collectors, analyzing thermal performance characteristics of these collectors in single and double-glazed configurations. Study the cost of current collectors, their potential for cost reduction, and their durability. Evaluate the entire water-collection system associated with a trickle-collector array, and discuss the effect of water evaporation over long periods of time. Define water quality control requirements and analyze the effect of high humidity on all collector components.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			9			9				10

I-C-3. Evaluate the potential for low cost, non-concentrating liquid heaters/radiators (probably unglazed) as heat sources and sinks in heat pump-based space heating and cooling system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			10			5				6

I-C-4. Develop low temperature (70 to 120° F), non-concentrating, liquid-heating collectors to be used as thermal energy sources for heat pumps. The collectors should offer significant advantages over current models in performance, cost, and/or reliability. Investigate the possibility of integrating the collectors into the building structure.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			9							

I-C-5. Develop medium temperature (120 to 170° F), non-concentrating, liquid-heating collectors for providing space heating and hot water. The collectors should offer significant advantages over current models in performance, cost, and reliability.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	9		5			9				

I–C–6. Develop high temperature (170 to 230° F) non-concentrating, liquid-heating collectors to drive cooling machines and for process heat applications. The collectors should offer significant advantages over current models in performance, cost, and reliability. Employ selective surfaces, coated glazing, convection suppressors, radiation traps, and other features where appropriate.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3		3			5		9	8	

I–D. Solar Air-Heating Collectors

I–D–1. Investigate the possibility of developing a standardized figure of merit for solar air-heating collectors. Study the effects of transmission characteristics, front face heat loss, pressure drop, and heat-transfer mechanisms on collector performance. Include cost/performance tradeoffs and the effect of manifolding on cost and pressure drops. Analyze the performance of conventional air heaters and of inflated, bag-type air heaters built into the building walls or roof.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		7	9		8				7	

I–D–2. Investigate the heat transfer characteristics of the various means proposed for promoting heat transfer from collector absorber surface to air. Study the effect of air flow velocity, fins, extended surfaces, expanded metal sheets, flow over depressions or cups, and the use of turbulators.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		8	6		10				10	

I–D–3. Investigate the possibility of building self-pumping air heaters or coolers, including natural convection types and systems using an internal, heat-actuated fan—for example, a Nitinol engine or a rubber heat engine.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		1	5	10						10

I–D–4. Establish one or more testing and evaluation facilities for air-heating collectors. Conduct tests and performance evaluations on collectors both as separate components and as parts of working systems. Evaluate the performance characteristics of air heaters in which the air travels in passages separated from the glazing and also passes against the underglazing of the collector. This evaluation should include a discussion of the effects of deposits on the glass.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		7	10	5	10				10	

I–D–5. Evaluate the effects of inlet and exit air manifold design on the performance and costs of air heaters. Study installation costs and the effects of pressure drop for such systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		5			6				6	

I–D–6. Develop low-temperature (70 to 120° F), non-concentrating, air-heating collectors to be used as energy sources for heat pumps. These collectors should offer significant advantages over current models in performance, cost, and reliability. Investigate the possibility of integrating these collectors into the building structure.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				9						

I–D–7. Develop medium temperature (100 to [illegible]° F), non-concentrating, air-heating collectors for space heating, drying, process heat, and service hot w[illegible]. These collectors should offer significant advantages over current models in performance, cost, and reliability.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		9	5		9					

I–D–8. Develop high temperature (170 to 230° F), non-concentrating, air-heating collectors for driving cooling machines and for process heat applications. These collectors should offer significant advantages over current models in performance, cost, and reliability. Where possible, use selective surfaces, coated glazings, convection suppressors, and radiation traps.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		3	3		5			9		

I-E. Advanced Non-Concentrating Collectors

I-Ea. Evacuated Tube Collectors

I-Ea-1. Evaluate current and proposed designs for evacuated collectors. The evaluation should include collector performance, potential cost effectiveness, and the implications of using the collector in various system configurations and for various applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6					5	10		

I-Ea-2. Continue the development of high temperature evac[illegible]ectors (200 to 300° F with over 50 percent efficiency) that have the potential for low costs. The [illegible] will be used to supply energy for conventional absorption chillers, for Rankine/vapor compressio[illegible]rid for process heat.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	10		

I-Ea-3. Evaluate the effect of various design parameters on the performance and cost effectiveness of evacuated collectors. The parameters should include anti-reflection coatings on the cover tube, geometry and shape of tube (acceptance angle, concentration, interception area, etc.), and mirror reflector characteristics. Establish at least two test facilities for these collectors in different climates, one with a high percentage of direct radiation and one with a high percentage of diffuse radiation. At the test facilities, det[illegible]ine loss coefficient, radiation absorbing characteristics, and other primary parameters of the collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6					5	10		

I-Ea-4. Develop performance standards for evacuated collectors, covering collector efficiency, figures of merit, and collector effectiveness in different climates.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	10		

I-Ea-5. Investigate the effects of snow, ice, hail, and thermal stress on evacuated collectors. Study solutions to any problems caused by the highly insulating nature of the evacuated tubes.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.								7		

I-Eb. Heat Pipes

I-Eb-1. Study the potential of heat pipes in various collectors, including air- and liquid-heating collectors, evacuated collectors, and stationary or movable concentrating collectors. Estimate cost and quality control requirements for heat pipes used in such collectors, and evaluate the effectiveness of the thermic diode characteristics of heat pipes.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3		4	2	4	5	6	10		

I–Eb–2. Evaluate heat pipe collector designs, determining types (e.g., mesh, groove, or artery) that are most useful. Optimize the working fluid for lifetime collector performance, and evaluate methods for eliminating problems caused by the high ΔT associated with heat removal at the heat pipe condenser. Study the possibility of making the design fail-safe against thermal runaway for heat fluxes characteristic of flat plate collectors and for heat fluxes associated with concentration ratios of up to 1:10. All of these evaluations should include cost considerations.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	1		3	3	4	6	10		

I–Eb–3. Develop the most promising high performance heat pipe collectors to be used with absorption or Rankine cycle chillers for solar cooling.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.								10		

I–Ec. Honeycombs

I–Ec–1. Evaluate the effect of varying conditions, cell geometries, IR coatings, etc., on the performance of thin-wall glass honeycomb flat plate collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6			5	4	3	8	4	

I–Ec–2. Develop cost-effective techniques for manufacturing thin-wall glass honeycomb for use in flat plate collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	2		5	5	2	7	6	

I–Ec–3. Continue to develop materials for use as honeycombs in radiation trap collectors. Possibilities include glass, plastics (Mylar, Teflon, Tedlar, Lexan, Teflon-nylon, etc.), and other non-glass materials (phenathalene polycarbonate, polyphenolene oxide, TPX, polyformethylpentane I, spiracell, rubber, etc.). Study the effect of thermal expansion and degradation on overheating and the effect of the index of refraction on collector performance. Analyze costs and manufacturability.

PATH	SERVICE HOT WATER		SPACE H				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	5			5	5	3	7	3	

I–Ec–4. Develop the most promising high performance honeycomb liquid heater to be used with absorption or Rankine cycle chillers for solar cooling.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.								10		

I–Ec–5. Continue to study heat-transfer mechanisms in honeycomb collectors, emphasizing the effect of coupled wall conduction and radiation on natural convection. Investigate the effect of cell shape, properties, and tilt angle on honeycomb designs.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	2		7	7	6	9	7	

I–Ed. Other

I–Ed–1. Design, build, and test prototype, high temperature honeycomb, transpired, [illegible]pus bed air heaters.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		7			6				6	

I–Ed–2. Investigate the potential of thermal-trap collectors, paying particular attention to the development of a fail-safe cover plate design and to control of cover plate degradation.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	3			3	4		6	5	

I–Ed–3. Evaluate the potential of black liquid collectors which use a carbon water slurry as an absorber. Study the corrosion effects of the mixture and estimate the expense of providing transparent containers for the fluid.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3					3	1			

LF-1. Develop a high performance, tracking Fresnel lens concentrator for high temperature applications. The concentrations ratio should be approximately 10X, and provision should be made for daily tracking of the sun. Investigate the reduction of heat loss by radiation or convection, the implications of protection against thermal runaway for a collector loss-of-coolant condition, and lifetime costs for the concentrating and tracking mechanisms. Consider how the design might be influenced by given applications—for example, as a source for absorption chillers or process heat.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.						2	10			

LF-2. Develop a high performance parabolic or compound parabolic mirror concentrator with a 10X concentration ratio. The concentrator should be designed for daily solar tracking and produce temperatures between 200 and 300° F at greater than 50 percent efficiency. Emphasize cost effectiveness of the thermal energy produced. Designs should provide for east-west mounting on flat-roofed buildings and for north-south tilted configurations for daily tracking. Designs should also provide for reduced energy loss through convection suppression and IR radiation suppression and for protection against thermal runway in case of a cooling failure.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.						2	10			

LF-3. Evaluate tracking mechanisms for concentrating collector systems that require daily tracking. Consider cost of the drive mechanisms, reliability of the drive systems, requirements for support structures, requirements for pivoting fluid coupling connections, means of fail-safing in case of coolant loss, and the capacity of the systems to withstand high wind and gust loads.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							10			

I–F–4. Investigate the potential of concentrating collectors that use plane or cylindrical mirrors of various types, from concentrating parabolic to V-trough. Analyze the effect on collector performance of surface irregularities and of reflectance for various concentration ratios.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	7			3	3	10		7	

I–F–5. Evaluate the effect on collector performance of dirt and other accumulations on the mirror or Fresnel lens of concentrating collectors. Establish requirements for maintaining quality in the concentrating collector optical systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	7		

I–F–6. Determine the availability of and need for rotary or flexible connections between the absorber tube and the heat transfer fluid line in linear, tracking, concentrating collectors. This includes both compound parabolic concentration and Fresnel lens collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7			

I–F–7. Monitor the Division of Solar Energy solar thermal and photovoltaic programs for design and analytical information applicable to concentrating collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							6			

I-F-8. Conduct a comparative study of the cost and performance of the most promising concentrating collectors. Analyze the effects of manifolding, energy collection, tracking, various heat-leak preventive mechanisms, etc.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	6		

I-F-9. Investigate the potential of high temperature, non-tracking, concentrating collectors that use a Fresnel lens. These collectors will have a concentration ratio of approximately 3X, achieve temperatures of 200 to 300° F, and have efficiencies over 50 percent. Investigate cost-performance tradeoffs for collectors used as sources for absorption chillers or for process heat. Study methods for reducing energy loss, including the use of selective surfaces and various means of convection suppression. Make comparisons with tracking Fresnel systems of the same aperture area.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		5					10	8		

I-F-10. Continue to develop non-tracking, concentrating, parabolic collectors with 3X concentration ratios. Consider how designs could be modified to reduce mass production costs. Study required manufacturing tolerances for collector shape and placement, and analyze the possibility of reducing energy loss through convection suppression or radiation suppression. Compare tracking and non-tracking parabolic concentrating systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.						4	6	7		

I–F–11. Investigate inexpensive, concentrating, tracking collectors for space heating and cooling applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.						6	10			

I–F–12. Investigate the use of evacuated tube absorbers as energy receivers in concentrating collectors. Because temperatures are expected to be very high, especially in stagnation conditions, the study should consider outgassing, helium penetration, and seal failure. Investigate possible efficiency gains resulting from use of selective absorber surfaces, anti-reflection coating of the outer glass envelope, and IR reflection coating of the inner surface of the envelope. Investigate the stability of these coatings under normal use and stagnation conditions. Evaluate the possibility of using heat pipe absorbers and study the fabrication costs for each of the features considered. Differentiate between the receiver requirements for 10X concentrators and those for 3X concentrators. Recommend candidate receivers for each concentration ratio. Perform tests to establish the behavior of prototype receivers.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							10			

I–F–13. Investigate the use of advanced absorber techniques and insulation for heat retention by the receivers of concentrating collectors. Analyze improvements in efficiency, costs and longevity of honeycombs, heat pipes, selective absorbers, IR outer coatings, IR reflective inner coatings, and black body traps. Study the potential of foam glass and polyimide foam for high temperature insulation. Choose candidate receivers for 10X and 3X concentrators. Build and test the receivers, using appropriate concentrators to test their behavior.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							10			

I-F-14. Choose the most cost-effective combinations of receivers and concentrators with concentration ratios near 10X. Conduct collector tests, construct a collector array, and test with available absorption or Rankine cycle chillers inappropriate climatic zones.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							10			

I-F-15. Choose the most cost-effective combinations of receivers and concentrators with concentration ratios near 3X. Conduct collector tests, construct a collector array, and test with standard or specially designed absorption or Rankine cycle chillers in appropriate climatic zones.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							10			

I-G. Reflectors for Collector Augmentation

I-G-1. Study the performance of movable and immovable collectors. Analyze the importance of reflectance by comparing diffuse and specular performance, analyzing the effects of collector and reflector geometry, and studying the necessity for periodic reflector adjustment. Estimate the effect of reflectance on collector loss-of-coolant temperature excursions. Study the effect of reflectance on collector performance in space heating and cooling applications. Study the use of diffusing or reradiating surfaces (e.g., white gravel) and specular reflectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	10	10	6	10	6	7	7	10	

I-G-2. Investigate means of mounting reflectors on buildings to enhance the performance of solar collectors. Study the durability of the reflectors and their supporting structure, the wind loading on large reflectors (particularly those mounted above the collector), the effect on the architecture of the house, and potential effects beyond the building's immediate surroundings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	4		5	10	5		6	10	

I-G-3. Identify reflectors that are attractive for use with diffuse and specular solar collectors. Study cost, stability, and durability of the various candidate materials. These materials should include white gravel on roof decks, white paint, white porcelain bonded to thin sheet metal, anodized or non-anodized aluminum, standard roofing materials, silvered microglass, conventional mirrors, metalized films, polished and coated aluminum sheet, and aluminized paints.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	4	10	5	10	5		5	5	

I-H. Materials

I-Ha. Selective Surfaces

I-Ha-1. Conduct a program for testing failure modes and mechanisms of selective surfaces. Expose candidate surfaces to UV radiation, elevated temperatures, and humidity. Determine their endurance, develop methods for overcoming failures, and assess economic tradeoffs.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	2		6	6	7	5	6	

I-Ha-2. Develop techniques for producing black chrome selective surfaces.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	7			5	5	7	7	6	

I-Ha-3. Evaluate instrumentation for making fast, accurate measurements of absorptance and emittance. The instrumentation would be used in production process quality control and detection of coating irregularities. Consider the use of CO_2 lasers; and evaluate the possible use of simplified testing procedures, in which only one or two representative temperatures and wavelengths are used. Recommend quality control testing standards for selective surfaces.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	3		6	6	6	6	6	

I-Ha-4. Evaluate selective surfaces based on metal oxides, including black chrome, black nickel, and copper oxide. The following aspects are to be considered in the evaluation: surface solar spectrum absorptance and IR spectrum emittance, surface stability in different environments (humidity, solar radiation, general abrasion), surface mechanical stability during multiple cycles of expansion and contraction, and surface cost as a function of production rate.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	9	2		4	7	6	7	6	

I-Ha-5. Evaluate the stability of the following types of selective surfaces: electroplated metal oxides, mildly selective black paints, dipped chemical conversion coating processes, interference films, and semiconductors. Investigate the possibilities of selective surfaces which do not use strategically scarce domestic materials.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	2		5	5	5	9	6	

I-Ha-6. Support the development of the most promising high performance flat plate collector with selective absorber (and other features as required) for use with absorption or Rankine cycle chillers for solar cooling.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.								8		

I-Ha-7. Evaluate various paints and other coatings for application to a night-sky radiative panel. This includes the characterization of materials that have high IR emittance and low absorptance.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.										10

I-Hb-1. Develop a range of polymeric and other non-glass materials resistant to weathering, UV radiation, and high temperatures (~ 300° F). These materials must be suitable for mass-produced collector glazings and housings, and they must be low cost (detailed economic studies will be necessary). Identify existing production techniques and products, and evaluate the products for resistance to UV radiation, abrasion, temperature, humidity, etc.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	7	7		8	7	7	7	5	7	8

I-Hb-2. Develop facilities for testing polymeric and other non-glass glazings in the following areas: accelerated aging, exposure to a variety of environments (dampness, cold, pollution, wind, altitude, salt spray, etc.), high temperature and UV degradation, inner glazing applications with glass as the cover plate, and others as appropriate.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	7	7	8	8	7	7	7	5	7	8

I-Hb-3. Determine the damage history of both glass and non-glass collector glazings, including hail damage and vandalism as well as thermal stress breaks. Determine the significance of such damage for collector performance.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	4	4	10	5	7	8	5	

I-Hb-4. Investigate the potential for large volume production of glass tailored for use in solar collectors. Include the transmissivity, reflectance, durability, thickness, and size limitations of the glass.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6	6	10	6	5	6	7	

I-Hb-5. Determine the effect of glass surface conditions on collector performance. Include an evaluation of traditional glass surface figuring and etching.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	4	5	6	4	4	5	5	4	

I-Hc. Glazing Surface Coatings

I-Hc-1. Develop durable coatings for plastic glazings. Compare the cost of applying a coating of polymeric plastic on PVC film to the cost of building the stabilizer into the polymeric material.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6	7	6	6	7	5	6	

I-Hc-2. Continue development of surface etching processes for reducing reflectivity on both glass and plastics. Determine the types of glass or plastic most appropriate for this treatment, their potential for mechanical surface failure, the effect on them of dirt and repeated washing, and their cost effectiveness.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	6	6	5	5	5	5	6	

I-Hc-3. Investigate means for applying IR or anti-reflection coatings uniformly in large volume production. Consider coatings for glass and plastics, and study the cost implications of the production process.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	5	6	4	4	5	6	5	

I-Hc-4. Develop IR reflection coatings. Emphasize increasing the solar spectrum transmittance of the coating while retaining the reflection characteristics. Study the effect of IR reflection and solar transmission on collector performance for both flat black absorber and selective absorber surfaces. Evaluate conventional and advanced collectors with honeycomb convection suppression and other advanced collector systems such as evacuated collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	5	6	4	4	5	6	5	

I-Hc-5. Continue to develop semi-conductor IR reflection coatings such as tin oxide and indium oxide. Pay particular attention to environmental stability, the optimization of the level of doping, and the coating thickness. Maintain close monitoring and interfacing with solar photovoltaic developments involving these coatings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	6	5	5	4	4	5	5	5	

I–Hd–1. Evaluate a large range of sealants for use in solar collectors. Investigate silicones, ethylene terpolymer-hydroxide (rubber) adhesive, polyvinyl butyral, EPDM, organic tars, etc. Study out-gassing, high temperature stability, UV degradation, strength characteristics, the matching of thermal coefficients of expansion with collector materials, cost of materials and installation, and durability.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	7	10	6	6	10	7	7	10	10	

I–Hd–2. Evaluate methods for controlling breathing in solar collectors. Candidate techniques are vents, solar regenerative desiccants, and pressure relief tubes. Investigate the effects of uncontrolled breathing on collectors which have been in service for many years. Complete a study of the corrosion or failure of cover plate or absorber plate due to water condensation; the effect of condensed water leaking into insulation material; the effect of condensed, then frozen, moisture; and any effects of moisture on absorber surfaces.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	10	5	5	10	6	6	5	6	

I–Hd–3. Develop a durable, high temperature, high humidity, glass-to-metal seal that could be used in a hermetically sealed collector for service between 250 and 300°F.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	1	1			1	1	8	9	3	

I-He. Coolants

I-He-1. Conduct a comprehensive evaluation in search of a superior liquid coolant for solar collectors. Evaluate the coolants for toxicity, freeze protection, boiling protection, heat capacity, viscosity, heat-transfer effectiveness, stability, cost, safety, flammability, sealing, and corrosiveness in metals such as mild-steel, aluminum, and copper. Analyze the following candidate liquids: ethylene or propylene-glycol in water, silicon fluids, paraffinic oils, hydraulic fluids, and pressurized mixtures of ethanol and water. Survey the state of the art for heat-transfer fluids in non-solar areas, and investigate ways in which these applications differ from solar applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8		7			10	10	10		

I-He-2. Document and characterize the properties and behavior of currently used collector coolants.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10		6			8	10	10		

I-He-3. Determine [illegible] antifreeze additives and the types of water (ionized tap distilled etc.) used as collector coolants. Indicate how the interaction influences mixture properties and corrosive tendencies.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	7		4			6	7	7		7

I–He–4. Compare the economic benefits of using control systems to avoid freezing and adding chemical antifreeze or non-water base coolants to increase collector area.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4		2			8	7	7		

I–He–5. Develop potable corrosion inhibitors for use in hot water systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10					7				

I–He–6 Study air filtering requirements and air filtering technology for air heaters. Investigate possible air contamination problems arising from disintegration of air system components such as sealants, insulation, etc.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO		4	4		10				4	

[illegible] systems including [illegible] conditions to emphasize elevated temperature and stagnation conditions. Correlate data from [illegible] this information. Use accelerated tests if necessary.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	10	10	8	8	8	10	10	10	8	

I–Hf. Insulation

I–Hf–1. Evaluate the problems of moisture absorption and out-gassing of adhesive binders in fibrous insulation. Continue the investigation of foil facing used as an out-gassing, moisture, and radiation barrier.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	3	6	6	6	8	8	7	

I–Hf–2. Support the development of CO_2 and air-blown polyurethane foams for use as collector insulation. Determine optimal void volume, thermal stability, and lifetime and insulating properties. Define methods for protecting the foam against fire.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	4	6	6	6	7	5	5	

A

I–Hf–3. Investigate the [illegible] insulation

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	4	4	4	5	5	5	7	7	6	

[illegible] aspects of foam glass [illegible] effects [illegible] dispersion, dimensional stability, and high temperature degradation [illegible]

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	4	4	3	4	4		6	4		

I-Hf-5. Survey and document the properties of known and candidate insulation materials, especially those originally developed for non-solar applications. These properties include out-gassing, moisture absorption, thermal degradation, etc. Identify new, high performance, insulating materials suitable for use in solar collectors.

PATH	SERVICE HOTWATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6	6	6	7	6	5	6	

I-Hf-6. Support the development of polyimide foams for use as collector insulation. Study the following aspects of the foams: dimensional stability, flammability, cost effectiveness and cost reduction, stability at evaluated temperatures, and the thermal conductivity/density relationship.

PATH	SERVICE HOTWATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	4	5	4	5	5	5	8	8	5	

I-Hf-7. Investigate [illegible] used in passive solar heating and cooling applications. Assess cost convenience safety lifetime and thermal performance characteristics.

PATH	SERVICE HOTWATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO				10						10

I–Hg. Absorber Surfaces

I–Hg–1. Evaluate the potential of long-life, stable, non-metallic films for use as absorber surfaces or other collector components. Study the problem of low temperature conductivity of these films; and consider the development of an integrated, sealed, all-plastic collector module.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	7	6	3	5	6	7	2	2	5	

I–J. Tests and Standards

I–J–1. Recommend standards for the dimensions of solar collectors. The standards should facilitate collector packaging, shipping, installation, and use. Review current collector sizes and mounting characteristics. Discuss the value of such standards and estimate their probable degree of acceptance.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	3	3	3		3	3	3	3	3	

I–J–2. Develop [illegible] methods for reflectors intended for use with solar collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	3	3	3	3	3			3	3

II. Thermal Storage and Heat Exchange

OBJECTIVE

The basic technology must be developed for cost-effective means of collecting solar heat in collector arrays, transferring it to thermal storage, maintaining it in storage, and transferring it to the load on demand.

EMPHASIS

The program emphasizes the identification and development of durable and effective material for piping, heat exchangers, thermal storage media, and storage tanks. It also stresses mathematical modeling and testing of various means of decreasing installed costs and increasing the thermal performance of the manifold/heat exchange/thermal storage system.

TASKS

II–A. Storage System Studies

II–A–1. Investigate the various means used for collecting energy from a solar collector array and transferring it to a storage medium. Study methods of manifolding collectors and running the thermal collection medium to a central storage point, and examine methods of heat exchange with the thermal storage material. For each approach, identify materials and installation costs, required building space, and thermal loss characteristics. Study means of combining or integrating collection and heat exchange processes to reduce costs.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	6	6	6		8	8	8	8	8	8

II–A–2. Study the characteristics of [illegible] of building components, materials and massive walls for passive thermal storage. Examine special media that could be used in buildings. Discuss how all these elements could be used to smooth out temperature variations in buildings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO			2	9						7

II–A–3. Develop mathematical modeling techniques for analyzing thermal storage as part of a whole building system. Emphasize computer-assisted analysis of solar energy systems. Develop two means for analysis: detailed models and simplified codes. The models will make it possible to determine the effect of stratification, phase-change, and non-equilibrium conditions on system performance. The codes can be used in system models. They will be validated for particular time steps and conditions and distributed for general use along with documentation on their function.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	3	3		5	3	5	5	5	3

II–A–4. Develop a theoretical model for the characterization of incongruent phase-change storage media. This model should identify and characterize the phenomena of crystallization and heat transfer within the medium. It should also be useful for characterizing long term effects such as precipitation. The model should be developed to be useful for determining the effect of varying the heat-transfer rate and the effect of varying the geometry of storage containers that use phase-change material. The model should be validated (or calibrated) against experimental data on phase-change materials.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			1	2	6				6	

II–A–5. Assemble a handbook of data on thermal storage materials. The handbook should be useful for architects and engineers. It should incorporate information on thermal storage systems installed in buildings, problems with installing thermal storage systems, and theoretical and actual performance characteristics.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	2	2	2		4	3	4	4	3	5

II–A–6. Study the economics and technical feasibility of seasonal storage, both for winter heating and summer cooling. Define the relevant subsystem parameters and climatic variables affecting cost-effectiveness.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			5		2	6				5

II–A–7. Design, construct, instrument, and operate storage subsystems necessary for improved systems. Develop and validate mathematical simulations for these improved subsystems. Consider storing heat and/or cold. If possible, choose these storage subsystems from among those available in the demonstration program.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	9	8	5	6	8	8	7	8

II–A–8. Prepare a comparative evaluation [illegible] both a performance and cost basis, of complete conventional storage subsystems. Subsystem components include the storage media, containerization, and heat transfer and heat exchange components.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	8	8	5	5	5	5	5	5	5	4

[illegible]

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	8	8	7	7	7	8	5	5	5	5

II–A–10. Conduct a system analysis of advanced thermal energy storage subsystems, emphasizing the physical requirements of various solar energy applications. Define the significant physical parameters, optimum parameter ranges, and boundary conditions for the subsystems when they function in each of several important solar energy systems. Study input and output requirements for the subsystems (phase-change materials, reversible chemical reactions, etc.). The results of this task will be used in setting priorities for additional R&D activities.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			5	4	5	3	10	9	9	

II–B. Piping, Ducting, Heat Exchangers

II–B–1. Develop a compact, packaged, air-handling unit for use in air-heating collector systems. The unit should incorporate the necessary dampers, controls, and an auxiliary heater and fan.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.					8				8	

II–B–2. Develop low cost efficient [illegible] energy loss leakage damper and control systems for use in air systems

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO					8				8	

II–B–3. Develop a fail-safe heat exchanger for use with a domestic hot water system. The heat exchanger must not leak the primary coolant into the domestic hot water system even when the exchanger malfunctions. Emphasize cost effectiveness.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8									

II–B–4. Investigate the effects of flow passage size and system layout on the performance of low velocity, natural convection, solar heating systems which utilize rock bed thermal storage and either air-heating collectors or direct heating of the space or structure. Analyze the stability of flow through the rock bed and the effect of turns, duct sizes, and obstructions on the overall air flow characteristics of the system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				6	6					

II–B–5. Investigate the use of direct contact liquid to liquid heat exchangers for use in liquid-heating-collector/water tank storage solar energy systems. Study the effects of transfer of liquids from loop to loop through the heat exchanger.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	2					5	2	4	2	

II-B-6. Identify low cost materials with low installation costs that are suitable for plumbing insulation for moderate temperature systems that use a liquid-heating collector.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6			8				

II-B-7. Identify low cost replacements for sheet metal ducting for air systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		8		8	8		6		6	6

II-B-8. Investigate the use of self-controlling self-pumping circulation systems, such as heat pipes, for transferring heat between collector and storage system and between storage system and heat load. Identify the most promising heat transfer methods and compare their cost-effectiveness with that of standard pumping systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	1	1	2	3	5	5	4	5	5	

II-B-[illegible] [illegible] 350°F

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			[illegible]			5	6	8	6	

II–C. Water Tank Storage

II–C–1. Investigate the heat flow characteristics for water tank thermal storage in a passive solar heating system. Consider transfer of heat into storage during direct sun irradiation and transfer of heat out of storage into the structure. Investigate the effect of color, surface shape, and form on subsystem performance.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			5	8						8

II–C–2. Investigate the problems associated with thermal storage in the temperature range from 195 to 350°F. Include the use of pressurized hot water, fluids such as paraffinic oils, solid materials such as rock, and phase-change materials. Consider the thermal performance characteristics and the cost characteristics of storage, including container and heat exchangers.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							8	8	6	

II–C–3. Write a handbook for water tank thermal storage. This handbook should identify the ways in which water has been used for thermal storage, various means of storing water and insulating the tanks, types of liner for tanks, and the corrosion characteristics of the various approaches. The handbook should also identify the basic cost characteristics of each approach.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	3	2	6		6	6	4	4	6

II–C–4. Investigate the use of multiple tanks to allow thermal storage at a number of temperature levels. Determine whether this approach is cost beneficial in various system applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6	5		6	6	6	4	

II–C–5. Investigate the potential of non-corrodible liners for water storage tanks. These liners might be made of plastic, fiberglass, or other materials. Different types of liner might be used with different types of tank.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5		5	5		7	5	5	3	5

II–C–6. Investigate the use of unconventional materials, such as lightweight concrete composite structure, for a water thermal storage tank. The material used should be waterproof and low in thermal conductivity so as to be insulating. It might also be capable of service as a structural element of a building.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	5	5		6	5	5	5	5

II–C–7. [illegible] tank wall. Investigate tank [illegible] separate heat exchange panel strapped on the outside. In considering cost characteristics allow for the reduced amount of equipment required and for the extra thermal tank manufacturing cost.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	3	5			5	5	5	3	

II–C–8. Investigate the effectiveness of temperature stratification in water storage tanks. This study should be a combination of a system analysis (to determine the effectiveness of stratification in a given application) and an analysis of the means by which stratification can be achieved. Identify theoretical models suitable for predicting the degree of stratification that can be achieved and validate the models. Examine the effects of the placement of heat exchangers and auxiliary heaters on producing and maintaining stratification. Identify the cost characteristics of the various means of achieving stratification.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	8	4	5		8	8	8	4	

II–C–9. Investigate a hybrid storage system in which a water tank is surrounded by a supporting rock bed. Identify the heat-exchange and thermal-storage characteristics of the rocks. Propose a suitable mathematical model for the hybrid storage system and validate that model with test data.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.		6			6				4	

II–C–10. Investigate the use of unconventional fabrication methods, both in factory and on site, for the construction of water tank thermal storage units. Include alternate-material-layer buildup, foam spray techniques, and incorporation of the tank as a structural element.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	8	7	3	5	5	6	5	5	

[illegible] design requirements, material selection, and cost factors involved in the retrofit of water [illegible] in existing buildings, including single and multiple residences and commercial buildings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	10	8	9	5	8	5	4	8	

II-C-12. Investigate all possible methods for combating aqueous corrosion of the various materials used for water tanks and heat exchangers. Include chemical additives and electrolytic processes.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	10	5	8	3	8	5	6	8	

II-C-13. Design, construct, and test water tanks with increased temperature stratification. Include the use of fixed or movable baffles, water flow controls, tank shape or orientation, etc. The cost effectiveness of each design should be emphasized.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	10	6	10	5	9		3	8	

II–D. Rock Bed Storage

II–D–1. Investigate the potential of rock beds for cooling applications. Rock beds can be used to store cool from night air for daytime applications and they can be cooled by evaporative chillers during the day or night. The stored coolness can then be used to cool the building. Study problems caused by water condensation in the rock bed, and investigate means of counteracting them.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				5	5					7

II–D–2. Promote an exchange of information with CSIRO of Australia on the performance of rock bed thermal storage systems (commonly called rock bed regenerators in Australia).

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			3	3	6				5	7

II–D–3. Prepare a handbook on rock bed or gravel bed thermal storage systems. Identify the basic characteristics of rocks commonly used in such beds, including their thermal heat capacity, density, and packing fraction. Use design charts to indicate the effects of bed length, air flow rate, rock size, distribution of rock size, etc. on the heat transfer and pressure drop characteristics of the rock bed. Discuss methods of constructing and supporting rock beds, methods of installing plena at the ends of the beds, the availability of various kinds of rock, rock costs, problems caused by dust in rock, and areas of the system where problems are likely to occur. Include several examples of typical rock bed installations.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			3	3	5				5	6

II–D–4. Investigate the potential for and cost of incorporating the evaporator portion of a heat pump into a rock bin thermal storage device. In computing costs, include the cost of the piping that may be necessary and the heat transfer rates to the piping, both with forced air flow and without air flow. Study the overall problems of building such a subsystem.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			5			5				

II–D–5. Investigate the potential for utilizing rock beds for storing heat above 212° F.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	4	4	

II–E. Phase-Change Storage

II–E–1. Analyze the influence of materials characteristics on the performance of phase-change systems in solar heating applications. Study the use of phase-change storage with air-heating collector systems and with liquid-heating collectors. Identify the phase-change temperatures most suitable for different climatic zones. Determine which phase-change materials are most suitable according to the fraction of heat to be supplied by solar energy and according to the characteristics of the solar heating system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			4	4	6		8	8	5	

II-E-2. Identify the cost characteristics of phase-change storage systems. Include the cost of the storage media itself, the cost of the storage container, and the cost reduction resulting from the decreased space required for storage in various applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			3	4	6		8	8	3	5

II-E-3. Continue the investigation of salt hydrate phase-change storage materials. Determine the nucleation heat-transfer and precipitation characteristics of the salt hydrates. Include means of promoting nucleation and preventing precipitation. The study should concentrate on those types of salt hydrates that are most appropriate for solar heating and cooling applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			2	3	6		8	8	3	5

II-E-4. Investigate the potential of phase-change materials for thermal storage in passive solar applications. Include an identification of the desirable temperature and heat-transfer characteristics of the phase-change material. Consider methods of encapsulating or containing the storage material and indicate how these methods might be incorporated into the structure of the building to be conditioned.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			6	6						6

II–E–5. Investigate the use of organic materials such as paraffins or waxes for phase-change thermal storage. Study micro-encapsulated paraffin spheres in packed beds or a water slurry and paraffin encapsulated in a thermally-conducting honeycomb structure.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			6		6		8	8	3	6

II–E–6. Investigate cost-effective methods for containerizing phase-change storage materials for thermal storage systems. Container designs must satisfy heat exchange requirements, both from air to water or other fluids and within the material.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			5	3	5		8	8	3	6

II–E–7. Compare phase-change storage materials with the other storage materials used in several different experimental solar heating systems. The comparison should be either a side-by-side test, in which the phase-change storage is set up so that it can be used within the building, or a test in which the phase-change storage replaces the current storage. Perform detailed tests to compare the performance of the phase-change storage with the conventional storage media.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.					5		7	5		7

II-E-8. Conduct a search for phase-change materials whose transition occurs at temperatures appropriate for use with absorption chillers, e.g., 195° F (91° C), 230° F (110° C), and 300° F (150° C). Develop container/heat exchangers for these materials.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							9	9		

II-E-9. Investigate safety hazards connected with the use of phase-change materials. These hazards include large expansion of paraffins and salt hydrates, paraffin flammability, etc. Suggest reliable and cost-effective methods for either avoiding or eliminating these dangers.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.					4	2	8	8		

II-F. Chemical Storage

II-F-1. Continue the investigation of the feasibility of heat storage using $LaNi_5$ and mischmetal-Ni_5.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.						2	2	2		

II–F–2. Initiate a search for inexpensive metal hydrides for use in thermal storage systems. These metal hydrides should have reactions which occur in the temperature ranges normally available from solar collectors. This study should also include a search for other materials or means of achieving chemical thermal storage. Identify reactions which have a high heat of reaction at low reaction temperatures.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.						2	2	2		

II–F–3. Initiate a search for chemical storage materials whose reaction temperature is appropriate for the operation of Rankine cycle/vapor compression chillers for solar cooling. A typical temperature might be 400 °F (200° C).

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	5		

II–G. Tests and Standards

II–G–1. Evaluate the NBS thermal storage test technique for water tank, rock bed, and phase-change systems. Examine the procedure, incorporate useful experience and suggestions, and recommend any necessary modifications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	2	2	2	2	2	2	2	2	2	2

8.C-2. Develop criteria for evaluating the durability of thermal storage devices and for evaluating the cyclability of such devices. The criteria must be incorporated into the thermal storage test and evaluation techniques.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				1	2				2	1

III. Solar Air Conditioning and Heat Pumps

OBJECTIVE

The present technology for using solar heat to cool buildings must be advanced. It will be necessary to identify the cost and performance characteristics required for a solar cooling system to be cost effective in various climatic zones. It will also be necessary to define climatic regions where heat pump systems can be used for both heating and cooling.

EMPHASIS

The program emphasizes the following:

- System analysis of the most effective approaches and configurations for solar cooling, with a separate analysis for each climatic zone.
- Optimization based on (the above) system analysis of absorption and Rankine chillers for use with a 220 to 250°F heat supply from thermal storage.
- Optimization of absorption and Rankine chillers for use with temperatures over 250°F, heat being supplied directly from the collector. Cold side storage will be evaluated.
- Development of cooling devices that couple well with heated air.
- Optimization of absorption chillers to operate with heat from thermal storage (180 to 220°F).
- Development of solar-actuated dehumidification.
- Determination of climatic zones and operating conditions which allow heat pump systems to be used for heating and cooling.
- Determination of climatic zones and operating conditions where a collector system can be used to both drive an air conditioner and provide building heating.

TASKS

III–A. System Studies for Air Conditioning and Heat Pumps

III–A–1. Analyze cooling and heating requirements for different climatic zones, identifying areas where a system designed for solar heating can be used for cooling when augmented by a heat actuated chiller. Identify also those areas where either direct or indirect evaporative cooling with thermal storage is effective. For areas where a separate solar cooling system is necessary, define collector area requirements for a system that uses a high performance collector producing energy at temperatures between 250 and 300°F. Also, define requirements for a moderate performance system that uses a high performance flat plate collector.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.						7	8	8	8	8

III–A–2. Identify computer models of chillers that can be used with the major dynamic solar system analysis codes. Models should be generated for absorption, Rankine cycle, and desiccant machines. The models should incorporate transient effects in the chillers.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							9	9	9	

III–A–3. Investigate the possibility and implications of varying the air conditioning evaporator temperature in the range from 45°F (the ASHRAE standard) to perhaps 60°F. Study the overall cost of obtaining an optimum temperature, considering climatic zone, the cost of distributing cooling in a building, and the cost of generating cold water. Use performance data from absorption and other types of cooling machines.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							9	9		

III–A–4. Prepare a dynamic model of an absorption type of cooling system suitable for studying on-off operation and variable-input-temperature operation in a typical solar cooling installation. Use this model to investigate the effects of on-off operation on overall system performance, and validate the model against results obtained in actual system tests.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							9	9		

III–A–5. Identify the utility load profile characteristics of solar cooling systems for various climatic zones and system configurations. Investigate means by which load profiles can be modified to lessen the impact on the electric utilities.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	7	7	6

III–A–6. Identify the tradeoff between using hot storage and cold storage in solar cooling systems in locations where solar cooling is warranted. Identify the optimum thermal storage characteristics for hot storage considering the cost of solar heat, the cost of thermal storage, and the cost and COP of energy conversion.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			4				7	7	7	

III–B. Absorption Chillers

III–B–1. Collect and disseminate information on the operation of the currently available 3-ton lithium bromide absorption chiller operated at temperatures of 180°F and up. Discuss the effects of modifications to the chiller. For the most part, this information can be derived from installations where these chillers are used.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	8		

III–B–2. Study in detail each of the following approaches to small absorption machines: miniaturization of large versions, air cooling without crystallization, and combined absorption and cooling tower. The third possibility has three potential advantages: the economic benefit of combining two components into one; consumption of less electricity; and more evaporative surface, reducing the scaling problem.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	7		

III–B–3. Investigate the possibility of using refrigerant absorber pairs other than lithium bromide and water and ammonia and water in absorption cooling units.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	7		

III–B–4. Develop an ammonia and water absorption chiller optimized for use with a high temperature solar heat supply (250 to 300°F) for a residential application with an air heat-rejection system. After settling on the design characteristics of such a system, have the system built and test it. In parallel with this, investigate the use of the system with various solar collector and storage configurations in different climates. Include an investigation of the cost characteristics of the entire system and the overall operating system COP.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	6		

III–B–5. Develop a lithium bromide absorption chiller optimized for use with a solar flat plate collector system for residential applications. The chiller should have a capacity of about three tons and should be optimized for use with generator inlet temperatures of approximately 195°F. Design the machine for use with a water cooled condenser and absorber.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.								10		

III–B–6. Develop and test absorption chillers that appear to satisfy the performance and cost requirements of various cooling systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							10	10		

III–C. Rankine Cycle Vapor Compression Chillers

III–C–1. Investigate various uses of piston compressors for air conditioners that use currently available mass production facilities and components. Consider the use of electric motors and hermetically sealed units or even units with rotary seals. Investigate the use of speed modulation to vary the capacity of the machine. This will generally improve the net COP of the machine at reduced capacity because of decreased heat-exchange temperature drops.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			8				8	8		

III–C–2. Investigate the potential of Rankine cycle chillers for use in solar cooling installations that use high temperature advanced collectors producing temperatures from 200 to 300°F. Identify the tradeoff between Rankine cycle chillers and absorption in this temperature range.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							8	7		

III–C–3. Compare absorption and Rankine cycle chillers of varying size (3 tons, 100 tons, etc.), considering the solar heat energy, the electrical energy, and other elements required for the operation of these machines. Compare the effects of transient operation for both systems. Define the advantages of the Rankine cycle units, considering the operating range of both types of system, the climatic zones in which they are effective, and the potential of the Rankine unit for mixed cycle operation. Discuss reliability, cost, and performance of both systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	7		

III–C–4. Develop a Rankine cycle vapor compression chiller optimized for residential applications. Use information from units currently in operation. (For the most part, these units were built with off-the-shelf components.) Study the potential for driving the Rankine cycle by a solar heat source with an electric motor as a system component. The motor can be powered by the solar heat source, or it can drive the vapor compression chiller. Identify the most attractive system configurations that use this principle.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	7		

III–C–5. Investigate the potential for using a solar collector array as the generator or the boiler in a Rankine cycle system. Consider the performance, cost, reliability, and leak-tightness requirements of the system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							7	7		

III–D. Evaporative and Night-Effect Chillers

III–D–1. Identify the radiant exchange rates that are possible for night air exchange and nocturnal radiation, considering type of surface, inclination, climatic zone, and time of year.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO										10

III–D–2. Investigate the viability and the effectiveness of using evaporation and/or night sky radiation in either active or passive systems to achieve a net cooling effect for buildings. Determine ways in which thermal storage can augment the performance of such systems. Identify climates in the U.S. where such methods might be effective.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO										10

III–D–3. Identify the performance characteristics of various means of using water spray for achieving net cooling, perhaps as the heat rejection component for absorption units or other chillers. Consider the use of ponds or sprays from ponds to achieve net cooling effects. Determine the operating and maintenance characteristics of such spray systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	5		7

III–D–4. Prepare a handbook summarizing the results of Tasks III–D–1 (nocturnal radiation cooling), III–D–2 (evaporation and nocturnal radiation cooling), and III–D–3 (water spray cooling).

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.										6

III–E. Desiccant Chillers

III–E–1. Develop desiccant cooling [illegible] molecular sieve and silica gel types, emphasizing dehumidification as an aid to other cooling methods. Identify the theoretical and experimental characteristics of these subsystems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.									10	

III–E–2. Identify the operating characteristics of desiccant chillers currently being developed, emphasizing their possible use on air-heating collector solar energy systems. Discuss chiller characteristics for different collector types and climatic zones.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.									10	

III–E–3. Develop those mathematical models of desiccant subsystems that are needed for system studies. Validate the models by system testing.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.									10	

III–E–4. Using system analysis results, develop desiccants suitable for solar cooling and dehumidification systems. Identify useful materials and determine and catalog their appropriate thermodynamic and physical properties. The toxicity of the desiccants must be considered

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.									10	

III–E–5. Develop [illegible] desiccant combinations found in Task III–E–3. These supports [illegible] and durable, and they must provide maximum air-surface contact area and minimum pressure drop

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.									10	

III–E–6. Investigate ways in which desiccants can be used to produce net cooling or dehumidifying effects in solar energy systems. Identify the desiccant characteristics desirable for use in such systems and compare them with the characteristics of known desiccant combinations. Include system requirements for air pumping, desiccant heat exchange, and mass exchange; and analyze the net effect on the overall system COP of the requirement for electrical fan energy. Explore any gains achieved by raising the temperature of the solar heat.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.									10	

III–E–7. Support the construction, testing, and simulation validation of the second generation desiccant systems that evolve from the preceding tasks. Several such systems should be built to satisfy the heating and cooling loads of a selection of basic national climatic/solar zones.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.									10	

III–E–8. Prepare appropriate [illegible] handbook for extending the use of viable desiccant cooling/heating systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO									10	

III–E–9. [illegible] for cooling applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO									7	

III–F. Other Chillers

III–F–1. Continue the development of Nitinol engines for use in solar cooling. Identify the thermodynamic and engineering characteristics of Nitinol engines.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							3	4		

III–F–2. Investigate the potential usefulness of the Vuilleumier air conditioner. Identify its operating characteristics and indicate how those characteristics relate to the production of net cooling usable in a building. Identify the cost characteristics of such a system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							3	4		

III–F–3. Monitor the development of [illegible] to determine their potential for driving compression cycle air conditioners.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	5		

III–F–4. [illegible]

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	3		

III–G. Heat Pumps

III–G–1. Evaluate the relative merit of using either natural or otherwise available elements for thermal storage in a solar-assisted heat pump system. These elements might be ponds; swimming pools; or the earth in, around, or under the building. Identify the cost characteristics of these systems and any adverse effects which they might cause. Evaluate the benefits to be derived from incorporating wastewater heat recovery in a solar-assisted heat pump system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			10							

III–G–2. Identify the electrical utility load characteristics of solar-assisted heat pump systems. Investigate means of using thermal storage for load leveling in solar-assisted heat pump systems. List both the positive and negative effects of adding solar energy and/or storage to heat pump heating systems, including benefits of using thermal storage on the high- and low-temperature sides of the heat pump system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			10							

III–G–3. Perform configuration [illegible] combinations of heat pumps (both water source and air source), collectors, and storage units to determine the characteristics of the best combinations and the sensitivity of each combination to changes in component performance. Identify the potential for re-optimization of heat pumps for use with the systems identified in this task.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			10							

III–G–4. Investigate various uses of piston compressors for heat pumps that use currently available mass production facilities and components. Consider the use of electric motors and hermetically sealed units or even units with rotary seals. Investigate the use of speed modulation to vary the capacity of the machine. This will generally improve the net COP of the machine at reduced capacity because of decreased heat-exchange temperature drops.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			8				8	8		

III–G–5. Prepare and validate transient models of heat pumps used in solar heat pump systems and evaluate their effect on the overall performance of the system

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			8							

III–G–6. Perform a side by side comparison of two solar assisted heat pump systems, one with an improved performance heat pump and one with a conventional heat pump. Analyze the performance of the two systems in typical cycles and use this information to determine the usefulness of an improved performance heat pump in a variety of climatic zones

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO			8							

III–G–7. Compare solar-assisted heat pump systems, pure solar energy systems, and pure heat pump systems for different climates. Choose the best configuration for each climate for both residential and commercial installations and for both new and old buildings. Identify the performance advantages of each system. Evaluate the performance of a solar-assisted heat pump system optimized without solar input, and evaluate the performance of the same system augmented by a small amount of solar heat. Define the value of the solar heat assist for various climates. This will indicate whether even a small solar energy system (e.g., a normal domestic hot water system) might substantially increase total system performance.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3		8							

III–G–8. Evaluate the feasibility and merit of heat pump systems in which the compressor is driven by a heat engine, such as a solar-driven Rankine cycle

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			7					7		

III–G–9. Evaluate the [illegible] for a centrifugal heat pump. Determine whether this system improves the performance of the solar-assisted heat pump (Account for extra losses associated with the variable speed drive.)

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.										

III-G-10. Use system analysis results to develop heat pumps optimized to work effectively in solar-assisted heating and cooling applications. Heat pumps usable in combined heating and cooling systems are required because of their cost-effective potential.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			7							

III-G-11. Evaluate the potential of a solar-assisted heat pump system using a solarium or atrium as a collector. Rock bed thermal storage could be used, the rock bed being both the heat source for space heating during periods without sunshine and the heat source for the heat pump.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			9							

III-G-12. Sponsor a design competition for solar assisted heat pump systems. The competition should be based on a standard set of weather and solar data the prize being Federal funding for the construction of one or more R&D system tests based on the winning design(s)

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO			10							

III-G-13. Evaluate the [illegible] in a solar assisted heat pump system. Identify the problems and costs associated with sealing leaks in such a system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			7							

IV. Systems and Controls

OBJECTIVE

The objective of the systems and controls tasks is the preparation of information on system options for various applications and climates. This information will be used to help provide direction to the overall R&D program. To accomplish this objective, all of the following are necessary:

- Data acquisition.
- Simulation modeling, analysis, and validation.
- System tests appropriate for the development of advanced active, passive, and hybrid systems for both new and retrofit applications.
- Technology for system-related controls, components, and instrumentation.

EMPHASIS

The program emphasizes the timely reporting of system test data, with cost-effective system configurations being identified for each path and each climatic zone. Indication will also be made of the sensitivity of each system, in performance and life cycle costs, to changes in design or location. The program also emphasizes the necessity of component interface information being provided to the suppliers of components and systems. Finally, a standardized basis will be developed for the optimization of system design and cost for active, passive, and hybrid concepts.

TASKS

IV-A. Integrated Active Solar Energy Systems

IV-A-1. Establish the capability for dynamic testing at current and future test facilities. Dynamic testing will be used to determine the transient response characteristics of solar energy system components and subsystems in various modes of operation

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	4	4	6		5	6	8	8	6	5

IV–A–2. Establish a subsystem test facility in which the collector output and building load can both be simulated (programmed as a function of both time and observed system parameters). This facility will be used to provide operating data on all components and subsystems except the collectors and the building.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	1	1			5	6	8	8	8	5

IV–A–3. Define a standardized method for reporting solar heating and cooling system performance, emphasizing the content of such reports rather than the format. Provide for inclusion of meaningful system performance parameters and variables and for data on mechanical design and operating defects (such as corrosion). This will make information on the operation of the existing system more useful to practicing engineers and researchers.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6	6	6	6	6	6	6	6

IV–A–4. Develop and [illegible] a standard method for evaluating the performance of solar energy systems that accounts for all solar and electrical inputs. The method should identify an overall COP for both the electrical and solar inputs.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	3	6	6	6	6	6	6	6	6

IV–A–5. Define minimum data requirements for evaluating the performance of solar heated and solar cooled buildings. Data required includes energy calculations and information on major operating and maintenance characteristics based on observation of operating systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			4	6	4	4	6	6	6	4

IV–A–6. Define a standardized rating procedure for solar heating and cooling systems. The procedure must relate total thermal output (for a defined solar input and a defined load) to the required energy input (from fans, pumps, auxiliary units, etc.). An overall, seasonal COP might be a good approach. Test the rating system to see that it provides satisfactory performance and economic analyses.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	3			3	3	4	4	4	2

IV–A–7 Identify [illegible] for different areas of the country

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	6	6								

IV–A–8 [illegible] of building types and locations, and [illegible] energy use

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			6	8	8	8	6	8	8	8

IV–A–9. Make a detailed analysis of failures in solar energy systems. Identify failures in past and present systems, methods that were used to avoid probable failure, and methods that might be used to avoid future failures. The methods should be cost effective in initial and operating costs and in the use of auxiliary energy units.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	8	8	6	8	8	8	8	8	6

IV–B. System Design Methods

IV–B–1. Identify, document, and disseminate computer codes for the performance simulation of solar heating and solar heating and cooling systems. The codes should be of several levels of sophistication, and one code should be established in the public domain as soon as possible.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	8	8	9	8	8	9	8	8	8	8

IV–B–2. Establish a mean [illegible] computer simulation codes. This will require defining methods of code validation, assembling the data making the validation tests, and providing a central place for the certification of analysis tools (computer code algorithms). Determine whether any of the complex load models adequately predict building energy loads for solar heating and solar heating and cooling systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	6	6	6	8	6	6	8	8	8	9

IV–B–3. Prepare standardized data for use in computer simulation analysis. Include solar radiation and climatic information from several cities for representative (standard) years. This data must contain all parameters required by researchers (wind direction as well as speed, for example).

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	7	7	8	7	7	8	7	7	7	7

IV–B–4. Analyze the costs for installing, operating, and maintaining current solar heating and heating and cooling systems. Develop a statistical data base for these costs and set realistic guidelines for them. Distribute the guidelines to appropriate industries, along with recommendations for meeting the guidelines.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	9	7	8	8	8	9	7	7	7	4

IV–B–5. Identify simplified [illegible] for solar heating and heating and cooling systems. The procedures should be based on detailed validated computer programs; detailed simulation studies; and simplified mathematical models that use summary input data for additional analysis. Prepare tables and maps for appropriate indices on solar capability for instance.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO	9	7	9	8	7	8	7	7	7	8

IV-B-6. Develop summary statistical data on typical solar radiation that can be used in solar energy analysis for various localities. Use localities where hourly readings have been taken.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	5	7	5	5	7	7	7	8

IV-B-7. Coordinate the efforts of ERDA and other groups to accumulate and organize solar radiation and climatic data.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	6	7	6	5	8	8	7	2

IV-B-8. Develop new simulation procedures for handling structures and collector systems based on other than flat plate collectors (for example, focusing collectors, passive buildings, etc.).

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	3	8			9	9		8

IV-B-9. Prepare, validate, and standardize a method for separating measurements of direct and diffuse solar radiation. The method should make possible the derivation of direct radiation values from total horizontal radiation readings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	3	5	8	3	3	8	3	3	

IV-B-10. Set up a Federal center for computer based solar and climatic data. The data base should include fundamental data and reduced or summary data derived during other tasks.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	5	4	5	5	5	5	5	6

IV-B-11. Determine and validate a method for deriving the daily horizontal solar radiation from other commonly recorded weather phenomena (cloud cover, wind, relative humidity, etc.). The method must be accurate for measurements over extended periods rather than for any given day. Use the method with data from as many stations as possible to arrive at estimates of monthly radiation. Merge the corresponding degree day heating and cooling data with the radiation value. Prepare maps of this information with fine resolution (approximately 20 miles) for the U.S.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	6	6	6	6	6	7	2	6	6	2

IV-B-12. Determine the relative importance of diffuse and direct-beam solar radiation for various solar heating and solar heating and cooling applications.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	2	2	2	7	2	2	7	3	2	

IV–B–13. Prepare a handbook identifying the cost and performance characteristics of solar domestic hot water heating systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	10	10								

IV–B–14. Perform a system study comparing various methods of configuring a solar domestic hot water heating system for various climates, use patterns, number of tanks, collector characteristics, etc.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	8	8								

IV–B–15. Prepare a handbook identifying the cost and performance characteristics of space heating techniques that are based on direct solar heating of the space or structure.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				10						

IV-C. Controllers, Valves, and Actuator Components

IV-C-1. Evaluate the purchase of more sophisticated control logic and additional sensors and control actuators for residential and small commercial solar energy systems. Study the tradeoff between first costs and the savings resulting from use of these components. Develop control algorithms for heating and cooling systems; the algorithms should control the time of day that auxiliary electrical energy is used. Check the algorithms against existing computer simulation programs. Investigate the possible use of systems that anticipate the next day's energy requirements and store energy accordingly. (These "smart" systems avoid the creation of peak demand loads.) Test the sensitivity of the system to storage size when the system is operated in the mode for avoiding peak loads.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	5	5	7	3	5	5	5	5	5	5

IV-C-2. Survey existing automatic solar tracking systems and identify inexpensive, reliable types than can be used with solar concentrators.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.							5	5		

IV-C-3. Identify special control logic and control actuator requirements for passive solar energy systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			6	8						8

IV-C-4. Determine from the suppliers and installers of all sizes of solar energy systems whether new controls are necessary for these systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			4		2	5	5	5	4	

IV-D. Instrumentation and Data Acquisition

IV-D-1. Develop a low cost instrumentation and data acquisition system for monitoring the performance of solar heated and solar heated and cooled buildings. This system should emphasize the measurement of the total integrated energy collected by the solar energy system and the total energy used by the building.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	3	4	4	4	4	4	4	4	4

IV-D-2. Investigate methods of compressing systems data by preprocessing. This will reduce the quantity of data which must be stored and provide a condensed output that will be more easily understood.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	3	3	4	4	4	4	4	4	4	4

IV-D-3. Determine instrumentation requirements for the evaluation of passive solar energy systems. Instrument buildings as required.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			5	8						8

IV-D-4. Set standards for sub-metering on solar energy projects to ensure adequate measurement of the use of auxiliary units.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.	2	2	3	3	3	3	3	3	3	3

IV-D-5. Develop microprocessor-based plug-in diagnostic systems to analyze system performance and to detect system failures. The diagnostic systems will be used in large, complex solar energy installations.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			2		1	2	3	3	3	

IV-E. Passive and Hybrid Systems

IV-E-1. Identify effective ways to control energy flow in passive solar energy systems. Include methods for controlling both the intake and the release of solar energy, and investigate how the methods selected influence the timing and effectiveness of the overall system, including solar-activated devices.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			6	10						8

IV-E-2. Investigate and tabulate the add-on cost characteristics of the various passive solar energy systems by reviewing existing passive solar energy system installations and costs, using standard cost-estimating procedures for buildings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			6	9						9

IV-E-3. Set up computer simulation models for the modeling of passive solar energy heating and cooling systems. Validate the models by comparing them with existing systems and test systems. Use the models to determine passive system life cycle costs and performance characteristics for different climatic zones.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			6	9						9

IV-E-4. Extend the evaluation of the passive roof pond collecting concept to better determine nighttime losses to the sky by radiation and to the air by convection and evaporation. Study the concept for different climates and correlate the results with observable weather parameters such as dew point, dry-bulb temperature, cloud cover, and wind velocity.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				9						10

IV-E-5. Analyze air motion effects in various passive and hybrid system configurations. Determine whether or not air motion in these systems is sufficient to satisfy customary comfort conditions within the building.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			4	6						8

IV-E-6. Define the dynamic characteristics of passive solar heating systems when they are coupled to conventional, active, fossil energy systems. Determine whether the comfort characteristics of passive solar heated buildings are different from those of typical non-passive buildings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.			4	6						6

IV-E-7. Devise a way to determine vertical surface solar data from other available solar data.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				8						8

IV-E-8. Study applications of thermic diodes to typical buildings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				8						8

IV-E-9. Study applications of inexpensive heat pipes to passive buildings.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				5						

IV-E-10. Investigate the possibilities for passive wall heating by thermosiphon from flat plate liquid collectors.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				8		8				

IV-E-11. Examine the possibility of using an air thermosiphon to heat or cool a rock bed in a passive system.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				8						

IV-E-12. Investigate heat transport fluids that expand on cooling to provide the possibility of a reverse thermosiphon.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				5						

IV-E-13. Use validated simulations of passive or hybrid systems to evaluate new building geometries and to improve the operation of existing heating and cooling systems.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				10						5

IV–E–14. Determine the characteristics, requirements, and costs of conventional cooling systems when they are coupled to passive heating systems to provide heating and cooling in various climates.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				10						10

IV–E–15. Design and construct buildings that incorporate innovative concepts for passive hybrid solar heating and/or cooling systems. Monitor and evaluate building performance and choose the designs that are most effective for various climatic regions.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				8						8

IV–E–16. Develop architectural concepts that use passive or hybrid solar heating and/or cooling techniques. Select techniques for development from among those found most promising in preliminary studies.

PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IMPORTANCE NO.				6						6

IV–F. System Studies

Analyze solar heating and combined solar heating and cooling systems. Identify performance and cost characteristics, varying system configuration, climatic zone, building type (or load category), competing energy type and cost structure, and control strategy. Determine the best system configurations for each climatic zone and calculate the sensitivity of system cost and performance to changes in system design. These studies should be performed for each path.

Each path will require an initial system study based on the best available mathematical model and a second study based on the final, validated simulation. Twenty tasks, then, will be required, the first ten for the initial studies of each path (IV–F–1 to IV–F–10) and the second ten for the final studies (IV–F–11 to IV–F–20).

The system studies will provide all of the following:

- A definition of system requirements.
- A calculation of the percentage of energy supplied by the sun for heating and cooling in various climatic zones.
- The sensitivity of solar load to various system parameters.
- A comparison of life cycle costs and savings for solar energy and conventional systems.
- Summaries of all of these results in appropriate forms (reports, charts, handbooks, etc.).

V. Non-Engineering Aspects

OBJECTIVE

The objective of the non-engineering tasks is the analysis of the economic, institutional, and social environments in which solar heating and cooling technology will be used. This includes a study of consumer behavior and a definition of the infrastructure for delivering solar technology. Providing this information will help make possible the more rapid development and commercialization of that technology.

EMPHASIS

The program emphasizes the following points:

- The collection and dissemination of information on economics, legislation, market structures, etc.
- An analysis of ERDA actions and policies to determine the impact on the commercialization of solar technology.
- Research on factors affecting consumer acceptance of solar energy systems and on means of increasing that acceptance.

TASKS

V–A. Economic and Financial Analysis

V–A–1. Collect, analyze, adjust if necessary, and distribute data on costs of production, installation, maintenance, depreciation, repair, and replacement of solar heating and cooling systems. Compare actual costs with cost estimates. Cooperate with FEA, FPC, and other agencies in determining auxiliary energy costs. Study the resale value of homes having solar energy systems; include interest rates and taxes paid by owners. Identify high cost items as targets for R&D efforts.

V–A–2. Develop a standard method for analyzing life cycle costs for solar heating and cooling systems and provide a manual based on that method. Develop separate models for residential and commercial/industrial applications. Include treatment of variable electricity rate structures and property resale values. Prepare economic analysis models that are flexible enough to accommodate varying assumptions on fuel price escalation, inflation, interest rates, etc.

V–A–3. Develop a simplified user's version of the life cycle cost manual called for in Task V–A–2. Manuals should be written for at least three levels of expertise: building owner (consumer), builder/contractor, and architect/engineer. These manuals should enable a potential user to calculate life cycle costs for a solar energy system he is considering and to compare those costs with costs for standard gas, oil, or electric systems.

V–A–4. Study the effect on costs to the consumer of various rate schedules for auxiliary energy (electricity, gas, fuel oil, or LPG). Calculate savings to consumer for systems controlled to use only off-peak electricity under various pricing schemes (time of day pricing, marginal cost pricing, etc.).

V–A–5. Collect data on skilled manpower and material requirements for production, installation, maintenance, and replacement of solar energy systems; and identify current and potential resources for meeting each type of requirement. Identify possible labor or materials shortages that might slow the rate of adoption of solar energy systems. Estimate the total impact of such shortages. Compare current supplies of each with demand, allowing for competing uses of the same resources. Estimate direct and indirect capital requirements for solar and conventional energy systems, and indicate how these will be likely to change during the next ten years.

V–A–6. Develop models for evaluating the effect of various incentive policies on market penetration, fossil fuel savings, etc. Use the models to determine the combinations of incentives that are most effective.

V–A–2. Study the economic incentives that have been granted to the fossil fuel and nuclear energy industries. Both industries have benefitted from subsidies for production and distribution, and recommendations for solar energy incentives should be based in part on an analysis of the support provided to these competing energy programs.

V–B. Consumer Attitudes and Behavior

V–B–1. Identify the considerations that influence decisions to purchase or lease a solar energy system. Study the importance of first cost, life cycle cost, lease or lease/purchase contracts, and expected increases in fuel costs. Determine the factors that particularly influence home owners, home buyers, contractors, and builders.

V–B–2. Analyze consumer incentive programs, either actual or planned, to determine their effect on consumer decisions to purchase. Evaluate the cost of such programs to governments (Federal, state, and local). Determine whether the incentive programs have a progressive or regressive effect on the redistribution of benefits.

V–B–3. Study the purchase of solar heating and cooling systems in the commercial sector, including the factors that govern purchase decisions. Determine the pay-back period required in various markets and identify other relevant accounting practices, including the effect of tax regulations. Describe changes in accounting procedures that would encourage life cycle costing in industry.

V–B–4. Evaluate consumer attitudes to passive direct solar energy systems, including devices that require active intervention by the resident (moving insulating panels at night, etc.). Assess consumer willingness to accept temperature swings. Compare consumer attitudes in this area with consumer reaction to other energy conservation measures.

V–B–5. Synthesize information on environmental parameters that affect human comfort—e.g., IR flux—and present it in a useful form. The information will be required for the design of structures that employ passive heating and cooling techniques. The information should include data on the comfort provided by cooling and air movement without dehumidification.

V–C. Marketing, Architecture, and Construction

V–C–1. Synthesize information on building industry experience with data on technology transfer, commercialization, and market diffusion. Identify factors that have slowed or prevented building technology innovations as well as factors that have accelerated the adoption of such innovations.

V–C–2. Define promising markets and marketing techniques for solar energy systems for buildings. Compare centralized mass production with local production and determine if economies of scale are likely. Compare the do-it-yourself and turn-key markets and recommend R&D priorities.

V–C–3. Develop models of alternative ownership arrangements for solar heating and cooling systems (such as co-ops, municipalities, or corporations). Assess the economics of such arrangements, especially the cost of delivered energy to the consumer. Investigate the regulatory and legal (especially anti-trust) aspects of such arrangements.

V–C–4. Sponsor competitions for the design of passive solar energy systems and for the integration of active systems into building structures. Competitions should be held for a variety of climates and building types, including single and multi-family residences, schools, and commercial and office buildings. Publish the winning designs.

V–C–5. Hold meetings for distributing information to producers and distributors of solar energy and other HVAC equipment, architects, and contractors. Examine the possibility of establishing centers for distributing this information.

V–C–6. Prepare background material for defining performance rating and warranty criteria for solar heating and cooling equipment. Evaluate public and private methods for providing protection to users and determine the effects of such methods on the industry.

V–C–7. Investigate the relationships and tradeoffs between solar energy systems and energy conservation practices. Determine how changes in the energy conservation features of buildings will affect energy system design, cost, marketability, etc.

V–C–8. Determine the proper role of ERDA/DSE and other Federal agencies in advancing the marketability and commercial use of solar energy systems. Evaluate the past efforts of the Federal Government in this area (e.g., Project Breakthrough).

V–D. Utility Interface

V–D–1. Predict the impact of solar energy systems on electric utility load curves. Make evaluations with and without controls on the time of day that the auxiliary energy is used. Assess the impact on distribution systems of peak load conditions in a highly solar community.

V–D–2. Determine the effect of various rate schedules (including time of day pricing) on the accounts of utilities customers, both those having solar energy systems and those without such systems. Evaluate the impact of utility rate structures (marginal cost, actual cost, two-part tariff, etc.) on market penetration.

V–D–3. Examine the legality of ownership by utilities of solar energy heating and cooling equipment. Include the question of exclusive franchise. Survey the policies and trends in policy of state utility regulatory commissions.

V–D–4. Assess the effect on utility accounts of ownership by the utilities of solar energy equipment. Discuss the option of the utility including the solar equipment in its rate base. Examine various depreciation allowances and the feasibility of climate maintenance agreements.

V–D–5. Investigate possible incentives for utility involvement, including utility ownership of solar energy equipment. Consider the cost to governments of incentive programs (for example, through lost tax revenue), and the probable impact on the market for solar heating and cooling.

V–D–6. Examine the desirability of home controlled, auxiliary storage of domestic heated/cooled water, and compare its advantages with utility controlled storage. Analyze the impact of interruptible power contracts on market penetration.

V–E. Legal, Regulatory, and Legislative

V–E–1. Determine whether the uses proposed for solar energy systems conflict with standard building, health, and safety codes. Consult with building inspectors if code interpretations become necessary. Where conflicts exist, suggest code modifications that allow the systems to be used while protecting builders and consumers. Consider both active and passive systems and various auxiliary energy sources.

V–E–2. Analyze the doctrine of regulated monopoly and equal protection arguments as they pertain to utility rate structures for solar and non-solar consumers of energy.

V–E–3. Develop a model definition of the term "solar" for use in legislation pertaining to the application of solar energy in buildings. The definition must provide for passive energy systems and other innovative approaches.

V–E–4. Prepare model laws for the allocation of sun rights. Include options for allocation by first use (as in western water law) and for purchase of adjacent development rights.

V–E–5. Investigate Federal anti-trust laws for their impact on solar energy applications. Emphasize potential problem areas including the following: typing agreements (a utility leasing solar equipment only to those who use it as a backup system), joint research by corporations on solar equipment, restraint of trade, resale restrictions, refusal to deal, and requirement contracts.

V–E–6. Analyze the impact of land use planning on solar energy development. Determine whether Federal legislation regarding planned unit development is desirable. Study zoning requirements for setbacks, landscaping, height limitations, etc.

V–F. Education and Training

V–F–1. Develop a comprehensive vocational training program, including seminars for training instructors and preparing courses. Various successful teaching techniques should be examined. The courses offered should be directed to craftsmen, building inspectors, etc.; and they should be given at existing schools or by existing trade associations whenever possible.

V–F–2. Evaluate current programs for training architects and HVAC engineers. Prepare resource material for the programs, including data on active and passive systems and on new and retrofit situations.

V–G. Social and Environmental Considerations

V–G–1. Investigate city and regional planning practices for their impact on solar energy heating and cooling. Define requirements for special zoning or limitations on development.

V–G–2. Evaluate community attitudes toward solar energy installations, placing emphasis on design aesthetics, impact on land values, and influences on future development of neighborhoods.

V–G–3. Collect information on materials and components under development in the heating and cooling R&D program. Determine whether problems exist in the areas of environmental impact and occupational and consumer hazards. Report the existence of such problems to administrators of the R&D program and help to solve the problems where possible.

APPENDIX C

Importance Numbers for Solar Heating and Cooling Tasks

TABLE C-1
IMPORTANCE NUMBERS FOR COLLECTOR TASKS

PATH / TASK		SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IA SYSTEMS	1	10	10	10	2	10	10	10	10	10	10
	2	10	10	10		10	10	10	10	10	10
	3	10	10	10		10	10	10	10	10	10
	4	8	8	8		8	8	4	9	8	
	5	6	6	6		10		8	8	7	5
	6	5	5	6		10	7	8	8	7	5
	7	2	1	3		4	5	6	7	4	1
	8	8	8	8	8	8	8	8	8	8	8
IB THEORY	1	10	10	10	8	5	10	10	10	8	
	2		4	8	8	4	4		2	4	7
	3	10	4	4	5	4	4	7	6	4	2
	4	6	6	2		7	7	6	9	7	
	5	4	6	6		7	5	3	3	7	
	6	3	5	5	5	6	5		2	6	
	7		6	4		7				7	
	8	4	4	3	4	5	5	4	7	5	
	9		6	3		6			7	6	
	10							6	9		
	11	3	3	3		3		3	3	3	
	12	8	10	10		10	10	10	10	10	
IC LIQUID HEATING	1	10		10	10		10	10	10		
	2			9			10				10
	3			10			5				6
	4			9							
	5	9		5			9				
	6	3		3			5		9	8	

TABLE C-1 (CONT)

TASK	PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
ID AIR HEATING	1		7	9		8				7	
	2		8	5		10				10	
	3		1	5	10	2				1	10
	4		7	10	5	10				10	
	5		5			6				6	
	6				9						
	7		9	5		9					
	8		3	3		5			9	9	
IEa NON CONCEN-TRATING	1	6	6					5	10		
	2							5	10		
	3	6	6					5	10		
	4							5	10		
	5										
IEb HEAT PIPES	1	3	2	4	2	4	5	6	10		
	2	3	1		3	3	4	6	10		
	3								10		
IEc HONEY COMBS	1	4	6			5	4	3	8	4	
	2	4	6	2		5	5	2	7	6	
	3	3	5			5	6	3	7	3	
	4								10		
	5	6	6	2		7	7	6	9	7	
IEd OTHERS	1		7			6				6	
	2	4	3			3	4		6	5	
	3	3					3		1		

TABLE C-1 (CONT)

PATH / TASK	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
1						2	10			
2							10			
3							10			
4	6	7			3	3	10		7	
5							7	7		
6							7			
7							6			
IF CONCEN TRATORS 8							5	6		
9		5					10	8		
10						4	6	7		
11						6	10			
12							10			
13							10			
14							10			
15							10			
1	5	10	10	8	10	6		7	10	
IF RE... TORS 2	4	4	10	5	10	5		6	10	
3	4	4	10	5	10	5		6	5	
1	4		4		6	6	7	5	6	
2	5				5	5	7	7	6	
3	4	6	4		6	6	6	6	6	
IF SEL... SURFACES 4	5	9	4		4	7	8	7	6	
5	4	6	4		5	5	5	9	6	
6								8		
7										10

TABLE C-1 (CONT)

TASK \ PATH		SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IHb GLAZING	1	7	7		8	7	7	7	5	7	8
	2	7	7	8	8	7	7	7	5	7	8
	3	5	5	4	4	10	5	7	8	5	
	4	6	6	6	6	10	6	5	6	7	
	5	4	4	5	6	4	4	5	5	4	
IHc GLAZING SURFACE COATINGS	1	6	6	6	7	6	6	7	5	6	
	2	5	5	6	6	5	5	5	5	6	
	3	4	6	5	6	4	4	5	6	5	
	4	4	6	5	6	4	4	5	6	5	
	5	4	6	5	5	4	4	5	5	5	
IHd SEALANTS	1	7	10	6	6	10	7	7	10	10	
	2	6	10	5	5	10	6	6	5	6	
	3	1	1			1	1	8	9	3	
IH[illegible] COATINGS	1	8		7			10	10	10		
	2	10		6			8	10	10		
	3	7		6			6	7	7		7
	4	4		7			8	7	7		
	5	10					7				
	6		2	7		10				4	
	7	10	10	6	8	5	10	10	10	8	

TABLE C-1 (CONT)

TASK \ PATH		SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IHf INSULATION	1	6	6	3	6	6	6	8	8	7	
	2	5	5	4	6	6	6	7	5	5	
	3	4	4	4	5	5	5	7	7	6	
	4	4	4	3	3	4	4	7	6	4	
	5	6	6	6	6	6	7	6	5	6	
	6	4	5	4	5	5	5	8	8	5	
	7				10						10
IHg ABS. SURFACES	1	7	6	3	5	6	7	2		5	
IJ TESTS AND STANDARDS	1	3	3	3		3	3	3	3	3	
	2	3	3	3	3	3	3			3	3

TABLE C-2
IMPORTANCE NUMBERS FOR THERMAL STORAGE AND HEAT TRANSFER TASKS

	PATH / TASK	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IIA SYSTEMS	1	6	6	6		8	8	8	8	8	8
	2			5	9						7
	3	3	3	3		5	3	5	5	5	3
	4			1	2	6				6	
	5	2	2	2		4	3	4	4	3	5
	6			5		2	6				5
	7	5	5	9	8	5	6	8	8	7	8
	8	8	8	5	5	5	5	5	5	5	4
	9	8	8	7	7	7	5	5	5	5	5
	10			5	4	5	3	10	9	9	
IIB HEAT EXCHANGERS	1					8				8	
	2					8				8	
	3	8									
	4				6	6					
	5	2					5	2	4	2	
	6	6	6				8				
	7		8		8	8		6		6	6
	8	1	1	2	3	5	5	4	5	5	
	9			5			5	8	8	6	

TABLE C-2 (CONT)

TASK	PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
	1			5	8						8
	2							8	8	6	
	3	3	3	2	6		6	6	4	4	6
	4	6	6	6	5		6	6	6	4	
	5	5		5	5		7	5	5	3	5
IIC WATER TANK	6	5	5	5	5		6	5	5	5	5
	7	6	3	5			5	5	5	3	
	8	8	8	4	5		8	8	8	4	
	9		6			6				4	
	10	8	8	7	3	5	5	6	5	5	
	11	10	10	8	9	5	8	5	4	8	
	12	10	10	5	8	3	8	5			
	13	10	10	6	10	5	9		3	8	
	1				5	5					7
	2			5	5	6				5	7
IID ROCK BED	3			5	5	5				5	6
	4			5			5				
	5							5	4	4	

TABLE C-2 (CONT)

TASK	PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IIE PHASE CHANGE	1			4	4	6		8	8	5	
	2			3	4	6		8	8	3	5
	3			2	3	6		8	8	3	5
	4			6	6						6
	5			6		6		8	8	3	6
	6			5	3	5			8	3	6
	7					5		7	5		7
	8							9	9		
	9					4	2	8	8		
IIF CHEMICAL	1						2	2	2		
	2						2	2	2		
	3							5	5		
IIG TESTS AND STANDARDS	1	2	2	2	2	2	2	2	2	2	2
	2				1	2				2	1

TABLE C-3
IMPORTANCE NUMBERS FOR AIR CONDITIONING AND HEAT PUMP TASKS

TASK \ PATH		SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IIIA SYSTEMS	1						7	8	8	8	8
	2							9	9	9	
	3							9	9		
	4							9	9		
	5							7	7	7	6
	6			0				7	7	7	
IIIB ABSORPTION	1							7	8		
	2							7	7		
	3							7	7		
	4							7	6		
	5								10		
	6							10	10		
IIIC RANKINE	1			8				8	8		
	2							8	7		
	3							7	7		
	4							7	7		
	5							7	7		
IIID EVAPORATIVE AND NIGHT EFFECT	1										10
	2										10
	3							5	5		7
	4										6

TABLE C-3 (CONT)

TASK	PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IIIE DESICCANT	1									10	
	2									10	
	3									10	
	4									10	
	5									10	
	6									10	
	7									10	
	8									10	
	9									7	
IIIF OTHERS	1							3	4		
	2							3	4		
	3							5	5		
	4							3	3		
IIIG HEAT PUMPS	1			10							
	2			10							
	3			10				8	8		
	4										
	5										
	6			8							
	7	3		8							
	8			7					7		
	9			7							
	10			7							
	11			9							
	12			10							
	13			7							

TABLE C-4
IMPORTANCE NUMBERS FOR SYSTEM STUDY TASKS

	PATH / TASK	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IVA INTEGRATED ACTIVE SYSTEMS	1	4	4	6		5	6	8	8	6	5
	2	1	1			5	6	8	8	8	5
	3	6	6	6	6	6	6	6	6	6	6
	4	3	3	6	6	6	6	6	6	6	6
	5			4	6	4	4	6	6	6	4
	6	3	3			3	3	4	4	4	2
	7	6	6								
	8			8	8	8	8	8	8	8	8
	9	8	8	8	6	8	8	8	8	8	6
IVB SYSTEM DESIGN METHODS	1	8	8	8	8	8	9	8	8	8	8
	2	6	6	6	8	6	6	8	8	8	9
	3	7	7	8	7	7	8	7	7	7	7
	4	9	7	8	8	8	9	7	7	7	4
	5	6	7	5	8	7	8	7	7	7	8
	6	5	5	5	7	5	5	7	7	7	8
	7	5	5	6	7	6	5	8	8	7	2
	8	5	5	3	8			9	9		8
	9	6	3	5	8	3	3	8	3	3	
	10	5	5	5	4	5	5	5	5	5	6
	11	6	6	6	6	6	7	2	6	6	2
	12	2	2	2	7	2	2	7	3	2	
	13	10	10								
	14	8	8								
	15			10							

TABLE C-4 (CONT)

TASK	PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
		W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
IVC CONTROLLERS VALVES AND ACTUATOR COMPONENTS	1	5	5			5	5	5	5	5	5
	2							5	5		
	3			6	8						
	4			4		2	5	5	5	4	
IVD INSTRUMENTATION AND DATA ACQUISITION	1	3	3	4	4	4	4	4	4	4	4
	2	3	3	4	4	4	4	4	4	4	4
	3			5	8						8
	4	2	2	3	3	3	3	3	3	3	3
	5			2		1	2	3	3	3	
IVE PASSIVE AND HYBRID SOLAR SYSTEMS	1			6	10						8
	2			6	9						9
	3			6	9						9
	4				9						10
	5			4	6						8
	6			4	6						6
	7				8						8
	8				8						8
	9				5						
	10				8		8				
	11				8						
	12				5						
	13				10						5
	14				10						10
	15				8						8
	16				1						6

TABLE C-4 (CONT)

IVF SYSTEMS

TASK \ PATH	SERVICE HOT WATER		SPACE HEATING				SPACE COOLING			
	W1	W2	H1	H2	H3	H4	C1	C2	C3	C4
1	9									
2		9								
3			9							
4				9						
5					9					
6						9				
7							9			
8								9		
9									9	
10										9
11	9									
12		9								
13			9							
14				9						
15					9					
16						9				
17							9			
18								9		
19									9	
20										9

APPENDIX D
Priorities for Non-Engineering Tasks

APPENDIX D
Priorities for Non-Engineering Tasks

The following table gives the importance of non-engineering tasks. The rating system used for the engineering tasks is not used here. Instead, tasks are simply given a high, medium, or low priority. In all cases, priority indicates importance of a task to the total R&D program.

TABLE D-1
PRIORITIES FOR NON-ENGINEERING TASKS

TASK CLASSIFICATION	TASK	PRIORITY
A. Economic and Financial Analysis	1. Economic Data	High
	2. Cost Analysis	High
	3. Layman's Costing Manual	High
	4. Rate Schedule Costs	High
	5. Resource Limits	Medium
	6. Incentive Assessment Modeling	High
	7. Incentives for Conventional Energy Sources	High
B. Consumer Attitudes and Behavior	1. Residential Decision Factors	High
	2. Incentive Programs	High
	3. Commercial Decision Factors	High
	4. Attitudes Toward Passive Systems	Medium
	5. Comfort Parameters	Low
C. Marketing, Architecture, and Construction	1. Experience in Industry	Medium
	2. Promising Markets	High
	3. Alternative Ownership	High
	4. Design Competitions	Medium
	5. Information Meetings	Medium
	6. Performance Warranties	High
	7. Solar-Conservation Tradeoffs	Medium
	8. ERDA Marketing Role	Medium
D. Utility Interface	1. Load Curves	High
	2. Rate Schedules	High
	3. Legality of Utility Ownership	Medium
	4. Economics of Utility Ownership	High
	5. Incentives to Utilities	High
	6. Ownership of Auxiliary Storage	Medium
E. Legal, Regulatory, and Legislative Considerations	1. Codes and Standards	High
	2. Legality of Rate Structures	Low
	3. Definition of "Solar"	Medium
	4. Sun Rights	High
	5. Anti-Trust Legislation	Medium
	6. Impact of Land Use Planning	Medium
F. Education and Training	1. Vocational Training Program	High
	2. Professional Resource Material	Medium
G. Social and Environmental Considerations	1. City and Regional Planning	Low
	2. Attitudes and Aesthetics	Medium
	3. Hazards	Low

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