InterTechnology Corporation
Report of
SOLAR ENERGY SYSTEMS INSTALLATION
COSTS FOR
SELECTED COMMERCIAL BUILDINGS

ITC Report No. 111076
ERDA Contract No. E(11-1)2688

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

December 1976

86
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

PREFACE

The InterTechnology Corporation (ITC) was one of two companies who received awards to conduct studies and analyses for the Energy Research and Development Administration (ERDA) in support of the National Solar Heating and Cooling Demonstration Program. The report entitled "InterTechnology Corporation Study, Solar Systems Installation Costs for Selected Commercial Buildings," was prepared as part of the requirements under contract E(11-1)2688. It is not intended to reflect an ERDA plan or position.

TABLE OF CONTENTS

	<u>Page Number</u>
ACKNOWLEDGEMENTS	iv
LIST OF FIGURES	v
LIST OF TABLES	xiii
I. INTRODUCTION	I-1
II. METHODOLOGY	II-1
A. Survey of Non-Residential Solar Energy Installations	II-1
B. Review and Evaluation of Survey Information	II-4
C. Sites Selected For Study	II-6
D. Data Collection During Detailed Studies	II-8
III. RESULTS OF INDIVIDUAL INSTALLATION STUDIES	III-1
A. Narrative Reports of Projects Studied	III-2
1. Whitney Veterinary Clinic Orange, Connecticut	III-2
2. Gump Glass Building Denver, Colorado	III-18
3. United Southwest National Bank of Santa Fe Santa Fe, New Mexico	III-31
4. Windmill Campgrounds Laundry Flagstaff, Arizona	III-44
5. Trinity University San Antonio, Texas	III-55
6. Community Recreation Center Santa Clara, California	III-63
7. Madeira School Greenway, Virginia	III-79

TABLE OF CONTENTS (cont'd)

	<u>Page Number</u>
8. George A. Towns Elementary School Atlanta, Georgia	III-91
9. Barefoot Mailman Hotel Hillsboro Beach, Florida	III-113
10. Alumni House - Conference Center Albany, New York	III-122
11. Miller and Smith Sales Office Towlston, Virginia	III-134
B. Summary Project Data Sheets	III-144
IV. SYSTEM COST SUMMARY	IV-1
A. Cost Comparison	IV-1
B. Cost Relationships	IV-2
V. POTENTIAL METHODS OF COST REDUCTION	V-1
A. Internal Manifolds	V-1
B. Prefabricated and Pre-piped Collector Groups and Support Framework	V-3
C. Preassembled Multiple Collector Modules	V-4
D. Longer Collector Modules	V-5
VI. DESIGN AND CONSTRUCTION MANAGEMENT CONSIDERATIONS	VI-1
A. Design Considerations	VI-1
B. Construction Management Considerations	VI-7
APPENDIX	
Solar Heating and Cooling of Buildings: Survey of Non-Residential Applications (Appendix included as a separate document.)	

ACKNOWLEDGMENTS

A study such as this would not have been possible without the cooperation of the many owners, engineers, architects, contractors and equipment manufacturers around the country involved with the projects reported herein.

Through their assistance by providing comments, drawings, materials, and their time, it is hoped others will benefit and that the success of future solar energy projects will be enhanced.

This study was prepared for the U.S. Energy Research and Development Administration by Mueller Associates, Inc. as a subcontractor to InterTechnology Corporation under ERDA Contract E (11-1)-2688.

LIST OF FIGURES

Page Number

SECTION II

- FIGURE II-1. Solar energy system information, format. II-3

SECTION III-A-1. WHITNEY VETERINARY CLINIC

- FIGURE 1-1. View looking northwest at building showing collector support structure partially erected. III-3
- FIGURE 1-2. Solar heating system flow schematic and sequence of operation. III-5
- FIGURE 1-3. View of clinic looking northwest. III-7
- FIGURE 1-4. View looking southeast showing existing building addition housing rock bed storage, air handling equipment and auxiliary energy source. III-7
- FIGURE 1-5. Elevation section view looking east showing supply and return duct runs and interconnection with storage subsystem. III-8
- FIGURE 1-6. Plan view showing location of collector modules and roof penetrations. III-9
- FIGURE 1-7. Sketch showing collector hold down points, and mounting and flashing details. III-11
- FIGURE 1-8. Sketch showing typical rock bed heat storage unit recommended by Solaron Corporation. III-13
- FIGURE 1-9. Plan view of component layout and distribution system. III-14

LIST OF FIGURES (cont'd)

	<u>Page Number</u>
<u>SECTION III-A-2. GUMP GLASS BUILDING</u>	
FIGURE 2-1. View looking west at the front of the Gump Glass Building.	III-19
FIGURE 2-2. View showing aluminum covered rectangular fiberglass supply and return air duct system serving the collectors.	III-19
FIGURE 2-3. Plan view sketch showing solar collector supply and return ducts in relationship to the collectors and the heat storage unit.	III-21
FIGURE 2-4. Schematic flow diagram of the solar collector, storage and distribution system.	III-23
FIGURE 2-5. View of collectors during installation.	III-23
FIGURE 2-6. Rooftop view of the collector penthouses installed and operational.	III-24
FIGURE 2-7. Closeup view of capping and flashing system between two collector modules.	III-24
FIGURE 2-8. Interior view of the wood framed solar collector penthouses showing insulated flexible supply duct penetrating the roof and connecting to the collector inlet.	III-25
FIGURE 2-9. View of the interior of a solar collector penthouse showing the flexible return air duct.	III-25
FIGURE 2-10. View showing fans and connections to concrete block heat storage unit located in the shop area.	III-27
FIGURE 2-11. Closeup view of concrete block heat storage unit.	III-27

LIST OF FIGURES (cont'd)

Page Number

SECTION III-A-3. UNITED SOUTHWEST BANK OF SANTA FE

FIGURE 3-1.	View looking east-northeast at the United Southwest National Bank of Santa Fe.	III-32
FIGURE 3-2.	Sketch of solar collector support and mounting detail.	III-33
FIGURE 3-3.	View showing tube-in-shell heat exchanger mounted on side of storage tank.	III-35
FIGURE 3-4.	View of auxiliary boiler next to storage tank on right.	III-35
FIGURE 3-5.	Wood framing supports for the collectors showing the vertical support penetrating through the pitch pocket, and the main horizontal beam resting on the raised parapet.	III-37
FIGURE 3-6.	View of Dresser coupling between internal manifolds of collectors.	III-37
FIGURE 3-7.	View showing glazing battens.	III-38
FIGURE 3-8.	View of insulated piping covered with roofing paper.	III-38
FIGURE 3-9.	View of interior of heat storage tank located under bank vault.	III-41

SECTION III-A-4. WINDMILL CAMPGROUNDS LAUNDRY

FIGURE 4-1.	View of the main building of the campground housing a small store and shower facilities downstairs and an apartment upstairs.	III-45
FIGURE 4-2.	View showing the solar collector array located to the left of the laundromat.	III-45
FIGURE 4-3.	Collector system pump and insulated piping attached to one of the array supports.	III-47

LIST OF FIGURES (cont'd)

		<u>Page Number</u>
FIGURE 4-4.	View looking south at the tracking device.	III-49
FIGURE 4-5.	Another view of the tracking device and the focusing collectors.	III-49
FIGURE 4-6.	Aluminum foil had to be placed on the insulation around the pipes between the troughs because it burned in the reflected sunlight.	III-50
FIGURE 4-7.	A closeup view of the reflector and flexible tubing clamped between the outlet of the absorber tubing system and return piping.	III-50
 <u>SECTION III-A-6. COMMUNITY RECREATION CENTER</u>		
FIGURE 6-1.	Architectural rendering of Santa Clara Community Recreation Center.	III-64
FIGURE 6-2.	Composite view of the south side of building showing three sloped roof sections.	III-66
FIGURE 6-3.	View of top of collectors on one section of sloped roof.	III-67
FIGURE 6-4.	View showing a portion of the copper manifold pipe set in place at the bottom of one of the sloped roofs though not yet connected to the collector inlet nipples.	III-67
FIGURE 6-5.	View of flat roof section and the two wooden support frames which will each hold two rows of collectors.	III-70
FIGURE 6-6.	Sketch showing interconnection between collectors using rubber hoses and Pete's Plug sensor well for temperature and pressure measurements.	III-72
FIGURE 6-7.	Cross-sectional sketch of storage tank configuration.	III-74
FIGURE 6-8.	Sketch of longitudinal section of hot water storage tank configuration.	III-75

LIST OF FIGURES (cont'd)

Page Number

SECTION III-A-7. MADEIRA SCHOOL

FIGURE 7-1.	View looking northwest showing the Science Building and the prominent trapezoidal shape of the solar collector.	III-80
FIGURE 7-2.	The simplified schematic diagram of the solar heating system.	III-83
FIGURE 7-3.	Overall view of storage tank located on lower level of building.	III-84
FIGURE 7-4.	Closeup view of heat exchanger inserted in storage tank.	III-84
FIGURE 7-5.	View showing pattern of absorber plates under glass cover.	III-87
FIGURE 7-6.	Closeup view of one of the manifolds serving multiple absorber plates	III-87
FIGURE 7-7.	View showing supply header located under the eave.	III-88
FIGURE 7-8.	View showing return header supported above roof ridge.	III-88

LIST OF FIGURES (cont'd)

Page Number

SECTION III-A-8. GEORGE A. TOWNS ELEMENTARY SCHOOL

FIGURE 8-1.	View looking northeast at the front of the Towns Elementary School.	III-92
FIGURE 8-2.	Simplified schematic diagram of the solar energy system.	III-95
FIGURE 8-3.	View from roof of school looking at the storage tank burial area.	III-97
FIGURE 8-4.	View looking in concrete vault housing automatic control valves.	III-98
FIGURE 8-5.	View of new collector fill pump, control valve and concrete block pit.	III-98
FIGURE 8-6.	View of back of solar collector panels showing foil backed collector insulation.	III-100.
FIGURE 8-7.	View of lower header insulated with fiberglass covered with roofing paper and asphalt coating.	III-100
FIGURE 8-8.	View looking west between collector rows: Solar collectors are on right and reflectors on left.	III-101
FIGURE 8-9.	Closeup view of Mylar reflector surface.	III-101
FIGURE 8-10.	Isometric sketch of collector support structure and joint and support details.	III-103
FIGURE 8-11.	Closeup view of collector mounting arrangement.	III-103
FIGURE 8-12.	View of piping and electrical conduits leading to roof penetration.	III-106

LIST OF FIGURES (cont'd)

	<u>Page Number</u>
<u>SECTION III-A-9. THE BAREFOOT MAILMAN HOTEL</u>	
FIGURE 9-1. Schematic diagram of solar augmented domestic water heating system.	III-115
FIGURE 9-2. Overall view of the solar collector array looking west-northwest.	III-116
FIGURE 9-3. View showing serpentine coil attached to absorber plate.	III-118
FIGURE 9-4. View showing peeling of flat black coating from absorber plate.	III-118
FIGURE 9-5. View showing typical arrangement of collector support brackets, wooden sleepers and piping.	III-119
<u>SECTION III-A-10. ALUMNI HOUSE - CONFERENCE CENTER</u>	
FIGURE 10-1. View of Alumni Center looking north-northwest.	III-123
FIGURE 10-2. View of Alumni Center looking west-southwest.	III-123
FIGURE 10-3. Sketches of the floor plans of Alumni Center.	III-124
FIGURE 10-4. View showing the cathedral ceiling above the meeting room/lounge area on the second floor.	III-124
FIGURE 10-5. Simplified schematic diagram of Alumni House solar heating system.	III-127
FIGURE 10-6. Sketch showing typical laminated panel roof and solar collector assembly and cross-section of batten used to secure glazing.	III-130
<u>SECTION III-A-11. MILLER AND SMITH SALES OFFICE</u>	
FIGURE 11-1. View looking northwest at the Miller and Smith Towlston Sales Office.	III-135
FIGURE 11-2. View looking east at the sales office.	III-135

LIST OF FIGURES (cont'd)

		<u>Page Number</u>
FIGURE 11-3.	Simplified sketch of the cross-section of built-up collector configuration.	III-137
FIGURE 11-4.	Closeup view of edge of the collector mounting arrangement and bottom perimeter flashing.	III-140
FIGURE 11-5.	View showing insulated 4000 gallon steel storage tank located in basement.	III-140
FIGURE 11-6.	Simplified schematic diagram of storage tank subsystem.	III-142
 <u>SECTION V</u>		
FIGURE V-1.	View showing two foot by 24 foot air-cooled collector module being installed by a crane at the Bighorn Visitors' Center in Lovell, Wyoming.	V-5

LIST OF TABLES

Page Number

SECTION II

TABLE II-1. Categorical Classification of Installations Selected For Study	II-7
--	------

SECTION III-A-1. WHITNEY VETERINARY CLINIC

TABLE 1-1. Solar System Cost Breakdown	III-15
--	--------

SECTION III-A-2. GUMP GLASS BUILDING

TABLE 2-1. Installed System Cost Breakdown	III-28
TABLE 2-2. Solaron Contract Cost Breakdown	III-29
TABLE 2-3. Estimated Costs to Duplicate Installation	III-30

SECTION III-A-3. UNITED SOUTHWEST NATIONAL BANK OF SANTA FE

TABLE 3-1. General Contractor's Estimate	III-42
TABLE 3-2. Mechanical Contractor Cost Breakdown	III-40

SECTION III-A-4. WINDMILL CAMPGROUNDS LAUNDRY

TABLE 4-1. Solar System Cost Breakdown	III-52
TABLE 4-2. Projected Cost for Duplicating Solar Installation	III-52

SECTION III-A-5. TRINITY UNIVERSITY

TABLE 5-1. Solar System Contract Costs	III-60
TABLE 5-2. Non-Solar Project Contract Costs	III-60
TABLE 5-3. Comparison of Bids From Four Collector Manufacturers	III-62

SECTION III-A-6. COMMUNITY RECREATION CENTER

TABLE 6-1. Project Cost Breakdown	III-76
-----------------------------------	--------

SECTION III-A-7. MADEIRA SCHOOL

TABLE 7-1. Solar System Cost Breakdown	III-89
--	--------

SECTION III-A-8. GEORGE A. TOWNS ELEMENTARY SCHOOL

TABLE 8-1. Labor Costs for Solar System Installation	III-108
TABLE 8-2. Material Costs for Solar System and Interface Equipment	III-109

LIST OF TABLES (cont'd)

	<u>Page Number</u>
TABLE 8-3. Possible Cost Savings for New Construction of Similar System	III-112
<u>SECTION III-A-9. BAREFOOT MAILMAN HOTEL</u>	
TABLE 9-1. Solar System Cost Breakdown	III-120
<u>SECTION III-A-10. ALUMNI HOUSE - CONFERENCE CENTER</u>	
TABLE 10-1. Summary of Estimated Installation Costs	III-132
<u>SECTION III-A-11. MILLER AND SMITH SALES OFFICE</u>	
TABLE 11-1. System Cost Breakdown	III-141
<u>SECTION IV.</u>	
TABLE IV-1. Solar Collectors Summary Data and Unit Component Costs as Provided by the Manufacturers	IV-3
TABLE IV-2. Summary of Total Installed System Costs and Unit System Costs per Square Foot of Solar Collectors	IV-4
TABLE IV-3. Collector Subsystem Installation (Labor and Materials) Costs and Percent of Total Costs	IV-6 & 7
TABLE IV-4. Summary of Thermal Energy Storage Subsystem Data and Costs	IV-9

I. INTRODUCTION

The cost of installing a solar energy system for space heating and/or cooling or providing domestic hot water to commercial facilities is not amenable to accurate estimates using any of the existing rule-of-thumb methods (e.g. twice the cost of the materials or "X" dollars per square foot of collector). Many factors combine to make ballpark estimates or even detailed cost estimates of planned projects risky business. Also, programs whose goal it is to reduce solar energy utilization costs have little data regarding the cost components of actual projects to permit indentifying potential areas for cost reduction.

This report presents the results of a study in which the primary objective was to determine actual costs associated with the installation of solar collector and thermal energy storage subsystems in specific non-residential building applications. A secondary objective of the study was to assemble details of existing solar collector and storage subsystem installations, including caveats concerning cost estimating, logistics and installation practices. These objectives were accomplished by detailed studies of projects selected to provide a cross-section of a variety of solar energy applications. The detailed studies included site visits, analysis of plans and specifications, where available, and discussions with engineers, architects, owners, and contractors involved with the individual projects. Although the number of detailed studies did not allow analysis of all types and sizes of solar installations, a wide diversity of system types, sizes, and locations were assessed. It was found that the quantity and quality of the cost and technical data varied considerably from project to project.

Ideally, installed system costs should be presented based on the amortized cost per unit of thermal energy produced over the useful life of the system. However, essentially no actual annual performance data are available for comparison to system costs, and system component life has not been well established for critical solar subsystems components.

The study began with the development of an exhaustive listing and compilation of basic data and contacts for non-residential applications of solar heating and cooling of buildings. Both existing projects and those under construction were surveyed. Survey summary sheets for each project encountered are provided as a separate appendix to this report.

Subsequently, the rationale used to select the projects studied in-depth is presented. The results of each of the detailed studies are then provided along with survey summary sheets for each of the projects studied. Section IV summarizes installation cost data and discusses the significance of the differences and similarities between the reported projects.

After evaluating the data obtained from the detailed studies, methods for reducing installation labor costs were postulated based on the experience of the study. Some of the methods include modularization of collectors, preplumbing and preinsulating, and collector placement procedures. Various installation concepts were discussed with manufacturers of solar collectors.

Methods of cost reduction and summary discussion of prominent problems encountered in the projects are the subjects of Sections V and VI respectively.

II. METHODOLOGY

This section describes the procedural steps that were pursued to perform this study. These steps included:

- A. Development of a list and survey of non-residential buildings employing solar energy systems.
- B. Review and evaluation of survey information based on solar collector and solar storage subsystem parameters.
- C. Selection of representative projects for detailed study.
- D. Performance of detailed studies of selected projects.
- E. Evaluation of methods for cost reduction translatable to future projects.

A discussion of the methodology employed in each of these subtasks follows, along with specific reasons for the methods employed and their impact on the study results.

A. Survey of Non-Residential Solar Energy Installations

Several surveys of existing solar energy systems in buildings are available, including Shurcliff's "Solar Heated Buildings; a Brief Survey," 12th Edition and "Solar Directory" edited by Carolyn Pesko. However, these surveys are not comprehensive, although it was found they do provide a good data base on which to build an exhaustive list of commercial solar energy installations. Because the number of sites that could be studied in detail was limited and because it was desired that the selected sites be representative of the existing types of installations, it was important to obtain an accurate listing of nearly all the existing non-residential installations.

The survey was focused on systems that had been completed or were under construction as of mid-1976, although data on projects in the latter stages of design were compiled and their status verified for the sake of completeness.

In general, the sources of data employed can be categorized as follows:

1. Available data from existing surveys.
2. Letters to the engineers involved with the projects described in the existing surveys, asking for other projects they are designing.
3. Follow-up telephone calls to those engineers and system owners to obtain more detailed data.
4. Letters to major manufacturers of solar collectors listed in the "Catalog on Solar Energy Heating and Cooling Products," ERDA-75.
5. Follow-up telephone calls to the new contacts provided by the collector manufacturers.
6. Letters to various state solar energy agencies and solar energy associations.
7. Follow-up telephone calls to the new contacts provided by those groups.
8. Review of the literature, trade journals, conference reports and the like.
9. Personal knowledge of installations.

After the names of persons involved with each project were obtained, the contact individuals were telephoned to confirm available information and provide additional project information. Combining all sources of information, it was possible to assemble comparative information for each project. Information was formatted as shown in Figure II-1. This format provides the basic information necessary to determine the "type" of system and to differentiate between significant aspects of the solar systems. The entire collection of completed information sheets is included as a separate appendix to this study. As this is the first attempt to develop a comprehensive annotated listing of non-residential projects, it should be realized that some data may be incomplete and may be incorrect, although attempts have been made to confirm all information included in the Appendix.

Although complete data were not available on all projects, this did not seriously impair the selection review process. For example, if an installation was a possible candidate for detailed study, an effort was made to obtain most information before final selection. The annotated list was meant

<p>1. PROJECT NAME -</p> <p>2. LOCATION -</p> <p style="padding-left: 40px;">Contact:</p> <p style="padding-left: 40px;">Address:</p> <p style="padding-left: 40px;">Phone:</p>	<p>19. COLLECTORS</p> <p style="padding-left: 40px;">Manufacturer -</p> <p style="padding-left: 40px;">Areas and Type -</p> <p style="padding-left: 40px;">Mounting Configuration -</p> <p style="padding-left: 40px;">Fluid -</p> <p style="padding-left: 40px;">Absorber -</p> <p style="padding-left: 40px;">Coating -</p> <p style="padding-left: 40px;">Glazings -</p> <p>20. STORAGE</p> <p style="padding-left: 40px;">Container -</p> <p style="padding-left: 40px;">Medium and size -</p> <p style="padding-left: 40px;">Location -</p> <p style="padding-left: 40px;">Insulation -</p> <p>21. SOLAR AIR CONDITIONING</p> <p style="padding-left: 40px;">Type -</p> <p style="padding-left: 40px;">Quantity and Size -</p> <p style="padding-left: 40px;">Manufacturer -</p> <p style="padding-left: 40px;">Percent Solar A/C -</p> <p>22. FREEZE PROTECTION -</p>
<p>3. BUILDING TYPE -</p> <p>4. FLOOR AREA -</p> <p>5. SOLAR APPLICATION -</p> <p>6. NEW/RETROFIT -</p> <p>7. DISTRIBUTION SYSTEM -</p> <p>8. PERCENT SOLAR HEAT -</p> <p>9. AUXILIARY HEATING -</p> <p>10. INSTALLER -</p> <p>11. ENGINEER -</p> <p>12. OWNER -</p> <p>13. ARCHITECT -</p> <p>14. SOLAR COST -</p> <p>15. FUNDING AGENCY -</p> <p>16. STATUS -</p> <p>17. OPERATIONAL DATA AVAILABLE -</p> <p>18. LABOR, UNION/NON-UNION -</p>	

FIGURE II-1. Solar energy system information format

to describe the population of projects which our sample for detailed studies was to represent.

B. Review and Evaluation of Survey Information

After assembling the survey information, the next step was to select representative solar heating and cooling projects for detailed study of costs and techniques associated with installation of collector and storage subsystems.

The studies were not to address the thermal performance of those systems, although the performance of the selected systems should be typical or representative of other similar state of the art installations.

The most difficult aspect of the selection process was the assessment of the great diversity of systems which exist. It is reasonable to expect that most of the categories of information listed on the data format can influence installation costs to some extent. Factors believed to be most important prior to completion of this study are itemized below, not necessarily in order of importance:

1. Heat transfer medium (air or water)
2. New or retrofit
3. Labor (union or non-union)
4. Size of system
5. Collector mounting configuration
6. Type and location of storage subsystem
7. Funding source
8. Type of collector
9. Building type
10. Geographic location
11. Experience of engineers and installers
12. Collector manifold configuration

It had originally been intended to develop a matrix of generic types of projects according to these and similar parameters. However, the number of detailed studies to be

performed was of the same magnitude as the number of parameters listed above. Also, there were only approximately 100 candidate solar installations which were currently operating or in final stages of construction. (We were able to identify 220 non-residential projects under design, construction or operation in the United States.) Because of the relatively large number of parametric combinations which would have made up the matrix, it became obvious that a meaningful generic matrix would be very difficult to construct. This was especially true since the relative importance of the parameters could not be accurately assessed prior to completion of the site visits and detailed studies.

An alternative tack was taken working within the limitation that approximately 12 sites would be studied. Seven broad categories were then established such that solar installations selected for study would fall into two or more categories to provide more points for comparison. These categories were 1) air collector systems; 2) water systems; 3) collectors in planar arrays; 4) systems with collectors in sawtooth arrays; 5) retrofit systems; 6) concentrating collector systems; 7) domestic hot water heating systems.

Solar installations were then chosen which fell into several of these categories with consideration also given to obtaining diverse representation of other parameters, such as union or non-union labor, geographic area, size of system and so forth.

Candidate selection was limited to systems which were operational or under construction. Originally it was desired to study only completed systems. However, no systems employing more than 15,000 square feet of solar collectors presently exist, though several are in the planning and design stages. Trinity University's system was selected as one of the concentrating collector systems to be studied even though construction had just started at the time this study was performed. It was chosen because it is a very large system (16,080 square feet of collectors) and very detailed contract and cost data were available because contracts had been issued

and construction was beginning. It was believed essential to try to investigate the possible economy of scale in such large installations.

C. Sites Selected for Study

The installations selected for in-depth study are listed on Table II-1 according to the categories listed in Section B above. Summary project data sheets for each of the selected installations can be found in Section III-B following.

This rather pragmatic approach to site selection lead to a group of installations with an interesting aggregation of characteristics. Some of these characteristics are listed below:

1. Five retrofit and seven new installations were included.
2. Nine installations employed union labor; three did not.
3. Nine used totally private funds; two were federally funded, one was partially state funded.
4. Eight flat plate, one Thomason, one evacuated tube, and two concentrating collectors were included.
5. Of the eight flat plate collectors, three employed a steel absorber plate, two aluminum, and three copper.
6. Eleven different manufacturers of collectors and absorber plates were represented:

Solaron (2 systems)	Thomason (design only)
Olin-Brass	PPG
Miromit	Sunpower Systems
Ametek	Northrup
Revere Copper and	Solar Dynamics
Brass	Owens-Illinois

7. Eleven different states were represented:
Colorado
Virginia (2 installations)

TABLE II-1. Categorical Classification of Installations Selected for Study

PROJECT/LOCATION	FUNDING G = Government P = Private	AIR COLLECTOR	WATER COLLECTOR	PLANAR ARRAY	SAWTOOTH ARRAY	RETROFIT SYSTEM	CONCENTRATING COLLECTOR	DOMESTIC HOT WATER SYSTEM (ONLY)	SOLAR COLLECTOR AREA, FT ²
1. Whitney Veterinary Clinic Orange, Connecticut	P	•		•		•			625
2. Gump Glass Building Denver, Colorado	P	•			•				1,600
3. United Southwest Bank Santa Fe, New Mexico	P		•		•				900
4. Windmill Campgrounds Flagstaff, Arizona	P		•				•	•	430
5. Trinity University San Antonio, Texas	G		•			•	•		16,080
6. Santa Clara Community Center Santa Clara, Calif.	G		•	•					7,011
7. Madeira School Greenway, Virginia	P		•	•					4,000
8. Towns Elementary School Atlanta, Georgia	G		•		•	•			10,000
9. Barefoot Mailman Hotel Hillsboro Beach, Fla.	P		•		•	•		•	720
10. SUNY Alumni House Albany, New York	G/P		•	•					2,300
11. Miller and Smith Sales Office Towlston, Virginia	P		•	•					750
12. Smith, Hinchman and Grylls Office Detroit, Michigan	P		•		•	•			1,000

New Mexico
Connecticut
California
Michigan
Georgia
Arizona
Texas
Florida
New York

8. Three heating and cooling, seven heating only and two domestic water heating only projects were included.
9. Nine installations employ steel tanks and one a concrete tank for water storage; one used wood and one used concrete block as enclosure for rock storage in conjunction with air systems.

D. Data Collection During Detailed Studies

After the installations to be studied were determined, personnel associated with each project were contacted and arrangements made to visit the site. A list of questions or desired data was compiled before the visit to ensure completeness. At the site, photographs were taken of the installation; drawings, specifications, bid packages and contracts were reviewed, where possible, and important project personnel were interviewed.

Very good cooperation was received from all parties after they were informed of the purpose of the visits. All interviewees were promised that proprietary information would not be released, although few of the data obtained were of a proprietary nature, and the lack thereof has not affected the value of the study.

Although it was thought desirable to include an evacuated tube type collector installation in the study, only limited cost data is now available. The Smith Hinchman and Grylls installation in Detroit employing 1500 square feet of Owens Illinois collectors was visited. Although this is the largest

installation of its type presently in existence, the owner could not provide any installation cost breakdown. Also, Owen-Illinois still considers their collector experimental. Commercialization of the collector is not expected until 1978. Therefore, only eleven installations were studied in detail; no system employing an evacuated tube collector has been included.

III. RESULTS OF INDIVIDUAL INSTALLATION STUDIES

The data collected during the site visits, phone calls and discussions with the owners, architects, engineers, and contractors involved with each of the projects are included in this section. Section III-A presents narrative reports describing each of the projects studied. The reports are presented in the approximate order the material was collected. For each project, background data are presented which include a building description, project history, status and managerial relationships among the project personnel. This is followed by brief descriptions of the overall solar energy system design. The solar collector and energy storage subsystems are then discussed in detail. A subsection describing collector installation has been included in each collector subsystem section. System costs are presented for each project and a general discussion area addresses problems encountered, possible areas for cost reduction, and other miscellaneous information.

The narrative reports are presented in approximately the same order they were visited and are not grouped according to system application. The summary tables of Section IV group data according to their application to facilitate comparison of information.

Section III-B consists of summary data sheets for each project. These sheets provide a brief synopsis of the pertinent aspects of each of the solar energy projects studied.

A. Narrative Reports of Projects Studied

1. WHITNEY VETERINARY CLINIC

ORANGE, CONNECTICUT

BACKGROUND

This clinic is a two-story structure which has recently been modernized and retrofitted with a solar heating system utilizing 625 square feet of collectors manufactured by Solaron, Inc. The solar heated portion of the building is approximately 2400 square feet with the first floor being the clinic and the second floor available as a rented apartment. An existing small building addition in the rear houses the rock bed storage, the air handling equipment and the oil-fired auxiliary boiler. This addition is not solar heated.

The building was originally of concrete block construction as shown in Figure 1-1. During the modernization, a six inch wooden frame was constructed around the outer block structure and insulated. The pitch of the front roof was increased to 55° with a wooden frame to improve collector performance.

At present, the solar heating system is operational but has not been used during a heating season.

No one involved with the project, except the collector supplier, had previous experience with solar energy utilization. The owner's enthusiasm and interest in energy conservation were the sole reasons for the project's development. Mr. Sandomirsky, the engineer who designed the system, "tried to talk him out of it" because he did not believe the system could be made cost-effective. Like the architect and the contractor, Mr. Sandomirsky has been a good friend of the owner for a long time.

All involved, especially the engineer, believed that an air-type solar collector offered advantages over a water-type system. Some of the advantages mentioned were:

1. No need for freeze protection.
2. No possibility of damage to the building from piping leaks.
3. Fewer corrosion problems and longer life (higher inherent reliability than water systems).
4. Less expensive installation.

FIGURE 1-1. View looking northwest at building showing collector support structure partially erected. Note chimney extension required to clear collector. Compare to Figure 1-3.

The system was first designed around Sunworks collectors. However, Solaron collectors were the final choice, largely because the internal manifolding was expected to reduce installation costs significantly and improve the appearance of the roof-top system. Also, the Solaron manufacturing plant is only an hour away by car, near Hartford, Connecticut. The engineering and installation manuals also appeared more complete and detailed for the Solaron system.

PERSONS INVOLVED IN PROJECT

Owner:	Dr. George Whitney Whitney Veterinary Clinic Oakwood Road Orange, Connecticut 06477 Telephone: (203) 799-2364
Engineer:	Alexander G. Sandomirsky, P.E. Plenco, Inc. 2781 Dixwell Avenue Hamden, Connecticut 06518 Telephone: (203) 281-6551
Architect:	Edward C. Johnson, AIA Edward Johnson & Co. 495 Orange Street New Haven, Connecticut 06511 Telephone: (203) 787-4131
Contractor:	Donald Wall The George Ellis Co. of New Haven, Inc. 301 Orange Avenue West Haven, Connecticut 06505 Telephone: (203) 934-6673

SOLAR SYSTEM DESIGN

The system is typical of Solaron design. It employs a central air handling unit supplied by Solaron which contains a blower and several automatic dampers. The system flow schematic and sequence of operation are given in Figure 1-2. The solar collectors are located on the raised portion of the

south-facing roof as shown in Figure 1-3. The air handling equipment, the storage box and the oil-fired auxiliary furnace are located in a small building addition behind the clinic. Because of the slope of the lot, the addition is level with the second floor of the main building as shown in Figure 1-4. For the most part, the ductwork that connects the components is run through the attic of the addition. Refer to Figure 1-5.

SOLAR COLLECTOR SUBSYSTEM

Solaron Series 2000 collectors were arranged in two rows of 16 modules each on the planar roof surface. Refer to Figures 1-3 and 1-6. The total gross area of the solar collector is 625 square feet, or approximately 20 square feet per module. The mounting angle is 55° from the horizontal.

This model of collector is designed with internal manifolding which allows the collectors to be plugged into each other and secured directly to the roof. The absorber is a blackened steel sheet with air channels underneath the surface. Glazing is by two sheets of 1/8 inch thick tempered glass with a sealed dry air chamber between. Insulation below the absorber plate air passage consists of 3-1/2 inches of fiberglass. The entire assembly is contained by an enameled steel casing.

Installation

The angle of the roof was built up with wood frame and plywood construction to optimize the performance of the collectors. The total cost of this support structure was between \$1500 and \$2000. The chimney also had to be extended above the new roof to meet code requirements. Prior to the mounting of the collectors on the roof, two layers of felt were placed on the plywood sheathing.

The collectors were picked up at the Hartford Connecticut manufacturing plant by the contractor and trucked to the clinic. One problem did arise with the mounting strips that tie down the collectors and provide a weather seal. These strips had

FIGURE 1-3. View of clinic looking northwest.

FIGURE 1-4. View looking southeast showing existing building addition housing rock bed storage, air handling equipment and auxiliary energy source.

FIGURE 1-5. Elevation section view looking east showing supply and return duct runs and interconnection with storage subsystem. (Basic sketch provided by Solar Energy Systems.)

FIGURE 1-6. Plan view showing location of collector modules and roof penetrations. (Drawing provided by Solar Energy Systems.)

just been redesigned by Solaron and were three weeks in being shipped from Denver. During this time, the building roof was open to possible water damage.

The contractor at first tried to slide the collectors up to the roof on a ladder. However, this proved to be too difficult and dangerous for the crew, so a small "cherry picker" crane was called in. The crane facilitated setting the collectors; however one collector's glass was broken when it was smashed against the chimney. Collector installation required three days, during which time a field representative from Solaron was on site. Solaron contends that the installation would have required only one day for an experienced crew. No one else agrees. The greatest problem was penetrating the roof to connect the back of the collectors. Each set of eight collectors requires one inlet and one outlet as internal manifolds interconnect each group of eight modules. The connections to the back can be made anywhere in the manifold sections of the collectors.

A special clamping tool supplied by Solaron is used to pull the individual modules together compressing a butyl seal between them.

Affixing the collector modules to the roof required one man inside the attic to place the nuts on the bolts that penetrated the roof to secure the collectors. However, at the roof peak, bolts could not be used because there was not adequate room underneath to install them. The contractor then searched for lag bolts to use, but finally had to cut longer bolts to size because a non-standard size was required.

The mechanical contractor who installed the collectors had estimated 3 men for 3 days would be required to perform the work. It actually took 5 men, 5 days using a crane. Putting the cap strips (see Figure 1-7) on required a full day in itself. Interestingly, this could not be done in the middle of the day because the collectors were too hot to handle. The workers had to start at dawn one morning and by mid-day they had gotten to the perimeter of the collector system where the heat was not as great a problem.

COLLECTOR DIMENSIONAL DATA

FIGURE 1-7. Sketch showing collector hold down points, and mounting and flashing details. (Drawing provided by Solaron Corporation.)

The perimeter flashing was also installed by the general contractor. The flashing had to be manufactured twice in the shop as the first flashing had a finish that could not be painted satisfactorily.

SOLAR STORAGE SUBSYSTEM

A rock bed heat storage unit is employed here, as with all Solaron installations. Storage volume is 315 cubic feet which is adequate to contain 16 tons of 3/4 inch diameter railroad track bed gravel. The heat storage unit was built of wood frame construction on a concrete slab using two inch by four inch studs, cross-reinforced with wire and covered with sheetrock. Three and one half inches of rigid insulation were placed in the stud space. Although river rock had originally be intended for the heat storage media, this material was not available at the time of construction. The track gravel had to be washed at the site in wheelbarrow load quantities and hand loaded into the storage container. This proved to be a time consuming task.

The moisture retained on the rocks has caused soaking of the sheetrock at the bottom of the tank. It is believed that this can be dried out quickly when the system is activated for the heating season.

The bottom of the container employs U-shaped concrete blocks to distribute the air. Wire screen is placed over the openings to prevent rocks from filling the U-shaped cavities of the blocks. Refer to Figure 1-8 which presents a sketch of a typical storage unit configuration recommended for use with Solaron systems.

Figures 1-5 and 1-9 depict the actual arrangement of equipment, duct work and storage unit size for this installation.

FIGURE 1-8. Sketch showing typical rock bed heat storage unit recommended by Solaron Corp. (Drawing provided by Solaron Corp.)

FIGURE 1-9. Plan view of component layout and distribution system.

SOLAR SYSTEM COSTS

The information which appears in Table 1-1 was supplied by the architect and represents his best available information on the overall project.

TABLE 1-1. Solar System Cost Breakdown - Whitney Veterinary Clinic

<u>ITEM</u>	<u>CONVENTIONAL EQUIPMENT</u>	<u>ADDITIONAL SOLAR INCREMENT</u>
Furnace	\$1,200.00	--
Oil Piping	100.00	--
Air Conditioner	1,700.00	--
Conventional Ductwork	2,760.00	--
Solar Ductwork (includes collector installation)		\$3,600.00
Solar Filter Boxes		170.00
Controls	100.00	1,050.00
Wiring	200.00	1,400.00
Hot Water System	250.00	825.00
Start and Test	200.00	--
Tax on Labor	240.00	266.00
State Tax on Materials	155.00	167.00
Collector Delivery	--	90.00
Collectors and Miscellaneous Hardware from Solaron	--	8,278.86
Field Representative - Solaron	--	456.01
Rock Storage	--	2,800.00
Ventilation Equipment	481.62	--
Roof Modifications	--	1,750.00
	<hr/>	<hr/>
TOTAL	\$7,286.62	\$20,852.87

DISCUSSION

The architect and engineer agreed that if the project was done again, even knowing what they know now, it would still be at least as expensive. Everyone involved had to put more time in than expected.

When the mechanical contractor was asked if this installation would give a competitive edge in bidding the next solar installation because of his experience, Donald Wall replied that he would probably have to bid higher than a contractor inexperienced in the field. He thinks he will lose jobs until most contractors have had a solar project and know what kind of problems to expect.

He did believe that Solaron's collector was the best he had seen in terms of ease of installation. He estimated that \$3000 was saved by not requiring external manifolding of the collectors.

When the engineer was asked what he would change if he had to do it again, he said that he would not do a retrofit again. He felt that in a retrofit the inability to specify component location in a least-cost configuration seriously affects the price.

The architect, on the other hand, believed that the building had offered many advantages such as available space and orientation that minimized its problems as a retrofit.

Controls present the only remaining problem to be debugged. The engineer and the mechanical contractor are working on this on their own time because they do not want their friend, Dr. Whitney, to pay for a field representative from Solaron in Denver to make these adjustments.

The mechanical contractor had both union and non-union men on the job. There were no conflicts. He said he simply assigned his best men to do the work.

The architect is worried about the possibility of future water leaks through the collector system, though there have been none to date. He is not yet convinced the cap strips, waterproofing and flashing system will be completely effective.

Government funding had originally been sought for the project but delays in government response and the building's dual use as a commercial installation -- clinic and rental residence -- caused them to eliminate that source of funds.

No building code problems were encountered during permit application or construction.

2. GUMP GLASS BUILDING DENVER, COLORADO

BACKGROUND

The Gump Glass Company began plans for its new headquarters building during the height of the energy crisis. The president of the company, Jerry Sigman, felt that solar energy should be considered. After many months of deliberation, during which time much of the building was completed, it was decided that they would use solar energy for heating the 139 foot by 56 foot office and showroom portion of the building. The remainder of the 41,000 square foot building consists of shops and a warehouse. Building design employs precast concrete walls supporting steel beam and joist roof framing. A portion of the walls is covered with a metal facade. See Figure 2-1.

The owners commissioned Al Cohen Construction Co. to design and construct the building. Cohen selected Intergruop of Golden Colorado as the architect and engineer. Brandt Engineering Co., mechanical contractors, won the contract for design coordination and the installation of the solar heating system. Solaron Corporation performed the solar system design, provided the collectors, and installed the heat storage box. No significant alterations were required to the building design to accommodate the solar energy installation.

None of the companies involved, except Solaron, had previous solar energy utilization experience. The architect and the contractor were at first apprehensive about using solar energy. They did overcome their initial fears before construction commenced and became enthusiastic participants.

The solar heating system has been operational for approximately one year.

FIGURE 2-1. View looking west at the front of the Gump Glass Building. The solar collectors are partially visible on the roof.

FIGURE 2-2. View showing aluminum covered rectangular fiberglass supply and return air duct system serving the collectors. Note circular branch ducts penetrating roof deck leading to collectors.

PERSONS INVOLVED IN PROJECT

Owner:	Gerald N. Sigman, President Gump Glass Co. 1265 South Broadway Denver, Colorado 80210 Telephone: (303) 778-1155
General Contractor:	Don Thorpe Al Cohen Construction Company Denver, Colorado Telephone: (303) 455-8800
Mechanical Contractor:	Stanley J. Simpson, Jr. Brandt Engineering Company 4995 Lima Street Denver, Colorado 80239 Telephone (303) 371-7550
Solar Equipment Supplier and Solar Engineer:	James P. Junk Solaron Corporation 4850 Olive Street Denver, Colorado 80022 Telephone: (303) 289-5971
Architect and Engineer:	Intergroup 787 Nile Golden, Colorado 80401 Telephone: (303) 279-2533

SOLAR SYSTEM DESIGN

The collectors are mounted over the shop area, directly behind the showroom-office portion of the building. The rock storage box is also in the shop area. The duct work distributing air to and from the collectors is suspended just below the steel roof joists as shown in Figure 2-2. A diagram of the duct work serving the collectors is shown in Figure 2-3. The shop ceiling is very high so that there was no disadvantage in lowering the useful ceiling height.

The storage box and the collectors are connected in series with the five rooftop mounted, electric cooling/gas heating units over the showroom/office space. From the rooftop units the air

FIGURE 2-3. Plan view sketch showing solar collector supply and return ducts in relationship to the collectors and the heat storage unit. (Basic sketch provided by Intergroup.)

distribution system to the space is conventional.

A schematic flow diagram showing the relationships between the major heating system components is given in Figure 2-4.

SOLAR COLLECTOR SUBSYSTEM

Sixteen collectors, each with a 10 foot by 10 foot area, were mounted on triangular penthouses 8 feet high by 6 feet wide. The total gross collector area is 1600 square feet. The collectors were manufactured by Solaron Corporation and represent their earlier model. Solaron furnished the collectors to the site mounted on the wooden frame penthouses. Brandt Engineering Co. set the penthouses on concrete curbs built into the roof by the general contractor. The Douglas Roofing Co. of Denver flashed the curbs during the roofing operation.

Each of the sixteen collector modules weighs 1200 pounds, increasing the roof load by about 10 tons. The weight is distributed over 3000 square feet so that no major roof design alterations were required to accommodate the extra weight of less than seven pounds per square foot.

An 82-ton crane with a 180 foot boom was used to place the collectors on the roof in eight pairs. The collector surfaces face south and are inclined at an angle of 53°. Figure 2-5 is a view of the last module being lowered into place. Figure 2-6 is an overall view of the collectors in place.

Local unions had decided that a composite crew would be required. This meant that both glaziers and sheet metal men had to be on-site during installation of collectors even though the collectors had been pre-glazed by Solaron. Five Gump Glass Co. employees, members of the glaziers' union, assisted in the collector installation in order to meet this requirement. The cost for their time has not been taken into account in the cost data which follow. The collector mounting took two days.

Johns-Manville offered the mechanical contractor a \$1000 credit if he would use their fiberglass duct in the installation as they wanted to be involved in the project. Accordingly, fiberglass duct was used in the collector supply and return air

FIGURE 2-4. Schematic flow diagram of the solar collector, storage and distribution system. (Sketch provided by Gump Glass Co.)

FIGURE 2-5. View of collectors during installation. The last module is shown being lowered into place. (Photo provided by Gump Glass Co.)

FIGURE 2-6. Rooftop view of the collector penthouses installed and operational.

FIGURE 2-7. Closeup view of capping and flashing system between two collector modules.

FIGURE 2-8. Interior view of the wood framed solar collector penthouses showing insulated flexible supply duct penetrating the roof and connecting to the collector inlet.

FIGURE 2-9. View of the interior of a solar collector penthouse showing the flexible return air duct. Also note sprinkler system.

distribution system. The contractor's unfamiliarity with fiber-glass duct caused some delay in the work: four weeks for four men had been estimated, but it actually took five weeks. Sheet metal duct was used to distribute heat to the building.

The collectors were Solaron's original collector design and were essentially handmade. The capping system used has been greatly improved according to Solaron. See Figure 2-7 for a closeup view of the capping and flashing technique. There has been some condensation between the double panes of glass, but it is not expected to impair efficiency significantly. Collector delivery from placement of order took one month.

The fire department required each collector penthouse to be equipped with sprinklers because "they were made of wood and produced heat." The mechanical contractor believed they could have appealed the ruling and had it reversed, however, the delay during arbitration would have been more costly than installing the sprinkler system. Figures 2-8 and 2-9 shown interior views of the collector penthouses.

SOLAR STORAGE SUBSYSTEM

The rock storage box shown in Figures 2-10 and 2-11, consists of a 16 foot long by 8 foot wide by 8 foot high concrete block structure with a wooden lid. It was lined with two-inch rigid insulation and contains 50 tons of 1-1/2 inch to 3 inch diameter rounded gravel. The storage box was intended to be placed below ground, but building construction had proceeded too far before the solar "go-ahead", so it was placed above ground near the wall between the shop area and the offices.

The storage container was installed eight feet from the location originally intended because a section of the prestressed concrete wall which had been formed with an opening for ductwork had been misplaced.

FIGURE 2-10. View showing fans and connections to concrete block heat storage unit located in the shop area.

FIGURE 2-11. Closeup view of concrete block heat storage unit. Enclosure is 16 feet long by 8 feet wide by 8 feet high with a wooden lid. The solar equipment control panel is located on the wall at right.

SOLAR SYSTEM COSTS

Table 2-1 presents the out-of-pocket costs incurred by Gump Glass for the installation of the solar system.

TABLE 2-1. Installed System Cost Breakdown --
Gump Glass Building

Solaron	\$40,372*
Collectors delivered to site	
Rock storage box	
Fans (supplied)	
Controls (equipment only)	
Brandt Engineering, Mechanical Contractor	
Materials**	8,600
Control wiring	2,200
Crane rental	730
Labor	12,300
General Contractor's markup (8%)	<u>1,906</u>
SUBTOTAL	\$25,736
Al Cohen Construction, General Contractor	
Curbs on roof for collectors	1,600
Stairway to roof	<u>3,000</u>
TOTAL	\$70,708

* No further breakdown available. See following page for estimated breakdown.

** Plus \$1000 subsidy from Johns-Manville for using fiberglass duct.

Because of the magnitude of the Solaron contract, an attempt was made to determine costs associated with individual items. Table 2-2 presents costs determined by conversations with Solaron representatives, other mechanical equipment vendors, and assumptions. The "total" figure below was Solaron's contract price for the Gump Glass installation: All other values should be considered as rough estimates only. Profit and overhead are considered to be proportioned into each item.

TABLE 2-2. Solaron Contract Cost Breakdown --
Gump Glass Building

Collectors (unmounted, assumed \$12/ft ²)	\$19,200
Collector Mounting (8 wooden penthouses, assumed @ \$500 per mounting at \$3/ft ²)	8,800
Collector Delivery	200
Storage Box	4,000
Fans	3,000
Damper and Motors	1,500
Other	<u>3,672</u>
TOTAL	\$40,372

DISCUSSION

Local utility commission regulations prohibit the use of gas as a standby or backup fuel in Denver. At the outset of the project, this was thought to pose the largest single problem since it was desired to use gas-fired rooftop units to supply auxiliary heat.

However, because the shop and warehouse rely completely on natural gas for space heating, gas-fired equipment was permitted for the office-showroom area also.

The mechanical contractor believes that if he had to install the same system again, it would cost just as much, even with this experience. He said the roof penetrations were not troublesome because the curbs under the collectors assured them that leakage would not be a problem and location of the penetrations would not be critical.

The contractor did believe that collector systems using water as the heat transfer medium would be much easier and less costly to install due to the relative cost of installing pipe versus duct work.

The owner has had many groups and individuals visit the installation and Gump Glass has received a lot of publicity because of it. Last winter was relatively mild but the solar-heated portion of the building required a "surprisingly" small amount of auxiliary gas. The Public Service Co. has now installed some simple instrumentation to determine fuel consumption and savings more accurately.

The solar collector supplier felt that a similar system could be installed at less cost using their newer Series 2000 collectors.

The following is a cost breakdown of what a similar system would be expected to cost according to estimates based upon discussion with the personnel involved with the project.

TABLE 2-3. Estimated Costs to Duplicate Installation -- Gump Glass Building

<u>ITEM</u>	<u>COST SOURCE</u>	<u>AMOUNT</u>
Collectors -- 1600 ft ² @ \$12.50/ft ²	Solaron	\$20,000
Collector Delivery	Estimate	200
Collector Penthouses -- 8 @ \$500 each	Estimate	4,000
Collector Mounting -- 1600 ft ² @ \$2.00/ft ²	Solaron	3,200
Rock Storage -- 1024 ft ³ @ \$3/ft ³	Solaron	3,072
Curbs on Roof	Previous Contract	1,600
Mechanical Contractor	Previous Contract	25,736
Fans, Controls, Dampers	Estimate	<u>4,000</u>
TOTAL		\$61,808

Comparing the above total to the actual installed system cost incurred, it can be seen that a savings of about 13% may be possible in future installations.

3. UNITED SOUTHWEST NATIONAL BANK OF SANTA FE
SANTA FE, NEW MEXICO

BACKGROUND

During the planning stages of the building, the mechanical engineer was asked to consider using solar energy in the building design and a solar consultant was hired. The building and solar systems were first put out to bids with a floor area of 10,000 square feet. The planned floor area subsequently was reduced to 7600 square feet and the contract was renegotiated with the low bidder to get it under budget. The one-story bank, completed in Spring 1976, is of adobe-type construction, as shown in Figure 3-1. The 49 flat-plate solar collectors face south on the 8° sloped roof. The collectors are tilted at 55° to the horizontal and mounted in five banks. See Figure 3-2 for support and mounting angle detail. The solar system is now operational although final flashing has not yet been finished because minor system trouble-shooting and leak tests are still underway.

This installation was the first solar experience for the architect, the mechanical engineer, the mechanical contractor and the general contractor. The solar consultant had had previous experience with smaller installations.

PERSONS INVOLVED IN PROJECT

Owner:	Jose Gonzales, President United Southwest National Bank of Santa Fe St. Francis Dr. and San Mateo Rd. Santa Fe, New Mexico 87501
Architect:	Bernabe Romero, AIA 322 Paseo De Perelta P.O. Box 5072 Santa Fe, New Mexico 87501
	Telephone: (505) 982-2123

FIGURE 3-1. View looking east-northeast at the United Southwest National Bank of Santa Fe.

FIGURE 3-2. Sketch of solar collector support and mounting detail. (Basic sketch provided by Benabe Romero, AIA.)

Mechanical Engineer:

Charles R. Wherritt, P.E.
Wherritt Engineering Co.
Suite 128 Marcy Building
Santa Fe, New Mexico 87501
Telephone: (505) 982-9718

Solar Consultant:

Herman Barkmann
107 Cienega Street
Santa Fe, New Mexico 87501
Telephone: (505) 982-8907

General Contractor:

W. W. Lamoreaux
P.O. Box 4848
Santa Fe, New Mexico 87501
Telephone: (505) 982-7945

Mechanical Contractor:

Frank Mares
Frank's Plumbing & Heating
1000 Santa Clara Drive
Santa Fe, New Mexico 87501
Telephone: (505) 471-4555

SOLAR SYSTEM DESIGN

The flat plate collector system is pressurized and transfers collected heat to the open storage tank through a Bell & Gossett shell and tube heat exchanger (Figure 3-3). Ethylene glycol is used in the collection loop for freeze protection. The solar heating system is backed-up by a natural gas boiler (Figure 3-4) located adjacent to the solar storage tank and piped in series with the space heat circulator. Nine hundred square feet of collectors provide heat to approximately 9500 gallons of water in the storage tank. As the fluid passages in the collectors consist of steel pipe, steel pipe was used throughout the system.

SOLAR COLLECTOR SUBSYSTEM

The 900 square foot array of 49 Miromit Model #100 collectors is arranged in five rows on the roof. The Miromit collector employs a selective coated steel absorber plate covered with a single glazing of water white crystal glass.

FIGURE 3-3. View showing tube-in-shell heat exchanger mounted on side of storage tank. Tank is finished with sheetrock.

FIGURE 3-4. View of auxiliary boiler next to storage tank on right. Crowded conditions prevented more than two men from working at any one time. Note covered interior insulation.

The portion of the roof itself containing the collectors was sloped at an 8° angle in order to decrease the required spacing between the collector rows and thereby increase the number of collectors that could be installed. The parapets were raised and large beams across the tops of the collectors were added for aesthetic purposes. The beams shown in Figure 3-5 form part of the collector support system and fit the Spanish styling of the building. The roof structure was strengthened to handle the added collector weight. The architect estimated that the architectural modifications to the originally planned flat-roof design added \$10,000 to the cost of the building which is not included in the normally quoted "solar cost."

The solar collectors are mounted in five banks. The banks have 8, 14, 14, 8 and 5 collectors respectively, starting from the rear of the building and moving to the front.

The mechanical contractor installed the collectors and glazed the collectors on-site. The manufacturer always ships them unglazed, to preclude damage in shipment. No difficulty was encountered while the glass was being installed. See Figures 3-6 and 3-7 for a close-up view of the batten strips and two-piece glazing.

A 40% ethylene glycol solution will be used as the heat transfer fluid to prevent freezing.

The collectors incorporate internal manifolding as shown in Figures 3-6, 3-7, and 3-8 with as many as eight collectors combined in a single group. The manifolds are joined with Dresser couplings (see Figure 3-8). For a time, the plumbing was the only thing holding the collectors down. Some temporary clamps have been added to the end collectors in each group and two by four inch wooden studs placed between the collectors because the couplings began to spread apart when the system was pressurized. Sheet metal finishing caps will be lag bolted to the wooden support structure between individual collectors to secure them after testing is complete.

FIGURE 3-5: Wood framing supports for the collectors showing the vertical support penetrating through the pitch pocket, and the main horizontal beam resting on the raised parapet. Note the piping support hanger.

FIGURE 3-6. View of Dresser coupling between internal manifolds of collectors. Note two by four inch wooden studs placed between collectors to keep them from spreading apart.

FIGURE 3-7. View showing glazing battens. Each collector was glazed in two sections by plumber. Absorber surface is selective. Note lag bolts between collectors that will be used to secure cap strip.

FIGURE 3-8. View of insulated piping covered with roofing paper. Note triangular collector support resting on roof. Also, note metal bracket at end near gauge. A painted metal capping has been placed between the collectors to demonstrate final appearance.

Installation

The total solar collector and piping installation took six weeks for the two to three man crew to complete. The crew consisted of one plumber and one to two helpers. The collectors were shipped by truck from Los Angeles in 18 to 24 days from date of order.

Collectors were hand-carried up a ladder to the roof of the building since it was only one story and nearly flat-roofed. No difficulty was encountered.

An insulation contractor and a control contractor were employed by the mechanical contractor to complete the job.

The wooden support frame was secured to the roof by posts which penetrated the roof through pitch pockets. Other beams which run across the top of each collector bank were mounted on the support posts and the raised parapet structure. Other frame members are tied to these and rest on the roof. Refer to Figures 3-5 and 3-8.

Piping is insulated with covered 1/2 inch fiberglass insulation inside the building. Exterior piping connections are insulated with 1 inch double wall fiberglass covered with roofing paper. Pipes are supported by hangers from the wooden frames. Roof penetrations are made through pitch pockets.

The roof had to be refinished near the collector angle braces because of the collector installation activity.

SOLAR STORAGE SUBSYSTEM

The four-sided concrete support under the bank vault forms the sides of the water storage tank for the solar heating system. The tank is located in the basement and has a capacity of approximately 10,000 gallons. The interior of the tank was sealed with epoxy grout after leakage problems occurred. The tank had to be reinsulated in part after leakage damaged some of the original 1-1/2 inch urethane insulation. Two inches of foam glass insulation are used on the tank roof. Tank walls are poured concrete 12 inches thick. The tank is open to the atmosphere

and heat from the collectors is transferred through a heat exchanger to the tank water. The tank water is then used in reheat coils in the building's air distribution system to provide heat to the building. The reheat coils were sized to use 110°F water. There are five heating zones in the building and the solar heated water can be used in the summer to reheat cooled air to provide temperature control.

An access door is located above the water line for inspection of the interior of the tank. See Figure 3-9. The ceiling of the tank is coated with a clear film to prevent water damage. Two sides of the tank face the mechanical equipment room, one faces a hallway, and one forms a portion of an exterior wall. The interior walls are finished with painted sheetrock. Details of the piping penetrations through the side of the tank are shown in Figure 3-10.

SOLAR SYSTEM COSTS

Table 3-1 shows the total contract cost as provided to the architect by the general contractor. The mechanical contractor's cost was \$28,817.00. The available information on the breakdown of the mechanical contractor's portion of the costs appears in Table 3-2, below.

TABLE 3-2. Mechanical Contractor Cost Breakdown--
United Southwest Bank

Solar Collectors	\$ 8,600
Collector freight from L.A. (truck)	500
Insulation Subcontractor	3,400
Solar Controls Subcontractor	400
Labor (estimated 6 weeks, 2-1/2 men @ about \$23/hour)	5,520
Other (materials, fee, etc.)	<u>10,397</u>
TOTAL	\$28,817

FIGURE 3-9. View of interior of heat storage tank located under bank vault. Picture was taken through access door. Note light grout about one foot above water level and condensation dripping from waterproof film on ceiling.

FIGURE 3-10. Storage tank piping sleeve detail. (Sketch provided by Bernabe Romero, AIA.)

TABLE 3-1. General Contractor's Estimate -- United Southwest Bank

	<u>Materials</u>	<u>Labor</u>	<u>Heavy Equip.</u>	<u>Subcontracts</u>
Heat Tank Penetrations (finished)	60.00	60.00		
Saw Teeth and Roof Framing (finished) (masonry & wood)	400.00	1,610.00	50.00	
Framing & Erection on Roof	1,800.00	2,300.00	100.00	
Painting Inside Heat Tank				621.00
Painting & Wood Treatment Roof				350.00
Mechanical - Frank's Plumbing				28,817.00
Electrical - Hughes Electric				350.00
Roofing & Roofing Sheet Metal Pitch Pans in Place				400.00
Insulate & Sheet Rock Three Sides Tank				750.00
Insulate NE Side Heat Tank (finished)				160.00
	<u>2,260.00</u>	<u>3,970.00</u>	<u>150.00</u>	<u>31,448.00</u>

SUMMARY

Materials	\$ 2,260.00
Labor	3,970.00
Equipment (job site)	150.00
Subcontracts	<u>31,448.00</u>
SUBTOTAL	\$37,828.00
Contractor's Overhead 7%	2,648.00
Contractor's Fee 5%	2,024.00
Bond 1% of Subtotal	425.00
New Mexico State, City and County Tax 4-1/4%	<u>1,824.00</u>
TOTAL	\$44,749.00

DISCUSSION

The architect expected that the solar system would add some maintenance problems to the building because of increased traffic on the roof, beams that require painting and parapet surfaces that will require some care. However, he does not expect these to be major maintenance items.

The solar consultant is considering relocating the collector temperature sensor from the outlet pipe very near the collector to the back of the collector panel. There seems to be a long lag time between available sunshine and startup of the system in the morning.

The mechanical contractor estimated that he could have reduced costs by completing the work in 5 weeks with two men instead of 6 weeks with 2 or three men if the construction on the building had not proceeded so far before the solar heating system was installed. He had to run pipes in the narrow spaces between ceiling and the roof because the ceilings had already been installed. The building was essentially complete when he started putting in the solar system. His estimated 40 hour savings for three men would be equivalent to about \$1200.

It is interesting to note on the contractor's price sheet, Table 3-1, that the miscellaneous add-ons such as contractor overhead, fees, bond and tax amount to \$6,921.06 above the materials and labor cost. This amounts to 19.5% of the total cost or \$7.69 per square foot of collector, nearly as much as the collectors themselves.

4. WINDMILL CAMPGROUNDS LAUNDRY FLAGSTAFF, ARIZONA

BACKGROUND

Windmill Campgrounds is a new facility located in a popular mountain vacation area on Route 17, the main highway between Phoenix and Flagstaff. It began operating this year. The owner is an acquaintance of Bill Matlock of Sunpower Systems in Phoenix who suggested that they use solar energy to supply the campground's energy needs. At first, it was intended to use solar energy to heat the main campground building (see Figure 4-1) which houses a small store, camp office and 8 showers on the first floor and an apartment on the second floor. However, building construction was nearly completed when it was decided to install a solar energy system, so it was decided to provide a solar heating system to serve the laundry facility's domestic hot water needs instead. The laundry facilities are housed in a separate building shown in Figure 4-2. Bottled propane at about 40¢ per gallon and electricity are virtually the only other alternatives to solar energy in this area.

Eight showers, twelve washing machines and domestic hot water needs for the apartment are served by 430 square feet of focusing, tracking solar collectors. Underground, insulated pipe connects the facilities. The owner does not have a good estimate of hot water usage, but the income from the washing machines indicates approximately 100 loads of laundry are done per day; a total of 5,000 gallons of water per day are used in the camp. His best estimate of hot water usage is 2,500 gallons of 140°F water per day. The propane bill for June was \$25 which indicates he obtained approximately 90% of his domestic hot water heating energy requirements from solar energy.

The solar equipment supplier, Bill Matlock, installed the system for what both he and the owner consider a low price, but the supplier was anxious to obtain another installation of his system.

FIGURE 4-1. View of the main building of the campground housing a small store and shower facilities downstairs and an apartment upstairs.

FIGURE 4-2. View showing the solar collector array located to the left of the laundromat. The array is supported on nine metal posts set in concrete and secured to the building by two metal braces to provide lateral stability.

PERSONS INVOLVED IN PROJECT

Owner:

Bernard Swier
Windmill Campgrounds
P.O. Box 307
Munds Park, Arizona 86017

Telephone: (602) 286-9171

Collector Manufacturer,
Solar System Engineer,
Installer:

Bill Matlock
Sunpower Systems Corporation
2123 S. Priest, No. 216
Tempe, Arizona 85252

Telephone: (602) 968-6387

SOLAR SYSTEM DESIGN

The solar collectors transfer their heat using an outside-mounted inline circulator (see Figure 4-3) to the 2500 gallon buried steel tank through a 100 foot coil of 3/4 inch copper tubing inside the tank. The collectors and coil are at present filled with pure ethylene glycol (nine gallons). The laundry obtains its cold water from a pressurized tank about 200 feet away supplied by a well. The water is piped underground to the solar storage tank to provide makeup water. The underground tank (from which hot water is pumped to a conventional storage tank) is maintained at atmospheric pressure. A gas boiler provides back-up heating of the water to maintain 140°F output temperature.

The collectors are mounted on a horizontal steel frame about 9 feet above the ground adjacent to the laundry. The storage tank is located in the rear of the laundry with buried, insulated pipe distributing the hot water to the main building for use in showers and bathroom.

SOLAR COLLECTOR SUBSYSTEM

The 430 square feet of focusing collectors are formed from aluminum parabolic troughs with stationary absorber tubes above the reflectors. The absorber tubes are piped in series. See

FIGURE 4-3. Collector system pump and insulated piping attached to one of the array supports. The bare copper tube acts as an expansion chamber.

Figure 4-6 . The troughs track the sun using an electronic device that incorporates a high temperature defocusing capability and a temperature comparator. See Figures 4-4 and 4-5. The focal axes of the troughs lie north-south and the tracking motor turns the ganged collectors from east to west. The azimuth control activates the tracking motor which turns a screw drive to track the sun within an accuracy of 10 minutes. The motor adjusts collector position about every two minutes of the day in order to follow the sun. At sunset (or during any period of prolonged overcast) the troughs are returned to the early morning position. The swing from night position to morning position takes a half hour due to the gear motor output speed.

The array consists of 24 troughs ganged to a single motor. Each trough is two feet wide and focuses sunlight upon a single black copper tube with a selective surface. All absorber tubes are connected in series. See Figure 4-6. The connections between collector absorber tubes are fixed so that the entire absorber tube system moves in unison. Flexible, high pressure rubber tubing is only required to connect the inlet and outlet of the absorber tube system to the supply and return piping. See Figure 4-7.

Aluminum supports hold each absorber pipe in place above the reflectors. The absorber pipe is loosely held so the support can rotate slightly under it as the collector tracks the sun. The reflectors are made of an aluminum alloy, polished, and coated in a proprietary process by either Reynolds or Alcoa.

The entire system, except the storage tank, was furnished and installed by Sunpower Systems of Phoenix.

The metal frame for the collector system was manufactured in the shop and assembled on site. The troughs were crated and shipped separately from the frame. The frame is supported nine feet above the ground by metal posts anchored in concrete footings. The entire system has been secured to the laundromat wall to provide greater stability.

Dirt on the reflectors has not been a problem in this region because of sufficient cleansing rain. Similar installations in Phoenix have required occasional hosing down to wash off the dust.

FIGURE 4-4. View looking south at the tracking device. Note the motor-driven screw mechanism and electronic control box.

FIGURE 4-5. Another view of the tracking device and the focusing collectors. Note the manner in which the screw-drive is linked to the collector absorber tubes with U-bolts.

FIGURE 4-6. Aluminum foil had to be placed on the insulation around the pipes between the troughs because it burned in the reflected sunlight.

FIGURE 4-7. A closeup view of the reflector and flexible tubing clamped between the outlet of the absorber tubing system and return piping. Also note position of the collector temperature sensor.

One pipe did break in June when an unexpected freeze occurred before the system was filled with glycol. There has been no trouble with leaks since then. The collector system is filled by pumping the fluid with a small portable pump from a drum until it flows out of a short standpipe. The standpipe is then capped. The system has a 125 psi pressure relief valve.

During the installation process, considerable rain occurred, making the ground very muddy. This and the two-hour drive to the shop for forgotten items presented the major problems. Estimated installation time for the collector system was 125 man-hours with a crew of three and sometimes four. It was one of the first installations for the non-union crew.

The supplier said that he would quote a price of \$1.50 per square foot of collector to install another system.

SOLAR STORAGE SUBSYSTEM

The storage tank was provided by the owner. It is a 2500 gallon galvanized steel tank buried two feet below ground. The interior of the tank is uncoated. It is insulated with 6 inches of sprayed-on polyurethane foam. The tank is located behind the laundromat about twenty-five feet from the collector array. The underground piping to the array and elsewhere is also insulated with sprayed-on insulation. No waterproofing of the insulation was done.

The tank was not filled immediately upon burial and was found floating out of the ground the next day because of the high water table. It was reburied and filled immediately.

The tank has a man-hole through which the heat exchanger coil was installed.

The owner paid \$50 to have a backhoe dig the hole for the tank and backfilled it himself. The pipes into the tank are installed through the top through oversized holes. No fittings were used. The urethane was used to seal the holes around the pipe.

The collectors automatically defocus if the storage tank temperature reaches 200°F.

SOLAR SYSTEM COSTS

The costs which appear on Table 4-1 are the actual costs incurred by the owner to complete the project. Also refer to the DISCUSSION section which follows for additional comments concerning costs.

TABLE 4-1. Solar System Cost Breakdown - -
Windmill Campgrounds Laundry

Sunpower Systems Provided	\$3,600
Collectors supplied (430 ft ²)	
Collectors installed	
Collectors piped	
Tracking system installed	
Plumbing to storage tank	
Owner Provided	
Storage tank	850
Insulation (includes some conventional piping)	800
Excavation	50
TOTAL	\$5,250

As alluded to previously, Sunpower Systems provided the system as inexpensively as possible. If the system installation were to be duplicated elsewhere, the supplier indicated the projected costs would be somewhat higher. These costs appear in Table 4-2.

TABLE 4-2. Projected Cost for Duplicating
Solar Installation - - Windmill
Campgrounds Laundry.

Collectors (430 ft ² @ \$10/ft ²) (includes all materials)	\$4,300
Collector Installation (430 ft ² @ \$1.50/ft ²)	645
Storage Tank (as before, plus backfilling)	1,750
TOTAL	\$6,695

DISCUSSION

The collector system pump had to be changed after limited operation because the flow was too low, causing the collector output temperature to exceed 240°F. The new pump (Teel 1P761) with a higher flow rate has reduced normal output temperatures to 160-180°F.

The system has a three-year warranty on materials and one year on labor.

The collectors weigh only 1-1/2 pounds per square foot of frame area. The collector manufacturer also has a four foot wide collector available with higher temperature capability but lower efficiencies.

Bill Matlock of Sunpower Systems admits that the price he charged for the collector system at Windmill Campgrounds was low, and he said he now charges \$10 per square foot for all the materials except the storage tank. He said a storage tank would normally cost 33¢ per gallon installed and another 30¢ per gallon to insulate. He said a pressurized tank would be an extra 50¢ per gallon. He likes to use a storage volume of 1-1/2 gallons per square foot of collector, though a much larger tank was used in the subject installation. This means that he would expect the storage system to cost \$1.74 per square foot of collector for a pressurized tank and \$0.99 per square foot for an unpressurized tank. Again using his figure of \$1.50 per square foot for installation of the collector system, complete installation would cost:

Collectors and materials	\$10.00
Installation	1.50
Pressurized storage tank, installed	<u>1.74</u>
TOTAL	13.24 per square foot of collector

The practice of employing ethylene glycol in the collector loop would not be acceptable in many jurisdictions because of the toxic nature of the chemical. A leak in the copper heat exchanger would contaminate the entire domestic

hot water supply -- hot water that could potentially be used for cooking. From the description of the piping penetrations of the tank, it appears ground water could conceivably enter and contaminate the tank contents. Welded bulkhead fittings on the tank would alleviate this potential problem. Also, pure glycol doesn't perform as well as water as a heat transfer medium. Thus there are penalties both of cost and performance. A 50% water/glycol mix would provide better performance and all the freeze protection required in the climate.

5. TRINITY UNIVERSITY
SAN ANTONIO, TEXAS

BACKGROUND

In the past, the University had investigated using solar energy to heat and cool a planned new library. Bridgers and Paxton were commissioned to perform a feasibility study but their conclusion was that it would not be a cost-effective installation. When ERDA announced its PON program, the consulting firm was again hired, but this time they studied the feasibility of using the solar energy in the University's central power plant. This plant supplies heating, cooling and domestic hot water to a portion of the physical education building-- the basketball arena-- and 6 dormitories. The total floor area of the dormitory buildings to be served is 153,712 square feet and the basketball arena is 131,216 square feet. The central plant is attached to the Sams Memorial Center which is an athletic/physical education/gymnasium facility.

A retrofit solar heating system was designed, bids were let and the results of the bidding were sent to ERDA for review. Trinity University subsequently received funding for their proposed solar system under the PON program. Contracts for the construction were then awarded and the system is now under construction with completion expected in January, 1977.

The system utilizes 16,800 square feet of linear concentrating collectors manufactured by Northrup. These collectors track the sun in order to focus the direct rays of sunlight through a plastic Fresnel lens onto an absorber at the base of the collector assembly.

Mr. Jud Abernathy is the Director of the Physical Plant and has been studying solar energy for about three years. It was his initiative and enthusiasm that resulted in this project. His main goal is to reduce the effect of the tremendous fuel cost increases the University faces for gas and electricity.

CONTACTS

Owner: Jud Abernathy
Director of the Physical Plant
Trinity University
715 Stadium Drive
San Antonio, Texas 78284

(512) 736-8411

Mechanical Contractor: Howard E. Decker
Jud Plumbing, Heating and
Air Conditioning, Inc.
1421 N. Colorado Street
San Antonio, Texas 78207

(512) 735-5239

Engineer: Bridgers and Paxton Consulting
Engineers, Inc.
213 Truman Street
Albuquerque, New Mexico 87108

(505) 265-8577

Collector Supplier: Northrup, Incorporated
302 Nichols Drive
Hutchins, Texas 75141

SOLAR SYSTEM DESIGN

The solar collectors are located on the flat roofs of the two buildings adjacent to the Central Plant that compose the Sams Memorial Center. It is expected that 85% of the heating and domestic hot water energy needs of the dormitories and the basketball arena and approximately 30% of the cooling energy requirements will be met with solar energy.

Cooling will be accomplished by using solar heated water in an existing gas-fired absorption chiller. The absorption unit will be backed up with a new centrifugal chiller connected in series. Auxiliary heating will be accomplished using the existing gas-fired boilers.

On the roof, Northrup concentrating collectors will be tilted toward the south at a 30° angle and will track the sun from east to west.

Freeze protection will rely on circulating water through the collectors when the outside temperature decreases to 32° F. This method was chosen because San Antonio has a relatively mild climate and the total amount of radiative surface to be heated with the fluid is small because of the absorber plate configuration of the Northrup collector.

The solar heated water is stored in two buried steel storage tanks. Solar heated water is circulated through large heat exchangers, one each for space cooling, space heating and domestic hot water heating, to interface with the conventional heating and cooling system equipment.

SOLAR COLLECTOR SUBSYSTEM

The collector array will utilize 1600 Northrup solar collectors. This collector is a linear concentrator employing a curved Fresnel-type lens made of extruded acrylic to focus direct solar radiation on a small copper absorber tube. The absorber is coated with a selective black surface. The collector is mounted on a tracking mechanism consisting of a motor attached to a cable and pulley system which causes it to follow the path of the sun from sunrise to sunset. The manufacturer states that up to forty collectors can be operated by a single motor. However, on this project each motor will control only 16 collectors. The motor controller employs two silicon cells set at a 90 degree angle to one another on the same base facing the sun. When one cell receives more radiation than the other, an electrical circuit becomes unbalanced and signals the motor to operate until equilibrium is restored.

The absorber tube, lens, and fiberglass insulation are housed in a galvanized steel trough.

Installation

The mechanical contractor is expecting collectors to be delivered to the site at the rate of 200 per week once the support structure is ready. The contractor expects to install them at the same rate for eight weeks. The collectors will be trucked in from Hutchins, Texas which is outside of Dallas. A motorized

conveyor system will be used to transport the collectors up to the high flat roof of the Center. A roller conveyor may be used on the roof to distribute them to different installation points. The mechanical contractor will make the judgement as to the roller conveyor's necessity when the installation commences. His cost estimate for the labor involved in setting each collector on its framework on the roof is \$0.85.

Most of the collectors will be mounted in groups of 16 on angle iron frames. There will be 39 groups on one roof area, and 58 groups, plus 6 groups of 8 collectors, on a second roof area. The angle iron frames for the collectors will be bolted to wooden 4 x 4 runners bolted through the roof. Three different types of roof structure were encountered: (1) concrete rib and pan, (2) concrete single tee, and (3) wooden frame.

The welded angle iron frame will support the collectors at 30° from the horizontal. Fortunately, one wall faces south so collector groups will be mounted parallel to that wall.

Each collector is ten feet long with an effective collecting area of 9.7 square feet. Swivel connections, supplied by the manufacturer, will be used at the inlet and outlet of each collector. A flow controller and shut-off valve will be installed at the outlet of each group of 16 and a gate valve will be located at each inlet to allow isolation of a group. Collector absorber tubes and the manifolds on the collector groups will be copper. The manifolding between the groups and main supply and return piping will be steel. Dielectric couplings will be used between the dissimilar metals. All piping will be insulated with fiberglass covered with a metal jacket. The cost for all piping insulation on the project including the conventional system piping is \$100,000.

In plan, the frame for each group of 16 collectors is about 11 feet wide by about 28 feet long. The lower end of the tilted collectors will be about 2 feet above the roof and the higher end will project 7 feet above the roof. Vertical supports for the framework will be spaced at four foot intervals.

A representative of Northrup in the San Antonio area, George Smith, Inc., will install the tracking mechanism.

SOLAR STORAGE SUBSYSTEM

Two steel storage tanks will be buried and insulated with 3 inches of foamed-in-place urethane or calcium silicate. Each tank will contain 20,000 gallons of hot water. The system will not incorporate any chilled water storage. A waterproof coating will be placed over the insulation.

The area has bedrock very close to the surface, so the price of excavation is higher than if it were in soil.

Each tank is 11 feet in diameter and 28 feet long. They will be equipped with access manholes and a manual gauging system. The interior will be coated with Koppers bitumastic coating.

SOLAR SYSTEM COSTS

Although the system is not yet operational, it was chosen for inclusion in this study because solar system costs are very well known since all prices are based on firm contracts. Tables 5-1 and 5-2 present a breakdown of direct solar system costs and related costs, respectively. The majority of the solar installation costs will be funded by ERDA. Related costs listed on Table 5-2 will be paid by Trinity University.

TABLE 5-1. Solar System Contract Costs - Trinity University

George Smith, Inc. - Solar Equipment Supplier

- Supply and Install Collectors, tracking mechanism	\$ 532,000
--	------------

Jud Heating - Mechanical Contractor

- Supply and Install	
o Storage Tanks	71,256
o Pumps	6,778
o Solar Piping	93,400
o Temperature Controls	39,900

Wallace L. Boldt - General Contractor

- Collector Support Structure	139,355
- Solar Electrical	23,445
- System Data Reduction and Control Room	3,500
- Roof Access	6,500

Allowance for Changes	80,000
-----------------------	--------

Personnel	90,900
-----------	--------

Labor Overhead (0.13 x \$90,900)	11,817
----------------------------------	--------

TOTAL	\$1,098,851
-------	-------------

TABLE 5-2. Non-Solar Project Contract Costs - Trinity University

Cooling Tower - Provide	\$ 88,400
-------------------------	-----------

Install	65,799
---------	--------

Chiller (Carrier Co.) - Provide	49,600
---------------------------------	--------

Electrical Work (Non-Solar)	78,120
-----------------------------	--------

Space Cooling Equipment and Piping (except chiller) - Provide and Install	66,303
---	--------

Space Heating and Domestic Hot Water Equipment and Piping - Provide and Install	59,033
---	--------

TOTAL	\$407,255
-------	-----------

DISCUSSION

Bids were received from four collector manufacturers to furnish and install the collectors. One company, Northrup, bid their concentrating collector and the other three proposed flat plate. Before receiving the bids, the engineers and the owner expected that one of the flat plate collectors would be the low bidder.

Table 5-3 shows the results of the bids. The basis for the number of collectors chosen in each case was filling the total available roof area. Preliminary drawings had been made by the engineers for a flat plate installation. All four collectors met the performance specification: Sunworks, for instance, based their bid on providing 25,792 square feet of collectors, compared to the 16,080 square feet to be provided by Northrup. However, the calculated annual outputs per square foot of collector for both heating and cooling modes is 247.8 Btu/day/square foot for the Northrup collector and 127.6 Btu/day/square foot for the flat plate. A yearly savings of \$124,473 in fuel costs has been estimated using the Northrup collectors.

No code or regulatory problems have been encountered while obtaining permits for the project.

Jud Plumbing, Heating and Air Conditioning, Inc. is a union contractor and expects no jurisdictional disputes during the project. He said these "types of problems" are not as severe in the Southwest as they are in the East.

Most of the contractors and major equipment suppliers have indicated some cost-sharing with the Federal Government which appears to be in the range of 2-3% of their cost. This indicates that the costs to duplicate the installation in the future would be somewhat higher than those reported here.

The heat exchangers are expected to be the items with the longest lead time; their arrival is expected in November, 1976.

Neither the mechanical nor general contractor has had previous experience installing solar energy systems.

TABLE 5-3. Comparison of Bids From Four Collector Manufacturers

<u>Bidder*</u>	<u>Costs Installed</u>	<u>Furnished</u>
Northrup	\$ 532,000	\$ 254,598
Flat Plate # 1	583,000	232,878
Flat Plate # 2	645,000	--
Flat Plate # 3	632,100	--

* The three flat plate collector manufacturers are Sunworks, Sunsource and Southwestern Sheetmetal, not necessarily in the same order as listed above.

6. COMMUNITY RECREATION CENTER
SANTA CLARA, CALIFORNIA

BACKGROUND

As the City of Santa Clara operates its own municipal electric, water and sanitary utilities, the City began to investigate applications of solar energy in an effort to reduce utility costs to their customers. It was decided that a demonstration project would provide valuable information through first hand experience of its potential and problems. The Community Recreation Center building, shown in the architectural rendering of Figure 6-1, was selected for the initial solar heating and cooling project. The Center is a 27,000 square foot multi-use facility located in the City's 52 acre Central Park. The adobe-colored walls are constructed of eight inch thick concrete with no additional insulation; the roof is insulated to an R-20 value.

The building contains a large multipurpose room with a stage, areas for preschool and handicapped children, an area for food preparation and several individual meeting rooms. A construction budget of one (1) million dollars (\$37 per square foot) did not include the solar heating and cooling system.

The decision to investigate the installation of a solar energy heating and cooling system was made in the building's planning stage. However, due to urgent community needs and lack of solar system monies, building design was completed and construction begun on the basis of using a conventional heating and cooling system. Major structural features were designed to incorporate a future solar energy system.

During construction, the city worked with architect David C. Thimman and with Lockheed Palo Alto Research Laboratory on the conceptual features of a solar heating and cooling system. At the same time, financial assistance for the solar energy system was sought and a \$404,200 grant was obtained from the National Science Foundation, Office of Public Technology Projects. (Grant responsibility was transferred to U.S. ERDA when that agency was created in January, 1975.)

FIGURE 6-1. Architectural rendering of Santa Clara Community Recreation Center. (Rendering provided by the City of Santa Clara.)

The city, its consultants, and the contractor have now modified the conventional heating and cooling system to incorporate the solar system. The building was occupied in June 1975 and the solar heating and cooling system is expected to become operational in late summer 1976.

PERSONS INVOLVED IN PROJECT

Owner: Robert R. Mortenson
Intergovernmental Assistance Director
The City of Santa Clara
City Hall, 1500 Warburton Avenue
Santa Clara, California 95050
Telephone: (408) 984-3255

Architect: David Thimgan, AIA
3016 Scott Boulevard
Santa Clara, California 95050
Telephone: (408) 248-4070

Solar System Engineer: Dr. L. B. Anderson
Technical Director, Energy Programs
Lockheed Palo Alto Research Laboratory
3251 Hanover Street
Palo Alto, California 94304
Telephone: (415) 493-4411, ext. 45904

Installer: Richard J. Bezerra
Water Maintenance Foreman
The City of Santa Clara, California
1705 Martin Avenue
Santa Clara, California 95050
Telephone: (408) 984-3170

SOLAR SYSTEM DESIGN

Approximately 7000 square feet of flat plate water cooled collectors are mounted on four sections of the roof. Collectors on the three south facing sections (see Figures 6-1 and 6-2) are mounted flush against the roof which is sloped at 18° to the horizontal. Also refer to Figures 6-3 and 6-4. The collectors on the flat roof are also mounted at 18° to the horizontal but are supported on wooden frames as illustrated in Figure 6-5.

FIGURE 6-2. Composite view of the south side of building showing three sloped roof sections. Collectors are in place, covered with white tempera paint to protect them from excessive temperatures due to the no-flow condition associated with construction. The block structure in front of the building is a cooling tower. The storage tanks are located to the left, under the unfinished berm.

FIGURE 6-3. View of top of collectors on one section of sloped roof. Note prefabricated manifolds prior to mounting.

FIGURE 6-4. View showing a portion of the copper manifold pipe set in place at the bottom of one of the sloped roofs though not yet connected to the collector inlet nipples. White paint is obvious on the collector glazing. Note the corrugated roof under the collectors.

A 10% solution of propylene glycol is used in the collectors to provide freeze protection in this relatively mild climate.

In the space heating mode, water heated by the collectors transfers its energy through a heat exchanger to the building's heating loop. In the absence of a heating load, thermal energy is transferred to water stored in a buried and insulated 10,000 gallon steel tank. Heated water provided by the solar collectors is used in the cooling mode to drive two 25 ton ARKLA lithium bromide absorption chillers. The ARKLA units operate alternately so that only one functions at any one time. Chilled water produced by the absorption refrigeration units is stored in a buried and insulated 50,000 gallon steel tank when there is no immediate cooling load. When required, solar heated or cooled water is pumped directly from storage to fan coil units located throughout the building.

Although actual performance information will not be available for some time, the solar system designers predict the following levels of performance:

- 84% of heating energy
- 65% of cooling energy
- 100% of domestic hot water energy
- 80% of total year-round heating and cooling energy requirements.

A natural gas-fired boiler is used as the backup energy source for the solar energy system when stored energy in the tanks is depleted or solar energy is otherwise unavailable. The building has been equipped with an extensive instrumentation/monitoring system provided by ERDA to obtain performance data for the utility. Most of this equipment is housed in its own separate control room located in the lobby of the building.

An unusual feature of the solar system is the use of a pyranometer to control collector pump operation rather than a differential thermostat between collector absorber plate and the storage tank water. Also, a 500 gallon buffer tank located between the collectors and main storage tank is used to warm the collectors in the morning and reduce temperature fluctuations in the main tank.

SOLAR COLLECTOR SUBSYSTEM

Flat plate modules manufactured by Ametek are the primary components of the solar collector subsystem. The Ametek design employs copper roll-bond absorber plates which have been selectively coated in a proprietary process resulting in values of $\alpha = 0.95$ and $\epsilon = 0.3$. The entire collector array employs 432 modules, each with an aperture area of 16.23 square feet. (Four spare units were purchased at the time of the original order.) Total effective collector area is 7011 square feet.

The two largest sloped roof sections contain three rows of 39 collectors each, the smaller sloped roof in the center contains two rows of 13 collectors each, and the flat roof section contains four rows of 44 collectors each. The south side of the building is shown in Figure 6-2.

Installation

Collectors located on the sloped roof areas are mounted directly on the corrugated Corten roofing material. Collectors are butted side-by-side and no cap strip or waterproofing system is employed between them. Collector modules are individually insulated and backed with a sheet metal pan for weather protection. Each module is then connected to a manifold to complete the installation. Figure 6-4 is a closeup of the lower portion of a sloped roof showing the manifold in place ready to be connected to the collector.

The collectors are secured with specially fabricated 12 gauge galvanized steel "Z" section brackets (See Figure 6-5). Fabrication of these special brackets caused a slight delay in collector installation.

System designers would have preferred to use a stock bracket, but it was not discovered until the system was installed that a similar bracket was available from a metal supply house. The bottom of each collector is fitted with a mating bracket which slips under the roof mounted bracket. On the sloped roofs the brackets are bolted directly to the corrugated metal roof deck; on

FIGURE 6-5. View of flat roof section and the two wooden support frames which will each hold two rows of collectors. Note "Z" shaped metal brackets running full length of support frame.

the flat roof, brackets are mounted on the two wooden frame supports (See Figure 6-5). The collector supports for the flat roof are shown in Figure 6-5 prior to collector mounting.

Connections between collectors and manifolds are made with 5/8 inch I.D. Hadbar 80-062 silicone rubber hose reinforced with braided Kevlar. Two spring clamps are used at each joint. Connections are covered, as is all exterior piping, with 1-3/16 inch thick Viking iso-cyanurate rigid foam insulation with fiberglass lining and weatherproof cover. The cover is painted with silicone paint. The insulation is hollowed out between panels for Pete's Plugs which permit temperature and pressure measurements using plug-in type sensors or indicators. This configuration is illustrated in Figure 6-6.

Relief valves, vacuum breakers and expansion compensators are provided on the roof along with hose bibs for filling the collectors .

Plans called for truck delivery of 63 collectors to the site each week and mounting of the 63 collectors in one day. Neither rate was consistently maintained. Collectors were lifted onto the roof with a crane which cost about \$800 per day for rental and operator.

The back of each absorber plate is insulated with inorganic silicate wool which has been processed in a blast furnace to assure that no outgassing will occur during high temperature collector operation.

Due to high collector surface temperatures which occurred subsequent to installation, the glazing was painted with white tempera paint to reflect solar radiation, thereby reducing surface temperatures, see Figure 6-3. This paint will be washed off with water when construction is complete and the system made operational. Santa Clara does not receive much rain during the summer (when construction took place) so water soluble paint could be used for this purpose.

FIGURE 6-6. Sketch showing interconnection between collectors using rubber hoses and Pete's Plug sensor well for temperature and pressure measurements. Hose clamps not shown.

SOLAR STORAGE SUBSYSTEM

The cylindrical hot water storage tank is 34 feet long, 8 feet in diameter and contains 10,000 gallons of water. It is made of steel and is insulated with 3-1/2 inches of urethane foam insulation. Half of the tank is buried in a pit lined with a 10 mil Visqueen liner and filled with 3/8 inch pea gravel. The top half of the tank is covered by a berm backfilled from excavation spoil. This is illustrated in Figures 6-7 and 6-8.

The chilled water storage tank is much larger, being 58 feet long and 12 feet in diameter. This tank is also made of steel, but it is insulated with only two inches of urethane foam insulation. Section views of these tanks are shown in Figure 6-8. The cold water storage tank is buried adjacent to the hot water storage tank. Pump pits are located near the storage tanks. It is now recognized that some savings could have accrued by locating the storage tanks (now about 100 feet from the building) closer to the building and placing the pumps in the mechanical equipment room.

Transporting the large storage tank proved to be a great problem because it was too high, when placed on a flatbed truck, to fit under many bridges and too long to make many turns. A special, complex route between the point of fabrication and the job site had to be plotted. In one case, the trailer had to back up an access ramp onto a highway in order to make the turn. The engineers on the project have said that in future projects, they would recommend use of smaller multiple storage tanks to eliminate this problem.

Lockheed has developed a proprietary system of inflow/outflow connections in the storage tanks to minimize mixing and assure thermal stratification.

The hot storage tank is equipped with a tall venting structure which protrudes above the ground to vent possible steam releases away from passersby.

FIGURE 6-7. Cross-sectional sketch of storage tank configuration.
(Basic Sketch provided by City of Santa Clara.)

III-75

FIGURE 6-8. Sketch of longitudinal section of hot water storage tank configuration. The chilled water storage tank is very similar. (Basic sketch provided by the City of Santa Clara.)

SOLAR SYSTEM COSTS

Total estimated expenditures for the solar energy project are itemized in Table 6-1. This table includes the original estimate as well as the revised costs as of March 1976.

TABLE 6-1. Project Cost Breakdown -- Santa Clara Community Recreation Center

<u>Item</u>	<u>Original Estimate</u>	<u>Revised 3/76</u>
Salaries & Wages:		
Senior Staff	\$ 20,000	\$ 24,000
Professional Staff	27,000	27,000
Clerical	7,500	10,000
Subtotal	\$ 54,500	\$ 61,000
Advertising and Community Promotion		
	\$ 2,000	\$ 7,000
Office Supplies & Postage		
	\$ 2,000	\$ 2,000
Printing, Binding and Books		
	\$ 8,000	\$ 8,000
Conference, Travel		
	\$ 8,000	\$ 8,000
Fringe Benefits		
	\$ 21,400	\$ 18,300
Contract Services:		
Architect	\$ 20,000	\$ 56,000
Univ. of Santa Clara	37,400	22,500
Lockheed Research Lab.	155,000	145,000
Oversight Committee	15,450	15,450
Utility Consultants	15,500	15,500
Legal Consultants	8,000	8,000
Science Advisor	34,000	40,000
Subtotal	\$275,350	\$302,450
Improvements:		
Solar Collectors	\$ 80,600	\$121,000
Piping	42,000	204,380
Storage Tanks	33,000	58,000
Absorption Chillers	26,310	25,000
Controls	32,000	37,600
Instrumentation	32,940	28,374
Miscellaneous	-0-	33,380
Subtotal	\$246,850	\$507,734
TOTAL	\$618,100	\$914,484

It should be noted that the costs listed on Table 6-1 cover more than the design and installation of a solar heating and cooling system. Primary attention should be directed to the section entitled "Improvements" which includes the installed costs for the solar system hardware. A cursory examination of these costs reveals the actual costs were more than double those originally estimated, with the largest increase being for piping -- more than 480% of the estimate.

Total installed system cost escalated from \$38 to \$78 per square foot of flat plate collector.

DISCUSSION

One member of the City government offered the opinion that it may be found that the system is too complicated from the standpoint of design, operation and maintenance. Another opinion was that too many trades were involved in the construction of the system. An analogy was made between the solar energy system and a large refrigeration unit which would be bought as components and fabricated on site by union tradesmen. It was a common statement that something must be done to simplify installation procedures and reduce installation costs.

An electricians' strike, unrelated to the solar system installation, delayed construction of the building which affected the schedule for construction of the solar system. In another instance, a certain trade union offered to do a portion of the collector installation for "free" to gain experience in solar energy projects. Upon work completion they concluded that the work had provided the precedent required to claim jurisdiction over that installation area for all additional work on the project for which they would get paid. Several problems also arose as a result of using both municipal utility employees and union labor on the same project. These problems were not significant.

The mechanical equipment room was originally expected to be spacious, but was found to be undersized and crowded when all equipment was installed.

As previously mentioned, the distance to the storage tanks and the pump pits added significantly to the cost. If the plumbing codes had been writted more specifically, CPVC piping could have been used in lieu of copper pipe for cold water transport thus reducing costs substantially.

Some of the large control valves had a long lead time and added to construction delays.

The necessity for applying a temporary reflective coating to the collector glazing (see Figure 6-4) to protect it from overheating is an important consideration. The stagnation temperatures which can occur under no-flow conditions, such as during installation or maintenance, can cause permanent damage to collector components and make physical handling difficult and unsafe.

7. MADEIRA SCHOOL
GREENWAY, VIRGINIA

BACKGROUND

The Madeira Science Building, completed in Autumn 1975, was the culmination of the School's interest in incorporating energy conservation as a prominent feature of the new building's design. The integral solar collector/roof became a major design element of the new building. The trapezoidal-shaped roof, shown in Figure 7-1, slopes 26° from the horizontal and faces approximately 60° east of south. Architecturally, the trapezoidal shape serves to reduce the impact of the collector when compared to that of a large rectangular configuration of the same area. Of the total roof area of 4600 square feet, the collector occupies 4000 square feet. Building orientation was dictated by the already existing gymnasium and swimming pool adjacent to the site and a desire to preserve the natural surroundings to the largest extent possible.

Total building area is 9000 square feet with 6000 square feet on the main level serving as classrooms and laboratories, and the remainder on the lower level housing the mechanical equipment room, print shop and photographic laboratory. All lighting fixtures, piping, ducts and HVAC equipment on the main floor is exposed and color coded to serve as a continuing science lesson.

Although no instrumentation has been incorporated in the solar system installation, system designers originally estimated 60 percent of the building's heat would be provided by the solar system. It was stated that the water storage tank has the thermal capacitance to carry the building through two to three sunless days before auxiliary energy is required. Backup heating energy is provided by a steam boiler located in the adjacent gymnasium. Excess heat produced by the solar system during the Spring and Autumn, when the space heat demand is low, can be used to provide hot water for the showers in the gymnasium and to heat the nearby swimming pool to extend the swimming season.

FIGURE 7-1. View looking northwest showing the Science Building and the prominent trapezoidal shape of the solar collector.

Project funding for the building and solar system came from private sources. The architect reports unsuccessful attempts were made to solicit Government interest and assistance. Madeira is a private girls' school located only 12 miles from downtown Washington, D. C.

PERSONS INVOLVED IN PROJECT

Architect:	K. Abraham Arthur Cotton Moore Associates 1214 28th Street, N.W. Washington, D. C. Telephone: (202) 337-9083
Mechanical and Solar Engineer:	Peter Flack and Norman Kurtz Flack and Kurtz 29 West 38th Street New York, New York 10018 Telephone: (212) 736-3733
General Contractor:	Douglas Cobb, President Commercial Industrial Construction, Inc. P. O. Box 108 Great Falls, Virginia 22066 Telephone: (703) 759-2921
Mechanical Contractor:	Richard Hottle Harvey W. Hottle, Inc. 12231 Parklawn Drive Rockville, Maryland 20852 Telephone: (301) 881-8100
Owner:	W. O. Snead, Business Manager Madeira School Greenway, Virginia Telephone: (703) 893-4200

SOLAR SYSTEM DESIGN

The basic elements of the solar system are illustrated in Figure 7-2. The solar collector subsystem is a closed loop isolated from the thermal energy storage tank by a heat exchanger. Heat transfer is accomplished by circulating oil (Exxon Caloria HT-43) through blackened aluminum absorber plates and back to a tube bundle heat exchanger inserted in the storage tank (see Figures 7-3 and 7-4). The oil serves two purposes: protection from freeze-up and prevention of corrosion of the aluminum collectors.

The space heating load is satisfied by circulating heated water to conventional heating coils located in the heat distribution and makeup air duct work. In the absence of adequate thermal energy from storage, a steam to hot water generator in series with the distribution loop provides auxiliary energy for space heating. Steam is provided by an oversized boiler located in the nearby gymnasium. Water is circulated through a second tube bundle (see Figure 7-4) inserted in the storage tank to a separate 200 gallon insulated domestic hot water storage tank. Excess solar energy heats the outdoor swimming pool located to the southeast. A water to water converter is used to heat the pool water.

All piping in the system is steel, except for the collector subheaders which are aluminum.

SOLAR COLLECTOR SUBSYSTEM

First glance at the large trapezoidal roof plane gives the impression that the entire roof is a solar collector as it is totally sheathed in glass. Closer inspection reveals that the actual area capable of absorbing solar energy is somewhat smaller. Figure 7-5 shows the series/parallel pattern of the absorber plates under the single glass cover.

FIGURE 7-2. Simplified schematic diagram of the solar heating system.

FIGURE 7-3. Overall view of storage tank located on lower level of building.

FIGURE 7-4. Closeup view of heat exchanger inserted in storage tank.

The aluminum absorber plates were manufactured by Olin Brass Company using their patented Roll-Bond process to form integral fluid flow passageways. Nominal size of each absorber plate is 27 inches by 104 inches or 19.5 square feet. The total project employs 200 of these plates. A non-selective coating of flat black paint was applied to their surface to improve absorptivity of solar radiation. A single glazing of conventional double strength window glass was employed to reduce thermal losses. Vandalism of the system was not considered to be a problem.

Installation

Prior to mounting the individual absorber plates on the roof, the entire roof surface was made waterproof with a silicone-based liquid coating which dried to form an impermeable membrane. The underside of the roof is insulated to reduce heat loss. Rabbitted wooden four by four inch batten supports were attached on 30 inch centers running up the roof. The absorber plates were then laid in place between the wood strips, resting on the rabbitted sections and affixed with plastic clips. The collectors are fastened only at the bottom to accommodate critical thermal expansion. However, some horizontal buckling of absorber panels has occurred because the spacing between the rabbitted sections of the four by four inch strips was too tight.

The collectors are mounted in a series/parallel flow configuration with steel pipe used for the main supply and return headers. Rubber pressure hoses and clamps are used to connect the main headers at about 13 points to heliarc welded aluminum tubing subheaders. These subheaders feed several parallel groups of three collectors connected in series. The subheader to collector connections and the collector to collector connections are made with Air Force type aluminum flare fittings. At each main header to subheader connection a plug valve is used for balancing. (Collector panel temperature measurements were used to make balancing corrections.) All steel piping is schedule 40 and exterior piping is insulated with two inches of fiberglass covered with an aluminum sheath.

Figures 7-5 and 7-6 illustrate a portion of the piping configuration serving the absorber plates.

The main supply header is suspended under the eave (see Figure 7-7); the main return header is supported above the roof ridge (see Figure 7-8).

After flow was balanced, the valve adjustment handles were removed and single glass covers were placed over the entire roof. The glass sheets, each approximately 30 inches by 48 inches, are held in place with one inch by two inch wooden cap strips screwed to the vertical battens. The glass sheets were set in caulk although the cover was not designed to be totally waterproof. The glass cover plates are laid shingle style, the top one overlapping the lower one to allow water to run off. Any water which gets under the glass will run down the waterproof roof membrane and drain away at the bottom. Leakage has not been a problem.

A fluid circulation rate through the collectors of 72 gallons per minute or approximately one gallon per hour per square foot of gross collector area is maintained by a pump located in the mechanical equipment room.

Delivery of the collectors took 16 to 17 weeks and approximately 30 of the collector panels were destroyed during shipping. Most of the damage was due to fracture of the connection nipples and bending of the panels.

The thickness of the glass used in the covers had to be increased over that originally planned to accept expected snow loads.

SOLAR STORAGE SUBSYSTEM

The thermal energy storage tank, shown in Figure 7-3, has a capacity to hold approximately 10,000 gallons of water. Located in the mechanical equipment room on the lower level, the tank is eight feet in diameter by about 28 feet long. Two immersion type tube bundle heat exchangers are inserted in the same end of the tank. The heat exchanger for transferring thermal energy

FIGURE 7-5. View showing pattern of absorber plates under glass cover. Also note balancing valves and piping arrangement.

FIGURE 7-6. Closeup view of one of the manifolds serving multiple absorber plates. A distribution header feeding the manifold is located under the eave. See Figure 7-7.

FIGURE 7-7. View showing supply header located under the eave.

FIGURE 7-8. View showing return header supported above roof ridge.

to the tank from the solar collector is located near the center of the tank; the heat exchanger for producing domestic hot water is located higher, in the hottest part of the tank. The entire tank is covered with a nominal four inch thick coating of calcium silicate insulation sprayed on in place.

Water in the tank is circulated as needed to the heating coils located in the air distribution duct work and in the outside air makeup units. The distribution system is designed to use water at 130°F although lower temperature water can be used depending on outside air temperature because the heating coils and the air handling unit are somewhat oversized.

Because the tank had to be set in place before the lower level was closed in, a premium price was paid for the tank to be delivered in about 4 weeks. A crane lowered the tank onto its concrete saddles.

SOLAR SYSTEM COST

Table 7-1 presents a cost breakdown of the main components of the Madeira School solar system. The majority of these costs were obtained during conversations with the general and mechanical contractors and are based on their records and recollection. Installation and insulation data associated with the storage tank are estimates determined by using standard cost estimating techniques.

TABLE 7-1. Solar System Cost
Breakdown -- Madeira School

Solar Collector Absorber Panels	\$12,000
Collector Installation, including on-roof piping and glazing	36,000
Storage Material	7,200
Insulation	1,400
Installation	450
Miscellaneous pumps, piping, insulation, controls, heat exchangers, valves	<u>18,800</u>
TOTAL	\$76,000

DISCUSSION

As initially installed, the control system automatically increased the minimum storage tank water set point temperature (temperature below which the auxiliary energy system was activated)

as the outside air temperature decreased. However, the tank water never seemed to get as high as the set point. The control system was then simplified by fixing the set point temperature near 100°F. Performance of the system has apparently improved since that change was made.

The heat exchanger which removes heat from the solar collector circulation loop is positioned in the middle of the storage tank and it was found that thermal stratification prevented the water below the heat exchanger from being heated. The problem of thermal stratification was eliminated by circulating water through an external pipe loop to achieve mixing.

The mechanical contractor stated that oversizing the coils and air handling unit proved to be helpful since during much of the winter 100°F water is sufficiently hot to meet the building's heating demand. The performance of the solar heating system has been better than expected according to the contractor.

Based on the installed cost of the solar collector subsystem, it is apparent that cost savings are possible for collectors which are built in place compared to modular collectors. With built in place collectors, no separate weatherproof casing is required to protect the integrity of the insulation since insulation is under the roof sheathing. The conventional roof insulation doubles as back insulation for the absorber surface. Also, the roof deck becomes the mounting surface eliminating the necessity for a complicated collector mounting system.

No instrumentation has been installed to assess actual system performance.

8. GEORGE A. TOWNS ELEMENTARY SCHOOL
ATLANTA, GEORGIA

BACKGROUND

The integrated solar energy system, which will provide heating and cooling for the George A. Towns Elementary School, has become known as the Atlanta School Project. The origin of this project was with the Phase O - Solar Heating and Cooling of Buildings Studies, commissioned by the National Science Foundation (N.S.F.); Westinghouse Corporation being one of the Phase O contractors. During the course of the Westinghouse work, N.S.F. asked that a solar heating and cooling "experiment" be identified. The Phase O analyses indicated that the Southeast region is an ideal area, since the seasonal heating and cooling degree-days are nearly balanced. Atlanta was thought to typify the region, with average heating and cooling degree-days of 2820 and 2550, respectively. Westinghouse surveys of the construction industry - architects, engineers, contractors - also indicated that a school was a good candidate and N.S.F. subsequently requested that a suitable school building be located.

Working with the Atlanta Public Schools System, the Towns Elementary School was chosen (see Figure 8-1). This school serves 500 students in the 32,000 square foot, single story structure which was built in 1962.

The heating system was readily adaptable to solar augmentation as heat distribution for the natural gas-fired hot water boiler was by a two pipe system feeding unit ventilators. Although not originally cooled, coils in the unit ventilators and piping were sized for chilled water. The addition of a conventional cooling system would have required only a chiller, cooling tower and minor modifications to controls and valves. The major constraint for integrating solar energy use was the limitation of chiller choice to an absorption refrigeration unit.

FIGURE 8-1.

View looking northeast at the front of the Towns Elementary School. Solar collectors are visible on the roof facing south. Access to the storage tanks is through the trap doors at the right center of picture.

The school faces one degree east of south with almost the entire roof capable of supporting solar collectors.

As the Atlanta School Project was "experimental" in nature, the total project was not expected to produce a currently economically competitive system. However, system design did employ off-the-shelf equipment, with installation and equipment contracts being awarded to the lowest bidder in all cases. Westinghouse acted as general contractor for the project, which probably reduced overall installed system costs by approximately five percent.

PERSONS INVOLVED IN PROJECT

Project and Construction Management:

Richard T. Duncan, Jr.
Special Energy Systems
Westinghouse Electric Corporation
Baltimore, Maryland 21203

(301) 765-3393

Architect:

P. Richard Rittlemann, AIA
Burt, Hill & Associates
Butler, Pennsylvania 16001

(412) 285-4761

Mechanical Engineers:

Barry D. Symmonds
Project Manager
Dubin - Mindell - Bloome Associates, P.C.
312 Park Road
West Hartford, Connecticut 06119

(203) 236-1654

Mechanical Contractor:

Walter Cohen, President
Delta Corporation
471 Glen Iris Drive, N.E.
Atlanta, Georgia 30308

(404) 577-4670

Collector Installation Contractor:

Duncan Construction Company
130 W. Wienza Road, N.W.
Atlanta, Georgia 30342

(404) 252-0264

Owner: John Martin
Atlanta Public School System
Atlanta, GA

(404) 659-3381 x241

Solar Collector Supplier: Neil M. Barker, Manager
Solar System Sales
PPG Industries, Inc.
1 Gateway Center
Pittsburgh, PA 15222

(412) 434-3552

SOLAR SYSTEM DESIGN

Figure 8-2 is a simplified, schematic diagram illustrating the major solar system components. Water circulating through 10,000 square feet of PPG Baseline collectors is heated and returns to one of three 15,000 gallon underground storage tanks. During the heating season, hot water is stored in all three tanks. In the summer, tanks #2 and #3 will store hot water and tank #1 will store chilled water.

A variable speed pump is used in the collector loop to attain as high a temperature as is practical for use in the absorption chiller. However, the temperature differential across the collectors is not allowed to exceed 10°F. The entire system is maintained at a working pressure of 25 psig, which allows collection and storage of thermal energy at temperatures above 212°F without boiling the fluid. Bottled nitrogen provides pressurization.

Numerous experimental operating modes are made possible through the installation of more than 20 automatic control valves. Fewer valves would have been required if the system were not meant for experimentation.

Freeze protection is accomplished through a drain down mode activated when the collector return water temperature drops below 40°F. Nitrogen fills the collectors as the

FIGURE 8-2 Simplified schematic diagram of the solar energy system.
(Diagram provided by Westinghouse Electric Corp.)

liquid contents of the collectors and above ground piping are drained into an underground 1600 gallon holding tank. When sufficient incoming solar energy is available, the collectors are filled by pumping water from the holding tank to the roof mounted collector array. Nitrogen is displaced and returns to the holding tank. The fill pump continues pumping until a preset level is achieved in the roof mounted 70 gallon header tank at which point the pump stops. Circulation through the collectors is handled by a second, variable speed pump.

As steel piping is used in conjunction with the aluminum absorber plates, precautions were taken to reduce ion exchange and electrolytic corrosion. A getter column, installed just before the aluminum absorbers, strainers at the inlet of each collector row, and Nutek water treatment chemicals provided by Nuclear Technology, Inc., combine to protect the mixed metal system. The automatic nitrogen purge which occurs when the system is dumped, reduces oxidation of the steel and aluminum components. Regular city water was used for the initial fill and will also be used for make up.

The storage and holding tanks are located outside, approximately 90 feet from the mechanical equipment room. The existence of a natural draw in this area (see Figures 8-1 and 8-3) required minimal excavation prior to tank placement. Piping connecting the tanks with the mechanical room is buried. Control valves serving the tanks are located in vaults near the tanks (see Figures 8-3 and 8-4).

Figure 8-5 shows the recently installed collector fill pump, now located on top of the underground holding tank. Installation of a new control valve was also required. A fill pump was previously located on the rooftop, but the high suction requirement proved unworkable.

FIGURE 8-3. View from roof of school looking at the storage tank burial area. Open trap doors provide access to tank manholes. Concrete vaults to right and left house automatic control valves. Holding tank and fill pump are located at concrete block pit. Note grade drop off at left of picture. The draw previously included the area where the tanks are now buried.

FIGURE 8-4. View looking in concrete vault housing automatic control valves. Note pneumatic actuators and asphaltic coating over roofing paper and fiber-glass insulation.

FIGURE 8-5. View of new collector fill pump, control valve and concrete block pit. The submerged pump is mounted directly in the top of the holding tank.

SOLAR COLLECTOR SUBSYSTEM

The "Baseline" model solar collector manufactured by PPG Industries was specified for the project. The sawtooth collector field consists of 576 panels, each 34 by 76 inches, for a total gross collector area of 10,330 square feet. Two Herculite-K tempered glass plates, each 0.122 inches thick, are separated by a 3/8 inch air-space maintained by a dessicant filled spacer. These materials are the same type and size as used on PPG's sliding glass door module. The absorber plate is 0.060 inch thick aluminum Roll-Bond panel, with integrated flow passages. The absorber plate is also separated from the inner glass by a 3/8 inch dessicant filled spacer. Each layer is sealed with a high temperature sealant and the entire assembly held together with a stainless steel channel, welded at the corners. This arrangement achieves a hermetically sealed assembly which precludes the formation of internal condensation. However, field replacement of broken glass is impossible.

Although a non-selective coating (PPG's DURACRON Super 600 L/G paint) was originally specified for use on the absorber plate, Alcoa's proprietary selective coating ($\alpha = 0.94$, $\epsilon = 0.34$) was employed in the final design to improve performance.

The back of the collector is insulated with 3 inches of 1.5 pound per cubic foot fiberglass with an aluminum foil backing. See Figures 8-6 and 8-7.

An integral portion of the collector array includes reflector panels on the back side of the collector support structure. See Figure 8-8. Calculations performed during the design process indicated that panels with a reflective index of 0.8 would increase insolation reaching the collector by 30%. Final design incorporated aluminized Mylar sheet covered with another protective coating of Mylar to improve

FIGURE 8-6. View of back of solar collector panels showing foil backed collector insulation. Also note polyurethane covered upper header nested in support structure and structure detail.

FIGURE 8-7. View of lower header insulated with fiberglass covered with roofing paper and asphalt coating. Pipe hangers are placed every six feet.

FIGURE 8-8. View looking west between collector rows: Solar collectors are on right and reflectors on left. Note overhead piping connecting upper headers.

FIGURE 8-9. Closeup view of Mylar reflector surface. Adhesive and wooden batten strips were used to hold reflector in place. Note wrinkled surface of reflector.

weathering capabilities, and bonded to 3/8 inch thick tempered hardboard. Resultant reflective index was 0.74.

Some problems were encountered during application of the Mylar sheet which was applied on site. High winds damaged a large portion of the material before it was permanently attached with adhesive and batten strips (see Figure 8-9). Figure 8-9 also illustrates another problem of field application - the wrinkled reflective surface. It is unknown whether any performance penalty will be incurred due to this surface condition, but aesthetics may be a problem in some installations.

Installation

Various collector support systems employing aluminum and steel members were evaluated prior to choosing a wood frame truss configuration made of two by four's. Wood trusses shown in Figure 8-10, could be prefabricated by local tradesmen off site, were easy to work with, had low maintenance requirements and had low initial cost. The trusses are supported by steel beams, running north and south and spanning the 27 by 27 foot building bays. Steel trusses running east and west provide lateral stability. The beams were placed on tubular supports positioned two feet above existing reinforced concrete columns to maintain columnar loading. (The two foot clearance was a school board requirement to allow access for roof repairs.)

Roof insulation and built-up asphalt membrane was removed above each column and the tubular support baseplate was then attached with four self drilling explosive bolts. Flashing was then installed between the roof deck and support and roofing material and insulation were replaced.

The wood trusses were tied to the steel support system using steel strap and cross-braced for stability until the one-

FIGURE 8-10. Isometric sketch of collector support structure and joint and support details. (Basic sketch provided by Westinghouse Electric Corp.)

FIGURE 8-11. Closeup view of collector mounting arrangement. One leg of horizontal aluminum angle is visible along bottom edge of collector. Two inch aluminum channel is used to secure collector along vertical edges.

and 3/8 inch thick tempered hardboard was attached to the north side. Trusses are placed on nominal 3 foot centers so as to fall below each side of the collector and thus provide a member for secure mounting.

A continuous 1½ by 1½ inch aluminum angle runs east and west across the lower end of the trusses to support the weight of the collector. See Figure 8-11. Rubber setting blocks (½ inch thick) are placed every 12 inches along the aluminum angle and the collector laid on glazing tape affixed to the sheathing. After the collectors were set, glazing tape was placed on the top edge and a two inch wide aluminum channel was placed over the joint between the collectors (or between collector and flashing or collector and filler between bays) and secured to the truss with pan head wood screws with neoprene washers. Refer to Figure 8-11.

A four man team was used to install the collectors. The team averaged 22 minutes to mount each collector module to the truss and connect it with flexible hose to the header pipe. Oetiker hose clamps were used to speed the connection. Not included in this figure was the time required to unload collectors from the truck, position collectors on the roof using a crane, uncrate and caulk collectors, and dispose of trash.

* * *

NOTE: Many publications and reports describing the collector mounting system designed for this project refer to the use of a neoprene structural glazing gasket, employing a locking strip. Due to a desire to reduce installation costs, the mounting method previously described was substituted for the neoprene gasket system.

* * *

Collector piping employs a reverse return arrangement with the absorber plates in parallel; thus the system flow is self balancing. Schedule 40 steel pipe is used throughout the system. Victaulic couplings and fittings are used in the system, in lieu of screwed or welded joints.

Two types of piping insulation were employed, sprayed in place polyurethane foam and fiberglass wrapped in roofing felt and covered with an asphaltic coating. These methods are respectively illustrated in Figures 8-6 and 8-7. Polyurethane foam was used on the upper header pipe of all assemblies. The header was nested in the truss, which would have made application of fiberglass insulation very difficult whereas the polyurethane could be sprayed on easily. The foam is well protected from weather and light at the peak of the collector/reflector assembly, and no apparent degradation has occurred. Insulation on the lower supply header and all exposed insulation is fiberglass covered with roofing paper and asphalt. Access to the lower header was somewhat better than to the upper, thus facilitating placement of fiberglass insulation.

All piping and electrical roof penetrations were made at a single location over the mechanical equipment room. The penetration was covered with a sheet metal "doghouse" (see Figure 8-12) for weather protection.

SOLAR STORAGE SUBSYSTEM

The thermal energy storage medium is water contained in three 15,000 gallon pressurized steel tanks. As previously mentioned, all tanks will store hot water in the winter; in the summer only two will store hot water and the other will store excess chilled water produced by the absorption refrigeration unit.

The storage tanks and holding tank are located underground in the area approximately 90 feet from the mechanical room, as shown in Figure 8-3. A natural draw in this area minimized the amount of hillside excavation required.

The tanks are uninsulated, but were covered with an asphaltum paint prior to burial. A tamped gravel drainage bed and drainage tile were placed in the excavation to provide

FIGURE 8-12. View of piping and electrical conduits leading to roof penetration. Actual penetration is covered with sheet metal "Dog House". Boiler stack is at right of picture.

some insulation value and prevent underground pooling of water around the tanks. The gravel (two inches diameter) was compacted in layers to the top of the tanks. A polystyrene foam insulation board (four inches thick) was then placed over the entire tank field and covered with 12 inches of earth fill, mounded over the tanks. Four layers of four mil plastic sheet were spread over the area, to shed surface water, and covered with 18 inches of topsoil. Vertical insulation board was placed between tank #1 and the other tanks which will always contain hot water.

Total installation cost of this storage tank system was \$18,735 for the 45,000 gallons of storage (\$0.42/gallon). The designers originally wanted the storage tanks installed with four coats of epoxy resin, and five inches of rigid fiberglass mat sealed with an asphaltum coating on the exterior. However, a low bid of \$38,948 (\$0.87/gallon) caused a change in plans.

The working pressure of the tanks is 25 psig and although the original plan was to maintain the tanks completely full, the water level has been lowered to provide for more space to accomodate thermal expansion. Water level is controlled by a float valve located in the 1600 gallon holding tank.

The storage tanks are tied to the pumps in the mechanical equipment room by underground steel pipe. Automatic control valves are located in pits near the tanks to perform the various modes of operation.

SOLAR SYSTEM COSTS

Both labor and material costs for the project are well known as it was the prime contractor's task to keep a careful accounting of all expenditures. Total installed system cost was \$443,963. This did not include costs for feasibility studies, design, instrumentation, and data analysis, or costs required for valve and pump replacement, as described in the Discussion section which follows. Solar system and building integration design fees were \$63,959.

A separate breakdown of labor and material costs is presented in Tables 8-1 and 8-2, respectively. Labor costs, listed by category on Table 8-1, also include some incidental materials and equipment rental fees. Westinghouse reports that skilled labor rates averaged \$15.125 per man-hour, including overhead and profit. Unskilled labor rates for earthwork, masonry, painting, carpentry and collector installation averaged \$9.075 per man-hour, including overhead and profit.

TABLE 8-1. Labor Costs For Solar System Installation - -
Towns School

<u>Labor Category</u>	<u>Cost</u>
Mechanical/Electrical	\$125,240
General Construction	52,930
Collector Installation	15,500
Steel Erection	7,290
Control System Design & Assembly	14,540
Total Labor & Incidentals	\$215,500

The Westinghouse project manager, Richard Duncan, performed the collateral duty of supervising subcontractors, thus obviating the need for a general contractor. He indicated the low bid from a general contractor for these duties was \$20,000.

Because this was a retrofit installation, material costs broke down into two major categories; solar system components and non-solar building system interface components. The costs are listed for all major items on Table 8-2.

TABLE 8-2. Material Costs For Solar System and Interface Equipment--Town's School

<u>Item</u>	<u>Quantity/Size</u>	<u>Solar System Costs</u>	<u>Interface Equipment Costs</u>
Piping & Wiring		\$39,505	\$ 5,116
Absorption Chiller	1/1.2mm Btu/hr		17,229
Storage Tanks	3/15,000 gal.	17,940	
Holding Tank	1/1600 gal.	1,517	
Corrosion Inhibitor	660 gal.	6,534	
Solar DHW Heater	1/200 gal.	1,176	
Cooling Tower	1/3.55mm Btu/hr		4,527
Pumps	6 each	6,482	860
Reflective Mylar	10,832 ft ²	5,720	
Collector Framing		15,000	
Earth Fill		900	
Solar Collectors	586	65,927	1,145*
Steel Grid	28 tons		19,645
Control Valves	22 each	6,382	1,418
Control Logic Subsystem		5,940	
Misc. Services & Materials		<u>4,800</u>	<u>700</u>
Subtotals		\$177,823	\$50,640
TOTAL MATERIALS		\$228,463	

* 10 spare collectors were purchased

DISCUSSION

As of mid-Summer 1976, the absorption refrigeration unit had not yet come on stream full-time due to a delay caused by replacement of some flow control valves and relocation of the collector fill pump. Because of the experimental nature of the design and the multimode operation desired, bi-directional flow was required in some pipe runs. Commercial grade "tight closing" poppet-type valves installed where watertight and airtight seals were required proved unacceptable. Leakage occurred when reverse flow partially lifted the poppet off the valve seat. All valves in critical locations were replaced with Norris Seal butterfly valves which provide a bubble tight seal. A side benefit was the improved flow factor through the valve which reduced system pressure drop. The valves also have visual position indicators which would be an aid in system trouble shooting and debugging.

It was also found desirable to relocate the system fill pump from a rooftop position to the top of the holding tank. The high suction head requirement of the roof mounted pump apparently necessitated the change. The fill pump was changed to a submerged type which is now mounted directly to the top of the 1600 gallon holding tank. The new pump, shown in Figure 8-5, required excavation down to the tank top and construction of a concrete block pit. The costs of these modifications do not show up in the system costs previously presented as they are being absorbed by Westinghouse. No further modifications are believed necessary for proper system operation.

Shipping and installation of solar collectors resulted in breakage of five out of 596 modules ordered. Ten of these were spares to allow for just such breakage. Since installation, the inner glass on 12 collectors and the outer glass on two others have failed. Glass failure is apparently due to thermally induced stresses. None of the breakage was due to vandalism. PPG has indicated that they will replace the defective panels with ones employing heat treated glass for the inner glazing and tempered glass for the outer. The original panels employed tempered glass for both covers.

Three of the aluminum absorber plates have failed since start-up. One failure was apparently due to a manufacturing defect, with the others from unknown causes.

Potential For Cost Reduction

As mentioned, the system was designed as an experimental vehicle and not for exact replication. The highly flexible system, particularly in the thermal storage arrangement and multiple mode capability, would not be required in even a prototype system design.

Inspection of the system reveals most of the mechanical equipment is off-the-shelf with little chance for cost reduction. Solar collectors are the only components where the cost may be reduced through mass production; however, even here, the savings potential is limited. According to Westinghouse, the greatest potential for system cost reduction is in refined system design and efficient incorporation of components, with the best opportunity for cost reduction being in new building construction. For example, the thermal energy storage tank should be placed in close proximity to the collector subsystem to eliminate expensive insulated and underground piping. Westinghouse has also stated that the cost of the steel substructure could be reduced by integrating collector supports with the roof. By using only two storage tanks of optimum size, two tanks could be eliminated and a simplified control and valving arrangement could be employed with resultant savings. Table 8-3 was prepared by Westinghouse to summarize possible material and labor savings for a system of similar performance if installed on new construction.

TABLE 8-3. Possible Cost Savings for New Construction of
Similar System -- Towns School

Structural Steel Grid	26,930	
Earth Moving	900	
Storage Tanks and Holding Tank	7,500	
Piping, Pumps and Wiring	35,640	
Piping Insulation	5,000	
Displaced Roofing Materials	15,000	
Controls and Control Valves	<u>10,000</u>	
Total	71,000 =	16% of \$443,963

9. THE BAREFOOT MAILMAN HOTEL
HILLSBORO BEACH, FLORIDA

BACKGROUND

The Barefoot Mailman Hotel, the oldest hotel in Hillsboro Beach, was purchased in May, 1975, by John Martin, President of Lauderdale Biltmore, Inc. Mr. Martin began an extensive renovation program of the 62 room hotel which included consideration of solar energy for heating domestic hot water for guest, restaurant and laundry usage. Mr. Martin was familiar with solar energy usage as his residence in Canada is equipped with a solar water heating system. Apparently, Mr. Martin became aware of the system presently installed through the marketing efforts of High Plumbing, Inc. of Pompano Beach, Florida. In 1975, Bill Staples of High Plumbing put together a "package" solar water heating system utilizing flat plate collectors manufactured by Solar Dynamics, Inc. Advertising literature was subsequently distributed, resulting in installation of several systems, primarily residential applications.

The system at the Barefoot Mailman employs 30 collectors, each nominally three feet by eight feet, giving a total collector area of 720 square feet. Potable water is circulated through the collectors from an insulated underground storage tank. This tank is piped in series with a conventional natural gas-fired water heater which activates automatically in the absence of adequate solar heated make-up water.

The solar system has now been in use for almost a year with no operational difficulties. Hotel personnel believe a major portion of their water heating load is being taken care of by solar energy, however no actual performance data are available.

As of Fall 1976, the hotel's solar system is believed to be the largest commercial installation in Florida.

PERSONS INVOLVED IN PROJECT

Owner: John Martin
c/o The Barefoot Mailman Hotel
1061 Hillsboro Mile (A1A)
Hillsboro, Florida 33062

(305) 941-0100

Mechanical Contractor/
System Designer:

Bill Staples
High Plumbing, Inc.
4011 N. Dixie Highway
Pompano Beach, Florida

(305) 943-1400

Solar Collector
Supplier:

Edwin Chester, President
Solar Dynamics, Inc.
4527 E. 11th Avenue
Hialeah, Florida 33013

(305) 688-4393

SOLAR SYSTEM DESIGN

Because the solar system is used only for domestic hot water preheat and is fortunate enough to be located in a subtropical zone (no freeze protection is required), design is greatly simplified. A schematic diagram of the piping arrangement is shown in Figure 9-1.

The oceanfront hotel is a three story "U" shaped concrete structure opening toward the Atlantic Ocean. The solar collector array shown in Figure 9-2 is located on the roof of the south leg of the "U". The collectors are angled approximately 35° from the horizontal (latitude $+10^{\circ}$) and oriented due south according to the contractor. All piping is copper, insulated with 3/4 inch thick foam rubber. When the solar collector surface is hotter than the water in the pipe coming from the underground storage tank, a solid state differential temperature control activates the collector circulating pump. A Del Sol controller was employed. Because one temperature sensor is located on a section of uninsulated pipe leading from the storage tank, it is possible for the pump to turn on even though the temperature in the storage tank is hotter than water at the collector. However, as soon as the

FIGURE 9-1. Schematic diagram of solar augmented domestic water heating system, Barefoot Mailman Hotel.

FIGURE 9-2. Overall view of the solar collector array looking west-northwest. System designer Bill Staples is shown in foreground. (Photo provided by High Plumbing, Inc.)

hotter water from the tank is pumped past the sensor, the pump shuts down again. As the water in the uninsulated portion of the pipe cools down the cycle is repeated.

Water at the bottom of the 1000 gallon storage/preheat tank is pumped up to the roof and through the flat plate collectors where it is heated by incoming solar energy. The heated water is returned to the top of the storage tank to accomplish some degree of thermal stratification. On demand, preheated water flows to or through the conventional water heater and makeup water from the public water supply flows into the underground tank. When the pump is turned off, check valves prevent thermosyphoning and subsequent reradiation of thermal energy from the storage tank through the collectors.

All installation work was accomplished by union plumbers without specific previous experience with solar collector installation.

SOLAR COLLECTOR SUBSYSTEM

The Model 3282 flat plate Solar Dynamics collector employs a 24 gauge galvanized steel absorber plate to which a serpentine copper coil (1/2 inch O.D.) is soldered. See Figure 9-3. The absorber plate assembly was given an acid treatment prior to receiving a baked-on coating of flat black paint. Inspection of Figures 9-3 and 9-4 reveals peeling of the coating on some plates: Not all plates exhibited this problem. Overall collector dimensions are three feet two inches wide by eight feet two inches long to the outside of the welded aluminum (6063-T5) frame. Each unit weighs slightly more than 100 pounds.

The double glazed collector employs an outer glazing of 1/8 inch Herculite "K" tempered glass and an inner glazing of polyester film ("Tedlar"). In several cases the inner glazing had apparently failed and had been removed instead of being replaced. The ruptured inner glazing on one collector was still in place and exhibited a rather interesting fracture pattern emanating from a central stress point (see Figure 9-4).

FIGURE 9-3. View showing serpentine coil attached to absorber plate. Note areas where absorber plate coating has separated from galvanized steel sheet. Corrosion is apparent on frame of collector in background as is condensed water vapor on inside

FIGURE 9-4. View showing peeling of flat black coating from absorber plate. Also note interesting pattern of fractured inner Tedlar glazing.

FIGURE 9-5. View showing typical arrangement of collector support brackets, wooden sleepers and piping. A pressure relief valve and manual air bleed valve are located at each collector. Note whitish blotches where corrosion has broken through protective asphaltic coating.

Completed piping was insulated with "Rubatex" foam rubber insulation with a 3/4 inch wall thickness. The closure seams on some portions of the insulation have opened up and now require repair.

SOLAR STORAGE SUBSYSTEM

The steel energy storage tank is buried 2 feet under the parking lot, within about 10 feet of the building. Tank capacity is 1000 gallons. Prior to the tank's being set with a crane, three inches of polyurethane insulation were sprayed on the tank, followed by a canvas membrane covering and asphaltic coating. The tank operates at city water pressure and is piped to feed the conventional water heater (see Figure 9-1).

SOLAR SYSTEM COSTS

The system cost information shown in Table 9-1 was developed from information provided by the solar system installer, supplemented by standard cost estimating techniques. For future reference, the system installer has changed collector suppliers and is now employing flat plate collectors manufactured by Solar Engineering Inc., Boca Raton, Florida. The Solar Engineering collector wholesales for \$325 versus \$280 for the Solar Dynamics unit, however, its larger absorber size offsets the cost penalty on a cost per square foot basis.

TABLE 9-1. Solar System Cost Breakdown - -
Barefoot Mailman Hotel

Collectors	
30 panels @ \$280/unit	
(720 ft ² total)	\$8,400
Collector Installation	
4 hours average/panel @ \$12/hour	1,440
Storage Tank installed and insulated	1,050
Controls	50
Piping and Insulation	900
Pump	100

Miscellaneous supports, sleepers, valves	\$ 200
	\$12,140
Overhead at 20%	2,428
	\$14,568
Profit at 20%	2,914
TOTAL	\$17,481

DISCUSSION

Since the solar system became operational in October, 1975, the plumbing contractor has only been called back once for adjustments to the system. However, those adjustments were not necessitated by solar system malfunction but because city water pressure was lost, allowing air into the system. After High Plumbing manually bled the system, operation returned to normal.

Representatives of the Barefoot Mailman Hotel are apparently very satisfied with the performance of the system to date, although they are not collecting any data to substantiate their belief of significant energy cost savings.

Peeling paint on the absorber plate, lack of inner glazing on some panels, condensation between the glazings, and partial separation of collector insulation will certainly lead to deterioration of collector performance over time. Seam separation of piping insulation will also have an effect on overall system output. Many of these deficiencies could be corrected through on site maintenance.

The warranty period for the collectors has not yet expired and the installer has been in contact with the supplier and expects him to make necessary repairs. In conversations with the supplier, it was learned he plans to wait until the end of the one year period and make all necessary repairs at the same time.

10. ALUMNI HOUSE - CONFERENCE CENTER
STATE UNIVERSITY OF NEW YORK
ALBANY, NEW YORK

BACKGROUND

On hearing that a new Alumni Center was to be built at the State University of New York (SUNY) - Albany, several campus environmental groups encouraged the Alumni Association to consider the use of solar energy in the building. The Association and its consultants agreed with the idea and several financial grants were pursued and obtained to help pay for the solar heating system. Both the State of New York and the Niagara Mohawk Power Company contributed to the successful completion of the project.

The building, shown in Figures 10-1 and 10-2, was first occupied in the Spring of 1976 and contains approximately 7000 square feet of space on two floors. The floor plans are shown in Figure 10-3. The new building, situated on a wooded site at the north end of the campus, houses Alumni Association offices, meeting and conference rooms. The building interior is very open with high cathedral ceilings with exposed beams and tongue and groove planking over a large portion of it (see Figure 10-4). Such a ceiling treatment was desired even before it was decided that solar energy would be used. The south facing roof contains a large planar array of approximately 2300 square feet of solar collectors sloped at 45°. Collector azimuth is 17.5° west of south.

The building is divided into three cooling zones and eight heating zones. In the heating mode, fan coil units deliver heat generated by a number of possible mechanisms. Experimental in nature, and equipped with an extensive instrumentation and monitoring system, the building mechanical system can be set up in a direct solar heating mode, a solar-assisted, water-to-water heat pump mode, a direct air-to-water heat pump mode or in one of several peak energy shaving or cooling modes. This diversity

FIGURE 10-1. View of Alumni Center looking north-northwest.

FIGURE 10-2. View of Alumni Center looking west-southwest. Storage tanks are buried in front of the portion of the building extending to the right.

FIGURE 10-3. Sketches of the floor plans of Alumni Center. Note location of storage tanks relative to the mechanical equipment room. (Sketches provided by SUNY, Albany Alumni Association.)

FIGURE 10-4. View showing the cathedral ceiling above the meeting room/lounge area on the second floor. Solar collectors are mounted to the exterior of the roof decking shown in the picture.

of space conditioning systems provides an opportunity to examine many alternative energy options in a single building. An electric hot water boiler is provided for ultimate backup energy.

Atmospheric Sciences Research Center, located on campus, has received a two year grant from the Electric Power Research Institute (EPRI) to monitor the performance and study the economics of the various systems.

PERSONS INVOLVED WITH PROJECT

Owner:	Gary Jones The Alumni Association State University of New York Albany, New York 12222 Telephone: (518) 457-4631
Architect:	John M. Kurtz Richard Jacques Associates 41 State Street Albany, New York 12207 Telephone: (518) 434-2161
Mechanical Engineer:	Richard Bodette Rist-Frost Associates Glen Falls, New York Telephone: (518) 793-4141
Solar Consultant:	Richard Rittleman Burt-Hill Associates Butler, Pennsylvania Telephone: (412) 285-4761
General Contractor:	John Reimherr Reimherr and Schmidt Schenectady, New York Telephone: (518) 393-6848
Monitoring:	James Healy Atmospheric Science Research Center State University of New York Albany, New York 12222 Telephone: (518) 377-6477

SOLAR SYSTEM DESIGN

Approximately 50% of the required heating energy for the Alumni Center is expected to be provided by a solar energy system comprising 2300 square feet of Revere Copper and Brass Inc. collectors, 8000 gallons of hot water storage and various heat pumps and other components. All plumbing and major components are copper. The collectors are protected from freeze damage by a drain down system.

Shown diagrammatically in Figure 10-5, the system could be classified as a solar-assisted heat pump application although solar heated water from the storage unit can be used directly in fan coil units if adequate temperatures are available. Total heat pump capacity for the water to water unit is 20 tons. Two other heat pumps, both twelve ton air-to-water units, operate totally independently of the solar energy system, but are not used simultaneously with the solar system.

The Alumni Center is also involved in an investigation of the application of a heat pump to peak energy shaving techniques. A second 8000 gallon steel tank serves to store hot or cold water produced during off-peak electrical generating hours for use during hours of peak energy demand. The simplified diagram of Figure 10-5 shows the integration of the peak storage tank with the other mechanical systems.

The two 8000 gallon capacity steel storage tanks are located very close to the rear of the building and the mechanical equipment room. See Figure 10-3.

Although the building is located on a site wooded with deciduous trees, shading of the collectors is not expected to substantially impact system efficiency. The deciduous trees drop their leaves in winter, thus minimizing shading when solar energy is most needed. Selective cutting will be undertaken if it is found that performance degradation is worse than anticipated.

FIGURE 10-5. Simplified schematic diagram of Alumni House solar heating system. (Diagram provided by the Atmospheric Sciences Research Center.)

SOLAR COLLECTOR SUBSYSTEM

The solar collector was built in place on the south facing roof of the Alumni Center. Gross collector area is 2300 square feet which occupies most of the 96 foot by 26 foot roof plane. The collector employs a built-up system of components manufactured by Revere Copper and Brass Incorporated. Components include copper sheet laminated to plywood, special rectangular tubing, heat conductive adhesive, and copper battens to support the glazing material. (Glazing materials are not provided by Revere but must be procured separately.) Figure 10-6 illustrates the typical battens provided with the system. Similar battens were employed at the Alumni Center for vertical joints; horizontal battens were somewhat modified to allow rectangular tubes to pass.

The rectangular tubes, nominally 25 feet long, run up and down the roof on six inch centers. A 3/4 inch diameter manifold is connected to the rectangular tubes top and bottom by a pipe "loop". The manifolds are not secured to the copper absorber plate to work in conjunction with the pipe "loops" to accommodate thermal expansion. The outlet manifolds feed a four inch diameter copper drain pipe leading to the storage tank. The relatively large downcomer is sized such that it will never flow full.

Installation

To begin the installation process, wooden two by four inch sleepers are nailed on edge to scored "Plydeck" subroofing. Three and one half inch thick rigid Styrofoam insulation was placed between the sleepers and Revere Copper laminated panels were then nailed to the sleepers. The factory made panels are 3/8 inch thick plywood with copper sheet and aluminum sheet laminated to the front and back, respectively.

The rectangular tubes and manifolds were delivered in prefabricated sections three feet wide by 25 feet long. The sections were manufactured in a Revere plant 90 miles away and trucked to the building site. A special thermally conductive flexible adhesive was then applied to the tubes before they were secured to the panels with screwed on clips. Application of the adhesive proved to be a difficult operation until the contractor fabricated a roller device to facilitate the process.

Nextel non-selective paint was applied by working from a "cherry-picker" in two separate one half day efforts. The first day the copper was cleaned with a special solution and the second day the paint was applied by spraying. No difficulties were encountered with this operation.

Double glazed insulated glass panels of the type and size used for sliding patio doors were used as cover plates. The glass panels are supported by the battens illustrated in Figure 10-6 and secured by a cap strip.

A scaffold was erected in front of the building for working on the roof and the contractor built a double ladder device, which rolled along the ridge, that was used to install and service the glazing system. See Figure 10-1. The distance between the two ladders was slightly wider than the width of one panel. The rollers at the top and bottom of the ladder permitted it to move easily laterally across the roof. Unfortunately, the chimney in the center of the roof presented an obstacle which necessitated an awkward dismounting and remounting of the ladder structure to allow movement from one end of the building to the other. The ladder had been dismantled upon completion of the installation; however, it had been reinstalled at the time of this study in order to repair a pinhole leak that developed in one of the tubes. (The leak was attributed to a defect in the pipe and was not believed to be indicative of significant corrosion problems.) It was suggested that future systems should be designed to incorporate a similar ladder system which could remain on the roof for servicing the collectors.

FIGURE 10-6. Sketch showing typical laminated panel roof and solar collector assembly and cross-section of batten used to secure glazing (Sketch provided by Revere Copper and Brass Incorporated.)

During most of the collector construction process, the contractor employed four men on the roof. The union crew consisted of two carpenters and two plumbers. The contractor started by using only carpenters on this job, but after the plumbers union objected because soldering of pipe was involved, the plumbers were added.

SOLAR STORAGE SUBSYSTEM

A buried steel storage tank holds 8000 gallons of solar heated water. The tank is insulated with four inches of expanded polyurethane foam that has been waterproofed. The tank was placed on buried concrete saddles to prevent crushing of the urethane insulation. A manhole is accessible at the ground surface. Another 8000 gallon steel storage tank is similarly installed next to the first tank but is used for evaluation of peak energy shaving techniques.

Originally, fiberglass tanks had been considered but availability problems and cost penalties prevented their use.

SOLAR SYSTEM COST

Cost data, including man-hours for specific tasks, material costs and subcontract invoices had not yet been compiled and summarized by project personnel at the time of this study. As a result, only their estimates were available for inclusion in this report. The costs for the "conventional" system of heat pumps and off-peak energy storage tank are not included in the following estimates. Table 10-1 lists the cost estimates that were obtained. Costs do not include engineering or solar system consulting fees.

TABLE 10-1. Summary of Estimated Installation
Costs -- Alumni Center, SUNY-Albany

Solar Collectors	\$15,000
Collector Installation	15,000
Solar System Piping and Pumps	8,000
Solar Storage Tank, 8000 gallons	5,000
Controls	<u>1,000</u>
TOTAL	\$44,000

The general contractor indicated that while he had originally estimated and contracted for a price of \$15,000 to install the solar collector array, installation should have cost about \$20,000.

DISCUSSION

During construction, a very high wind lifted a plank that had been temporarily placed on the roof causing it to crash through a glass panel. The panel was easily replaced and was the only glass breakage to occur on the project.

Delivery of solar collector components caused some delay during construction. The primary problems were incomplete and incorrect shipments and late deliveries. It was believed that the installation of systems using built-up collectors are more sensitive to delivery problems than those using modular collectors. Modular collectors can be installed as delivered, even if partial shipments are made. Components of built-up collectors must be installed in sequence -- absorber plates, tubes, clamps, battens, coating, and glazing. Any anomalies in the receipt of these materials can have a significant impact on installation time and costs.

If construction must begin before all components are on-site, the contractor should have a very good estimate of the installation time associated with each phase of collector assembly and firm assurances from the manufacturer that component delivery will conform to the installation schedule. If materials are not available in stock, conformance to the schedule would probably be difficult to assure. It is also doubtful that a contractor

who has not had previous experience with a similar system could make an accurate estimate of component installation times.

Another factor impacting project scheduling is the delivery of glazing material. The contractor may not desire the glazing to be delivered to the site until he is ready for its installation to minimize the necessity for on-site storage and protecting it from other construction activity.

Beginning building construction in bad weather in January and collector component delivery problems were deemed to be the major causes delaying completion of the building.

The equipment required to operate the variety of heating modes and integrate the various types of systems serving the building has caused the mechanical equipment room to become very crowded, leaving little space to service equipment. Also, the control system is quite complex with a large number of automatic valves and motors. A Barber-Coleman control panel, visible from outside the equipment room, indicates important system parameters.

Union labor was used throughout the project. No problems with building codes were encountered.

11. MILLER AND SMITH TOWLSTON SALES OFFICE
TOWLSTON, VIRGINIA

BACKGROUND

Miller and Smith, Inc. is a residential construction company that has been emphasizing the energy conserving features of its homes for some time. At the height of the "energy crisis," the company decided to construct a solar heated building to bring attention to their interest in reducing residential energy requirements. Miller and Smith does not plan to offer solar energy systems on their homes in the near future although the solar heated building, which is now the company's sales office building for homes in the Towlston community in Northern Virginia, eventually will be converted into a residence. The building presently comprises 1768 square feet of open office and display area on one floor and a full basement containing the 4000 gallon solar storage tank and related solar system equipment.

Figure 11-1 depicts the prominent 750 square foot Thomason type collector array on the south roof. In this type of collector system, water is trickled down the surface of a blackened corrugated metal roof, collected at the bottom and returned to the storage tank. The steep 60° roof angle and the architectural modifications to the otherwise simple roof line are evident in Figure 11-2. Note in these figures that a platform has been constructed to give visitors to the sales office a closeup view of the collector array.

The building was completed in early 1974. None of the personnel involved in the project had previous experience with solar energy systems.

FIGURE 11-1. View looking northwest at the Miller and Smith Towlston Sales Office.

FIGURE 11-2. View looking east at the sales office. Note 60° angle of collector system and platform for closeup viewing of collectors

PERSONS INVOLVED WITH PROJECT

Owner/Installer: David Miller
Miller and Smith, Inc.
1301 Beverly Road
McLean, Virginia 22101
Telephone: (703) 821-2500

Architect: David N. Yerkes
David N. Yerkes and Associates
1511 K Street, N.W.
Washington, D. C.
Telephone: (202) 466-2080

Plumber: Ronald Bryant
Federlines
26 W. Diamond Avenue
Gaithersburg, Maryland
Telephone: (301) 948-8950

Solar Consultant: Jim Cummings
Goodwin H. Taylor Co.
6121 Linconia Road
Alexandria, Virginia 22312
Telephone: (703) 941-7600

SOLAR SYSTEM DESIGN

The water is circulated in insulated copper piping to the top of the 750 square foot solar collector array. A distribution header directs water into each corrugation of the roof. (See Figure 11-3.) Water flows down the roof by gravity and is collected at the bottom in a covered aluminum gutter, and returned to the storage tank in a copper pipe. Freeze protection is automatic since no water remains in the collector system after the circulating pump is deactivated.

Water is circulated at the rate of six gallons per minute to the Thomason type collector array to provide solar heated water which is stored in a 4000 gallon steel tank located in the basement.

FIGURE 11-3. Simplified sketch of the cross-section of built-up collector configuration.

A 30 KW electric immersion heater, mounted in the bottom of the horizontally positioned cylindrical tank, serves as a backup energy source to maintain a minimum water temperature. An optimum minimum temperature has not yet been established. Domestic hot water is preheated by circulating supply water through a coiled 30 foot long copper pipe located in the storage tank.

A 2000 cubic foot per minute blower forces air past a water to air heat exchanger through which heated water from the storage tank is circulated. The air handling subsystem also incorporates a refrigerant filled coil which is part of an air to air heat pump unit. A conventional warm air duct work distribution system then delivers the conditioned air to the building.

The owner has estimated that the solar heating system provides 30% of the total heating energy for the building.

SOLAR COLLECTOR SUBSYSTEM

Reynolds Aluminum Company corrugated "Rain-lok Rib" siding painted with a non-selective black paint was used as the collector absorber plate. Single glass cover plates are secured with wooden batten strips running top to bottom on the roof as shown in the cross-section in Figure 11-3. Aluminum tees serve to hold the caulking in place at the horizontal glass joints. Each glass panel is two feet wide by three feet high. The total planar collector array is 50 feet long by 15 feet high and is mounted at an angle of 60° from the horizontal. A second truss system was added to the conventional roof truss system to obtain the desired angle.

A one inch diameter copper supply manifold runs across the top of the collector array under the perimeter flashing. A short length of 3/8 inch diameter pipe is tee connected to the manifold at the center of each two foot wide panel. This pipe then center feeds a 22 inch long 3/8 inch diameter pipe which forms the headers for the individual two foot wide panels. Equally spaced 1/16 inch diameter holes were drilled in the 3/8 inch headers to allow water to trickle down the collector plates. At the bottom of the array, an aluminum rain gutter collects the water and feeds it to a 1-1/2 inch copper pipe for return to the storage tank.

The gutter and the return pipe are mounted under the lower perimeter collector flashing shown in Figure 11-4.

Installation

Two of the owner's carpenters installed the entire solar collector subsystem except the glass in about 3 days. A glazing subcontractor was hired to install the glass cover plates.

Although the corrugated panels were ordered unfinished, they were incorrectly shipped painted white. It was decided to remove the paint and refinish rather than wait for another shipment. Removing the paint proved to be a very time-consuming task. The panels were then repainted with a non-selective black paint.

The refinished panels were fashioned into assemblies at the plant with one inch by four inch wooden sides, a 3/8 inch plywood backing and two inch urethane insulation as shown in Figure 11-3. The preassembled absorber panels were then delivered to the site and placed on one inch by six inch nailers on the roof. Steel angles were used to position the panels and tie them to the nailers. The single glazing was then applied and held in place with wooden one inch by two inch batten strips screwed in place. This configuration is also shown in Figure 11-4 along with the lower perimeter flashing.

The trusses for the roof were also fabricated in the company's plant. They had to be made in two sections because a single truss with the 60 degree rafter angle modification would have been too high to ship over the road by truck in one piece.

SOLAR STORAGE SUBSYSTEM

The steel 4000 gallon capacity storage tank is located in the basement of the building. It was modified by the manufacturer to accept a 30 KW electric immersion heater and other piping fittings. A front end loader set the tank in place on concrete saddles before the basement was enclosed. The tank is insulated with two inches of covered polyurethane foam. All visible piping, the

FIGURE 11-4. Closeup view of edge of the collector mounting arrangement and bottom perimeter flashing. The flashing encloses an aluminum gutter return channel. Note corrosion which is occurring at bottom of the channels in the corrugated panels

FIGURE 11-5. View showing insulated 4000 gallon steel storage tank located in basement. The control/display panel is visible at the left center of the photograph. Note piping labels.

storage tank and other mechanical equipment are graphically painted and labelled for display purposes as illustrated in Figure 11-5.

Figure 11-6 schematically portrays the storage tank and the associated piping composing the energy storage subsystem.

The county building department required that a pressure test be conducted on the tank even though it is vented to the atmosphere at all times. The test was made at about one and one half times atmospheric pressure.

SOLAR SYSTEM COST

A complete breakdown of individual system component installation costs had not been identified prior to this study. The single cost that the owner had determined was the total installation cost for the collector subsystem which was \$2.75 per square foot. The other costs that are given in Table 11-1 below have been found through discussions with other project personnel involved in the actual installation.

TABLE 11-1. System Cost Breakdown -- Miller and Smith
Towlston Sales Office

<u>Item</u>	<u>Cost</u>
Collectors, 750 ft ² at \$2.75/ft ²	\$2,063
Storage tank, including insulation	1,400
Controls	1,000
Piping, pumps, insulation	<u>4,000</u>
	\$8,463

The cost of the architectural modifications to the building to accommodate the steep collector angle has not been included in the system cost breakdown. The owner stated that the cost for the entire mechanical system for the building, including the solar energy system, was \$12,000.

FIGURE 11-6. Simplified schematic diagram of storage tank subsystem. (Basic sketch provided by Miller and Smith, Inc.)

DISCUSSION

The owner indicated that the installation would be modified somewhat if it were done again. The roof angle would be decreased to permit construction and shipment of the trusses in single sections rather than in two pieces. The storage tank is larger than is currently believed to be the optimum size. Dave Miller said that he thought a 1500 gallon tank would have sufficed and would have been less expensive than the 4000 gallon tank.

He also believes the use of the immersed electric heater in the storage tank is less efficient than employing a separate series or parallel auxiliary heating system. It was also found that water in the storage tank had to be treated when iron deposition and corrosion became a problem. The holes in the supply headers still become clogged occasionally. Ron Bryant, whose company installed the piping subsystem said that the job was relatively simple: It took a plumber and his helper about 3 to 3-1/2 days to complete.

B. Summary Project Data Sheets

Summary data sheets for each of the solar installations described in the preceeding Section III-A appear on the following pages, III-145 through III-155, in the order listed below.

1. Whitney Veterinary Clinic
Orange, Connecticut
2. Gump Glass Building
Denver, Colorado
3. United Southwest National Bank of Santa Fe
Santa Fe, New Mexico
4. Windmill Campgrounds Laundry
Flagstaff, Arizona
5. Trinity University
San Antonio, Texas
6. Community Recreation Center
Santa Clara, California
7. Madeira School
Greenway, Virginia
8. George A. Towns Elementary School
Atlanta, Georgia
9. Barefoot Mailman Hotel
Hillsboro Beach, Florida
10. Alumni House - Conference Center
Albany, New York
11. Miller and Smith Sales Office
Towlston, Virginia

1. PROJECT NAME - Whitney Veterinary Clinic	19. COLLECTORS
2. LOCATION - Orange, Connecticut	Manufacturer - Solaron Corporation
Contact: Solaron Corporation, Jim Junk	Areas and Type - 625 ft ² , Flat Plate
Address: Commerce City, Colorado	Mounting Configuration - On roof; Planar
Phone: 303-289-5971	Fluid - Air
3. BUILDING TYPE - 2 stories	Absorber - Steel
4. FLOOR AREA - 2500 ft ²	Coating - Non-selective black
5. SOLAR APPLICATION - Heating, DHW	Glazings - Double glazed
6. NEW/RETROFIT - Retrofit	20. STORAGE
7. DISTRIBUTION SYSTEM - Forced air	Container - Concrete & wood
8. PERCENT SOLAR HEAT - 60-70%	Medium and size - Track gravel, 312 ft ³
9. AUXILIARY HEATING - Oil fired furnace	Location - On 1st floor
10. INSTALLER - George Ellis Construction Co.	Insulation - Fiberglass Insulation
11. ENGINEER - Alexander Sandomersky	21. SOLAR AIR CONDITIONING
12. OWNER - Dr. Whitney	Type -
13. ARCHITECT - Edward Johnson & Assoc.	Quantity and Size -
14. SOLAR COST - \$20,800	Manufacturer -
15. FUNDING AGENCY - Private	Percent Solar A/C -
16. STATUS - In operation	22. FREEZE PROTECTION - Not Required
17. OPERATIONAL DATA AVAILABLE -	
18. LABOR, UNION/NON-UNION - Union	

1. PROJECT NAME -	Gump Glass Company Building	19. COLLECTORS	
2. LOCATION -	Denver, Colorado 40° N, Latitude	Manufacturer -	Solaron
Contact:	G. Sigman (303) 289-5971	Areas and Type -	1,600 ft ² , Flat plate
Address:	S. Broadway & W. Louisiana Ave.	Mountings Configuration -	1600 ft ² , saw-tooth on flat roof
Phone:	Denver, Colorado (303) 778-1155	Fluid -	Air
3. BUILDING TYPE -	1 story, 1 wing solar heated flat roof	Absorber -	Steel
4. FLOOR AREA -	7200 ft ²	Coating -	Non selective black
5. SOLAR APPLICATION -	Heating	Glazings -	Two
6. NEW/RETROFIT -	New	20. STORAGE	
7. DISTRIBUTION SYSTEM -	Warm Air	Container -	Cement block bin, 8 ft x 8 ft x 16 ft.
8. PERCENT SOLAR HEAT -	75%	Medium and size -	1½ in. diam. stones 60 tons
9. AUXILIARY HEATING -	5 gas-fired burners on roof	Location -	On ground floor
10. INSTALLER -	Solaron Corp (303) 289-5971	Insulation -	Fiberglass
11. ENGINEER -	Solaron Corp.	21. SOLAR AIR CONDITIONING	None
12. OWNER -	Gump Glass Co.	Type -	
13. ARCHITECT -	Unknown	Quantity and Size -	
14. SOLAR COST -	\$70,700	Manufacturer -	
15. FUNDING AGENCY -	Private	Percent Solar A/C -	
16. STATUS -	Operational April 1975	22. FREEZE PROTECTION -	None Required
17. OPERATIONAL DATA AVAILABLE -	Fortune Mag. Feb. 1976		
18. LABOR, UNION/NON-UNION -	Union		

1. PROJECT NAME - United Southwest National Bank	19. COLLECTORS
2. LOCATION - Sante Fe, New Mexico	Manufacturer - Miromit
Contact: Charles Wherritt, Wherritt Engineering	Areas and Type - 1200 ft ² , Flat Plate
Address: P.O. Box 2430	Mounting Configuration - On roof, Saw tooth
Phone: Sante Fe, N.M. 87501	Fluid - Water, Ethylene Glycol
	Absorber - Steel
3. BUILDING TYPE - 1 story, Bank	Coating - Selective black
4. FLOOR AREA - 3,500 ft ²	Glazings - Single
5. SOLAR APPLICATION - Heating	20. STORAGE
6. NEW/RETROFIT - New	Container - Concrete tank
7. DISTRIBUTION SYSTEM - Central Station/Reheat coils	Medium and size - Water, 12,000 gallons
8. PERCENT SOLAR HEAT - 50-60%	Location - Basement
9. AUXILIARY HEATING - Gas; Hot water boiler	Insulation - 1 1/2" polyethylene insulation 2" foam glass insulation on top
10. INSTALLER - Lamareaux Construction	21. SOLAR AIR CONDITIONING
11. ENGINEER - Wherritt Engineering	Type -
12. OWNER - United Southwest Nat'l Bank	Quantity and Size -
13. ARCHITECT - Bernable Romero, A.I.A.	Manufacturer -
14. SOLAR COST - \$75,000	Percent Solar A/C -
15. FUNDING AGENCY - Private	22. FREEZE PROTECTION - Ethylene Glycol
16. STATUS - Operational	
17. OPERATIONAL DATA AVAILABLE -	
18. LABOR, UNION/NON-UNION - Union	

1. PROJECT NAME - Windmill Campgrounds Laundry	19. COLLECTORS
2. LOCATION - Flagstaff, Arizona	Manufacturer - Sunpower Systems
Contact: Bill Matlock, Sunpower Systems	Areas and Type - 430 ft ² , concentrating
Address:	Mounting Configuration - Ganged tracking
Phone: (602)-968-6387	Fluid - Water & Ethylene glycol
3. BUILDING TYPE - Coin Op Laundry	Absorber - Copper pipe, Aluminum reflect
4. FLOOR AREA - N/A	Coating - Selective
5. SOLAR APPLICATION - DHW	Glazings - None
6. NEW/RETROFIT - New	20. STORAGE
7. DISTRIBUTION SYSTEM - N/A	Heat exchanger in tank
8. PERCENT SOLAR HEAT - 70% HW	Container - Galvanized steel
9. AUXILIARY HEATING - Propane	Medium and size - Water, 2500 gallons
10. INSTALLER - Sun Power Systems	Location - Buried
11. ENGINEER - Bill Matlock	Insulation - None
12. OWNER - Bernard Swier	21. SOLAR AIR CONDITIONING
13. ARCHITECT - N/A	Type -
14. SOLAR COST - \$3400	Quantity and Size -
15. FUNDING AGENCY - Private	Manufacturer -
16. STATUS - Operation	Percent Solar A/C -
17. OPERATIONAL DATA AVAILABLE - Sept. 76	22. FREEZE PROTECTION - Ethylene glycol
18. LABOR, UNION/NON-UNION - Non-union	

1. PROJECT NAME - Trinity University Central Power Plant Ctr.	19. COLLECTORS
2. LOCATION - San Antonio, Texas	Manufacturer - Northrup, Inc.
Contact: Bridgers & Paxton	Areas and Type - 16,080 ft ² of tracking concentrating collectors
Address: 213 Truman Street, N.E.	Mounting Configuration Roof mounted
Phone: Albuquerque, N.M. 87108	
(505) 265-8577	
3. BUILDING TYPE - Central Power Plant	Fluid - Water
4. FLOOR AREA - 280,000 ft ²	Absorber - Copper
5. SOLAR APPLICATION - Heating, Cooling, DHW	Coating - Selective
6. NEW/RETROFIT - Retrofit	Glazings - Fresnel lens
7. DISTRIBUTION SYSTEM - Water	20. STORAGE
8. PERCENT SOLAR HEAT - 90%	Container - Steel tank
9. AUXILIARY HEATING - Natural gas	Medium and size - Water; 40,000 gallons total (2 tanks)
10. INSTALLER - Jud Heating & Plumbing Co.	Location - Buried
11. ENGINEER - Bridgers & Paxton	Insulation - Urethane, 4"
12. OWNER - Trinity University	21. SOLAR AIR CONDITIONING
13. ARCHITECT - None	Type - Absorption chiller
14. SOLAR COST - \$1,100,000	Quantity and Size - Existing ~600 tons
15. FUNDING AGENCY - ERDA	Manufacturer -
16. STATUS - Under construction, completion Sept. 1976	Percent Solar A/C - 30%
17. OPERATIONAL DATA AVAILABLE -	22. FREEZE PROTECTION - Circulating fluid
18. LABOR, UNION/NON-UNION - Union	

<p>1. PROJECT NAME - Community Recreation Center</p> <p>2. LOCATION - Santa Clara, California; 37°N Latitude</p> <p>Contact: Robert R. Mortenson</p> <p>Address: City of Santa Clara Santa Clara, California 95050</p> <p>Phone: (408) 248-4070</p>	<p>19. COLLECTORS</p> <p>Manufacturer - Ametek Co.</p> <p>Areas and Type - 7011 ft², flat plate</p> <p>Mounting Configuration - 4 Separate roof areas</p> <p>Fluid - Water and 10% Propylene-Glycol</p> <p>Absorber - 8'x 2' copper roll-bond; Olin-Brass</p> <p>Coating - Selective black $\alpha=0.95$ $\epsilon=0.3$</p> <p>Glazings - Double Glazed</p>
<p>3. BUILDING TYPE - 1 story; 8" thick concrete walls (Non-insulated)</p> <p>4. FLOOR AREA - 27000 ft²</p> <p>5. SOLAR APPLICATION - Cooling, Heating</p> <p>6. NEW/RETROFIT - Retrofit</p> <p>7. DISTRIBUTION SYSTEM - Fan coils in rooms</p> <p>8. PERCENT SOLAR HEAT - 84%</p> <p>9. AUXILIARY HEATING - 1.2 x 10⁶ gas fired boiler feeds chiller or fan coils</p> <p>10. INSTALLER - Welch Construction Co.</p> <p>11. ENGINEER - Lockheed Palo Alto Research Lab</p> <p>12. OWNER - City of Santa Clara</p> <p>13. ARCHITECT - D.C. Thimgan</p> <p>14. SOLAR COST - \$436,000</p> <p>15. FUNDING AGENCY - ERDA</p> <p>16. STATUS - Installation complete Sept. 1976</p> <p>17. OPERATIONAL DATA AVAILABLE - NSF & Santa Clara Releases and Brochures</p> <p>18. LABOR, UNION/NON-UNION - Union</p>	<p>20. STORAGE</p> <p>Container - 2 steel, cylindrical water tanks</p> <p>Medium and size - 1,000 gallon hot water 50,000 gallon chilled</p> <p>Location - Underground</p> <p>Insulation - Plastic foam</p> <p>21. SOLAR AIR CONDITIONING</p> <p>Type - LI-BR Absorption chillers</p> <p>Quantity and Size - 2-25 Ton</p> <p>Manufacturer - ARKLA</p> <p>Percent Solar A/C - 65%</p> <p>22. FREEZE PROTECTION - Propylene Glycol</p>

<p>1. PROJECT NAME - Madeira School Solar Energy Science Bldg.</p> <p>2. LOCATION - Greenway, Virginia; 39°N Latitude</p> <p>Contact: Peter Flack & Norman Kurtz</p> <p>Address: Flack & Kurtz 29W. 38th street- New York, NY 10018</p> <p>Phone: 1-212-736-3733</p>	<p>19. COLLECTORS</p> <p>Manufacturer - Olin-Brass Co.</p> <p>Areas and Type - Flat plate</p> <p>Mounting Configuration - 4600 ft² planar against roof</p> <p>Fluid - Exxon Caloria Ht-43</p> <p>Absorber - Aluminum Roll-Bond</p> <p>Coating - Non-selective black</p> <p>Glazings - One</p> <p>20. STORAGE</p> <p>Container - Steel tank, 8 ft diam.</p> <p>Medium and size - Water, 10,000 gallons</p> <p>Location - Mechanical room</p> <p>Insulation - Calcium Silicate (sprayed in place)</p> <p>21. SOLAR AIR CONDITIONING</p> <p>Type - None</p> <p>Quantity and Size -</p> <p>Manufacturer -</p> <p>Percent Solar A/C -</p> <p>22. FREEZE PROTECTION - Exxon Caloria HT-43</p>
<p>3. BUILDING TYPE - 1 1/2 story modern science bldg. & class-room</p> <p>4. FLOOR AREA - 9,000 ft²</p> <p>5. SOLAR APPLICATION - Heating, DHW</p> <p>6. NEW/RETROFIT - New</p> <p>7. DISTRIBUTION SYSTEM - Warm Air</p> <p>8. PERCENT SOLAR HEAT - 60%</p> <p>9. AUXILIARY HEATING - Steam boiler</p> <p>10. INSTALLER - Commercial Industrial Construction, Inc.</p> <p>11. ENGINEER - Flack & Kurtz, Inc.</p> <p>12. OWNER - Madeira School</p> <p>13. ARCHITECT - Arthur Cotton Moore Assoc, (K. Abraham)</p> <p>14. SOLAR COST - \$69,000</p> <p>15. FUNDING AGENCY - Private</p> <p>16. STATUS - Complete</p> <p>17. OPERATIONAL DATA AVAILABLE -</p> <p>18. LABOR, UNION/NON-UNION - Non-union</p>	

1. PROJECT NAME - George A. Towns Elementary School	19. COLLECTORS
2. LOCATION - Atlanta, Georgia 33 $\frac{1}{2}$ ⁰ N. Latitude	Manufacturer - PPG Industries
Contact: Richard Duncan	Areas and Type - Flat plate, 10,000 ft ²
Address: Westinghouse Corp.	Mounting Configuration - On roof
Baltimore, Md. 21203	Fluid - Water & Special Inhibitor
Phone: (301) - 765-3393	Absorber - 34"x76" aluminum
	roll-bond panels (Olin-Brass)
3. BUILDING TYPE - 1 story school	Coating - Selective black Alcoa
4. FLOOR AREA - 32,000 ft ²	Glazings - 2 layers of 1/8" PPG
5. SOLAR APPLICATION - Heating, cooling, domestic hot water	Herculite tempered
6. NEW/RETROFIT - Retrofit	20. STORAGE
7. DISTRIBUTION SYSTEM Fan coils, cabinet heaters unit venti- lators	Container - Steel tanks
8. PERCENT SOLAR HEAT - 60%	Medium and size - Water, 45,000 Gal.
9. AUXILIARY HEATING - Gas-fired boiler	Location - 3-15000 gallon tanks)
10. INSTALLER - Delta Corp.	Insulation - None
Westinghouse Corporation	21. SOLAR AIR CONDITIONING
11. ENGINEER - Dubin Mindell-Bloome Assoc.	Type - LI-BR Absorption Chiller
Burt, Hill, & Associates	Quantity and Size - 1-100 Ton
12. OWNER - George A. Towns Elem. School	Manufacturer - Arkla
13. ARCHITECT - Burt, Hill & Associates	Percent Solar A/C - 60%
(P. Richard Rittelman)	22. FREEZE PROTECTION - Drain down--Nitrogen fill
14. SOLAR COST - \$445,000.	
15. FUNDING AGENCY - NSF & ERDA	
16. STATUS - Operational Oct. 1975	
17. OPERATIONAL DATA AVAILABLE - "Cooling by Solar Heat"	
Westinghouse Corp.	
18. LABOR, UNION/NON-UNION - Union	

1. PROJECT NAME - Barefoot Mailman Hotel	19. COLLECTORS
2. LOCATION - Hillsboro Beach, Florida	Manufacturer - Solar Dynamics, Inc.
Contact: Bill Staples	Areas and Type - 720 ft ² , Flat Plate
Address: High Mechanical Contractors	Mounting Configuration - On roof, Saw tooth
Phone: 4011 N. Dixie Hwy. Pampano Beach, Florida	Fluid - Water
1-305-943-1400	Absorber - Copper
	Coating - Selective black
	Glazings - Double
3. BUILDING TYPE - 3 stories, hotel	20. STORAGE
4. FLOOR AREA - Unknown	Container - Steel
5. SOLAR APPLICATION - DHW	Medium and size - 1,000 gallons
6. NEW/RETROFIT - Retrofit	Location - Underground
7. DISTRIBUTION SYSTEM - Conventional hot water loop	Insulation - 4" Urethane foam
8. PERCENT SOLAR HEAT - 90%	21. SOLAR AIR CONDITIONING
9. AUXILIARY HEATING - Gas fired boiler	Type -
10. INSTALLER - High Mechanical Contractors	Quantity and Size -
11. ENGINEER - High Mechanical Contractors	Manufacturer -
12. OWNER - Unknown	Percent Solar A/C -
13. ARCHITECT - Unknown	22. FREEZE PROTECTION - Not required
14. SOLAR COST - \$18,500	
15. FUNDING AGENCY - Private	
16. STATUS - In operation 13 months	
17. OPERATIONAL DATA AVAILABLE -	
18. LABOR, UNION/NON-UNION - Union	

1. PROJECT NAME - Alumni House	19. COLLECTORS
2. LOCATION - State University of New York at Albany	Manufacturer - Revere
Contact: Burt Hill Assoc.	Areas and Type - 2300 ft ² flat plate planar
Address: 610 Mellon Bank Building	Mounting Configuration - roof
Butler, Pa.	Fluid - Water
Phone: 1-412-285-4761	Absorber - Copper
3. BUILDING TYPE - 2 story office	Coating - Non-selective black
4. FLOOR AREA - 8000 ft ²	Glazings - Double
5. SOLAR APPLICATION -H, DHW	20. STORAGE
6. NEW/RETROFIT - New	Container - Steel tank
7. DISTRIBUTION SYSTEM 4 Pipe Fan coil	Medium and size - Water, 16,000 Gal. (2-8000 Gal)
8. PERCENT SOLAR HEAT -75%	Location - Underground
9. AUXILIARY HEATING - Electric boiler and heat pump	Insulation - Urethane foam
10. INSTALLER -	21. SOLAR AIR CONDITIONING
11. ENGINEER - Rist Frost Assoc, Glens Falls, N.Y.-Mech.	Type -
Burt Hill Assoc, Butler, Pa.-Solar Consultant	Quantity and Size -
12. OWNER - Alumni association	Manufacturer -
13. ARCHITECT - Richard Jacques Assoc.	Percent Solar A/C -
14. SOLAR COST - 30,000	22. FREEZE PROTECTION - Drain down
15. FUNDING AGENCY - Private	
16. STATUS - Operational	
17. OPERATIONAL DATA AVAILABLE -	
18. LABOR, UNION/NON-UNION -	

1. PROJECT NAME - Miller and Smith Towlston Sales Office	19. COLLECTORS
2. LOCATION - Fairfax County, Virginia 39° N. Latitude	Manufacturer - on site assembly by Miller & Smith Construction
Contact: Jim Cummings of Goodwin H. Taylor Co.	Areas and Type - 750 ft ² Flat plate, trickling water
Address: 6121 Linconia Rd.	Mounting Configuration - 750 ft ² planar against pitched roof
Phone: Alexandria, Va. 22312	Fluid - Water
1-703-941-7600	Absorber - Reynolds corrugated aluminum roofing
3. BUILDING TYPE - 1½ story office building	Coating - Non-selective black
4. FLOOR AREA - 1500 ft ² heated living space	Glazings - One pane, double strength glass
5. SOLAR APPLICATION - heating and hot water	20. STORAGE
6. NEW/RETROFIT - New	Container - Steel tank, 64 in.diam, 24 ft. long
7. DISTRIBUTION SYSTEM - Fan-coil	Medium and size - Water, calgon inhibitor, 4000 gallon
8. PERCENT SOLAR HEAT - 30-50 (predicted)	Location - Basement
9. AUXILIARY HEATING - 30 KW immersion heater in storage tank	Insulation - 2 in. polyurethane foam
10. INSTALLER - H & AC Metcalf & Sons	21. SOLAR AIR CONDITIONING
11. ENGINEER - plumb.Federlines	Type - None
Goodwin H. Taylor Co.	Quantity and Size -
12. OWNER - Miller and Smith, Inc.	Manufacturer -
13. ARCHITECT - Yerkes and Associates	Percent Solar A/C -
14. SOLAR COST - \$12,000	22. FREEZE PROTECTION - Drain-down
15. FUNDING AGENCY - Private	
16. STATUS - in operation, Nov. 1974	
17. OPERATIONAL DATA AVAILABLE -	
18. LABOR, UNION/NON-UNION - Non-union	

IV. SYSTEM COST SUMMARY

A. Cost Comparison

When comparing the costs of two or more solar energy systems, the basis for comparison must be established and conditions or qualifications placed on the comparison. "Dollars per square foot of collector area" for the entire system or specific components has been used in the past as a comparison parameter, but it does not account for the differences in performance of the systems. For instance, a system using a tracking focusing solar collector array will usually cost more than a flat plate array per square foot of collector, but the focusing array may yield more usable heat per square foot. "Dollar per Btu output" is, therefore, a better basis for cost comparisons than collector area. However, few system performance data are available and determining system performance was not within the scope of the present study. Therefore, this basis could not be used here. Also, the quality of the workmanship or expected lifetime of the system and its components have not been addressed so that a fair comparison cannot be made based on life cycle costs.

Because of these limitations, the greatest value of the cost data presented in this report is not in being able to compare the cost of individual systems, but in identifying major cost components for each project, determining a range of costs for the major components and their installation and determining cost trends for types of systems. Some of the major factors influencing installed cost can also be identified.

The data collection was hindered by the lack of a uniform accounting procedure for each project. In many cases, accurate estimates could not be made for the installed cost of many major components due to incomplete record-keeping by the owners or architects during construction. In general, it must be said that these persons had little reason to keep accurate records of system component installed costs except for personal interest.

Usually, lump sum contracts were obtained for major portions of work on each system with no breakdown for individual tasks. Contractors were not as concerned with hours spent on each component as on making a profit on the overall job. Thus, they did not keep detailed records appropriate for this study.

Another difficulty lies in the definition of system components. One reference might list "collector system installed cost" and not include the cost of the piping and manifolds to the collector. Another might include all the piping between the collector and the storage tank under that same heading. When possible, the items included in each cost category are listed in this report.

It should also be restated that the main objective of the economic analysis was evaluation of installation costs for solar collector and thermal energy storage subsystems.

B. Cost Relationships

A variety of comparative cost relationships are included on the following tables.

1. Solar Collector Subsystem Costs

Although the f.o.b. factory prices for solar collectors are not very meaningful, unless coupled with performance and system integration cost data, unit collector costs of the systems studied are tabulated on Table IV-1 for reference.

These costs should not be taken as the present price of the collectors supplied by the respective manufacturers since discounts were given in some installations and inflation can be expected to have caused some cost increases.

Table IV-2 lists the gross installed system costs and unit system cost per square foot of solar collectors in the various systems studied. Upon first inspection there appears to be a wide fluctuation in unit costs. However, when the projects are assessed by system application (i.e. space heating and cooling, space heating, and domestic hot water) some cost consistency becomes apparent.

TABLE IV-1. Solar Collectors Summary Data and Unit Component Costs as Provided by the Manufacturers

PROJECT	COLLECTOR MANUFACTURER	ABSORBER PLATE MATERIAL	TOTAL COLLECTOR AREA-FT ²	TOTAL COLLECTOR COST-\$	UNIT COLLECTOR COST-\$/FT ²
<u>SPACE HEATING AND COOLING</u>					
Trinity University	Northrup	Copper	16,080	254,598	15.83
Santa Clara Community Center	Ametek	Copper	7,011	105,840	15.10
Towns Elementary School	PPG	Aluminum	10,000	65,927	6.59 (a)
<u>SPACE HEATING</u>					
Gump Glass Building	Solaron	Steel	1,600	19,200	12.00 (b)
United Southwest Bank	Miromit	Steel	900	8,600	9.56
Whitney Veterinary Clinic	Solaron	Steel	625	7,079	11.33
Madeira School	Olin-Brass	Aluminum	4,000	12,000 (d)	3.00
Miller and Smith Sales Office	Thomason (design)	Aluminum	750	2,063	2.75
SUNY Alumni House	Revere	Copper	2,300	14,950	6.50
<u>DOMESTIC HOT WATER HEATING</u>					
Barefoot Mailman Hotel	Solar Dynamics	Steel/ Copper tubes	720	8,400	11.67
Windmill Campground	Sunpower Systems	Copper	430	4,300	10.00 (c)

(a) Collector replacement in the future is estimated to cost \$10.00 per square foot.

(b) Includes integral collector support structure.

(c) Also includes all materials except storage tank.

(d) Includes absorber plate only.

TABLE IV-2. Summary of Total Installed System Costs and Unit System Costs per Square Foot of Solar Collectors

<u>PROJECT</u>	<u>COLLECTOR AREA-FT²</u>	<u>TOTAL INSTALLED COST</u>	<u>UNIT COST \$/FT²</u>
<u>SPACE HEATING AND COOLING</u>			
Trinity University	16,080	\$1,098,851	\$68.33/ft ²
Santa Clara Community Center	7,085	454,360	64.13/ft ²
Towns Elementary School	10,000	443,963	44.40/ft ²
<u>SPACE HEATING</u>			
Gump Glass Building	1,600	70,708	44.19/ft ²
United Southwest Bank	900	44,749	49.72/ft ²
Whitney Veterinary Clinic	625	20,853	33.36/ft ²
Madeira School	4,000	76,000	19.00/ft ²
Miller and Smith Sales Office	750	8,463	11.28/ft ²
SUNY Alumni House	2,300	44,000	19.13/ft ²
<u>DOMESTIC HOT WATER HEATING</u>			
Barefoot Mailman Hotel	720	17,481	24.28/ft ²
Windmill Campground	430	6,695*	15.57/ft ²

* Projected cost for duplication of project at present costs.

The attempt to evaluate total collector installation costs (labor and materials) alone proved to be a somewhat more tenuous pursuit. In some cases it was necessary to estimate the proportion of total labor costs required for collector installation and collector piping to arrive at the values listed. In cases where assumptions were made, comments have been noted on Table IV-3. The main problem area was in estimates required to determine labor costs associated with collector piping, manifolds and piping insulation. Assumptions which were made are based on observations of the actual systems and plans with estimates being made of the relative percentage of total system piping required for plumbing the solar collector array. It is ironic that the one area where possibly the most significant potential for cost reduction exists - installation of collector manifolds, piping and insulation - is the most nebulous. Detailed cost accounting of the solar collector subsystem installation was not practiced at any of the sites. The total collector subsystem installation costs listed on Table IV-4 include the installation of the collectors, piping and manifolds, flashing, support structure, and insulation. Not included are controls, storage tanks, pumps and auxiliary equipment.

TABLE IV-3. Collector Subsystem Installation (Labor and Materials) Costs and Percent of Total Costs

<u>PROJECT</u>	<u>TOTAL INSTALLED SUBSYSTEM COST, \$</u>	<u>UNIT COST, \$/FT²</u>	<u>PERCENT OF TOTAL SYSTEM COST</u>	<u>COMMENTS</u>
<u>SPACE HEATING AND COOLING</u>				
Trinity University	671,355	41.75	61%	
Santa Clara Community Center	172,095	24.29	38%	Includes 25% of total piping costs.
Towns Elementary School	179,132	17.39	39%	Includes 50% of piping materials and 20% of total construction labor for installation of Mylar, framing and piping insulation.
<u>SPACE HEATING</u>				
Gump Glass Building	33,530	20.96	47%	Does not include cost of ducts connecting collectors to storage tanks.
United Southwest Bank	29,051	32.28	65%	Includes 50% of total piping insulation and materials. Two man-weeks were allowed for collector insulation and piping.
Whitney Veterinary Clinic	11,775	18.84	56%	Five man-weeks were allowed for collector installation.
Madeira School	48,000	12.00	63%	Includes on-roof piping and glazing.

TABLE IV-3. Collector Subsystem Installation (Labor and Materials) Costs and Percent of Total Costs (continued)

<u>PROJECT</u>	<u>TOTAL INSTALLED SUBSYSTEM COST, \$</u>	<u>UNIT COST, \$/FT²</u>	<u>PERCENT OF TOTAL SYSTEM COST</u>	<u>COMMENTS</u>
<u>SPACE HEATING (cont'd)</u>				
Miller and Smith Sales Office	2,063	2.75	24%	
SUNY Alumni House	30,000	13.04	68%	
<u>DOMESTIC HOT WATER HEATING</u>				
Barefoot Mailman Hotel	10,515	14.02	60%	Includes 75% of the piping, insulating costs.
Windmill Campground	4,945	11.50	74%	

2. Solar Storage Subsystem Costs

Several relationships were investigated to evaluate installed storage subsystem costs and to determine the sensitivity of those costs to overall project costs. Summary data describing the installations studied as well as a tabular presentation of cost and inter-system relationships are presented on Table IV-4.

Unit installed costs varied from \$0.17 per gallon for the United Southwest Bank, where the vault foundation could be modified to serve as storage, to \$1.78 per gallon at Trinity University. Another interesting relationship was the ratio of storage volume to collector area. Here, values ranged from 1.33 gallons per square foot for the domestic water heating system at the Barefoot Mailman Hotel to 11.1 gallons per square foot at the United Southwest National Bank. Rock storage for the two air systems was 0.64 and 0.50 cubic feet per square foot of solar collector.

The contribution of the storage subsystem to total installed system costs varies from a low of 3.7% to a high of 26.1%. However, the low ratio was due to being able to adapt the foundation of the bank vault for storage and the high ratio was for the system with the lowest total installed cost per square foot of collector area. As the median was around 10% of the total installed system costs, there does not appear to be much opportunity for overall system cost reduction in this area.

TABLE IV-4. Summary of Thermal Energy Storage Subsystem Data and Costs

PROJECT	CONTAINER TYPE/MEDIA	INSULATION SYSTEM	LOCATION	CAPACITY	TOTAL COST	COST/UNIT VOLUME	RATIO OF STORAGE VOLUME TO COLLECTOR AREA	COST/FT ² COLLECTOR AREA	STORAGE COST AS PERCENTAGE OF TOTAL
<u>SPACE HEATING AND COOLING</u>									
Trinity University San Antonio, Texas	(2) Steel/Water	Urethane or Calcium Silicate	Underground	40,000 gal	\$71,256	\$1.78/gal	2.49 gal/ft ²	\$ 4.43	6.5%
Santa Clara Community Center Santa Clara, Calif.	(2) Steel/Water	Drained Crushed Stone & Urethane on Cold Tank	Underground	60,000 gal	58,000	0.97/gal	8.55 gal/ft ²	8.27	12.8%
Towns Elementary School Atlanta, Georgia	(3) Steel/Water	Drained Crushed Stone Covered with Bead Board	Underground	45,000 gal	19,566	0.43/gal	4.50 gal/ft ²	1.96	4.4%
<u>SPACE HEATING</u>									
Gump Glass Building Denver, Colorado	Concrete Block/ Rocks	Polystyrene	In Building	1,024 ft ³	4,000	3.90/ft ³	0.64 ft ³ /ft ²	2.50	6.0%
Whitney Veterinary Clinic Orange, Connecticut	Wood Frame and Plasterboard/Rocks	Fiberglass	In Attached Building	315 ft ³	2,800	8.89/ft ³	0.50 ft ³ /ft ²	4.48	13.4%
United Southwest Bank Santa Fe, New Mexico	Cast Concrete/ Water	Fiberglass	Under Vault In Building	10,000 gal	1,651*	0.17/gal	11.1 gal/ft ²	1.83	3.7%
Madeira School Greenway, Virginia	Steel/Water	Calcium Silicate	Basement	10,000 gal	9,140	0.91/gal	2.5 gal/ft ²	2.29	12.0%
Miller and Smith Sales Office Towlston, Virginia	Steel/Water	Polyurethane	Basement	4,000 gal	1,400	0.35/gal	5.33 gal/ft ²	1.87	16.5%
SUNY Alumni House Albany, New York	Steel/Water	Polyurethane	Underground	8,000 gal	5,000	0.65/gal	3.48 gal/ft ²	2.17	11.4%
<u>DOMESTIC HOT WATER HEATING</u>									
Barefoot Mailman Hotel Hillsboro Beach, Fla.	Steel/Water	Polyurethane and Canvas	Underground	1,000 gal	1,050	1.05/gal	1.33 gal/ft ²	1.40	6.0%
Windmill Campgrounds Flagstaff, Arizona	Steel/Water	Polyurethane	Underground	2,500 gal	1,750	0.70/gal	5.81 gal/ft ²	4.07	26.1%

* Includes modifications only.

** Includes two man-weeks for installation labor; foundation was used for shell.

V. POTENTIAL METHODS OF COST REDUCTION

Beyond the design and construction management considerations to be discussed in Section VI and which can impact costs for solar energy systems on commercial buildings, several specific cost reduction concepts were discussed with solar collector manufacturers. These concepts were directed toward reducing the installed costs of solar collectors and included such techniques as internal manifolds, prefabricated and pre-piped collector groups and support framework, pre-assembled and pre-piped multiple collector modules, and long collector modules.

Most commercial buildings are larger than a typical residence and many are flat-roofed. Because of this, commercial buildings are probably more amenable to the collector installation cost reduction techniques discussed than are residences.

A. Internal Manifolds

The typical flat plate collector which uses a fluid transfer medium contains closely spaced rows of narrow fluid passages which are joined to a larger tube or header at the top and bottom of the collector. This tube or header, commonly $3/8$ to $3/4$ inch in diameter, penetrates the collector module housing from the side, top or back to be connected to the other collectors or external manifolds. Generally, groups of collectors are arranged in parallel flow configurations by using larger pipes (one to three inches in diameter) as manifolds (or headers). One manifold is required to connect the inlets and one for the outlets of the individual collectors. Sometimes valves are used at the inlet and outlet of each collector to regulate flow or to permit isolating a collector for removal from the system. Collector inlets and outlets are also convenient points to place sensor receptor wells to permit measurement of temperature and pressure across the collectors. If dissimilar metals are used in the collector

system, dielectric couplings are often used to connect the collectors to the manifold. Flexible hoses and clamps have been used for these connections with some successes and some failures.

In any case, connecting the inlets and outlets of each collector to an external manifold is time consuming, expensive and critical from a design standpoint. All external piping must be supported and insulated, which usually requires water-proofing. An obvious alternative to this practice is the use of internal manifolds such that the tube or internal individual collector header at the top and bottom of an absorber plate also forms the manifold for a group of collectors. The tube, which would have to be properly sized, depending on the number of collectors in parallel, could penetrate the side of the collector module housing and a fitting used to connect it to the adjacent collector manifold. The fitting could be contained in the collector housing if sufficient access were provided to make the connection. The access would have to be weather proof. The Miromit collector, as installed on the United Southwest National Bank, utilizes internal manifolds and external "Dresser" compression couplings between the collectors. However, this arrangement requires a separation of approximately four inches between collectors. Other manufacturers presently employ internal manifold collectors or have them available: Manufacturers include, R-M Products, Solar Corporation of America, Solaron and PPG. The greatest problem with internal manifolds is accommodating thermal expansion.

Another limitation is on the number of collectors which can be placed on a single manifold pipe due to interior collector size constraints. Also, a common manifold eliminates the ability to isolate individual collectors from the piping systems as one is able to do when gate valves are used at the inlet and outlet of each collector. Also, it is more difficult to obtain temperature and pressure measurements for individual collectors.

B. Prefabricated and Pre-Piped Collector Groups and Support Framework

Many of the installations studied employed a sawtooth framework made of wood or metal (United Southwest National Bank, Trinity University, Towns Elementary School, Gump Glass and Barefoot Mailman). All but one project required a significant effort to design and install the support structure and collector mounting system. At least one additional construction trade (usually carpenters or steelworkers) was often required to complete the installation. The concept of a standard prefabricated support system with a group of pre-piped, insulated and mounted collectors which would be shipped with the support collapsed against the collectors and opened up into an A-frame support at the site was investigated. It was discussed with several solar collector manufacturers, some of whom had already considered the idea.

Several comments concerning potential problems associated with this concept were mentioned during these discussions. For example,

- 1) It would probably be limited to flat-roofed buildings.
- 2) It must be easily structurally integrated with the roof.
- 3) It must withstand large wind loads.
- 4) The permissible location of piping penetrations through the roof from the collector must be flexible to accommodate all roofs, or it must be specifically designed for each project.
- 5) It might limit the possible mounting angles to those that were available in the manufacturer's standard line.
- 6) It might be limited in length to that which could be easily shipped by truck and set in place with a single crane.
- 7) It might be difficult architecturally to incorporate the collector system in an aesthetically pleasing manner.

The requirement of structural integration with the roof might limit the application of this concept to new buildings designed to be integrated with the supports. Alternatively, very heavy structures could be used which could withstand the windloads without being structurally tied to the roof. However this would present other problems as the roof would have to be sturdy enough to support it, trucks would be able to transport fewer assemblies, and large cranes would be required to set them in place.

The problem with piping connections can be overcome by running piping between groups of collectors over the roof rather than penetrating it for each group.

The mounting angle could be made variable by adjusting the distance the rear support of the A-frame structure is pulled during emplacement.

While these problems remain to be solved, the development of premounted and piped groups of collectors on prefabricated support structures has great cost reduction potential. Even though this technique may not be universally applicable, savings of \$5 to \$10 per square foot of installed collector area would not be unreasonable to expect when compared to present systems utilizing individual flat plate collector modules.

C. Preassembled Multiple Collector Modules

A technique similar to the above concept would be the prefabrication, prepiping and insulating of a group of collectors. This would essentially create single large collector units to expedite piping and securing to a support structure in the field. Again, thermal expansion would have to be allowed for in the design. However, this technique may increase the number of workmen required at one time to mount the collector in place and a crane would almost certainly be needed. Where two men can handle a single collector, four or five might be needed to position a large collector assembly accurately. The support structure would

have to be specifically designed to receive the assembly but the design could be much more simple than those required to receive many smaller units.

D. Longer Collector Modules

A concept that has possible installed cost reduction implications for planar, flush-mounted arrays is the use of long collector modules. The design of R-M Products exemplifies this technique. They currently manufacture air and water cooled collectors in two foot widths in any length from six feet to twenty-five feet. A twenty-five foot long collector module has the obvious advantage of substantially reducing the number of manifold connections required. Figure V-1 shows such a collector ready to be set in place with a crane. Fastenings for such collectors would have to allow for thermal expansion and contraction of the unit and connections.

FIGURE V-1. View showing two foot by 24 foot air-cooled collector module being installed by a crane at the Bighorn Visitors' Center in Lovell, Wyoming. Note roofing felt underlayment and roof penetrations for manifold connections. (Photo provided by R-M Products.)

VI. DESIGN AND CONSTRUCTION MANAGEMENT CONSIDERATIONS

Each of the solar installations studied in-depth encountered technical, managerial and/or financial difficulties of varying magnitudes. These were discussed for each individual project in Section III of this report. To be sure, very few building projects -- solar or non-solar -- are trouble-free during design and construction. However, there were some problems or pitfalls which became obvious in one or several of the installations studied and which have implications for the design and execution of future solar heating and cooling projects in general. These significant areas have been extracted from the detailed studies and are discussed below. They have been divided into two general groups, 1) Design Considerations and 2) Construction Management Considerations.

A. Design Considerations

1. Collector Receiving and Roof Placement

In general, solar collectors are an awkward size and weight to handle. Most flat plate collectors are between 3 feet by 6 feet and 4 feet by 8 feet and most weigh a minimum of 100 pounds. Under ideal conditions, such as in the United Southwest National Bank, two men can take the collector up to the roof on a ladder. One man would pull with a rope from the roof while another man would guide the module up the ladder. However, if the roof is not flat, or nearly so, or the height is much greater than one story, the task becomes hazardous and strenuous.

The next option which found wide-spread application is the use of a small crane or "cherry picker". A disadvantage of this technique is that a trained operator is required and crane rental is relatively expensive for a small installation. Also, if the system is large and all the collectors cannot be placed in one day, the cost of crane rental becomes increasingly expensive. Scheduling is also a problem. Collectors may be delivered in several shipments and the

contractor may desire to set them in place as they arrive. Or, the roof may be so crowded that all the collectors cannot be placed on the roof and still allow room for mounting. In any case, consideration should be given to the logistics of installation, ideally during design, but if not during design, then at least the contractor must be aware of potential problems when he estimates costs and schedules work. If a crane is required, it may or may not add to overall costs but it does mean the involvement of another labor source and possibly another union or trade.

In one case it was strongly recommended that the collector manufacturer be required to ship only on open top trucks. Although the manufacturer may be able easily to load an enclosed trailer with a fork lift truck, conditions will be different at the site, i.e., no loading dock and no fork lift. Obviously, it is impossible for a crane to unload directly palletized collectors from a closed truck. Extra handling will be required at the minimum and it may also be necessary to unpack collectors on the ground and lift one at a time to the roof. An alternative is to rent a flat-bed truck, back it up to the loaded trailer and, in essence, use it for an off-loading dock. Such expenses could be avoided by advance planning.

2. Collector Mounting Details

Solar collectors are not at all equivalent in terms of ease of mounting. In fact, the difference in per square foot mounting and piping costs for collectors of different manufacturers can often be greater than per square foot cost of the collectors. This effect can easily render less important the several dollars per square foot cost difference that is found between most flat plate collectors. For example, a more expensive collector designed for easy installation may be a better buy than one with a lower unit cost which is awkward to install and manifold. Also, built in place collectors have a lower installed unit cost since no casing is necessary to protect the integrity of the insulation and the conventional roof insulation serves as a back insulation for the absorber panel. These lower installed unit costs may be offset by performance penalties.

Collector installation manuals, when available, appear to be very helpful to designers and contractors. Those collectors that are not provided with such manuals are often secured inappropriately or not cost-effectively. It should not be up to a project design engineer to design or select mounting brackets and details.

Flashing of the collectors to a roof to achieve a weather tight installation must often be designed specifically for each project. However, the responsibility for flashing installation is often uncertain at the outset of a project. A mechanical contractor might expect the general contractor to have a roofer install it, while the general contractor believes it should be done by the collector installer. Attention should be given to designing an inexpensive flashing system and deciding who is the proper installer before the project is too far along.

3. Insulation

Several methods of insulating above-roof piping were encountered during the site visits. The most expensive was metal-jacketed fiberglass. The insulation contract on that job amounted to \$6.20 per square foot of installed collector area. This price was for all insulation, including the storage tanks. This long lasting method of insulation may be justified on roof-top solar installations because they are often exposed to considerable roof-top visitor traffic and it would remain attractive for a long time.

Several installations had fiberglass insulation wrapped with roofing paper and covered with an asphalt coating. This did not appear unattractive and the total insulation contract on one of these jobs was about \$3.75 per square foot of installed collector area. The durability of this insulation is not known but the technique is widely used on conventional piping jobs.

Preformed foam insulation has been used extensively although it, too, is expensive.

Many different methods of insulating buried storage tanks were observed. They ranged from burying the tanks in gravel pits to unprotected sprayed-on foam to elaborate, lined, gravel-filled pits equipped with sump pump facilities to protect 2 to 3½ inches of sprayed-on foam. It is believed that the more elaborate methods were employed to be "safe", not because they were known to be necessary. It was not known how critical moisture protection of the insulation is.

A standard practice has not yet evolved which provides the designer with the confidence that a particular buried storage tank insulation system will be cost-effective over the life of the solar energy system.

4. High Collector Temperatures During Construction

Solar collectors are designed to capture the sun's heat. Unfortunately, an uncovered collector can get too hot to handle during construction. Some high performance collectors could also be degraded by high heat, under no-flow conditions during construction. Several of the projects studied had required special measures to get around this problem, including starting work at dawn, avoiding mid-day construction, and painting the glazing with a white tempera paint that could be washed off after installation. Using a water soluble paint would not be feasible if rain was expected.

This problem could be avoided by requiring or specifying that flat plate collectors be shipped with an easily strippable cover over the glazing. This could be a peel-off paper or plastic cover that would hopefully serve some dual purpose.

5. Storage Tanks

The larger the system, the larger the size of the energy storage subsystem and contained medium. Usually water is the choice because of its low cost, availability and high specific heat. One may think that a single large tank offers advantages in ease of installation over several smaller tanks; however, in two instances the steel storage tanks ordered were too big

(12 feet diameter by 58 feet long and 10 feet diameter by 24 feet long) to ship conveniently. This added greatly to storage costs. Tank diameters greater than 8 feet and lengths greater than about 30 feet should be examined carefully to assure that delivery will not be a problem. Even on a flat bed truck overall height may not allow passage under highway overpasses. Routes should be planned well in advance. One case required backing up a highway entrance ramp to negotiate a direction change.

One installation visited had to rebury a steel tank after it floated from the ground because it was not filled upon installation. Provisions should be made to prevent this possibility during construction.

6. Glass Breakage

Five of the installations studied had collector glazings damaged during construction. Prior arrangements for dealing with such occurrences should be made to prevent schedule delays and cost increases.

7. Aesthetics

The importance placed on the appearance of the solar collector array in a specific installation was found to impact the total cost significantly. If the array must be incorporated into the architectural style of the building, instead of being simply placed on a flat roof and supported on steel or wood framework, the incremental cost of the architectural modifications to the building may increase the installed costs appreciably. Aesthetic considerations appear most applicable to smaller commercial buildings, less than about 10,000 square feet (e.g. banks, stores, clinics), because they are frequently less utilitarian in design and roof-mounted, saw-tooth arrays would have a greater impact on overall appearance than on a large building. Architects should attempt to limit architectural modifications as much as possible. It may be less expensive to

hide the collectors from view than to make them look as if they are integrated architecturally with the structure.

8. Building Trades Involved

A solar heating and cooling system often requires plumbers, steam fitters, sheet metal workers, carpenters, crane and heavy equipment operators, glaziers, insulation installers, roofers, electricians and laborers. Sometimes steel workers are employed for the collector supports and sometimes control contractors are hired to handle the more complex control systems.

The owner of a system that was operational made a particularly apt comment: He said that installing a solar heating and cooling system is like purchasing a large refrigeration unit as a kit and constructing it on-site. He concluded that there were many components that could have been fabricated in a shop, brought to the site and set in place. Each extra trade involved in installation adds to the cost of the system, scheduling problems, and overhead.

Systems should be designed to limit the number of talents (trades) required to install them on the building. However, in one case even though the collectors came to the site preglazed, it was necessary to pay union glaziers while the collectors were being installed although no glass was installed on-site.

9. Building Codes

Most building codes and building inspectors have had little interaction with solar energy technology and vice versa. As a result, some problems have arisen. In one case, wooden pent-houses that supported collectors on a flat roof had to be provided with sprinklers at a significant cost because the collectors were considered as "furnaces". In another case, fiberglass hot water storage tanks could not be used because they could not be incorporated as part of a boiler system according to applicable codes. In another instance, a solar heating installation could have been prohibited from using gas as an auxiliary fuel, because

a local regulation did not allow its use as a back-up to other fuels. Fortunately, the entire building was not solar heated and was exempt from the regulation. In another case, each of 30 collectors in an array was required to have its own pressure relief valve since each was considered a water heater. This requirement has since been changed. Another jurisdiction required pressure testing of a storage tank that was installed open to the atmosphere and not structurally capable of withstanding significant pressure. Fortunately, the tank was not damaged by the test.

Being aware of potential problem areas and early discussions with regulatory officials could help reduce the likelihood of unnecessary code restrictions in system design.

B. Construction Management Considerations

1. Construction Scheduling

If a solar system is to take advantage of the economic benefits of a new versus retrofit installation, investigation of the solar design must begin early in the building's planning stages. Many of the "new buildings" visited had their solar energy systems installed when the building was nearly complete, partially negating possible benefits for new construction. They were essentially retrofit installations and the costs incurred were higher because of it.

2. Project Configuration

A typical building project involves an architect, engineer, general contractor, mechanical contractor, solar equipment supplier, solar equipment manufacturer, and various other subcontractors.

A solar project might also include a solar consultant and a structural engineer. This represents a large number of "middle-men" who take a percentage of the total cost or operate on a fixed fee basis. These fees and mark-ups combine to increase the installed system cost and thus the payback period and make a marginally feasible system even less attractive. The solution

to this problem is not obvious. While an owner could work directly with a solar equipment manufacturer, he might lose the objectivity and unbiased expertise that a professional engineer provides. The owner may also attempt to be his own general contractor, but may encounter difficulty in the scheduling of construction and site supervision required of a successful project.

3. Taxes

Many states and cities have construction taxes which are imposed on new construction and materials. These can be in the range of 1% to 5%. These too add to the pay-back period and may make the solar energy system a poor investment. It is hoped that in time, these taxes will be removed to improve system viability.

4. Prebid Conference and Negotiation

It was also suggested that a prebid conference be held to allow contractors to ask questions and to explain recommended installation procedures. In this way, the contractors' fear of the unknown would hopefully be alleviated somewhat, resulting in lower bids. This "fear factor" was believed to have caused more than a 15% increase in the bid price for one job studied.

It may also be desirable to reserve the right to negotiate with the lowest bidders. Often a contractor may know of a better (i.e. less expensive) way to accomplish functionally the desired results.