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USAF SOLAR THERMAL APPLICATIONS CASE STUDIES

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FOREWORD

This report is the product of the second phase of research for the USAF Engineering and Services Laboratory, performed under NASA/JPL management, under JPL contract number 955887, "USAF Thermal Applications Analysis". The first phase of research was a generic USAF applications analysis, as reported in "USAF Solar Thermal Applications Overview", dated May 4, 1981.

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I. INTRODUCTION

A. BACKGROUND

This report of five USAF solar thermal application case studies represents the second step in a cooperative program between the U.S. Air Force Engineering and Services Laboratory (ESL) and NASA's Jet Propulsion Laboratory (JPL), to investigate the potential of solar energy technologies to meet USAF mission-related applications for process heat.

It is a stated DoD and USAF objective to reduce the dependence of military installations on fossil fuels by promoting the use of more abundant resources where liquid hydrocarbons and natural gas are now used. Concerns for energy availability and rising energy prices have led to the establishment by the U.S. Air Force of a goal of replacing 10 percent of current facilities' energy consumption with alternative fuels and 1 percent with solar and geothermal resources by 1985.

The major use of fossil fuels by USAF installations is to produce heat. If USAF facilities' energy goals are to be met, emphasis must therefore be placed on the test, evaluation and utilization of renewable energy systems to provide process heat and space heating. Of these two areas, the more critical to USAF mission accomplishment is that of process heat generation.

As a step toward meeting its facilities energy objectives, ESL sponsored this research into solar energy technologies' potential to meet USAF applications' operational requirements for process heat. Because NASA's Jet Propulsion Laboratory had a history of interest in USAF energy applications and was responsible to the U.S. Department of Energy for carrying out a "Thermal System Engineering Experiment" to provide industrial process steam from a point focussing solar collector, JPL was asked to manage the research.

As originally conceived in early 1980, the ESL/JPL effort to investigate solar thermal energy systems in USAF applications was to be a four step effort: 1) A USAF applications analysis to investigate the potential operational and cost-effectiveness of selected thermal technologies in USAF applications; 2) Selection of a site and preliminary design of a point focussing solar thermal plant for a USAF application; 3) Construction and test of an engineering prototype; and 4) Installation and operation of a solar thermal energy plant in a selected USAF application. Initial estimates were that a joint USAF/DOE effort to complete such a program could be accomplished for \$1.2 million, over 3 to 4 years.

The results of this first step and of successful collateral work during the last year and a half, have made us believe that the original schedule could be accelerated. Efficient management by JPL has led to the accomplishment of both steps one and two within the funding originally established for the first phase alone. A USAF thermal applications overview was delivered to ESL on May 4, 1981, which evaluated four solar technologies' potential to meet generic USAF process heat needs. This volume presents analyses of a selected point focussing system to meet five specific USAF process needs. Applied Concepts has also completed and delivered under separate cover, a detailed design for a single module, point focussing plant to provide process steam to the Worldwide Landing Gear Facility at Hill AFB, Utah.

During the time that this work was being accomplished for ESL, parallel research and development for the civil sector has taken place which can forward USAF objectives. In December 1980, Applied Concepts Corporation and its manufacturer/subcontractor, Power Kinetics, Inc. (PKI), were awarded a competitive contract to apply PKI's system design to an industrial process heat application. At that time, JPL evaluated the PKI system as being the most advanced and most proven design for this application category. Applied Concepts has attempted to take maximum advantage of progress in plant design and checkout in the civil sector to advance its understanding of point focussing systems for USAF needs. Specifically, we believe that the installation and operation of two PKI systems as part of DOE/JPL's Thermal System Engineering Experiment represents a sufficient prototype test, and therefore the accomplishment of the third step of the earlier USAF program plan.

This means that by the end of calendar year 1981, the first three steps of this USAF facilities energy initiative, conceived in 1980, will be completed. The installation and operation of a point focussing solar thermal steam plant in a USAF application is now a reasonable goal for 1982. The projected total cost of the complete program is now less than \$300,000 versus \$1.2 million. The total time to completion can be two and a half years.

The following case studies and final report are therefore oriented toward this practical scenario. The energy system which has been defined and costed for the study is a real operating system as opposed to just a design. The costs assume no further technical advances, and no reductions in prices for the solar equipment.*/

B. THE RESULTS OF THE USAF APPLICATIONS OVERVIEW AND THE SELECTIONS OF FIVE APPLICATIONS FOR CASE STUDY

From the outset, the problem of determining the attractiveness of solar thermal energy systems for USAF applications was divided into two parts. The first was to gain a general understanding of USAF process heat needs, of the ability of different solar technologies to meet those needs, and of the economic aspets of their utilization in an Air Force environment. The second was to select a few likely applications for detailed study against a specific solar technology. JPL's charter to develop point focussing distributed receiver technologies led to the early specification of this solar hardware alternative for a case study. The results of Phase I, the generic analysis, led to the selection of five applications for the analysis.

The results of the generic analysis are summarized in Figure I-1. The major thrust of analytical results was that a number of solar technologies now appear to be cost-effective in a variety of USAF process heat applications. Point focussing systems are most suited for low- to mid-temperature process steam applications of the sort typical of USAFLC logistics centers, but also found at bases with central steam plants which support both summer and winter loads. These same applications can also be met with line focussing solar thermal systems which are in a more advanced stage of development. Point focussing systems are of interest because they have a potential for higher efficiency in the delivery of heat, for higher efficiency cogeneration of electricity, and for near-term price reductions.

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*/ The system costs used here do not include funds for special instrumentation or test and evaluation. They therefore do not represent the total cost of an evaluation plant. They do represent all of the installed energy plant costs for a near-term USAF installation, i.e., the second and subsequent plants after evaluation of a preliminary installation.

Figure I-1. Summary of Results
USAF Applications Overview

CONCLUSIONS

- Solar thermal technologies have the technical and operational capabilities to meet a large variety of USAF process heat needs.

- There is no single favored technology option. Flat plate and line focussing systems are attractive for some applications and are available immediately. Solar ponds and point focussing systems will be attractive for some applications, and will be available in the near term (1-3 years).

- USAF has a large number of low temperature applications which are immediately attractive on the basis of cost, yielding a projected annual return on investment (ROI) of 19-29% in high insolation areas and 4-14% in low insolation areas. These applications are best met with low temperature collectors.

- Mid-temperature applications show ROIs of 4-20% in high insolation areas. These applications can be met with line focussing or parabolic dish collectors.

- Highest benefit/cost applications are:

  1) On bases with the best solar climate.
  2) Where back-up fuel is most expensive.
  3) In low- to mid-temperature processes.
  4) Where heat is provided directly to the application.

- Site specifications will often inhibit solar retrofit applications, and will strongly impact on system design, cost, and payback.

Applications for case study were selected according to the following criteria and limitations:

1. They were selected from bases visited in Phase I (Eglin, Lowry, March, MacDill, Tinker, and Robins AFBs).
2. They represent the best group of technologies (i.e., replacement of low- to mid-temperature steam) found at these bases, according to the methodology of Task 1.
3. They represent a variety in application and location, while emphasizing USAFLC needs which are the dominant and most standardized USAF process heat applications.
4. They represent applications for which the most rigorous and available characterizing data exists.
5. They were selected from bases which exhibited a command interest in project success during Phase I.

The application of these criteria led to the selection of five process heat applications:

1. Tinker AFB, Plating Shop
2. Tinker AFB, Degreaser
3. Tinker AFB, Insertion into Central Plant
4. Lowry AFB, Environmental Control, Bldg. 1307
5. MacDill AFB, Insertion into Hospital Steam Plant.

Cases 4 and 5 are representative of non-USAFLC applications, which largely consist of space conditioning or central plants whose major loads are space conditioning. Cases 1, 2, and 3 are representative of plant requirements at the USAFLC Logistics Centers.

These five cases form the object and basis for this study and report. Part II, General Approach, addresses the methods, tools, and assumptions of the study. Part III presents the five individual analyses for the above applications. Part IV, Results and Conclusions, presents the comparative results and reports on sensitivity studies which depart from the baseline case.

II. GENERAL APPROACH

A. ASSUMPTIONS

The general technical feasibility of using point focussing distributed receiver (PFDR) solar energy systems to provide process steam is taken to be proven. The current installation of a Power Kinetics, Inc. designed and manufactured collector at Capitol Concrete Products in Topeka, Kansas and of a General Electric Corp. designed and Solar Kinetics, Inc. manufactured plant at Bleyle of America, Inc., in Shenandoah, Georgia, will confirm this assumption.

The five cases for study were selected in May 1981, as a result of Phase I of this analysis, for their operational feasibility. The major problem for this Phase II analysis, therefore, is that of economic feasibility. For each of the five cases, then, it was necessary to specify a conceptual plant design whose costs and performance could be compared to the fossil fuel alternative.

The economics of solar energy differ from that of fossil energy. Fossil fueled energy systems are characterized by relatively low capital investment, followed by a steady stream of subsequent fuel and maintenance costs. In general, fuel costs represent the overwhelming proportion (up to 90%) of the overall cost of energy for conventional systems. Hence, the cost of such energy is closely tied to fuel prices.

Solar systems, by contrast, are extremely capital intensive. They are characterized by high initial cost, followed by a stream of relatively small annual costs for maintenance. The cost of solar energy is thus tied very closely to collector purchase and installation costs, and collector performance. The cost to purchase and install a solar collector is essentially independent of the actual energy output of that collector (per unit area). For any collector, at any initial cost, the cost per unit of energy produced is inversely proportional to collector output. In other words, because an identical system will produce more or less energy depending on the amount of incident sunlight, solar energy is least expensive where sunlight is most readily available and thus when collector energy output per unit of area is maximized.

In the case studies that follow, it is assumed that USAF a PFDR installation would operate in a fuel displacement mode. In this case, the solar energy plant provides heat in parallel to a conventional system, whenever the sun shines. The net present value of the solar system is the difference between the present value of the fuel saved and the present value of all solar systems costs over the life of the system.

Several economic assumptions were made in the following analyses that are specific to Air Force applications of solar energy. There were no tax considerations and land costs were assumed to be zero. It was assumed that the Air Force would have design and installation of the solar system performed by outside contractors and that routine operation and maintenance would be performed by Air Force civilian or military personnel.

In order to found technical and economic analyses in this study on a realistic data base, actual performance and cost data for a specific PFDR collector were used in the analysis. The collector used in this analysis is manufactured by Power Kinetics, Inc. (PKI) of Troy, New York. It is the most developed and least costly PFDR collector per unit energy output of those systems now being actively marketed.

The distinguishing characteristic of the PKI concentrator is its faceted reflector (see Figure II-1). Rather than employing expensive large curved reflective surfaces, the PKI design incorporates 864 flat mirror tiles in a Fresnel configuration. Specific cost and performance assumptions for the PKI design are listed in Figure II-2.

$$B/C = \frac{PV_E}{PV_S}$$

Benefit/cost ratio is commonly used in Air Force energy planning and decision-making, and is therefore included in this report.

For reference purposes, the annual levelized price of fossil fuel and of solar energy are also included. They are calculated according to the equations

$$L_E = CRF \cdot PV_E/E_S$$

$$L_S = CRF \cdot PV_S/E_S$$

where

L_E = Levelized price of fossil fuel, 1983 \$/MBTU
L_S = Levelized price of solar energy, 1983 \$/MBTU
CRF = Capital Recovery Factor = $\frac{D(1+D)^N}{(1+D)^N-1}$

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III. THE CASE STUDIES

A. LOWRY AFB - ENVIRONMENTAL CONTROL

1. Introduction

The first potential solar application studied was environmental control of Lowry AFB classroom building 1307. Lowry AFB is an Air Training Command installation whose primary mission is education. It is located to the east of Denver, Colorado. It has the best insolation of the sites studied.

2. Process Description

Building 1307 is a large, one-story classroom facility with 87,360 square feet of floor space. The building has an installed natural-gas fired steam plant with 5.65 MBTU/hr. capacity. Steam is used to provide space heating and air conditioning. The building is in year-round use, and although classroom facilities are not used 24 hours per day, 7 days per week, the base engineering staff has indicated that the steam plant is in constant operation. According to the Lowry AFB Civil Engineering staff, 240°F steam is produced at a constant rate of 3 MBTU/hr. Condensate return temperature has not been measured, but the heat plant is reportedly similar to that of the steam system in building 361 which returns condensate at 170°F. Actual fuel use is not metered at the building, so that reported boiler efficiency must be regarded as an estimate. The authors used an estimate of 70% combustion efficiency for this study. One man is assigned part-time for boiler maintenance; there are no personnel assigned for operation.

3. Solar Application

The solar application considered was steam insertion into the building steam network. The solar energy system was assumed to operate in steam flashing mode. The collector outlet temperature equals the required steam temperature of 240°F. Collector inlet temperature was assumed to be equal to the condensate return temperature of 170°F.

Using PROSYS, net collector output was calculated to be 0.506/MBTU/ft.^{2} average annual performance. These values take collector and heat transport losses into account. Load matching using PROSYS indicates an optimum array of 13 PKI collectors (for a total of 11,232 sq. ft.) to meet the load. A conceptual design for collector array layout at Lowry is illustrated in Figure III-1. This site plan is based on the conceptual fluid loop design of Figure II-3, and a foundation design (Figure II-4).

As shown in the figure, collectors are to be placed at 50' intervals, 50' from a central above-ground insulated pipeline. In the middle of the pipeline is a pumphouse to be connected to building 1307 via a 300' buried pipeline. Collectors are staggered along the pipeline to ensure that collecter center-to-center distance exceeds 100'.

4. <u>Economic Evaluation</u>

Of the economic parameters included in the analysis performed for this study, three were site/application dependent: (1) solar system cost, (2) conventional fuel cost, and (3) conventional fuel escalation rate.

A detailed estimated solar system cost breakdown is presented in Figure III-2. The 1983 cost per square foot is the fundamental input to ECONMAT.

The conventional fuel now used to heat the building 1307 boiler is natural gas, for which Lowry currently (23 July 1981) pays $3.75 per MBTU. In the baseline scenario, natural gas prices at Lowry were assumed to escalate at 32% per year from 1981 to 1986 and at 11% thereafter (see Chapter II).

Figure III-1. Site Plan, Lowry AFB

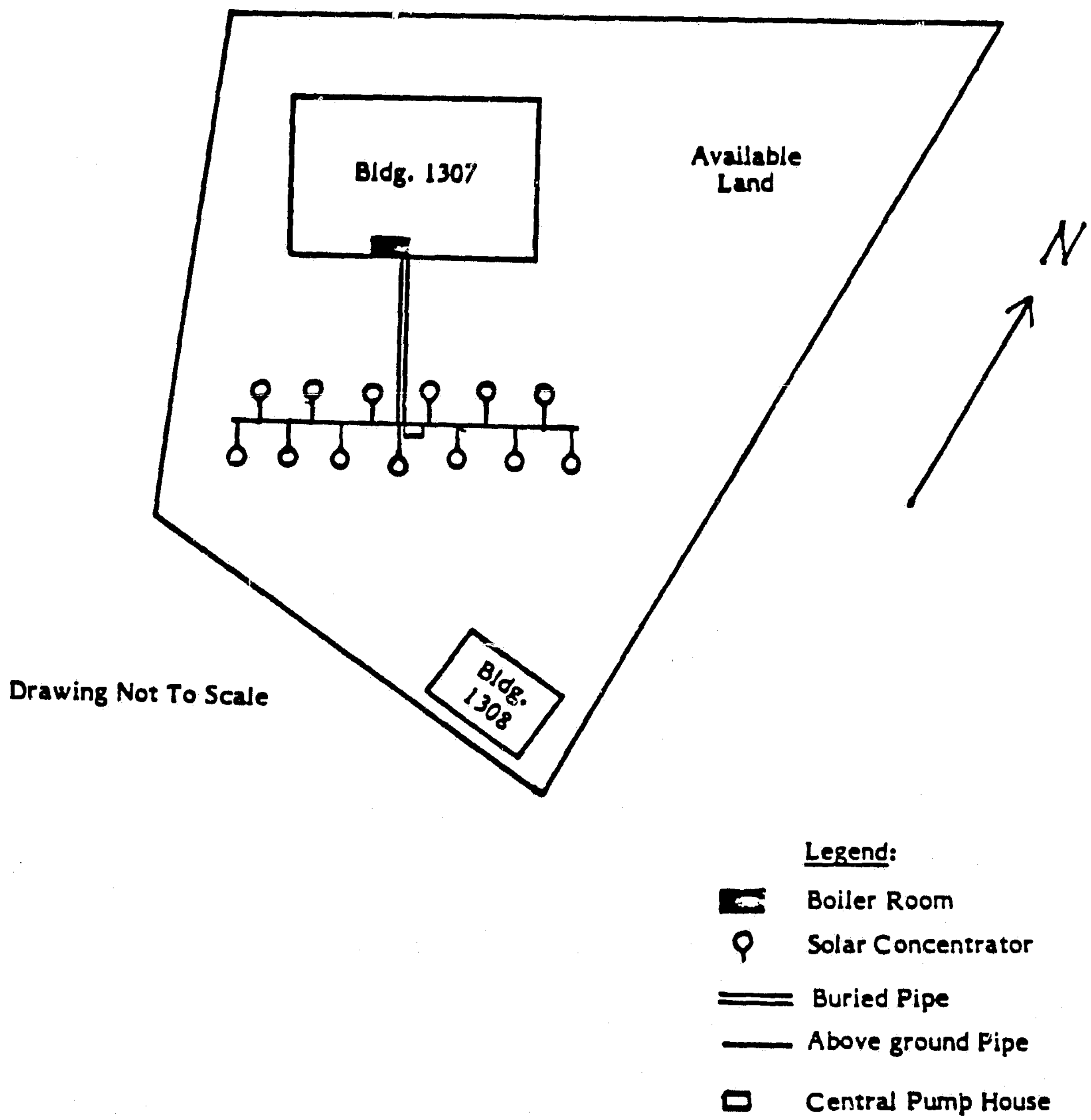


Figure III-2.

Detailed Cost Breakdown: Solar Energy Plant Conceptual Design for Lowry AFB Building 1307

I. Installation (Costs are 1981 $ per collector unit)

	Materials	Labor
Foundation		
20 yds.^{3}/unit	$140/yd.^{3} = $2800	$170/yd.^{3} = $3400
Mechanical & Electrical		
Piping & Insulation 150'/unit	$11.20/ft. = $1680	$15.55/ft. = $2332
Power Wiring 150'/unit	$1.00/ft. = $150	$2.10/ft. = $315
Control Wiring 150'/unit	$1.00/ft. = $150	$2.50/ft. = $375
Supports 15/unit	$15/Ea. = $225	$25/Ea. = $375
Power Bus & Boxes	$100	$200
	$5105	$6997

Total Materials & Labor	$12,102
6% Engineering Fee	726
Subtotal	**$12,828**
PKI Installation Costs	7,800
Freight	2,300
Subtotal	$22,928
25% Contingency	5,732
Total Installation Cost Per Unit	**$28,660**

(Continued)

Figure III-2 (Continued)

II. Interface (for 13 unit installation; not per unit)

	Materials	Labor
300' Ricwil pipe (buried) (3" steam, 1" cond. ret.)	$50/ft. = $15,000	$15/ft. = $4,500
300' Feedwater pipe	$2/Ft. = $600	$3/ft. = $900
Pump Package	$2,500	$1,500
Separator	$800	$300
Tie-in	$1,500	$3,000
Electrical & Miscellaneous Interface	$1,200	$1,500
Pump House	$3,000	$1,500
	$24,600	$13,200

Total Materials & Labor		$37,800
6% Engineering Fee		2,268
	Subtotal	$40,068
25% Contingency		10,017
	Total Interface Costs	$50,085

(Continued)

Figure III-2 (Continued)

III. Overall Lowry 13 Unit Estimate

Subcontract Costs (from preceding pages)

Unit installation to common interface points, loaded labor & materials:

13 x $28,660 =	$372,580
System interface from collection point, loaded labor & materials:	50,085
Installation and Interface Subtotal	**$ 422,665**
PKI Hardware 13 x $44,000 =	572,000
Contract Supervision (1050 Hrs. @ $40/Hr.)	42,000
	1,036,665
5% Profit	51,833
Project Total	**$1,088,498**

(To find 1983 cost, escalate all costs at 8%/year, except PKI hardware for which no escalation is assumed.)

PROJECT TOTAL 1983 COST: $1,169,685

Collector cost per square foot, 1981: $96.9

Collector cost per square foot, 1983: $104.1

The results of the economic analysis are summarized in Figure III-3. As indicated by a positive net present value, the potential solar system described herein would, if installed, result in significant savings to the Air Force over the system lifetime.

Figure III-3. Economic Analysis for Case 1

Discounted Net Present Value (NPV) (1983 dollars)	\$172,000
Benefit to Cost Ratio (B/C)	1.10
Levelized Price of Natural Gas (\$/MBTU)	\$39.80
Levelized Price of Solar Energy (\$/MBTU)	\$36.20

B. MacDILL AFB - HOSPITAL

1. Introduction

The second potential solar application studied was steam insertion into the central heating facility at the MacDill AFB Hospital. The hospital steam plant at MacDill is typical of USAF hospitals, except that it utilizes only fuel oil as a primary fuel. For this reason, the facility is of special interest for a potential solar application.

2. Process Description

The hospital building (#711) at MacDill AFB is a 150 bed, 3 story facility, of 124,000 square feet gross area. The hospital must be maintained at $72^{\circ} \pm 1^{\circ}$ F and 50% $\pm$ 1% humidity at all times. Steam is used at the facility for space conditioning, hot water, and steam processes such as autoclaving. The current source of steam is 3 oil-fired, high pressure steam boilers, each rated at 178 h.p., located in building 712 adjacent to the hospital. Cooling is provided by water cooled centrifugal and absorption chillers, with a refrigeration capacity of 900 tons. Number 2 oil is used as a fuel since installation of natural gas lines would be prohibitively expensive. The plant is manned at all times and metered. A monthly load profile in average MBTU/hr. is shown in Figure III-4; average loads vary from 3.42 MBTU/hr. in February to 6.67 MBTU/hr. in November of a typical year. Measured fuel utilization efficiency is 65.4%. Steam is supplied at 338°F, and condensate is returned at 170°F.

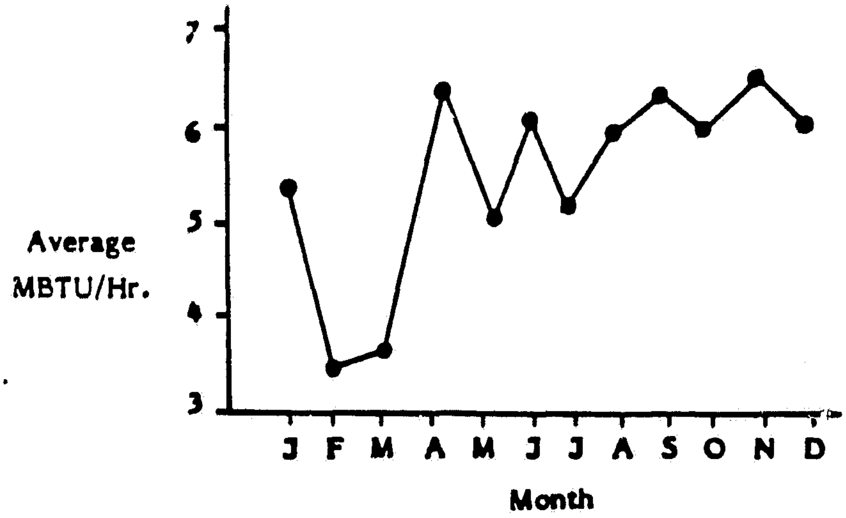


Figure III-4. Monthly Load Profile in Average MBTU/HR (MacDill AFB)

3. Solar Application

The solar application considered was steam insertion into the central steam network. The solar system was assumed to operate in steam flashing mode, hence the collector outlet temperature equals required steam temperature of 338°F. Collector inlet temperature was assumed equal to the condensate return temperature, 170°F.

Using PROYSYS, net collector output (i.e., taking losses into account) was calculated to be 0.36841 MBTU/ft.^{2}/year average annual performance. Under the assumption that peak array output should match minimum process demand, the solar array was sized at 16 collectors (13,824 ft.^{2}).

A conceptual site design for a collector array at MacDill AFB is illustrated in Figure III-5. As shown in the figure, collectors are assumed to be placed at 50' intervals, 50' from two central, above ground insulated pipelines. These lines feed into a central pumphouse, which is connected to building 712 (hospital boiler facility) via a 275' buried pipeline. As with Lowry, concentrators are staggered to assure proper center-to-center distance.

2. Economic Evaluation

An estimated solar system cost breakdown is presented in Table III-6. Unit installation costs should be similar to those for Lowry AFB, except that freight charges were calculated to be $1500 per unit. The costs of process interface materials and labor, including pump package and house, separator, tie-in, and electrical and miscellaneous interface equipment were scaled linearly from those at Lowry. Contract supervision, on the other hand, was assumed to be the same as at Lowry. This is because installation elapsed time was assumed to be the same for both plants.

The conventional fuel now used by the hospital boiler is #2 fuel oil. In the baseline scenario, #2 fuel oil price was assumed to escalate at 11% per year (3% differential fuel escalation).

The results of the economic analysis are summarized in Figure III-7. As indicated by a negative net present value, the conceptual solar design described in the preceding would not result in savings to the Air Force under the baseline fuel escalation scenario, and a system lifetime of 20 years.

Figure III-5. Collector Array Layout/MacDill AFB

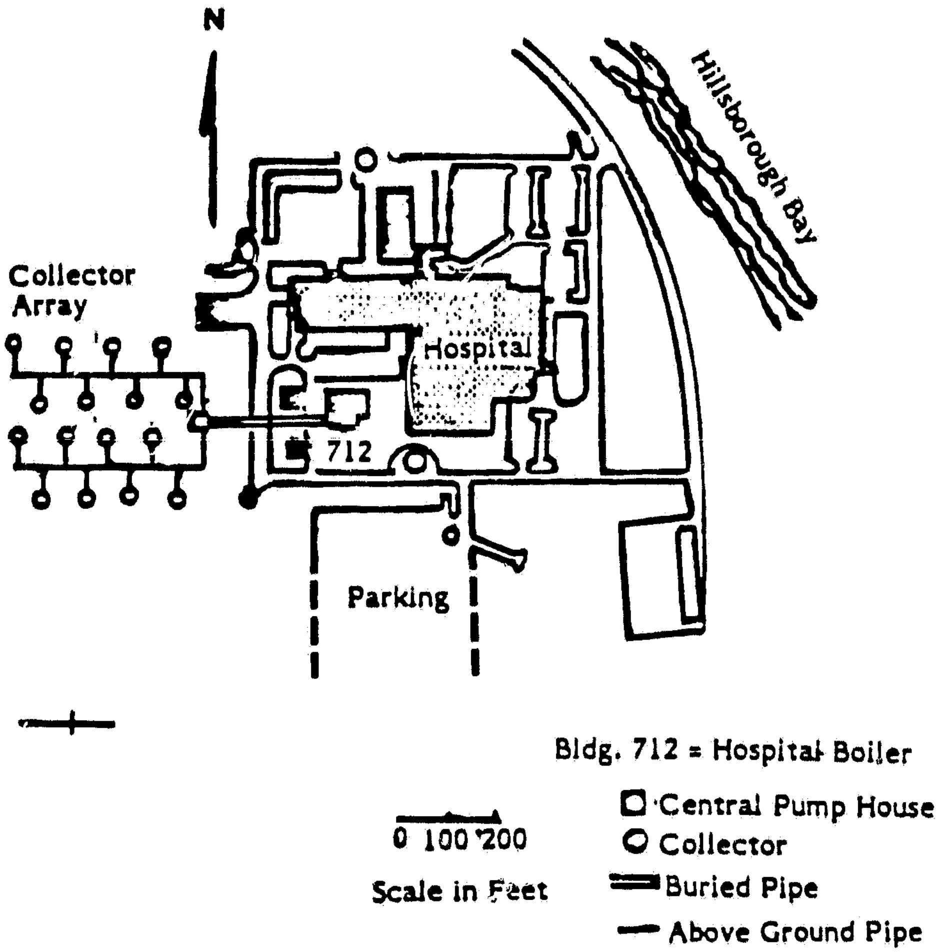


Figure III-6

Detailed Cost Breakdown, Solar Energy Plant Conceptual Design for MacDill AFB Hospital

I. Installation (1981 $/Unit)

Total materials, labor, fee PKI installation (same as Lowry)			$20,628
Freight			1,500
		Subtotal	$22,128
25% Contingency			5,532
	Total Installation Cost Per Unit		$27,660

II. Interface Costs

	Materials	Labor	
275' Ricwil (buried) pipe (3" & 1" steam & cond. ret.)	$50/ft. = $13750	$15/ft. = $4125	
275' 1" Feedwater pipe	$ 2/ft. = $550	$ 3/ft. = $825	
Pump package, house, separator, tie-in, electrical & miscellaneous (scaled from Lowry)	$11,077	$ 9,600	
	$25,377	$14,550	
Subtotal, Materials & Labor			$39,927
6% Engineering Fee			2,396
		Subtotal	$42,323
25% Contingency			10,580
		Total Interface Costs	$52,903

(Continued)

Figure III-6 (Continued)

III. Overall 16 Unit Estimate

Subcontract Costs (from preceding page)

Unit installation to common interface point, loaded labor & materials:

16 x $27,660 =	$442,560
System interface from collection point, loaded labor & materials:	52,903
Total Installation & Interface Costs	**$495,463**
PKI hardware	
16 x $44,000 =	704,000
Contract Supervision	
1,050 Hrs. @ $40/Hr. =	42,000
Subtotal	**$1,241,463**
5% Profit	62,073
Project Total	**$1,303,536** (1981 dollars)
Project Total 1983 Cost:	**$1,397,442**

Collector cost per square foot, 1981: **$94.3**

Collector cost per square foot, 1983: **$101.1**

Figure III-7

Economic Analysis for Case 2

Discounted Net Present Value (NPV) (1983 dollars)	-$214,000
Benefit to Cost Ratio (B/C)	0.90
Levelized Price of #2 Oil ($/MBTU)	$43.40
Levelized Price of Solar Energy ($/MBTU)	$48.30

C. TINKER AFB - DEGREASER

1. Introduction

Three applications were chosen for study at Tinker AFB. The USAFLC Logistics Center has more process applications than all of the other bases visited in Phase I. These applications are representative of a range of USAFLC industrial heat application temperature and load requirements. This third case study investigated the use of solar process steam from a small, single collector plant to meet a medium temperature process load.

2. Process Description

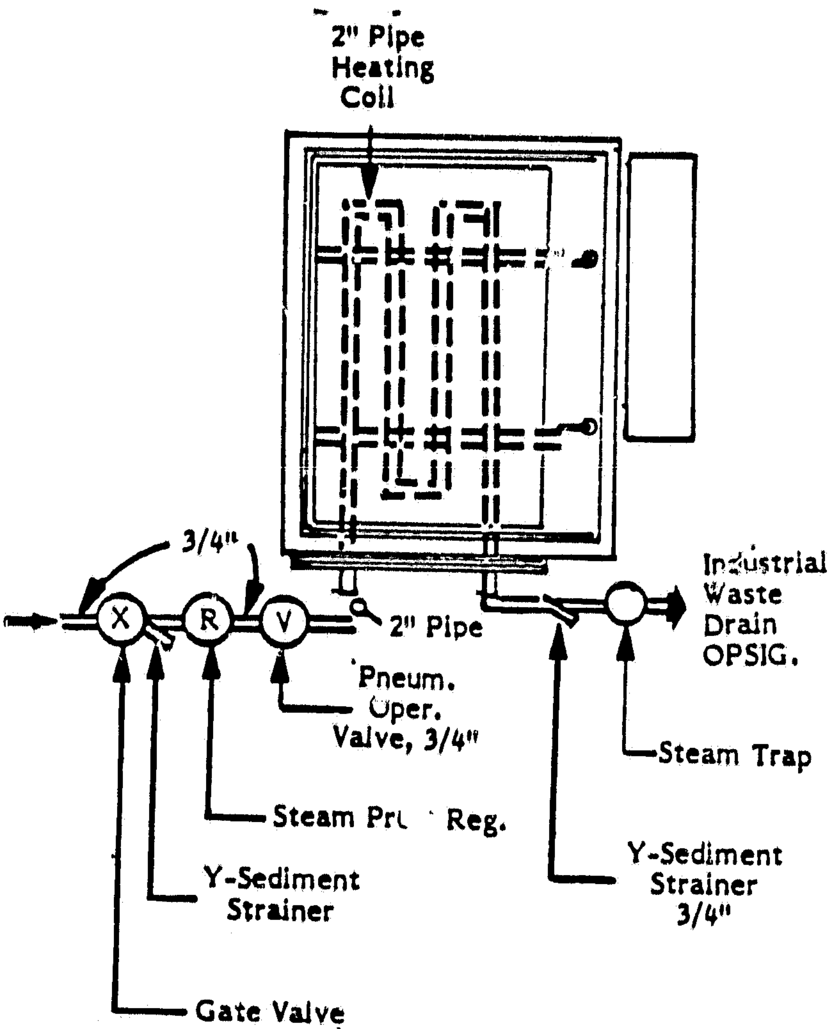
Vapor degreasers are used to remove grease from metal parts using steam-heated organic solvents. Two types of degreasers are currently employed at Tinker. They are distinguished chiefly by the solvent used: perchloroethylene versus trichloroethane 1.1.1. This analysis is based on four trichloroethane degreasers which are in use at Tinker, two in building 3001 and two in building 2210. The present case examines application at the latter site.

Figure III-8 illustrates a fluid loop schematic for a typical trichloroethane degreaser. The boiling temperature of the solvent used is reported as 158°-174°F, and the pressure of steam used to heat the degreaser is 3-10 p.s.i.g. (corresponding to 220°-239°F, assuming saturated steam). Steam runs into the heating coil and is condensed in the loop or in the steam trap and is then dumped into the industrial waste drain (no condensate return). Heat rate is reported as 0.105 MBTU/hr. per degreaser. Degreasers are in continuous operation, 24 hours a day, 365 days a year. Steam currently used to heat the degreasers is produced in the central boiler in building 3001, which burns natural gas with an overall efficiency, including transport losses, of 60%.

3. Solar Application

The solar application considered was direct provision of solar-produced steam to the two degreasers. Steam was assumed to be provided at 220°F. This was therefore

Figure III-8. Fluid Loop Schematic, Trichlorethane Degreaser



the assumed collector outlet temperature. Collector inlet temperature was assumed to be 55°F (nominal groundwater temperature), since no condensate is returned.

Using PROSYS, net collector output was calculated to be 0.438 MBTU/ft.^{2}/yr. annual performance. One 864 ft.^{2} collector produces 0.235 MBTU/hr. peak, sufficient to meet the demand of both degreasers (2 x 0.105 = 0.21 MBTU/hr.).

A conceptual site diagram for a single collector installation is illustrated in Figure III-9. The collector is assumed to be located 100' to the east of building 2210. As the building's height is approximately 15 feet, there should be no significant shading loss.

4. Economic Evaluation

An estimated cost breakdown is presented in Figure III-10. Freight charges were calculated to be $1900 for the one collector unit. As with MacDill, all process interface costs except underground (Ricwil) piping and contract supervision costs were scaled linearly. Contract supervision costs were calculated assuming a four week installation period.

Conventional fuel now used for the degreaser was considered to be natural gas, which is used by the central boiler in building 3001. Tinker currently (23 July 1981) pays $2.76/MBTU for natural gas. In the baseline scenario, natural gas prices at Tinker were assumed to escalate at 40% per year from 1981 to 1986, and at 11% thereafter (see Chapter II).

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Figure III-9. Site Plan: Tinker AFB Degreaser

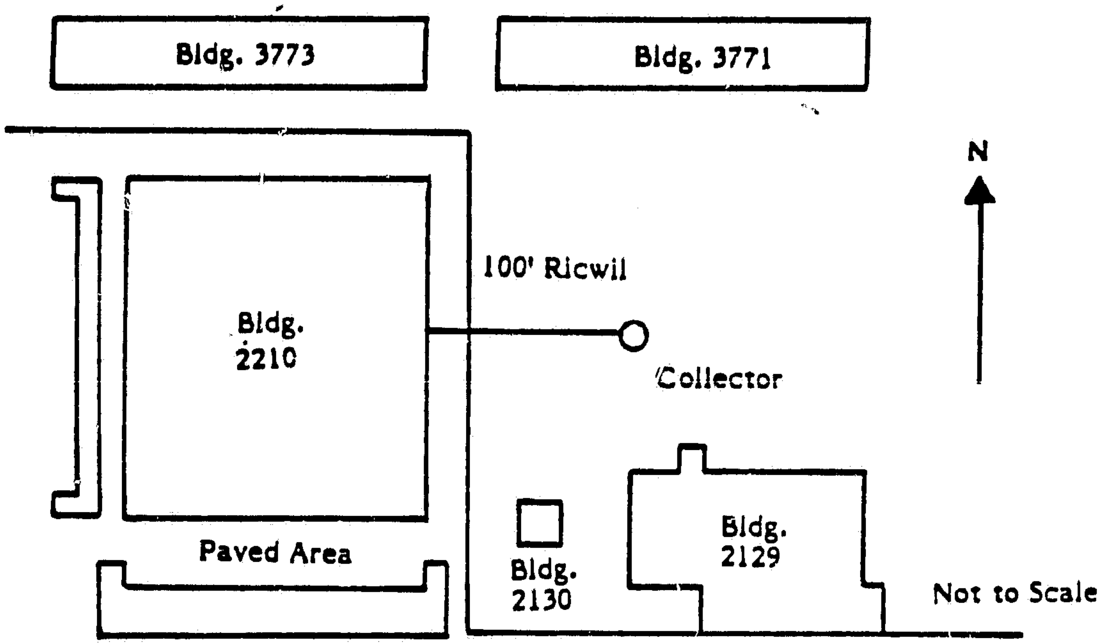

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Figure III-10

Solar Energy Plant Conceptual Design for Detailed Cost Breakdown - Tinker AFB Degreaser

I. Installation (1981 $/Unit)

Total materials, labor, fee, PKI installation	$20,628
Freight	1,900
	22,528
25% Contingency	5,632
Total Installation Cost per Unit	**$28,160**

II. Interface Costs

Interface Costs	Materials	Labor
100' Ricwil (buried) (3" steam, 1" cond. ret.)	$50/ft. = $5000	$15/ft. = $1500
100' 1" Feedwater Pipe	$2/ft. = $200	$3/ft. = $300
100' Insulated Pipe (indoor)	$11.20/ft. = $1,120	$15.55/ft. = $1,555
Pump package, house, separators, tie-in, electrical & miscellaneous (scaled from Lowry)	$ 692	$ 600
	$7,012	$3,955

Subtotal, materials & labor	$10,967
6% Engineering fee	658
Subtotal	**$11,625**
25% Contingency	2,906
Total Interface Costs	**$14,531**

(Continued)

Figure III-10. (Continued)

III. Overall Cost Estimate

Subcontract Costs (from preceding page)

Total installation and interface, loaded labor & materials		$ 42,691
PKI hardware		44,000
Contract Supervision 160 hrs. @ $40/Hr. =		6,400
	Subtotal	**$93,091**
5% Profit		4,655
	Project Total	**$ 97,746 (1981 $)**
	PROJECT TOTAL 1983 COST:	**$106,323**

Collector cost per square foot, 1981:	**$113.1**
Collector cost per square foot, 1983:	**$125.5**

The results of the economic analysis are summarized in Figure III-11. As indicated by a negative net present value, the conceptual solar design described in the preceding table would not result in savings to the Air Force under the baseline fuel escalation scenario.

Figure III-11. Economic Analysis Results for Case 3

Net Present Value (NPV) (1983 dollars)	-$16,000
Benefit to Cost Ratio (B/C)	0.90
Levelized Price of Natural Gas ($/MBTU)	$45.60
Levelized Price of Solar Energy ($/MBTU)	$50.40

D. TINKER AFB - PLATING SHOP

1. Introduction

The fourth potential solar application studied was the electroplating facility in building 3001 at Tinker AFB. This represents a large, low temperature application, typical of USAFLC Logistics Centers.

2. Process Description

The electroplating facility at Tinker occupies 38,000 square feet in building 3001. Figure III-12 illustrates the location of the plating shop, together with surrounding buildings and land. The plating facility includes 11 major plating lines consisting of 170 tanks distributed over the pit floor, which also contains the piping for the tanks. Tanks are currently heated using steam from the building 3001 central boiler, which has a reported efficiency of 60%. Condensate from the plating shop is discarded to prevent corrosive chemicals from a defective tank from ever entering the central steam network. Required process temperature varies from tank to tank. Except for black oxide and wax-dewax tanks (which were excluded from this study), tank temperatures ranged from 110^{o} -210^{o}F. Temperature in a given tank is maintained via thermostatic valves at each tank. Tanks are in use 24 hours per day, 7 days per week, 52 weeks per year.

Actual steam usage of each plating tank, or of the shop as a whole, have not been measured. Thermal requirements of each tank have been estimated based on computed heat losses from the tank, less thermal input due to the resistive heating of the plating solution by plating current in a June '78 Battelle Institute study for AFLC. Total daily thermal usage for the tanks considered in this study was calculated to be 102.51 MBTU, corresponding to a required heat rate of 4.271 MBTU/hr.

3. Solar Application

The solar application considered was insertion of steam into the plating shop steam network. The solar system was assumed to operate in steam flashing mode, and to provide steam at 225^{o}F. Since condensate is not returned, collector inlet temperature was assumed to be that of ground water, 55^{o}F.

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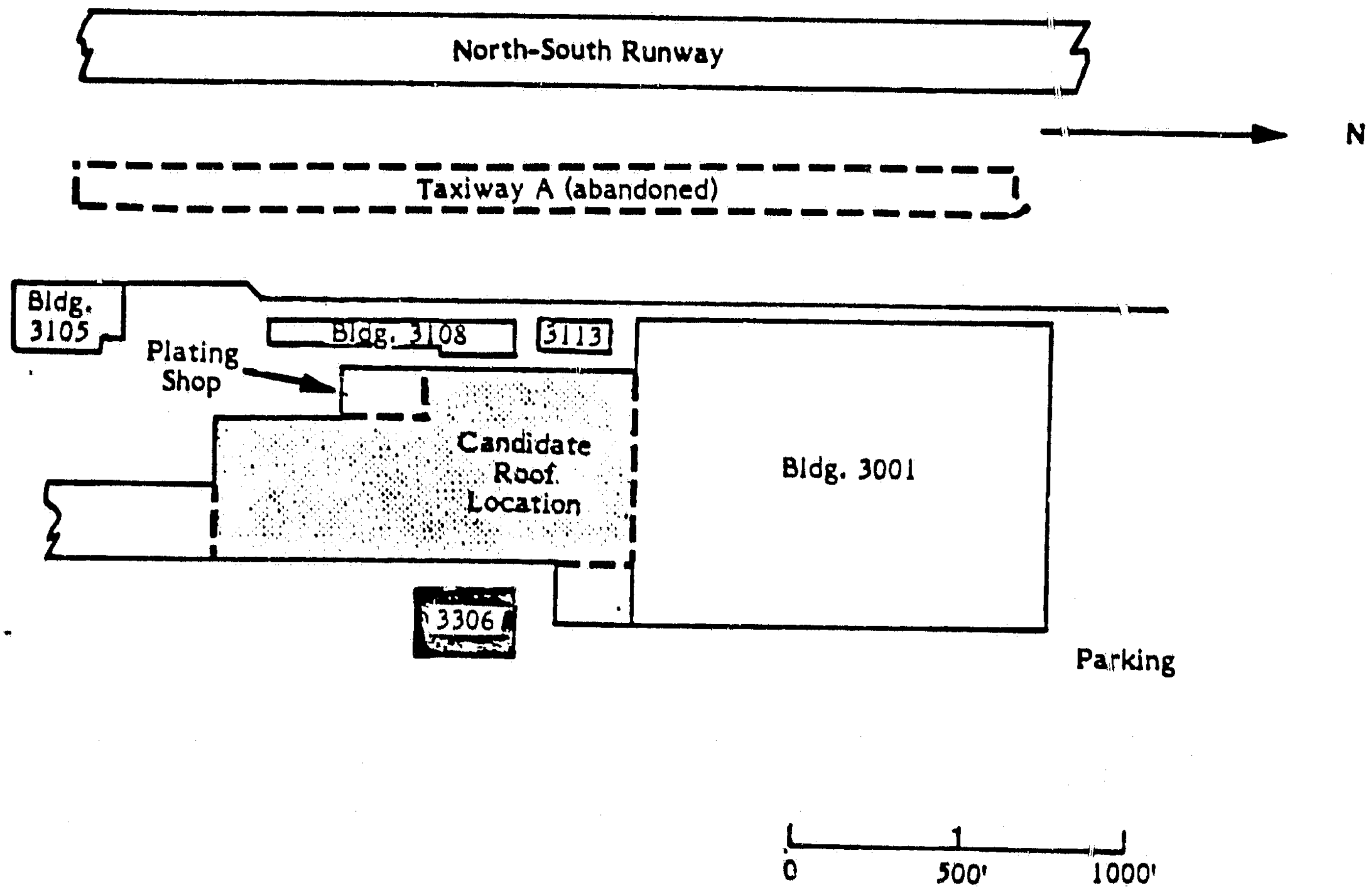
Figure III-12. Tinker Building 3001 Plating Shop and Environments



Using PROSYS, net collector output (i.e., taking losses into account) was calculated to be 0.43710 MBTU/ft.^{2}/year annual performance. Under the assumption that peak array output should match minimum process demand, the solar array was sized at 19 concentrators (16,416 ft.^{2}).

Due to height restrictions, land to the west and south of the plating shop is not available for collector installation. Moreover, the roof of the shop is of lightweight construction, and cannot be assumed to bear the loads that a collector would impose. The most feasible location for collector placement is the roof of building 3001 adjacent to the shop (see Figure III-12). Although calculated load capacity does not exist, this area is probably strong enough to support a collector array. Actual design of a foundation roof-mount foundation was beyond the scope of this study, and hence a conceptual diagram showing the locations of specific collectors was not prepared.

Approximately 300 feet of indoor insulated piping was assumed to be required to link the concentrator array to the plating facility. Steam piping was assumed to be 3½" rather than the 3" piping assumed for the smaller arrays at MacDill and Lowry.

4. Economic Evaluation

An estimated solar system cost breakdown is presented in Figure III-13. Roof mounting of the collectors imposes technical difficulties not associated with ground mounting. Therefore, the following adjustments in the cost estimates for ground-mounted arrays were made:

1. In the absence of a detailed design, foundation costs for roof mounting were assumed to be twice those for ground mounting. This is consistent with the limited experience to date with roof mounting of a single PKI collector in Troy, New York.
2. All other costs except those of freight, PKI hardware, contract supervision, and piping from array to installation were assumed to be 10% greater for roof mounting than for ground mounting.
3. The cost of pipe linking the array to the plating facility was assumed to be 50% less per linear foot than that for equivalent buried pipe.

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Figure III-13. Detailed Cost Breakdown, Solar Energy Plant Conceptual Design for Tinker AFB Plate Shop

I. Installation Cost (1981 $/Unit)

	Materials	Labor
Roof Mounting	$5,600	$ 6,800
Mechanical & Electrical	2,536	3,957
	$8,136	$10,757
	Subtotal	**$18,893**
6% Engineering Fee		1,133
		$20,026
PKI Installation		7,800
Freight		1,900
		$29,726
25% Contingency		7,432
	Total Installation Cost per Unit	**$37,158**

II. Interface Costs

	Materials	Labor
300' Insulated Pipe (3½" steam, 1½" cond. ret.)	$32.50/ft. = $9,750	$7.50/ft. = $2,250
300', 1" feedwater pipe	$1/ft. = $300	$1.50/ft. = $450
Pump package, house, separators, tie-in, electrical & miscellaneous	$14,463	$12,540
	$24,513	$15,240
	Subtotal	**$39,753**
6% Engineering Fee		2,385
		$42,138
25% Contingency		10,535
	Total Interface Cost	**$52,673**

(Continued)

Figure III-13. (Continued)

III. Overall Project Costs

Subcontract Costs (from preceding page)

Total installation and interface, loaded labor and materials		$ 758,675
PKI Hardware 19 x 44,000		836,000
Contract Supervision 1050 hrs. @ $40/hr.		42,000
	Subtotal	**$1,636,675**
5% Profit		81,834
	Project Total (1981 $)	**$1,718,509**
	Project Total 1983 Cost	**$1,858,403**

Collector cost per square foot, 1981: **$104.7**

Cost per collector square foot, 1983: **$113.2**

Conventional fuel now used for the plating shop was considered to be natural gas, which is used by the central boiler in building 3001. Tinker currently (23 July 1981) pays $2.76/MBTU; in the baseline scenario, natural gas prices at Tinker were assumed to escalate at 40% per year from 1981 to 1986, and 11% thereafter.

The results of the economic analysis are summarized in Figure III-14. As indicated by a zero discounted net present value, the solar design would be equally cost competitive with fossil fuel under the baseline fuel escalation scenario.

Figure III-14.

Economic Analysis Results for Case 4

Net Present Value (NPV) (1983 dollars)	0
Benefit to Cost Ratio (B/C)	1.00
Levelized Price of Natural Gas ($/MBTU)	$45.60
Levelized Price of Solar Energy ($/MBTU)	$45.60

E. TINKER AFB - CENTRAL BOILER

1. Introduction

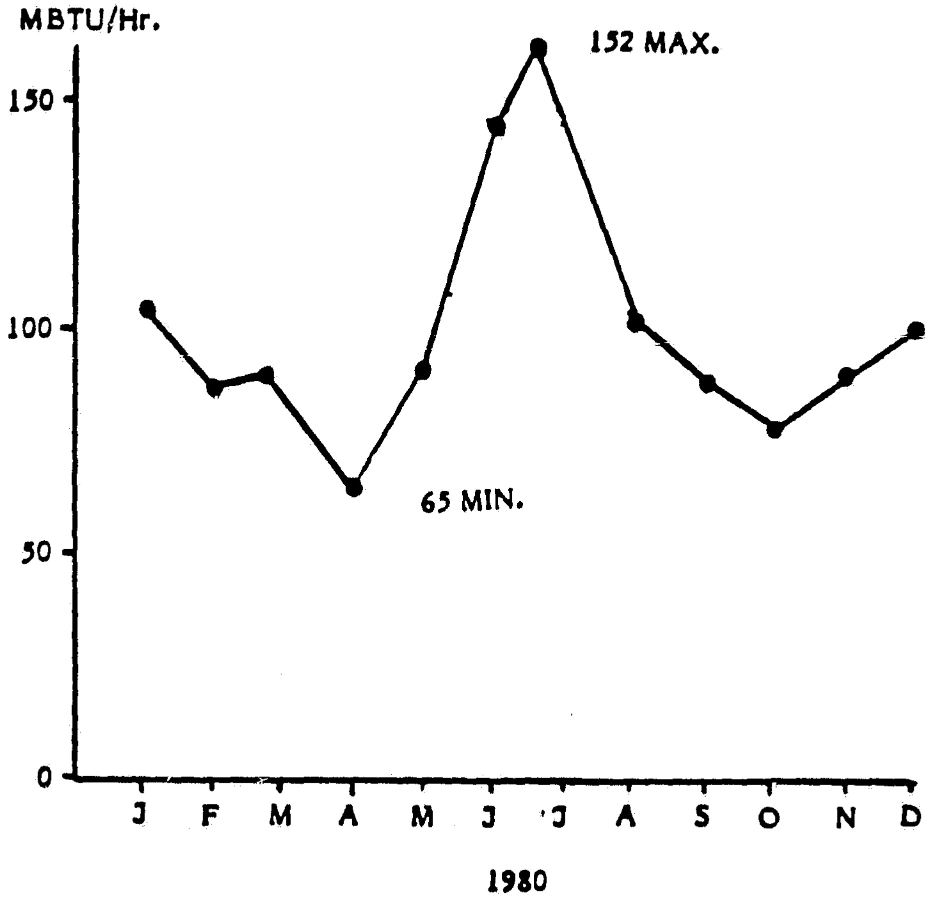
The final case studied was steam insertion into the central steam network, building 3001, Tinker AFB. Steam insertion into central boiler systems may often prove to be the most practical solar retrofit strategy because of the interface problems imposed by sites whose layout has been determined by concerns other than access to sunlight.

2. Process Description

The central boiler in building 3001 provides steam for building 3001 and several outer buildings. The boiler was constructed in 1942. Natural gas is the primary fuel with #2 oil as a back-up. Peak fuel utilization efficiency at optimum output is reported as 78%. 70% was used as an average figure. Transmission losses which decrease net efficiency to 60% must be applied to the solar energy system as well as for this application.

The boiler operates 24 hours per day, 365 days per year. Fuel consumption is greater during the summer than the winter. Average hourly load data for each month in 1980 is presented in Figure III-15. Steam is provided at 220 p.s.i.g. or 400°F, and condensate is returned at 140°F.

Figure III-15. Tinker AFB Average Hourly Load Profile (by month) for Central Boiler, Building 3001



3. Solar Application

The solar application considered was steam insertion into the central steam network. The solar system was assumed to operate in a steam flashing mode, thus the collector output temperature equals the required steam temperature of 400°F; collector inlet temperature was assumed to be condensate return temperature (140°F).

Using PROSYS, net collector output was calculated to be 0.389 MBTU/ft.^{2}/year annual average performance. In theory, the full output of up to 300 collectors could be utilized by this application. In practice, however, available space limits the number of collectors that can be used. The issue is complicated by height restriction regulations, which may or may not be enforced (for example, the western edge of the Tinker plating shop is said to be in violation of current height restrictions).

Candidate areas for collector installation are located along the steam distribution system. These include both ground and roof top areas. Although the precise number of collectors that could be packed into any given candidate area will vary, most contiguous areas will not support more than approximately 20 collector units.

Preliminary cost estimates indicate that minimum array installation costs for arrays of less than 20 collectors are achieved when array size equals 16 collector units; hence technical and economic analyses for this application are based on a 16 unit array similar to that considered in the MacDill hospital case-study. One major difference is that only 100' of buried piping was considered necessary. The array is assumed to be tied into the steam network via the steam line that runs south from building 3001. The design for this application is to be regarded as a generic module, rather than a complete system. More than 16 collectors could be installed by erecting several 16 collector modules in various candidate areas.

4. Economic Evaluation

An estimated cost breakdown is presented in Figure III-16 for the 16 collector array. Unit installation costs were assumed to be the same as Case 1, except that freight charges were calculated to be $1900 for each collector unit. As before, all process interface costs except underground piping and contract supervision costs were scaled linearly.

Figure III-16
Detailed Cost Breakdown, Tinker AFB Solar Energy Plant
Conceptual Design for an AFB Central Boiler

I. Installation Costs (1981 $ Unit)

Total materials, labor, fee, PKI installation (same as Lowry)	$20,628
Freight	1,900
	$22,528
25% Contingency	5,632
Total Installation Cost per Unit	**$28,160**

II. Interface Costs

	Materials	Labor
100' Ricwil (buried) (3" steam, 1" cond. ret.)	$50/ft. = $5000	$15/ft. = $1500
100' Feedwater Pipe	$2/ft. = $200	$3/ft. = $300
Pump package, house, separators, tie-in, electrical & miscellaneous (Scaled from Lowry)	$11,072	$ 9,600
	$16,272	$11,400

Subtotal, Materials & Labor	$27,672
6% Engineering Fee	1,660
	$29,332
25% Contingency	7,333
Total Interface Costs	**$36,665**

(Continued)

Figure III-16 (Continued)

III. Overall 16 Unit Estimate

Subcontract Costs (from preceding page)

Unit installation to common interface point, loaded labor & materials	
16 x $28,160 =	$ 450,560
System interface from collection point, loaded labor & materials	36,665
Total Installation and Interface Cost	**$487,225**
PKI Hardware	
16 x $44,000 =	$704,000
Contract Supervision	
1,050 Hrs. @ $40/Hr.	42,000
Subtotal	**$1,233,225**
5% Profit	61,661
Project Total (1981 $)	**$1,294,886**
Project Total 1983 Cost:	**$1,387,352**

Cost per collector square foot, 1981: **93.7**

Cost per collector square foot, 1983: **100.4**

Conventional fuel now used for the central boiler is natural gas. Again, Tinker currently (23 July 1981) pays $2.76/MBTU for natural gas. In the baseline scenario, natural gas prices were assumed to escalate at 40% per year from 1981 to 1986, and 11% thereafter.

The results of the economic analysis are summarized in Figure III-17. As indicated by a negative net present value, the conceptual solar design for Case 5 would not result in savings to the Air Force under the baseline fuel escalation scenario.

Figure III-17

Economic Analysis Results for Case 5

Net Present Value (NPV) (1983 dollars)	-$293,000
Benefit to Cost Ratio (B/C)	0.86
Levelized Price of Natural Gas ($/MBTU)	$39.00
Levelized Price of Solar Energy ($/MBTU)	$45.00

IV. RESULTS

A. INTRODUCTION: INFORMATION UNDERLYING AN INTERPRETATION OF RESULTS

Because of the study methodology by which generic applications were defined and analyzed prior to the selection of five cases for further study, there were no major technical problems to be resolved by the case studies. The most cost-effective, currently available equipment, as represented by the PKI collector, was utilized in a simple plant design, based on two industrial installations now being installed by Applied Concepts Corporation for JPL. Each plant utilizes no storage. It operates in parallel with an existing boiler to provide heat to a common distribution system, and thus to displace fuel. The heat transfer medium in each case is the same: low- to mid-temperature steam.

Technical and cost assumptions were made regarding the PKI system, which influence study results. As of this writing, two PKI dishes have been installed and operated to produce steam, both in Troy, NY. Two additional systems are in the process of installation, in Albuquerque, NM and Topeka, KS. The two New York installations are prototype and engineering development plants. The two current installations are to be operated as industrial plants in an operational test and evaluation to be conducted by JPL from October 1981 through October 1982.

As of this writing, therefore, the point focussing systems have demonstrated that they can produce steam. They will begin testing in an industrial environment within 30 days. Based on experience with the prototype and engineering development plants, we expect those tests to be successful. The assumed system lifetime of 20 years and the estimated annual O&M cost of $1,300/system, however, remain to be proven.

PKI system costs were taken to be $44,000 as a baseline. This is the price quoted by the manufacturer based on annual production of 20 units or fewer. PKI has a bid outstanding to provide systems in quantities of 50 at a 20 percent reduction in unit price. The collector cost figure used in this study ($44,000) is thus realistic, and likely to decline with increased production. It represents the actual cost USAF would pay today for one to twenty modules, FOB the manufacturer.

The only anticipated engineering problems are those of installation. These reduce, ultimately, to economic problems. A foundation and utilities can be provided at almost any location with available sunlight. The question is at what expense?

The question of installation expense cannot be totally resolved without proceeding to the detailed design stage. Detailed design is beyond the scope of this study, therefore installation costs were estimated, based upon experience to date, namely, the cost or cost estimates of three completed detailed designs.

The potential exists for less expensive installations than those estimated here because their foundations are known to be "over designed" for the wind loads which would be experienced by a collector presenting a "full sail" to a 90 mph wind. Since this is an impossible configuration for the collector, the real wind loads will always be less than the calculated loads. An experiment is now underway to measure actual loads and foundation designs may be modified when an adequate knowledge of the real loads which a foundation must bear is available.

For ground mounted installations, then, foundation and installation costs are fairly well known for the present, and likely to decline. Two ground mounted installations of the PKI dish have been made, and two more have been designed. No technical problems have yet surfaced.

One of the case studies (the Tinker AFB plating shop), and potentially many USAF applications and sites, would require roof mounting for retrofit installation. One roof mounted installation of the PKI dish has been accomplished and a roof-level platform installation is in process. No major, generic technical barriers exist, but the engineering designs to transfer the load from the collector to existing structural members will be site specific.

The Tinker facility dates to World War II, and existing blueprints do not explicitly reveal the load bearing capacity of the structure, although no obvious barriers are evident. A detailed cost estimate would require a detailed engineering evaluation of the current structure and a detailed design for a foundation interface. We have somewhat arbitrarily, therefore, estimated the cost of this type of installation to be double that of a ground mount. This is consistent with our limited general knowledge to date.

The major uncertainty in this analysis is the projection of future fuel prices, which largely determine the economic attractiveness of the solar system. As a baseline, we have chosen an annual fuel oil escalation rate of eleven percent. Thus, at a discount rate of ten percent, the present value of the displaced fuel (and thus of the solar system) will increase over time. For comparison, the annual fuel oil escalation rate between 1973 and 1981 averaged 18 percent.

The projection of economic variables is an unavoidable step in assigning a dollar value to solar energy. We believe our choice of variables is conservative, given that petroleum and natural gas are finite resources subject to increasing worldwide demand as population increases and more countries industrialize. Our assumptions imply that in 20 years with an average 8% inflation rate, the real price of fossil fuels will be 1.8 (i.e., 1.03 raised to the twentieth power) their present price. We believe an 11% annual escalation rate is realistic for a baseline analysis. In fact, it could be considered conservative because it does not take into account the possibility of embargo or other causes of supply interruption which could drastically affect fuel supplies and thus fuel costs.

Natural gas, which is the principal fuel for four of the cases, is even more difficult to project costs for. Because price deregulation of most natural gas is currently slated by steps through 1985, we chose to escalate gas prices up to the price of fuel oil in 1986, and at the same rate thereafter.

Finally, it should be noted that the three locations for the five case studies are all good solar locations, but not necessarily the best USAF sites. Figure IV-1 presents the average and relative annual direct normal solar isolation for selected USAFBs.

Figure IV-1. Average Annual Direct Normal Insolation

Location	1000 BTU/ft.^{2}/year	Relative Amount
MacDill AFB	557	1.00
Tinker AFB	598	1.07
Lowry AFB	736	1.32
McClellan AFB	755	1.36
Hill AFB	760	1.36
Kirkland AFB	865	1.55

The analysis and presentation of the case study results are supportive of USAF objectives in conducting this research. They should identify USAF process heat applications for near term technology test and evaluation. They also help provide an understanding of the general, near-term suitability of the new technology to meet USAF needs.

In sum, the technical, economic, and site variables for the five baseline case studies were conservative. Under these circumstances, the results of each analysis must also be conservative. To place results in some sort of perspective, variations on the baseline cases would be valuable. Similarly, variations on the baseline case would shed light on the general feasibility of point focussing solar thermal systems in USAF applications.

For these reasons, the research team has defined five alternative scenarios to elaborate and provide a context for the baseline case studies. The following sections present the results of the baseline and alternative scenario cases.

B. THE BASELINE CASE RESULTS

Figure IV-2 presents the baseline case study results in tabular format.

Figure IV-2. Baseline Economic Results

Application	N	Plant $/Collect.	Costs $/MBTU/ Year	LS $/MBTU	LF $/MBTU	NPV per Collector (1983 $)	B/C
Lowry Bldg.1307	13	90,000	206	36.20	39.20	13,200	1.10
Tinker Plating Shop	19	97,800	259	45.60	45.60	0	1.00
MacDill Hosp.	16	87,300	275	48.30	43.40	-13,400	0.90
Tinker De-greaser	1	108,000	287	50.40	45.60	-16,000	0.90
Tinker Central Boiler	16	86,700	258	45.40	39.00	-18,300	0.86

N = Number of collectors
LS = Levelized cost of solar energy in $/MBTU of delivered energy
LF = Levelized cost of fuel in $/MBTU of delivered energy

$$\text{Costs per MBTU/Year} = \frac{\text{Installation cost of the plant in 1983 \$'s}}{\text{Average Annual Delivered Energy}}$$

Among the five cases studied, the most attractive for an early PFDR installation is the classroom at Lowry AFB. As the sensitivity analyses will make clear, the principal reasons for its attractiveness is the relatively high insolation in Denver. The plating shop at Tinker AFB is second best, demonstrating a levelized cost similar to that of fossil fuels under the baseline assumptions. Comparison with the other applications at Tinker AFB show that there are two reasons for this relative attractiveness: (1) the unit installation costs are lower with a larger number of collectors, and (2) transmission losses are minimized when steam is inserted directly at the application.

It is of great interest and some surprise that point focussing solar process heat systems should look so attractive in the baseline case. This analysis, after all, is for a brand new product just out of prototype development, being manufactured in small quantities, and which is expensive to install. It assumes a very near-term installation (FY 1983 operation). The results indicate that such a plant will probably pay for itself over its useful life.

The results of this research indicate that point focussing technologies in simple, fuel displacement process heat plants have a real potential for USAF applications to reduce both fossil fuel dependence and costs. The evidence is that USAF can install such plants in the near-term for operational test and evaluation of the technology with a very small risk of a cost/benefit fiasco. To the contrary, the evaluation plant, if carefully considered, will probably pay for itself in displaced fossil fuel during its lifetime.

Having used the baseline case studies to investigate the immediate potential for an operational test and evaluation plant, we now examine five alternative scenarios, variations on the baseline, to extend our conclusions.

C. THE ALTERNATIVE SCENARIO RESULTS

1. Scenario 1 - Declining Collector Price

In the baseline case, the 1983 price of PKI solar hardware was assumed to remain at its current level of $44,000 per concentrator. Increase in the production base and/or learning curve effects might not merely hold price constant, but could actually force prices down over the next two years. In fact, in a recent proposal, PKI offered to sell its hardware in 1983 at $36,500 per concentrator in quantities of 50 or more. In the first alternative scenario, therefore, results were recalculated using the $36,500 hardware price figure. These results are summarized in Figure IV-3.

Figure IV-3. Scenario I Results

Application	N	Plant $/Collect.	Costs $/MBTU/ Year	LS $/MBTU	LF $/MBTU	NPV per Collector (1983 $)	B/C
Lowry, Bldg. 1307	13	82,476	189	33.10	39.80	25,000	1.20
Tinker Plating Shop	19	90,300	239	41.90	45.60	11,700	1.09
MacDill Hosp.	16	79,840	236	43.90	43.40	-1,600	0.99
Tinker De-greaser	1	100,900	268	46.70	45.60	-4,000	0.97
Tinker Central Boiler	16	79,210	236	41.30	39.00	-6,400	0.95

A seventeen percent reduction in solar collector price results in an improvement of about ten percent in benefit-to-cost in all applications. The relative ranking stays the same. There is a mild favoring of systems with the simplest installation, as is to be expected.

Obviously, system price reductions will make solar thermal plants more attractive to USAF, but dramatic improvements in economic attractiveness will not occur due to anticipated price declines alone. It would seem that there is no strong motive or pay-off to USAF in waiting for less expensive systems to appear, a tactic that could be self-defeating, since lower prices depend upon growing markets.

The general attractiveness of the technology is about the same for this scenario as for the baseline. Both indicate a probable, general cost competitiveness with fossil fuel. The differences in anticipated pay-off are similar to our estimated margin of error in the study. The conclusion to be drawn in both cases is that if the conservation of mobility fuels is a desirable goal, then the use of solar thermal process heat plants is one potentially cost-effective way to help meet that goal.

2. Scenario II - Efficiency in Installation and Foundation Design

In the baseline scenario, a 25% contingency factor was added to installation and interface costs, primarily to cover the uncertainty in labor costs. Although the addition of a contingency factor is standard engineering practice, the resulting costs define the high end of the range of probable costs. There is also a known potential for cost reduction in this area due to savings in foundation design. This scenario anticipates a 25% reduction in overall installation costs to account for these factors.

Figure IV-4. Scenario II Results

Application	N	Plant $/Collect.	Costs $/MBTU/ Year	LS $/MBTU	LF $/MBTU	NPV per Collector (1983 $)	B/C
Lowry Bldg. 1307	13	82,400	189	33.00	39.80	25,000	1.20
Tinker Plating Shop	19	89,900	238	41.00	45.60	14,600	1.11
MacDill Hosp.	16	80,100	237	44.10	45.60	-2,000	0.98
Tinker De-greaser	1	98,400	261	45.50	43.40	0	1.00
Tinker Central Boiler	16	79,600	237	41.50	39.00	-7,000	0.94

Overall, a reduction in installation costs has an impact similar to that of energy system price reductions. Those plants with higher installation expenses (the plating shop and degreaser) benefit slightly more than larger or ground-mounted plants. The result of this scenario defines the upper limit of system payback under a near-term (1983) installation and assuming a gradual fuel price escalation for the next twenty years.

3. Scenario III - Higher Fuel Costs

The third alternative scenario assumes a higher fuel escalation rate than in the baseline. Specifically, #2 fuel oil was assumed to escalate at 14% per year as opposed to the baseline 11%. Natural gas prices were once again assumed to escalate at a rate such that in 1986, the price of natural gas would equal that of #2 oil. This corresponds to an annual price escalation for the period 1981-1985 of 43.9% at Tinker AFB and 35.3% at Lowry AFB. After 1985, natural gas prices were assumed to escalate at 14%. Economic results under the third scenario are summarized in Figure IV-5.

Figure IV-5. Scenario III Results

Application	N	Plant $/Collect.	Costs $/MBTU/ Year	LS $/MBTU	LF $/MBTU	NPV per Collector (1983 $)	B/C
Lowry Bldg, 1307	13	90,000	206	36.20	56.30	75,700	1.55
Tinker Plating Shop	19	97,800	259	45.60	65.60	64,200	1.44
MacDill Hosp.	16	87,300	275	48.30	61.70	36,400	1.28
Tinker De-greaser	1	108,000	287	50.40	65.60	49,000	1.30
Tinker Central Boiler	16	86,700	258	45.40	56.20	30,800	1.24

The results of this scenario implicitly reveal the major value of solar energy systems. They are a tool to lower the risk of fossil fuel interruptions or shortages. They transfer the risk from the fuel supply, which is largely in the hands of others, to the solar energy system, which is under the control of its purchaser and whose costs are known from the time of purchase. It should be noted that the 14 percent annual fuel escalation rate assumed for this scenario is higher than that projected by most economists for conditions of no major international supply disruption or military conflicts. It is also lower than that experienced from 1973 - 1981.

Again, the value of solar energy to the user is a strong reflection of the future price and availability of fossil fuels. If fuels continue to become more expensive or become extremely scarce over the next twenty years (1983-2003), as might be caused by international political or military conflict, the value of solar will be extremely high. If more moderate price increases occur and availability remains no problem, then, as Scenario 1 indicates, solar thermal plants purchased in 1983 will not impose an undue expense for the insurance of energy availability at a known price.

4. Scenario IV - Installation at Higher Insolation Sites

The fourth alternative scenario was designed to test the economic attractiveness of solar energy systems under the favorable insolation conditions at Hill

AFB, which is similar to those at McClellan and other southwestern AFBs. Bases such as Kirkland or Davis-Monthan will show even better performance. All economic parameters in this scenario are identical to those of the baseline. It should be noted that the fourth scenario serves as a climatological standard for the five applications studied. That is, it allows comparison of attractiveness of solar for each application on the basis of application characteristics alone, since site characteristics are the same. The economic results under Scenario IV are presented in Figure IV-6. Note that Lowry AFB Building 1307 loses its prominence as the most attractive application. This is because Lowry AFB has insolation characteristics nearly as good as Hill AFB. It thus has the least to gain under the assumptions of this scenario.

Figure IV-6. Scenario IV Results

Application	N	Plant $/Collect.	Costs $/MBTU/ Year	LS $/MBTU	LF $/MBTU	NPV per Collector (1983 $)	B/C
Lowry, Bldg. 1307	13	90,000	201	33.30	39.80	16,800	1.19
Tinker Plating Shop	19	97,800	206	36.30	45.60	37,100	1.25
MacDill Hosp.	16	87,300	203	35.80	43.40	27,600	1.21
Tinker De-greaser	1	108,000	227	40.10	45.60	22,000	1.14
Tinker Central Boiler	16	86,700	205	36.10	39.00	10,600	1.08

The conclusions to be drawn from this scenario are:

1. Best performance for all USAF process heat applications will be found at bases with the best solar climate.

2. Virtually any process heat application at such bases can be expected to pay back its expense of installation, operation and maintenance. The best applications will yield a net benefit of hundreds of thousands of dollars per installation.

It should be noted also that all of the scenarios assume a twenty year lifetime. System lifetimes may be more than this. Even if an entire new system had to be installed after twenty years, full foundation and utility costs would not likely be incurred, thus yielding a higher payback for the second, replacement system.

Finally, it can be concluded from Scenario IV that multiple collector installations connected directly to the process are the favored applications. The higher unit installation price of small installations, and system transmission losses from general insertion applications make them less attractive.

5. Scenario V - The Upper Bound

The fifth alternative scenario combines all the assumptions of the previous four scenarios: $36,500 PKI concentrator price; 25% reduction in installation costs; 14% annual fuel price escalation; and more favorable insolation characteristics.

Although it is the most favorable of all scenarios with respect to solar cost-effectiveness, it should not be thought of as completely or unreasonably optimistic. For Air Force bases with insolation characteristics comparable to those of Hill, the fifth scenario may ultimately prove to be the most accurate. The economic results under this scenario are summarized in Figure IV-7.

Figure IV-7. Scenario V Results

Application	N	Plant $/Collect.	Costs $/MBTU Year	LS $/MBTU	LF $/MBTU	NPV per Collector (1983 $)	B/C
Lowry Bldg. 1307	13	74,900	167	29.10	56.30	104,000	1.93
Tinker Plating Shop	19	81,000	171	29.80	65.60	144,000	2.20
MacDill Hosp.	16	72,600	169	29.50	61.70	118,000	2.09
Tinker De-greaser	1	90,900	191	33.30	65.60	130.000	1.97
Tinker Central Boiler	16	72,100	170	29.70	56.20	95,000	1.89

The results of this scenario may be interpreted as representing the best case, near-term potential for point focussing process heat plants in southwestern USAF applications. Once system prices start to decline due to orders of 50 or more units, and as experience is gained with foundation design and installation techniques, systems may be installed for as little as $72,000 - $91,000 per collector. A 50 unit installation, then, would cost $3.6 million to $4.6 million and provide up to $22 * 10^9$ BTU/year in process heat. Over a twenty year lifetime, the discounted present value of the displaced fuel would be at least 25 percent greater than the discounted present value of all solar energy system costs under a modest fuel escalation scenario, and up to double that for the solar energy system if fuel prices continue to rise as they have in the last decade.

D. EVENTS WHICH COULD INVALIDATE THE ANALYSES

Two factors could operate to make these analyses overly optimistic. The first is that fuel prices could escalate less than assumed (11% per year or 3% real escalation per year). We know of no way to forecast this possibility. The finitude of the resource, a growing world population, and increasing industrialization seem to the authors to imply at least a moderate long-term escalation in fossil fuel costs. Any major constriction of fuel supply due to embargo or war in the coming 20 year period would also cause price escalations whose magnitude could be extremely high, but again, impossible to predict.

The second factor is that of system performance. If solar thermal heat systems do not convert a reasonable fraction of incident energy to useable heat (65 percent) over a reasonable period of time (nominally 20 years), their economic value will be less than determined here. The only way to determine system performance potential is to build and operate plants in typical USAF environments.

E. CONCLUSIONS

The following is a summary of conclusions and recommendations which follow from this research.

1. Conclusions Regarding a Test and Evaluation Plant

   a. Point focussing solar thermal heat plants show sufficient near-term cost-effectiveness to warrant a USAF operational test and evaluation of the technology.

   b. A test and evaluation plant should be sited in a high insolation area to maximize the return on investment in the plant to be tested. Of the cases studied here, Building 1307 at Lowry AFB is the best site for such a plant. Other southwestern AFBs such as Hill, McClellan, Kirkland and Davis-Monthan, should also be considered.

   c. The risk that a test plant will be a technical or economic failure is low because:

      (1) JPL is currently installing and testing two single module plants which will detect any major discrepancies between system technical expectations and technical performance prior to any USAF installation.

      (2) Under realistic cost scenarios, plants indicate a positive net return ($\bar{B}/\bar{C} > 1$) for many applications and locations. All applications tested show a B/C ratio of at least .86.

   d. Solar thermal systems offer USAF a large payoff in terms of energy cost and security of supply under scarcity scenarios. This "insurance" function of solar thermal plants offers a sound motive to USAF to become familiar with the technology and to evaluate the technical performance of solar technologies for rapid utilization should these scenarios prove likely to occur.

2. Conclusions Regarding Near-Term USAF Applications of Point Focussing Process Heat Plants

   a. The technology has a high promise for utilization at USAF bases with process heat loads in the American Southwest. B/C ratios of 1.1 to 2.2 can be anticipated in the near-term (1983) for areas with insolation as good as or better than Lowry AFB.

   b. Large installations (10 or more collectors) are more cost effective than small ones because the unit installation price decreases.

   c. A total purchase of 50 collectors or more can increase plant economic pay-off by 10 percent.

d. In the event of fuel scarcity and/or price escalation on the order of 14%/year, systems will be generally attractive in the southern and western two thirds of the U.S., with B/C ratios of 1.25 up to 2.2.

e. Under wartime conditions where international transportation of fossil fuels declines and USAF use of mobility fuels increases, solar thermal process heat plants' fuel displacement will provide a national benefit whose dollar value is hard to calculate or predict.

f. It would be wise for USAF to validate these conclusions through purchase and operation of one or more test and evaluation plants for several years before general investment in the technology.