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COMMERCIAL APPLICATIONS OF SOLAR
TOTAL ENERGY SYSTEMS

Third Quarterly Progress Report,
November 1, 1976—January 31, 1977

MASTER

Date Published—September 1977

Work Performed Under Contract No. EY-76-C-03-1210

Rockwell International
Atomics International Division
Canoga Park, California

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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THIRD QUARTERLY PROGRESS REPORT
COMMERCIAL APPLICATIONS
OF
SOLAR TOTAL ENERGY SYSTEMS
NOVEMBER 1, 1976 – JANUARY 31, 1977

ERDA Research and Development Report

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*Prepared for
Energy Research and Development Administration
Division of Solar Energy
under Contract E(04-3)-1210*

MAY 16, 1977

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FOREWORD

This report, submitted by Atomics International (AI), Division of Rockwell International Corporation, to the Energy Research and Development Administration (ERDA), Solar Energy Division, Washington D.C., provides a summary of the technical progress for the third quarter period activities under Contract E(04-3)-1210.

The task activities described herein were conducted in the Advanced Programs area with Mr. S. J. Nalbandian, Project Manager. Mr. J. E. Rannels is the ERDA Program Manager. Technical direction for the study is provided by Dr. R. W. Harrigan, the technical monitor at Sandia Laboratories, Albuquerque, New Mexico. Technical support to the study (primarily Task 1) is provided by the Space Division (SD) of Rockwell International, Seal Beach, California, and by two subcontractors, Envirodyne Energy Services, Anaheim, California and The Energy Group, a subsidiary of Welton-Becket Associates, Los Angeles, California.

The study commenced on May 10, 1976, and is scheduled for completion on May 9, 1977. This document presents a summary of activities for the third quarter period from November 1, 1976, through January 31, 1977. The work represents the contributions of several individuals. Dr. M. G. Boobar (AI) is responsible for the application analysis and costing studies. Mr. B. L. McFarland (AI) developed the application analysis computer program and system component definitions. Mr. K. E. Smith (SD) and Mr. W. W. Willcox (AI) developed the requirements data and Dr. E. P. French (SD) developed the site climatic data. Mr. G. W. Neal, Vice President of Envirodyne Energy Services and Mr. M. Meckler, President of the Energy Group have also provided valuable assistance.

ABSTRACT

This report investigates the application of Solar Total Energy System (STES) to the commercial sector (e.g., office buildings, shopping centers, retail stores, etc.) in the United States. Candidate solar thermal and solar photovoltaic concepts are considered for providing on-site electrical power generation as well as thermal energy for both heating and cooling applications. The solar thermal concepts include the use of solar concentrators (distributed or central receiver) for collection of the thermal energy for conversion to electricity by means of a Rankine cycle or Brayton cycle power conversion system. Recoverable waste heat from the power generation process is utilized to help meet the building thermal energy demand. Evaluation methodology is identified to allow ranking and/or selection of the most cost-effective concept for commercial building applications.

LIST OF SYMBOLS

A, B	Equation Constants
A_a	Absorber area that is illuminated
A_c	Collector area
A_r	Absorber area that radiates
A_w	Absorber area that is wetted by heat transport media (coolant)
C, c_p	Specific heat
CEL	Coefficient of heat generation from electrical lighting
CHD	Coefficient of process heat
CHL	Coefficient of heat loss
CRL	Coefficient for humidity effects
CVH	Coefficient of heating ventilation
CVR	Coefficient of cooling ventilation
COP	Coefficient of performance
D	Diameter
EL(t)	Fraction of maximum electrical as a function of time
F_o	Eigenfunction of matrix temperature
g_c	Gravitational constant
h	Heat transfer coefficient
HL(t)	Fraction of maximum process heat as a function of time
J	Mechanical equivalent of heat
k	Thermal conductivity
L	Length
p	Wetted perimeter
P	Pressure
PL(t)	Fraction of maximum occupancy load
Q	Energy
q	Heat transfer rate
Q_{BS}	Battery electrical storage energy
Q_{CS}	Cold thermal storage energy
$\dot{Q}_{ED}$	Electrical load demand
$\dot{Q}_{HD}$	Heat load demand

Q_{HS}	Hot thermal storage energy
q_{ins}	Insulation heat transfer loss rate
$\dot{Q}_{RD}$	Cooling load demand
T_{cell}	Temperature of solar cell
T_{ref}	Reference temperature of solar cell (nominally 28°C)
Q_T	Maximum load constant for building
q_{use}	Useable heat transfer rate
r	Reflectivity
S	Direct insolation
T	Temperature
$\bar{T}$	Average temperature
t	Time
T_a	Ambient temperature
T_c	Collector inlet temperature
T_h	Collector outlet temperature
T_{SP}	Building internal temperature setpoint
ΔT_g	Maximum fluid temperature change
ΔT_w	Matrix material temperature change
U	Overall heat transfer coefficient
V_{dm}	Dual media fluid volume
V_{sm}	Single media fluid volume
$\dot{w}$	Fluid mass flow rate
W	Weight
x	Quality
y	Distance coordinate
y_d	Submersion depth of diffuser

GREEK

α	Absorptivity
β	Solar cell temperature loss coefficient
γ	Specific heat ratio
δ	Fluid temperature degradation

ϵ	Void fraction of matrix material
ϵ_c	Emissivity
ξ	Dimensionless distance $hpx/\dot{w}c_p$
η	Efficiency
η_{st}	Storage tank thermal efficiency
η_{oc}	Optical efficiency
μ	Viscosity
ρ	Density
σ	Stefan-Boltzman constant
τ	Transmissivity
Δ	Incremental change

CAPITAL

θ	Dimensionless time ($h\dot{p}Lt/\dot{w}c$)
Π	Dimensionless time at end of cycle
Λ	Dimensionless length of storage material ($h\dot{p}L/\dot{w}c_p$)

ECONOMIC PARAMETERS USED IN COMPUTER PRINTOUT

FCR	Fixed charge rate
G	General inflation
gF	Fuel escalation rate
N	Number of years
Y_{co}	First year of operation
K	After tax cost of money

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1.0 INTRODUCTION

The application of solar energy to help meet the nation's future energy requirements is a potential alternative to presently used energy sources for the generation of electricity and thermal energy. The purpose of this study contract is to assess the feasibility of using solar energy to provide a significant fraction of the energy needs of the commercial sector. The specific type of application is the solar total energy system (STES) concept where electricity is generated on-site with the recovery of waste heat to help satisfy building heating and/or cooling requirements. Both solar thermal power conversion and solar photovoltaic system concepts are considered. Figures 1, 2, and 3 present generic diagram representations of a solar thermal-Rankine cycle, a solar thermal-Brayton cycle, and a photovoltaic STES concept, respectively. The specific system configurations would permit the selection (on the basis of performance and cost effectiveness) of the amount of electricity to be purchased from the utility, type(s) of energy storage and the split between vapor compression and absorption chiller subsystems. This report summarizes the activities and findings during the third quarter period of the study. Reference 1 presents a summary of the activities during the previous quarter which provides a basis for the data presented herein.

1.1. Program Objectives

The objectives of the engineering study relative to the applicability of solar total energy systems to commercial buildings are:

- 1) Develop conceptual designs and establish requirements data.
- 2) Identify key technology items and advanced technology requirements.

Figure 1. Diagram of Solar Thermal STES Concept
(Rankine Cycle Power Conversion System)

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- 3) Define methodology for configuration and site selection criteria.
- 4) Assess performance, cost, and market projections.
- 5) Define requirements for demonstration program plan for system capability greater than 200 kilowatts electric (kWe) from solar energy.

1.2 Summary of Study Activities

The study effort commenced on May 10, 1976, with the primary emphasis during the first quarter aimed at developing a data base to support activities associated with meeting the first two program objectives mentioned above. This effort is summarized in Reference 2. During the second quarter of the study, effort continued with emphasis on defining conceptual designs, evaluation of requirements data, defining methodology for concept selection criteria as well as costing methodology. A summary of these activities is contained in Reference 1. The third quarter activities have continued with developing additional data, further conceptual design analyses, and refinement of the methodology and evaluation computer programs. The program schedule is shown in Figure 4. The study consists of six tasks with milestones as shown in the schedule. The interrelationship of the five technical tasks (1-5) is shown in Figure 5 and is discussed in the following paragraphs.

Information regarding commercial buildings is collected and evaluated in Task 1. These data include building configurations, sizes, energy requirements, operating characteristics, as well as site characteristics (environmental and solar insolation). Task 2 activity includes identifying system concepts, configuration and component characteristics applicable for STES. The Task 3 effort evolves about a methodology to evaluate the various system concepts/application areas using information

Figure 4. STES Program Schedule

Figure 5. STES Evaluation Methodology

developed in Tasks 1 and 2 along with system/component cost data developed in Task 4.

The parametric results for concept performance are then evaluated in conjunction with Task 4 economic considerations and commercial building type applicability to establish potential market penetration for STES. The Tasks 1 through 4 results will be utilized in Task 5 to define demonstration project requirements and to recommend further development of key technology items required for cost-effective STES application for commercial buildings.

During the previous reporting period, a methodology for simulating the solar thermal power conversion concept utilizing distributive solar concentrators and a Rankine cycle power conversion system was developed. The relatively simple computer model can also be used to evaluate the effectiveness of either a central receiver tower concept or a distributive concentrator concept.

1.2.1 Third Quarter Significant Accomplishments

The third quarter activities in the Task 1 area have continued with obtaining and/or developing additional requirements data on commercial buildings and energy demand characteristics.

The component evaluation effort (Task 2) continued with updating component parameters and incorporating the Rocketdyne thermal stability data for hot oil storage to give a more realistic estimate of STES storage system costs. Photovoltaic cells have also been characterized for analysis of the photovoltaic STES concept.

The computer simulation model utilized in the Task 3 evaluation analyses has been updated to obtain realistic definitions of the system concept performance. This has been accomplished by making trade-off

studies of various operating conditions and applying practical constraint limits (e.g., available land area) where applicable. Similar computer models were developed for the Brayton cycle power conversion system STES and the photovoltaic STES concepts. However, evaluation of the Brayton cycle has been concluded after review of the several absorber designs being developed under other ERDA contracts. The analysis indicates that a new absorber concept for the solar concentrator system needs to be developed in order to utilize the inherent advantages of the Brayton cycle in a STES for commercial buildings. A detailed discussion of this analysis is presented under the Task 2 activities presented later. As a consequence of this analysis, the Brayton cycle STES simulation program activity has been curtailed. The computer model has been developed but has not been "debugged" to verify operational status.

The photovoltaic STES computer model has also been developed and was used in the analysis. Although this computer program is capable of evaluating a sun-tracking solar concentrator/photovoltaic configuration, the specific configuration discussed later in Task 2 and 3 activities considered a non-sun tracking solar configuration for an "all electric" building application.

The Task 4 activities have resulted in updated cost algorithms for system components, operational parameters, and utility (electric power) cost trends for various regions of the country.

The Task 5 activities have just commenced with primary emphasis on identifying building/system interface characteristics such as acceptance by potential users, code and safety limitations. This data (along with information from the other tasks will be utilized to identify preferred system configurations and potential market penetration.

A more detailed discussion of activities by task for Task 1 through Task 4 is provided in the following sections of the report.

2.0 TASK 1 - REQUIREMENTS DEVELOPMENT

This task effort has continued with developing a data base for use in the study as discussed in the previous quarterly report, Reference 1. In addition to the site, building and energy demand characteristics, information on application constraints due to codes, standards, and energy conservation trends are presently being investigated.

2.1 Site Characteristics

The continental U.S. has been divided into six regions based upon isolation and humidity considerations as shown in Figure 6. Regions were initially selected as falling within areas bounded by lines of constant insolation. This was based upon the strong dependency on insolation as a primary driver in STES energy availability while ambient conditions exert a relatively weak influence on the relatively massive, internally loaded buildings found in commercial applications. The total degree days within Regions 1, 2 and 5 influenced the selection of the dashed boundary lines. This appears desirable since the total degree days (both heating degree days and cooling degree days) is a good indicator of energy demands as influenced by environmental factors. The total degree days for the selected sites within this insolation area varies considerably (about 4200 for Region 1, 5400 for Region 2, and 7200 for Region 5) and may influence the building energy consumption.

The definition of significant climatic and insolation parameters has been completed for the twelve (12) sites shown in Figure 6. These parameters are presented in Tables 1 through 12. Sources and methodology are briefly discussed in the following paragraphs.

Geographical information is limited to the site (city) name and the latitude and longitude. The latter are generally associated

Figure 6. Candidate STES Study Regions/Sites
(Six Regions, Twelve Sites)

CLIMATE AND INSOLATION SUMMARY

TABLE 1SITE NAME LAKE CHARLES, LA. LATITUDE 30.12° LONGITUDE 93.22°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 0.6 °C, 33 °F;WIND SPEED M

SUMMER - 2 1/2%

DRY BULB TEMP 33.9 °C, 93 °F;WET BULB TEMP 26.1 °C, 79 °F;DESIGN RELATIVE HUMIDITY 60 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	721	170	111	14	0	0	0	0	0	20	98	188
°F	415	306	200	26	0	0	0	0	0	36	177	338
COOLING °C	12	16	30	79	176	262	299	296	223	106	18	4
°F	21	29	54	143	316	471	539	533	402	191	33	7

PERCENT POSSIBLE SUNSHINE:

49	50	57	63	66	64	58	60	64	70	60	46
----	----	----	----	----	----	----	----	----	----	----	----

AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	17.8	19.4	21.7	25.6	28.9	32.2	32.8	32.8	30.6	26.7	21.1	18.3
°F	64	67	71	78	84	90	91	91	87	80	70	65
MIN D.B. °C	7.2	8.9	11.1	14.4	17.8	21.7	22.8	22.8	20.6	16.1	10	7.8
°F	45	48	52	58	64	71	73	73	69	61	50	46

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	2.42	3.68	4.55	5.20	6.48	5.87	6.23	5.68	5.00	4.48	3.06	2.52
Btu/ft ²	768	1167	1443	1649	2055	1862	1976	1802	1586	1421	971	799
DIRECT kWh/m ²	3.35	4.89	4.54	5.53	7.29	6.43	7.10	6.68	5.83	5.94	4.35	3.87
Btu/ft ²	1063	1551	1729	1754	2312	2040	2252	2119	1849	1894	1380	1220

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.608	0.732	0.752	0.721	0.909	0.876	0.966	0.967	0.756	0.765	0.659	0.662
CLOUD FACTOR	0.683	0.742	0.755	0.793	0.020	0.701	0.783	0.757	0.863	0.907	0.836	0.763

CLIMATE AND INSOLATION SUMMARY

TABLE 2SITE NAME MIAMI, FLA. LATITUDE 25.80° LONGITUDE 80.27°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 8.3 °C, 47 °F;WIND SPEED M

SUMMER - 2 1/2%

DRY BULB TEMP 32.2 °C, 90 °F;WET BULB TEMP 26.1 °C, 79 °F;DESIGN RELATIVE HUMIDITY 65 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	29	37	9	0	0	0	0	0	0	0	7	31
	°F	53	67	17	0	0	0	0	0	0	0	13	56
COOLING	°C	67	81	118	167	224	267	298	308	278	221	127	88
	°F	121	145	212	300	403	480	536	555	501	397	229	159

PERCENT POSSIBLE SUNSHINE:

66	72	73	73	68	62	65	67	62	62	65	65
----	----	----	----	----	----	----	----	----	----	----	----

AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	24.4	25.	26.7	28.3	29.4	31.1	31.7	32.2	31.1	29.4	26.7	25
	°F	76	77	80	83	85	88	89	90	88	85	80	77
MIN D.B.	°C	14.4	15.	16.1	18.9	21.1	23.3	23.9	23.9	23.9	21.7	18.3	15
	°F	58	59	61	66	70	74	75	75	75	71	65	59

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	3.81	4.79	5.90	6.67	6.68	5.97	6.42	5.71	4.80	4.90	3.80	3.65
	Btu/ft ²	1205	1518	1870	2114	2118	1892	2035	1810	1522	1553	1205	1157
DIRECT	kWh/m ²	5.52	6.50	7.32	7.47	7.55	6.63	7.19	6.10	5.27	6.48	5.20	5.58
	Btu/ft ²	1750	2061	2320	2368	2393	2102	2279	1934	1671	2064	1648	1769

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.77	0.87	0.89	0.85	0.94	0.92	0.95	0.80	0.71	0.86	0.69	0.78
CLOUD FACTOR	0.84	0.80	0.85	0.91	0.84	0.76	0.82	0.84	0.82	0.86	0.90	0.88

CLIMATE AND INSOLATION SUMMARY

TABLE 3SITE NAME NASHVILLE, TENN. LATITUDE 36.12° LONGITUDE 86.68°

ASHRAE DESIGN CONDITION:

WINTER – 97 1/2%

DRY BULB TEMP -8.9 °C, 16 °F;WIND SPEED L

SUMMER – 2 1/2%

DRY BULB TEMP 35 °C, 95 °F;WET BULB TEMP 25.6 °C, 78 °FDESIGN RELATIVE HUMIDITY 50 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	460	373	291	98	25	0	0	0	6	100	277	424
	°F	828	672	524	176	45	0	0	0	10	180	498	763
COOLING	°C	0	0	11	16	85	193	252	233	122	29	0	0
	°F	0	0	19	29	153	348	453	419	220	53	0	0

PERCENT POSSIBLE SUNSHINE:

42	47	54	60	65	69	69	68	69	65	55	42
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	9.4	10.6	15	21.7	26.7	31.1	32.8	32.2	29.4	23.3	15	10
	°F	49	51	59	71	80	88	91	90	85	74	59	50
MIN D.B.	°C	-0.6	0.6	3.9	8.9	13.9	18.9	21.1	20.0	16.1	9.4	3.3	0
	°F	31	33	39	48	57	66	70	68	61	49	38	32

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	1.97	2.89	3.71	5.07	6.13	5.77	5.90	5.61	4.37	3.87	1.94	1.84
	Btu/ft ²	625	917	1177	1608	1944	1830	1871	1779	1386	1228	615	584
DIRECT	kWh/m ²	3.26	4.04	4.48	5.63	6.68	5.90	6.19	6.23	5.03	5.39	2.90	3.06
	Btu/ft ²	1034	1281	1421	1786	2119	1871	1963	1976	1596	1710	920	971

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.697	0.680	0.675	0.737	0.799	0.727	0.760	0.784	0.654	0.711	0.583	0.614
CLOUD FACTOR	0.834	0.695	0.700	0.788	0.845	0.821	0.850	0.869	0.882	0.933	0.680	0.733

CLIMATE AND INSOLATION SUMMARY

TABLE 4

SITE NAME WASHINGTON, D.C. LATITUDE 38.89° LONGITUDE 77.03°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -7.2 °C, 19 °F;

WIND SPEED M

SUMMER - 2 1/2%

DRY BULB TEMP 33.3 °C, 92 °F;

WET BULB TEMP 25.0 °C, 77 °F

DESIGN RELATIVE HUMIDITY 55 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	506	431	343	147	40	0	0	0	8	106	283	476
°F	911	776	617	265	72	0	0	0	14	190	510	856
COOLING °C	0		4	5	62	148	216	191	101	21	0	0
°F	0	0	8	9	111	267	388	344	181	37	0	0

PERCENT POSSIBLE SUNSHINE:

46	53	56	57	61	64	64	62	62	61	54	47
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	6.7	7.8	12.2	18.9	24.4	28.3	30.6	29.4	26.1	20.	13.9	7.8
°F	44	46	54	66	76	83	87	85	79	68	57	46
MIN D.B. °C	-1.1	-1.7	2.2	7.8	13.3	18.3	20.6	20	16.1	10.	3.9	-0.6
°F	30	29	36	46	56	65	69	68	61	50	39	31

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	2.20	2.90	4.20	5.20	5.70	6.40	5.90	5.40	4.60	3.50	2.30	2.00
Btu/ft ²	699	919	1331	1648	1807	2029	1870	1712	1458	1110	729	634
DIRECT kWh/m ²	3.80	4.10	5.00	5.70	5.60	6.40	5.50	5.50	5.20	4.70	3.60	3.60
Btu/ft ²	1205	1300	1585	1807	1775	2029	1744	1744	1648	1490	1141	1141

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.68	0.64	0.63	0.69	0.63	0.68	0.59	0.63	0.61	0.60	0.54	0.67
CLOUD FACTOR	0.79	0.77	0.87	0.85	0.89	0.94	0.97	0.96	1.00	1.00	0.91	0.84

CLIMATE AND INSOLATION SUMMARY

TABLE 5

SITE NAME ALBUQUERQUE, N.M. LATITUDE 35.05° LONGITUDE 106.62°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 8.3 °C, 94 °F;

WIND SPEED L

SUMMER - 2 1/2%

DRY BULB TEMP 34.4 °C, 94 °F;

WET BULB TEMP 18.3 °C, 65 °F;

DESIGN RELATIVE HUMIDITY 20 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	513	389	331	156	32	0	0	0	4	121	342	496
°F	924	700	595	282	58	0	0	0	7	218	615	893
COOLING °C	0	0	0	3	37	162	236	200	89	4	0	0
°F	0	0	0	6	67	291	425	360	160	7	0	0

PERCENT POSSIBLE SUNSHINE:

70	72	72	76	79	84	76	75	81	80	79	70
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	8.0	11.2	14.9	20.6	25.7	31.4	32.9	31.1	27.9	21.5	13.4	9.1
°F	46.4	52.2	58.8	69.1	78.3	88.6	91.2	88.0	82.3	70.7	56.1	48.3
MIN D.B. °C	-4.7	-2.5	0.4	5.7	11.1	16.2	18.8	17.9	14.2	7.4	-0.5	-3.6
°F	23.5	27.5	32.7	42.2	51.5	61.1	65.8	64.3	57.6	45.3	31.1	25.6

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	3.58	4.50	6.00	7.30	8.29	8.63	7.39	7.23	5.87	6.23	3.80	3.48
Btu/ft ²	1136	1427	1903	2116	2630	2738	2343	2292	1861	1658	1205	1105
DIRECT kWh/m ²	6.77	7.11	8.48	9.10	10.00	10.40	8.43	8.90	7.37	8.19	6.90	7.23
Btu/ft ²	2149	2254	2591	2887	3172	3299	2691	2824	2337	2599	2189	2292

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	1.00	0.93	1.01	0.98	1.03	1.08	0.93	1.00	0.85	1.01	0.95	1.09
CLOUD FACTOR	0.90	0.89	0.90	0.95	0.98	0.98	0.95	0.97	1.00	1.00	1.00	0.96

CLIMATE AND INSOLATION SUMMARY

TABLE 6SITE NAME FT. WORTH, TEXAS LATITUDE 32.83° LONGITUDE 97.05°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -4.4 °C, 24 °F;WIND SPEED H

SUMMER - 2 1/2%

DRY BULB TEMP 37.8 °C, 100 °F;WET BULB TEMP 25.6 °C, 78 °F }DESIGN RELATIVE HUMIDITY 40 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	348	253	186	49	0	0	0	0	0	33	159	294
	°F	626	456	335	88	0	0	0	0	0	60	287	530
COOLING	°C	0	0	14	52	131	260	341	343	212	78	6	0
	°F	0	0	25	94	236	468	614	617	381	141	11	0

PERCENT POSSIBLE SUNSHINE:

56	57	65	66	67	75	78	78	74	70	63	58
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	13.3	15.6	19.4	24.4	28.3	33.3	35.6	35.6	31.7	26.1	18.9	14.4
	°F	56	60	67	76	83	92	96	96	89	79	66	58
MIN D.B.	°C	1.7	3.9	6.7	12.2	17.2	21.7	23.9	23.9	20	13.3	6.7	2.8
	°F	35	39	44	54	63	71	75	75	68	56	44	37

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	3.06	3.86	5.19	5.20	6.81	6.81	7.42	7.10	5.27	4.39	2.94	2.61
	Btu/ft ²	971	1224	1646	1649	2160	2160	2354	2252	1672	1393	933	828
DIRECT	kWh/m ²	5.10	5.61	6.71	5.67	7.55	7.58	8.65	8.74	6.47	6.42	4.61	4.55
	Btu/ft ²	1618	1779	2128	1799	2395	2404	2744	2772	2052	2052	1462	1443

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.824	0.830	0.853	0.738	0.857	0.897	1.000	1.050	0.807	0.888	0.736	0.780
CLOUD FACTOR	0.797	0.767	0.827	0.793	0.900	0.865	0.913	0.910	0.907	0.864	0.825	0.799

CLIMATE AND INSOLATION SUMMARY

TABLE 7

SITE NAME LOS ANGELES, CA. LATITUDE 34.05° LONGITUDE 118.23°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 6.7 °C, 44. °F;

WIND SPEED VL

SUMMER - 2 1/2%

DRY BULB TEMP 32.2 °C, 90. °F;

WET BULB TEMP 21.1 °C, 79. °F

DESIGN RELATIVE HUMIDITY 36 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	149	115	106	69	33	14	0	0	3	19	63	121
°F	268	207	190	124	60	25	0	0	5	35	112	218
COOLING °C	6	8	6	14	28	64	143	157	131	78	24	0
°F	10	14	10	25	51	115	258	282	236	140	44	0

PERCENT POSSIBLE SUNSHINE:

70	69	70	67	68	69	80	81	80	76	79	72
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	18.3	18.9	20.3	21.4	22.9	25.1	28.5	28.5	28.0	25.2	22.9	19.7
°F	65.0	66.0	68.6	70.6	73.3	77.1	83.3	83.3	82.4	77.3	73.3	67.5
MIN D.B. °C	8.1	9.0	10.1	11.7	13.3	14.9	17.0	17.2	16.3	14.1	11.2	9.0
°F	46.6	48.2	50.2	53.0	56.0	58.9	62.6	62.9	61.4	57.4	52.1	48.8

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	2.94	3.32	5.23	6.57	6.23	6.27	8.13	7.49	5.87	4.19	3.27	3.03
Btu/ft ²	931	1054	1658	2083	1975	1988	2579	2353	1861	1330	1036	962
DIRECT kWh/m ²	5.32	4.86	7.32	8.00	7.03	6.73	9.32	8.84	7.50	6.23	5.63	5.16
Btu/ft ²	1688	1541	2323	2538	2231	2136	2957	2804	2379	1975	1787	1637

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.94	0.80	1.01	0.94	0.88	0.82	0.98	0.97	0.87	0.85	0.84	0.73
CLOUD FACTOR	0.74	0.70	0.77	0.88	0.81	0.84	1.00	1.00	0.99	0.90	0.91	1.00

CLIMATE AND INSOLATION SUMMARY

TABLE 8SITE NAME PHOENIX, ARIZ. LATITUDE 33.43° LONGITUDE 112.02°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 1.1 °C, 34 °F;WIND SPEED VL

SUMMER - 2 1/2%

DRY BULB TEMP 41.1 °C, 106 °F;WET BULB TEMP 24.4 °C, 76 °F;DESIGN RELATIVE HUMIDITY 27 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	238	162	103	33	0	0	0	0	0	9	101	216
	°F	428	292	185	60	0	0	0	0	0	17	182	388
COOLING	°C	0	8	12	78	197	327	451	415	313	133	14	0
	°F	0	14	21	141	355	588	812	747	564	240	26	0

PERCENT POSSIBLE SUNSHINE:

76	79	83	88	93	94	84	84	89	88	84	77
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	17.8	20	23.9	28.9	33.9	38.9	40.6	38.9	36.7	30.6	23.3	18.9
	°F	64	68	75	84	93	102	105	102	98	87	74	66
MIN D.B.	°C	1.7	3.9	6.1	10	13.9	18.9	23.9	22.8	19.4	12.8	5.6	2.8
	°F	35	39	43	50	57	66	75	73	67	55	42	37

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	3.61	4.50	5.97	7.23	8.00	8.10	7.74	6.87	5.93	5.13	3.74	3.42
	Btu/ft ²	1145	1427	1894	2293	2538	2569	2455	2179	1881	1627	1186	1085
DIRECT	kWh/m ²	6.42	6.86	8.16	8.97	9.65	9.67	9.19	8.26	7.43	7.81	6.39	6.65
	Btu/ft ²	2036	2176	2588	2845	3061	3067	2915	2620	2357	2477	2027	2109

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.940	0.917	0.971	1.000	1.053	1.066	1.042	0.980	0.842	0.963	0.875	0.990
CLOUD FACTOR	0.887	0.853	0.886	0.925	0.935	0.927	0.928	0.921	1.000	0.974	0.970	0.931

CLIMATE AND INSOLATION SUMMARY

TABLE 9SITE NAME BLUE HILL, MASS. LATITUDE 42.22° LONGITUDE 71.02°

ASHRAE DESIGN CONDITION:

WINTER – 97 1/2%

DRY BULB TEMP -12.2 °C, 10 °F;WIND SPEED H

SUMMER – 2 1/2%

DRY BULB TEMP 31.1 °C, 88 °F;WET BULB TEMP 23.3 °C, 74 °F;DESIGN RELATIVE HUMIDITY 50 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	668	583	513	312	151	30	3	8	62	203	378	608
°F	1202	1060	974	661	271	54	6	14	111	366	681	1084
COOLING °C	0	0	0	0	6	38	108	83	18	0	0	0
°F	0	0	0	0	10	69	195	150	33	0	0	0

PERCENT POSSIBLE SUNSHINE:

47	66	67	66	59	62	64	63	61	58	48	48
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	2.8	2.8	7.2	13.3	20.	24.4	27.8	26.7	22.8	17.2	11.1	4.4
°F	37	37	45	56	68	76	82	80	73	63	52	40
MIN D.B. °C	-5	-5	-0	4.4	10	16	19.2	17.2	13.0	8.2	2.2	-2.8
°F	23	23	31	40	50	59	65	63	57	47	38	27

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	1.87	2.68	4.03	5.07	6.00	6.33	5.71	5.23	4.17	3.35	1.71	1.90
Btu/ft ²	593	850	1278	1608	1903	2008	1811	1659	1323	1063	542	603
DIRECT kWh/m ²	4.06	4.64	5.94	6.33	7.03	7.10	6.42	6.42	5.60	5.48	3.42	4.26
Btu/ft ²	1288	1472	1804	2008	2230	2252	2036	2036	1776	1738	1085	1361

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.964	0.887	0.913	0.871	0.881	0.838	0.830	0.894	0.787	0.866	0.823	0.832
CLOUD FACTOR	0.652	0.657	0.714	0.751	0.793	0.834	0.793	0.786	0.843	0.857	0.660	0.885

CLIMATE AND INSOLATION SUMMARY

TABLE 10

SITE NAME MADISON, WIS. LATITUDE 43.13° LONGITUDE 89.33°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -20.6 °C, -5 °F;

WIND SPEED M

SUMMER - 2 1/2%

DRY BULB TEMP 31.1 °C, 88 °F;

WET BULB TEMP 23.9 °C, 75 °F

DESIGN RELATIVE HUMIDITY 53 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	830	696	599	328	165	40	8	22	96	263	505	742
°F	1494	1252	1079	591	297	72	14	39	173	474	909	1336
COOLING °C	0	0	0	0	10	53	96	86	8	3	0	0
°F	0	0	0	0	18	96	172	154	14	6	0	0

PERCENT POSSIBLE SUNSHINE:

44	49	52	53	58	64	70	66	60	56	41	38
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	-3.3	-2.2	2.8	11.7	18.9	24.4	28.3	27.2	22.2	16.1	5.6	-1.1
°F	26	28	37	53	66	76	83	81	72	61	42	30
MIN D.B. °C	-12.2	-12.2	-6.1	1.7	7.2	13.9	15.6	15	10.6	4.4	-2.2	-8.9
°F	10	10	21	35	45	57	60	59	41	40	28	16

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	1.77	2.46	3.68	5.47	6.03	7.13	6.71	6.16	4.50	3.26	1.80	1.56
Btu/ft ²	563	780	1167	1734	1912	2260	2127	1953	1427	1033	571	495
DIRECT kWh/m ²	3.52	4.18	5.10	6.90	7.29	8.67	8.19	7.97	6.30	5.26	3.43	3.35
Btu/ft ²	1116	1325	1617	2187	2311	2448	2596	2526	1997	1667	1087	1062

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.75	0.82	0.77	0.88	0.94	1.01	0.99	1.00	0.84	0.77	0.71	0.72
CLOUD FACTOR	0.75	0.65	0.74	0.81	0.77	0.85	0.85	0.88	0.89	0.92	0.79	0.83

CLIMATE AND INSOLATION SUMMARY

TABLE 11

SITE NAME OMAHA, NEB. LATITUDE 41.37° LONGITUDE 96.02°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -18.3 °C, -1 °F;

WIND SPEED M

SUMMER - 2 1/2%

DRY BULB TEMP 34.4 °C, 94 °F;

WET BULB TEMP 25.6 °C, 78 °F

DESIGN RELATIVE HUMIDITY 53 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	730	576	481	217	82	11	0	3	39	167	417	637
°F	1314	1036	865	391	148	20	0	6	71	201	750	1147
COOLING °C	0	0	0	6	48	131	210	186	61	11	0	0
°F	0	0	0	10	86	236	378	334	110	19	0	0

PERCENT POSSIBLE SUNSHINE:

57	59	60	60	63	69	76	71	67	66	69	55
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	1.7	3.9	9.4	17.8	23.9	29.4	33.9	32.2	27.8	21.1	11.1	5
°F	35	39	49	64	75	85	93	90	82	70	52	41
MIN D.B. °C	-8.3	-6.7	-1.7	5	11.1	17.2	20.0	19.4	13.9	7.2	-0.6	-8
°F	17	20	29	41	52	63	69	67	57	45	31	18

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	2.45	2.89	4.19	5.33	6.84	6.90	6.84	5.94	4.67	3.84	2.40	2.10
Btu/ft ²	777	916	1328	1690	1851	2187	2168	1883	1480	1217	761	668
DIRECT kWh/m ²	5.58	4.68	5.90	6.60	6.55	7.83	7.90	7.32	6.10	6.29	4.77	4.81
Btu/ft ²	1769	1484	1870	2092	2076	2482	2504	2320	1934	1994	1512	1526

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	1.16	0.78	0.84	0.87	0.81	0.87	0.89	0.92	0.76	0.85	0.85	0.88
CLOUD FACTOR	0.73	0.74	0.77	0.78	0.81	0.89	0.91	0.87	0.95	0.97	0.87	0.92

CLIMATE AND INSOLATION SUMMARY

TABLE 12SITE NAME SEATTLE, WASH. LATITUDE 47.45° LONGITUDE 122.30°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 0 °C, 32 °F;WIND SPEED L

SUMMER - 2 1/2%

DRY BULB TEMP 26.1 °C, 79 °F;WET BULB TEMP 18.3 °C, 65 °FDESIGN RELATIVE HUMIDITY 47 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	410	319	329	238	143	69	31	32	68	184	297	372
°F	738	574	592	429	258	124	56	57	123	332	534	670
COOLING °C	0	0	0	0	0	12	50	38	10	0	0	0
°F	0	0	0	0	0	22	90	69	18	0	0	0

PERCENT POSSIBLE SUNSHINE:

27	34	42	48	53	48	62	56	53	36	28	24
----	----	----	----	----	----	----	----	----	----	----	----

AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	6.7	8.3	10.6	14.4	18.9	21.1	24.4	23.9	22.8	15.6	10.0	7.8
°F	44.	47.	51.	58.	66.	70.	76.	75.	73.	60.	50.	46.
MIN D.B. °C	0.6	1.7	2.2	5.0	7.2	10.0	12.2	12.2	8.3	6.7	3.3	2.2
°F	33.	35.	36.	41.	45.	50.	54.	54.	47.	44.	38.	36.

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	1.19	1.96	3.10	4.20	5.94	6.00	6.19	5.13	4.03	2.19	1.10	0.84
Btu/ft ²	379	623	982	1332	1883	1903	1965	1627	1279	696	349	266
DIRECT kWh/m ²	2.68	3.46	4.52	5.10	7.00	6.97	7.45	6.45	5.70	3.48	2.20	1.90
Btu/ft ²	849	1099	1433	1618	2220	2210	2364	2046	1808	1105	698	604

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.74	0.74	0.74	0.73	0.82	0.85	0.89	0.83	0.76	0.60	0.60	0.63
CLOUD FACTOR	0.65	0.68	0.70	0.72	0.83	0.79	0.84	0.85	0.94	0.87	0.70	0.65

the reporting weather station. The ASHRAE design conditions are included (e.g., winter dry bulb and wind severity, summer dry bulb and wet bulb conditions).

Heating and cooling degree days based on long-term averages are included for each month of the year (65°F base). Similar long-term averages of percent possible sunshine and average ambient temperature maxima and minima are also provided by month.

Both total horizontal and direct normal values of incident radiation are presented for each month. For the most part, these values were obtained from two-year averages of the Aerospace Corporation tapes. In each case, only the total horizontal values are directly measured. The direct normal values are inferred by means of correlations.

The clearness number and cloud factor parameters are obtained directly from the values of incident radiation, using the deterministic method described in Appendix B of the previous quarterly progress report, Reference 1.

Table 13 lists the sources used to supply the data presented in the climate and insolation summaries. In certain cases, it was necessary to substitute data from nearby sites of similar climatology. In such cases, the substitute is indicated in parenthesis. For dry bulb temperatures a slight adjustment was sometimes made if the mean temperature at the substitute site differed significantly.

2.2 Building Characteristics

Table 14 provides a preliminary estimate of commercial building population, gross area and energy consumption in the U.S. for the years shown. The information is based on population growth assumptions of 4-6 percent per year and energy conservation trends for future installations (e.g., reduction of power demand from about 100 W/m² to 50 W/m²). Six building models previously defined (Reference 1) as idealized examples of

TABLE 13

DATA SOURCES FOR CLIMATE AND INSOLATION SUMMARY DATA

Site	ASHRAE Design Conditions	Degree Days	Percent Sunshine	Dry Bulb Temperatures	Average Daily Incident Radiation
Lake Charles, La.	4*	2	1 (New Orleans)	1 (New Orleans)	5
Miami, Fla.	4	2	1	1	5
Nashville, Tenn.	4	2	1	1	5
Washington, D.C.	4	2	1	1	6
Albuquerque, N.M.	4	2	1	3	5
Ft. Worth, Texas	4	2	1		5
Los Angeles, Ca.	4	2	1	3	5
Phoenix, Ariz.	4	2	1	3	5
Blue Hills, Mass.	4 (Boston)	2	1 (Boston)	1 (Boston)	5
Madison, Wis.	4	2	1	1 (Green Bay + 1.2°F)	5
Omaha, Neb.	4	2	1 (Lincoln)	1 (Lincoln + 0.5°F)	5
Seattle, Wash.	4	2	1	1	5

*Data Source Legend:

- 1 - Climatic Atlas of the U.S.
- 2 - Climatology of the U.S. No. 81 (By State)
- 3 - Local Climatological Data (1972)
- 4 - ASHRAE Handbook of Fundamentals
- 5 - Arizona State/Spectrolab
- 6 - Sandia Laboratories

See References 3 through 8

TABLE 14
CENSUS OF POTENTIAL COMMERCIAL APPLICATIONS

BUILDING TYPE	YEAR		
	1975	1980	1990
SHOPPING CENTERS			
POPULATION	16,000	20,000	34,000
GROSS AREA (M ² X 10 ⁸)	2.0	2.7	4.6
ENERGY DEMAND			
CAPACITY (MW)	20,000	27,000	35,000*
BBLS OIL EQUIVALENT/DAY	430,000	580,000	750,000
OFFICE BUILDINGS			
POPULATION	366,000	475,000	750,000
GROSS AREA (M ² X 10 ⁸)	4.3	5.6	9.2
(10 STORIES OR LESS)	(0.6)	(0.7)	(1.2)
ENERGY DEMAND			
CAPACITY (MW)	34,000	45,000	55,000*
BBLS OIL EQUIVALENT/DAY	690,000	910,000	1,100,000
OTHER**			
POPULATION	940,000	1,100,000	1,400,000
GROSS AREA (M ² X 10 ⁸)	10.0	11.7	14.9
ENERGY DEMAND			
CAPACITY (MW)	50,000	55,000	60,000*
BBL OIL EQUIVALENT/DAY	1,250,000	1,400,000	1,500,000

*ASSUMES IMPLEMENTATION OF ASHRAE 90-75 ENERGY STANDARDS

**INCLUDES RETAIL STORES, HEALTH RELATED FACILITIES, HOTELS & MOTELS, WAREHOUSES, ETC.

commercial construction and use were selected from among actual buildings designed by Welton Becket Associates with the aid of its subsidiary, the Energy Group. Table 15 summarizes the model building characteristics. Using the AXCESS computer program, energy demands analyses were conducted on these buildings to investigate the effects of the heating, ventilating, and air conditioning (HVAC) internal system variations. The number of HVAC systems simulated by the Energy Group for each building is also shown in Table 15 and is discussed below.

2.2.1 HVAC System Analyses Methodology and Results

For a given HVAC system, operating in a specific building, AXCESS will synthesize and categorize the energy usage on an hourly, monthly, and yearly basis and present the data in the form of periodic meter readings. The HVAC system types considered were Dual Duct, Multi-Zone, Single Zone Reheat, Variable Volume with Reheat, 4-Pipe Induction, 4-Pipe Fan coil, Unitary Heat Pumps, and Unitary Cooling with Separate Reheat. Table 16 shows which of the HVAC systems were considered for each building.

The dual duct systems utilized in the AXCESS codes consist of a central unit which supplies heated and cooled air, each at a constant temperature, to two separate ducts per space or building zone. Mixing boxes in each space, fed by the ducts, supply the proper air temperature by combining the properly dampered hot and cold flow from the ducts. A simplified schematic flow diagram of a typical dual duct system is shown in Figure 7.

A multizone system, as shown in Figure 8, heats and cools several separate zones, of varying load requirements from a single central heating/cooling unit. Each zone is served by a separate thermostat which controls the flow of hot or cold air to that zone from the central unit. Flow control and mixing are achieved in mixing units, one of which is located in each zone.

A single zone-reheat system is a modified single zone system capable of providing a high degree of temperature and humidity control. The

TABLE 15
TYPICAL COMMERCIAL BUILDING TYPES

OFFICE BUILDING	LOW RISE	HIGH RISE
FLOOR AREA:	25,000 SQ FT (2323 m ²)	248,000 SQ FT (23,048 m ²)
COMPLETION DATE:	1964	1970
LOCATION:	LOS ANGELES, CALIFORNIA	LOS ANGELES, CALIFORNIA
DESCRIPTION:	THREE STORIES PLUS BASEMENT; PRECAST CONCRETE AND SOLAR BRONZE GLASS EXTERIOR; PRECAST CONCRETE FRAME	FIFTEEN STORIES; EXPOSED AGGREGATE CONCRETE AND SOLAR BRONZE GLASS EXTERIOR; REINFORCED CONCRETE FRAME
INTERNAL SYSTEMS:	6 SIMULATED	5 SIMULATED
RETAIL STORE	SMALL	LARGE
FLOOR AREA:	55,000 SQ FT (5111 m ²)	260,000 SQ FT (24,163 m ²)
COMPLETION DATE:	1987	1972
LOCATION:	NEWPORT BEACH, CALIFORNIA	CERRITOS, CALIFORNIA
DESCRIPTION:	TWO-LEVEL STORE ON OPEN WALL IN MAJOR SHOPPING CENTER; SPLIT BLOCK, TERRA COTTA TILE, AND WHITE CONCRETE FACADE.	TWO-LEVEL ABOVE GRADE AND ONE BELOW ON ENCLOSED MALL IN MAJOR SHOPPING CENTER; HEAVILY TEXTURED STUCCO AND YELLOW TONE GLAZED, CERAMIC VENEER TILE FACADE, SLOPING WALLS.
INTERNAL SYSTEMS:	3 SIMULATED	2 SIMULATED
SHOPPING CENTER	SMALL	LARGE
FLOOR AREA:	224,000 SQ FT (20,876 m ²)	775,000 SQ FT (72,026 m ²)
COMPLETION DATE:	1977	1962
LOCATION:	NEWPORT BEACH, CALIFORNIA	TORRANCE, CALIFORNIA
DESCRIPTION:	OPEN, STAGGERED MALL; SINGLE LEVEL SHOPS, TWO-LEVEL DEPARTMENT STORE; TILE AND CONCRETE FACADES.	OPEN MALL, 50 SHOPS IN SINGLE-LEVEL BUILDINGS, A FOUR-LEVEL AND A TWO-LEVEL DEPARTMENT STORE; NATURAL STONE AND CONCRETE FACADE.
INTERNAL SYSTEMS:	4 SIMULATED	4 SIMULATED

TABLE 16
BUILDING - HVAC SYSTEM ANALYSIS MATRIX

	Low-Rise Office	High-Rise Office	Small Retail Store	Large Retail Store	Small Shopping Center	Large Shopping Center
Dual Duct	X	X				
Multi-Zone	X			X	X	X
Single-Zone Reheat	X	X	X	X	X	X
Variable Volume Reheat	X	X				
4-Pipe Induction		X				
4-Pipe Fan Coil	X	X				
Unitary Heat Pumps	X		X		X	X
Unitary Cooling With Separate Reheat			X		X	X

Figure 7. Dual Duct

Figure 8. Multi-Zone

single zone system provides heating and cooling to the entire building, or one area of the building which has uniform heat gain or loss considered as a "single zone" by means of a single thermostat. A typical zone system is shown in Figure 9.

Variable volume with reheat systems, as shown in Figure 10, provides heated or cooled air at a constant temperature to all zones through variable air volume boxes located in each zone. The boxes adjust the air quality to match the load requirements of each space. Reheating is supplied as necessary at each box exit.

The 4-pipe induction system consists of an air handling unit which supplies heated or cooled, high pressure primary air, to individual induction boxes located in each space. The boxes induce room air into the primary air and discharge the resultant mixture into the space through heating or cooling coils which fine tune the mixture temperature. As shown in Figure 11, the heating and cooling coils are supplied by separate 4-pipe hot and chilled water sources.

4-pipe fan coil is a combination four (4) pipe hot and chilled water supply, fan coil system. The fan coil system, as shown in Figure 12, consists of several units each with its own fan and heating and/or cooling coil.

Figure 13 shows the schematic of a unitary heat pump system. In this scheme, each zone or space is served by a single unit or if the space is small enough several spaces may be combined and served by one unit.

A unitary cooling with separate reheat is illustrated in Figure 14. It consists of one or more unitary air conditioning (cooling units) serving one or more zones with separate reheat prior to zone air discharge. Each heat coil is controlled by a separate thermostat.

Figure 9. Single Zone Reheat

Figure 10. Variable Volume with Reheat

Figure 11. 4-Pipe Induction

Figure 12. 4-Pipe Fan Coil

Figure 13. Unitary Heat Pump

Figure 14. Unitary Cooling with Separate Heating

While the output from the AXCESS code is comprehensive and complete, its format is too detailed to be directly compatible with the input requirements of the computer codes discussed in the Task 3 effort which analyze candidate STES. Typical output of the AXCESS code includes the following categories of usage: total electricity, interior lights, total gas primary heating system, gas primary heating systems auxiliary and terminal systems. The required energy usage input for the STES codes derived from this data and the methodology used is discussed in Appendix A.

Based on the data presented in Appendix A, the ratio of thermal (heating and cooling) to electric power usage for each system is shown in Table 17 for each of the six model buildings. The systems are listed in order of increasing energy consumption. Generally, as consumption increases the ratio of thermal to electrical power usage also increases.

The hourly usage data is summarized on a system-by-system basis in Figure 15 for the low-rise office building. This data was compared to the hourly energy profile of two systems for the large retail store model as shown in Figure 16 and good agreement on a qualitative basis was obtained.

The results from this analysis suggest that a criteria for selection of buildings for retrofit application of Solar Total Energy Systems is the consumption of the current HVAC systems installed in the buildings. There is more incentive to retrofit a low consumption HVAC system coupled to a STES in a building which currently uses a relatively high energy consumption system than to simply install a STES in a low consumption HVAC system equipped building. This is because the relative cost savings would be significantly greater for the first alternative than the second.

If this criteria is adopted then the consideration that an optimum candidate building for STES application should have a thermal to electrical usage ratio of ~ 5 , needs to be modified for commercial

TABLE 17
RATIO OF THERMAL TO ELECTRICAL ENERGY USAGE

	Consumption Rating	Low-Rise Office	High-Rise Office	Small Retail Store	Large Retail Store	Small Shopping Center	Large Shopping Center
Unitary Cooling With Separate Reheat	1	NC	NC	0.4	NC	0.4	0.3
4-Pipe Fan Coil	2	0.9	1.1	NC	NC	NC	NC
Unitary Heat Pumps	3	1.2	NC	0.4	NC	0.5	0.3
Variable Volume With Reheat	4	2.9	2.0	NC	NC	NC	NC
Multizone	5	4.0	NC	NC	0.7	1.8	1.8
Dual Duct	6	5.4	4.0	NC	NC	NC	NC
Single Zone Reheat	7	5.7	3.8	0.6	1.1	1.6	2.1
4-Pipe Induction	8	NC	3.9	NC	NC	NC	NC

NC = System not considered in this building.

Figure 15. Simulated Total Energy Demand (Low Rise Office Building)

Figure 16. Simulated Total Electrical Demand
Large Retail Store (3 Stores, 24,163 m²)

applications. As shown in Table 17, the HVAC systems which consume the least amounts of energy, and would therefore be strong candidates for STES application under this criteria, have ratios of 1.0 or less.

2.3 Energy Demand

From the preceding, it can be concluded that energy data (load profile) on actual buildings can be of little use in this study unless the type of internal system, building characteristics, and operational modes are also known. Furthermore, any pronounced similarity between the actual buildings and those finally selected as candidates for demonstration would be as likely as a model reference building where the required characteristics can be defined. Also, obtaining real load profile data on actual buildings is difficult since little measurements have been made in the past, except for cases where a specific problem may have necessitated such data. Figure 17 shows actual energy profile data being developed under another ERDA contract for a peak leveling program. Information on load data that is obtained will be provided in the final report. A sample summary sheet for this data is shown in Table 18.

2.3.1 Energy Conservation

The Energy Management Service in Portland, Oregon, has implemented an energy conservation design into an existing building through modifications of lighting loads and other conservation methods. Figure 18 shows good correlation of the actual demand in 1975 with that estimated for an average year.

Figure 19 presents data on the potential energy savings that may be expected in future designs implementing energy conservation trends. The trend implies minimizing energy requirements for the internal HVAC system, which will also result in the type of HVAC system most compatible with a STES concept.

DATE: 12 - 15 - 76

ERDCON>C61215
ERDRPT>D11215ELECTRICAL DEMAND
IN KILOWATTS (KW) ENGINEERING SUPERVISION CO., NEWPORT BEACH, CA.
CONTRACT NO. E(04-3)-1152Figure 17. National Energy Peak Leveling Program
Daily Demand for All Complexes

TABLE 18
SAMPLE COMMERCIAL BUILDINGS SUMMARY

I. BUILDING DESCRIPTION

TYPE: OBH OFFICE HIGH RISE CODE: _____
 LOCATION: CITY OF COMMERCE ORIENTATION/EXPOSURE: ~N
 TOTAL FLOOR AREA: 4 WALLS EXPOSED
10.86 km² (117.5 k ft²) NO. OF FLOORS 10
 OCCUPANCY TYPE: _____ PERSONS/m²: ~0.1

ITEM	CONSTRUCTION TYPE	AREA		U-VALUES	
		m ²	ft ²	kJ/m ² ·hr·°C	Btu/ft ² ·hr·°F
ROOF	STEEL CONCRETE		~11.8 k		0.10
WALLS	STEEL CONCRETE		~52 k		0.3
GLAZING*	~10% OF WALL AREA		~5.2 k		1.13

*SHADING COEFFICIENT _____ PERCENT OF TOTAL WALL AREA: _____%

NORMAL OPERATING:

HOURS: 7:30 am DAYS: 5:30 pm (M-F)
 HOURS: 9:00 am DAYS: 1:00 pm (SAT)
 HOURS: — DAYS: — (SUN)

MONTH/SEASONAL VARIATIONS:

CLOSED HOLIDAYS

II. LOAD DATA

DAY <u>19</u>	MONTH	<u>FEBRUARY</u>	YEAR <u>1969</u>
ELECTRICAL	PEAK	TIME	AVERAGE
LIGHTING	<u>283 kW</u>	<u>1100</u>	<u>3378 kWh</u>
AIR CONDITIONING	<u>228 kW</u>	<u>1530</u>	<u>4046 kWh</u>
OTHER	<u>144 kW</u>	<u>1100</u>	<u>1763 kWh</u>
THERMAL			
HEATING	<u>1069 MJ/h</u>	<u>1700</u>	<u>2249 MJ</u>
COOLING	<u>302 MJ/h</u>	<u>1500</u>	<u>4802 MJ</u>
HOT WATER	<u>36 MJ/h</u>	<u>1700</u>	<u>136 MJ</u>

TABLE 18 (Continued)
SAMPLE COMMERCIAL BUILDINGS SUMMARY

III. LOAD PROFILE DATA

AVERAGE PEAK HOURLY ELECTRICAL AND HOT WATER LOADS (kW) FOR 1969

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ELECTRICAL LOAD	178	174	177	190	207	238	274	365	436	433	441	443	444	460	456	441	368	335	291	257	241	221	217	209
HOT WATER LOAD	0	1	1	0	1	0	1	3	3	3	2	3	4	4	3	4	8	4	2	0	4	0	0	1

AVERAGE DAILY PEAK ELECTRICAL USAGE (kWh) 7552

STANDARD DEVIATION 728.03

AVERAGE DAILY HOT WATER USAGE (kWh) 50

STANDARD DEVIATION 8

MONTHLY USAGE (MWh) FOR 1969

MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
ELECTRICAL	185.4	184.5	210.4	181.1	193.8	189.7	230.1	239.2	228.8	248.2	219.6	222.3
HEATING	63.1	78.8	50.9	4.4	2.0	0.9	0	0	0	0	0	27.8
COOLING	26.2	22.8	17.6	50.2	46.1	47.1	106.9	120.6	90.7	46.0	46.0	37.3
HOT WATER	1.3	1.1	1.3	1.2	1.2	1.0	1.0	1.0	1.1	1.2	1.1	1.2

INTEGRATED YEARLY USAGE (MWh)

ELECTRICAL 2438.45

HEATING 227.94

COOLING 673.38

HOT WATER 13.79

IV. EQUIPMENT DATA

TOTAL CONNECTED ELEC. SERVICE: 1905 kW

VAPOR COMPRESSOR RATING: 2 X 160 TONS, 7 COP

LIGHTING AVERAGE: 3 W/R²; INCANDESCENT PERCENTAGE UNKNOWN %

MISC. ELECTRICAL: 3.87 W/R²

AIR CONDITIONING ELECTRICAL 3.19 W/R²

SPACE HEATING TYPE/CAPACITY: ELECTRICAL, RATING 2.18 (643) MBtu/h (kW)

WATER HEATING TYPE/CAPACITY: ELECTRICAL, RATING: 153,585 (45) Btu/h (kW)

UTILITY BASIC SERVICE: 1969 DOLLARS

ELECTRICITY 45042.84 \$/YEAR, RATE: 1.35 \$/kWh

NATURAL GAS NA \$/YEAR, RATE: NA \$/kWh

FUEL OIL NA \$/YEAR, RATE: NA \$/10⁶ Btu

Figure 18. Energy Conservation.

Figure 19. Energy Conservation Potential

3.0 TASK 2 - CONCEPT DEFINITION AND COMPONENT EVALUATION

Component characterization for the STES concepts is provided in the previous quarterly report (Reference 1). Additional effort during this report period is discussed below.

3.1 Brayton STE Concept Evaluation

The low pressure Brayton cycle concept is felt to be one of the most suitable STES concepts for commercial buildings because of several inherent advantages that are listed in Table 19 where the several concepts that have been considered during this study are compared in a qualitative manner. In particular, the low pressure (<15 psig) air Brayton cycle and the photovoltaic cycle are the only concepts that will not require a licensed operator and the attendant operating costs. Consequently, the absorber designs currently being developed (References 9 through 11) were reviewed to determine if they would be suitable for operating at pressure below 15 psig (usual code limit) at the temperatures required by the cycle (700 to 900°C) and it was concluded that none of the current designs would be suitable for application to a commercial STES. The principal problem area is the large internal surface area required to transfer the energy to the low pressure gas without an excessive pressure loss. Figure 20 shows the effect of concentration ratio on wall-to-fluid temperature difference for several values of the gas heat transfer coefficient covering the range of experimental values reported in Reference 10 and indicates that concentration ratios greater than 70 are probably not attainable without excessive gas to wall temperature differences. However, to operate in the 700 to 900°C region with reasonable thermal losses requires concentration ratios greater than 1000:1. A closed cavity receiver must be used to limit radiation losses and, therefore, the high intensity radiation impinging on the cavity walls will require some type of thermal transformer to be used to produce the extended area internal heat transfer area required. Existing concepts do this to some degree, but require high-pressure gas and have a large hot external shell that must be supported and insulated with a

TABLE 19
COMPARISON OF STES CONCEPTS

<u>Power Conversion System Concept</u>	<u>Advantages</u>	<u>Disadvantages</u>
Organic Rankine	<ol style="list-style-type: none"> 1. Distributed Collector Can be Used 2. Can be Cascaded for Thermal Load 	<ol style="list-style-type: none"> 1. Requires Licensed Operator 2. Fire Hazard 3. Low Performance
Steam Rankine	<ol style="list-style-type: none"> 1. High Performance Potential 	<ol style="list-style-type: none"> 1. Requires Licensed Operator 2. Requires Central Receiver 3. Fire Hazard Because of Second Fluid 4. Large Performance Loss to Cascade
Brayton Cycle (High Pressure)	<ol style="list-style-type: none"> 1. High Performance Potential 2. Can be Cascaded for Thermal Load 	<ol style="list-style-type: none"> 1. Requires Licensed Operator 2. Requires Central Receiver 3. Thermal Storage Not Feasible for STES 4. Fluid Leakage Problems
Brayton Cycle (Low Pressure)	<ol style="list-style-type: none"> 1. High Performance Potential 2. Can be Cascaded for Thermal Load 3. No Operator Required 4. Thermal Storage Feasible for STES 	<ol style="list-style-type: none"> 1. Requires Advanced Central Receiver Concept 2. Probably Requires Fossil Fuel Topping Cycle to Produce Needed Turbine Inlet Temperatures
Photovoltaic	<ol style="list-style-type: none"> 1. High Performance Potential 2. Simple Control Systems 3. No Operator Required 	<ol style="list-style-type: none"> 1. High Cost of Array 2. Cascading Difficult

Figure 20. Effect of Concentration Ratio on Wall to Fluid Temperature Difference

surface area that is approximately equal to the internal heat transfer area so that the effective concentration ratio for the design would be limited to ~100:1. The intensity maldistributions currently estimated for high concentration ratio designs of the cavity type further complicate the absorber design with the result that the Brayton cycle has been deleted from this study effort since neither the performance nor the cost of the collector system required can be estimated on a basis comparable with the other systems.

3.2 Component Characterization

The effort on component characterization is continuing to provide a more realistic basis for concept comparisons and has been primarily concerned during this report period with evaluation of storage subsystems and photovoltaic arrays. Cost algorithms for a central receiver STES concept is contained in Appendix B.

Recurring cost estimates have been developed for both the hot oil and battery storage subsystems covering replacement of oil and batteries respectively to be consistent with the JPL/ERDA annualized cost methodology. The storage system life is assumed to be equal to the STES life with maintenance and replacement costs included as yearly recurring costs.

3.2.1 Hot Oil Thermal Stability

An important aspect of the cost of organic Rankine concept is the thermal stability of the oil used as the heat transfer fluid. Consequently, the thermal stability data developed at Rocketdyne (References 12 and 13) has been incorporated into the analysis effort of this study. An Arrhenious-type equation is used to relate the decomposition of the oil to the peak system temperature and used with the Rocketdyne estimate (Reference 12) of the stay time at this temperature. Decomposition data for both Therminol 66 and Caloria HT-43 were obtained (and are in

reasonably agreement with the data reported in Reference 14) and used to compare the storage system costs for the two fluids. Caloria HT-43 was found to be less expensive and, therefore, is the fluid used for this study effort.

3.2.2 Battery Storage System Life

A survey of the literature on battery storage systems has been made but did not turn up specific information on either system efficiency or costs. Table 20 from Reference 15 indicates the type of information found during the survey. Based on the optimistic estimated life of seven (7) years, a recurring cost of 20% of the battery cost has been assumed to include both battery replacement and maintenance of the battery system.

3.2.3 Dual Media Storage Volumetric Requirements

As discussed in Reference 13, the major portion of the cost of hot oil thermal storage systems is that of the oil and consequently dual media systems can reduce the cost significantly by substituting a less expensive material for some of the oil. A generalized analysis of this type of storage under cyclic conditions does not exist although a number of analyses of single fluid regenerators have been made (References 16-20) under various conditions.

Reference 16 presents a discussion of the early work on regenerators by Hausen which shows that a dramatic decrease in the media volumetric efficiency occurs during successive charge/discharge cycles. Reference 17 presents a simplified analysis of the thermal conditions in the storage media after a number of charge/discharge cycles have stabilized thermal conditions in the storage media (at a constant fluid flow rate). Although, the charge flow rate in a STES will not be constant, the use of a constant flow rate in the analysis should give a reasonably accurate estimate of the volumetric efficiency of the media and hence, Reference 17 has been used as the basic for this analysis.

TABLE 20
CHARACTERISTICS OF PUMPED HYDROELECTRIC
AND BATTERY ENERGY STORAGE
(Reference 15 Data)

<u>Characteristic</u>	<u>Pumped Hydro</u>	<u>Batteries</u>	
		<u>Lead-Acid</u>	<u>Advanced</u>
Efficiency (round trip)	67-75	60-75	60-80
Energy Density (kWh/cu ft)	0.03	1-2	1-5
Duty Cycle (typical daily charge time (hours) discharge time (hours))	6-8 8-10	possibility of shorter duty cycles	
Response			
load change (min)	1-5	rapid response	
charge to discharge (min)	2-20	(< 1 sec)	
Capital Cost			
power-related components (C _p , \$/kW)	120-160	60-100	60-100
energy storage-related components (C _s , \$/kWh)	3-12	40-70	20-40
total capital cost* (C _T , \$/kW)	200-300	500-800	250-400
O&M Cost (mills/kWh)	~1	1-2 (?)	2-4 (?)
Availability (%)	85-90	90 (?)	?
Useful Plant Life (years)	50	7-10	?

*total capital cost is given by

$$C_T = C_p + t_{\max} \times C_s \text{ where}$$

$t_{\max}$ = maximum time during which storage system can deliver energy at
rated power; total storage system cost calculated for $t_{\max} = 10$ hr.

Figure 21 shows the basic concept of the simplified theory developed in Reference 16 (which was verified by the work presented in Reference 18) where the temperature of the matrix material is approximated by a linear function that satisfies the differential equations usually used to evaluate the thermal behavior of the media (Reference 16). Using the terminology of Reference 17, the discharge cycle matrix temperature function is assumed to be*

$$F_0(\xi, \tau) = T_0 + A + B(\xi - \theta). \quad (1)$$

At the end of the discharge cycle, the matrix material temperature is given by

$$F_0(\xi, \pi) = T_0 + A + B(\xi - \pi). \quad (2)$$

As shown in Reference 17, the fluid temperature differs from the matrix temperature by the coefficient B, so that the fluid temperature degradation, δ , at the end of the discharge cycle is given by

$$\delta = A + B \quad (3)$$

The matrix temperature at the exit end of the storage media is given by

$$\Delta T_g - A = A + B(\Lambda - \pi). \quad (4)$$

The ratio of the energy transferred from the matrix to the fluid during the discharge cycle to the total matrix energy is

$$Q = \left[\Delta T_g \pi - A^2/B \right] / \Lambda \Delta T_g \quad (5)$$

The volumetric storage efficiency, η_v , is, therefore,

$$\eta_v = \frac{\pi}{\Lambda} - \frac{A^2}{B \Delta T_g} \quad (6)$$

*See List of Symbols

Figure 21. Temperature Field in Dual Material Matrix

The relationship of the coefficients A and B to the discharge period was approximated in Reference 17 by

$$A/B \approx 2(2\pi)^{1/2} \quad (7)$$

However, in comparing the predictions of the simplified analysis with the results given in Reference 16, it was found that better agreement was obtained by using the relationship

$$\frac{A}{B} = 1.7 \pi^{1/2} \quad (8)$$

Figure 22 compares the end matrix temperature predicted by the simplified analysis with the results given in Reference 16 as a function of the dimensionless charge/discharge time for the storage media. Although the number of transfer units in the storage media is much smaller than would normally be considered, the agreement between the simplified theory and the more exact calculations is good.

Using these relationships, the discharge period for a given degradation in fluid temperature, δ , is given by

$$\pi + \frac{A}{B} \left(\frac{\Delta T_g}{\delta} - 2 \right) - \Lambda + \frac{\Delta T_g}{\delta} = 0 \quad (9)$$

Therefore, the relationship between π and δ is given by

$$\pi + 1.7 \left(\frac{\Delta T_g}{\delta} - 2 \right) \pi^{1/2} - \Lambda + \Delta T_g / \delta = 0 \quad (10)$$

Solving this equation for the dimensionless discharge period corresponding to a given fluid temperature degradation and substitution into Equation 6, allows the volumetric storage efficiency of the dual storage media to be predicted. Figure 23 shows the effect of the media number of transfer units (NTU) on dual media storage efficiency predicted by the simplified analysis for 10, 15, 20, and 30% fluid temperature degradation at the end of the charge/discharge cycle and indicates that the storage system NTU should be of the order of 1000 to 10,000 for high efficiency storage.

Figure 22. Variation in Erd Wall Temperature Versus Dimensionless Period (Charge Time = Discharge Time) of Flow

Figure 23. Effect of Available NTU on Volumetric Efficiency of Dual Media Storage (Charge Time = Discharge Time)

A dual storage media has the potential of reducing the amount of liquid (hot oil) required to store a given amount of energy. The simplified analysis can be used to predict the amount of this reduction by the relationship

$$\left(\frac{V_{dm}}{V_{sm}} \right)_{\text{fluid}} = \left[\eta \frac{(1-\epsilon)(\rho C)_w}{\epsilon (\rho C)_f} + 1 \right]^{-1} \quad (11)$$

The properties of the two oils (Therminol 66 and Caloria HT-43) are listed in Reference 14. The void fraction to be expected for beds of different type particles and indicates that void fractions, ϵ , between 0.3 and 0.4 are to be expected. Using granite-type rocks in conjunction with the oil, as suggested in Reference 13, gives a (fluid to matrix) volumetric specific heat ratio of 0.91. Using these property values, allows the volume requirements for dual media storage systems to be compared with a single media two-tank system.

Figure 24 shows the predicted reduction in fluid volume required for energy storage as a function of the system NTU for 10% and 30% degradation in fluid outlet temperature at the end of each cycle.

The simplified analysis of Reference 17 allows prediction of dual media storage system performance under conditions of constant flow rate and equal charge/discharge times. Although the actual usage conditions will be somewhat different, the results from this analysis allows comparisons to be made for the NTU required to save a fixed quantity of fluid.

3.2.4 Photovoltaic Array Performance

Since many of the commercial buildings considered in this study have all electric power systems, the photovoltaic STES concept is the most likely candidate for retrofit conversion to solar power. In the previous quarterly report (Reference 1), a reference 15% conversion efficiency at 28°C was given for the photovoltaic cell. However, temperature has an important effect on the cell output and its effect has been added to the simplified model of the cell so that

Figure 24. Effect of Available NTU on Fluid Volume Requirements for the Hot Oil/Rocks Dual Media System

cell efficiency = reference efficiency $\times [1 - \beta (T_{\text{cell}} - T_{\text{ref}})]$
where β is 0.2%/°F or 0.36%/°C.*

Reference 21 presents a good discussion of the relative merits of nontracking versus tracking array systems and concludes that reflector augmented nontracking arrays of solar cells provide the most economical configuration for land limited applications. The simplicity of this type of array also makes it very suitable for retrofit applications with a minimum of building modifications.

Although the analysis reported in Reference 21 predicts that a 25% enhancement of the array output can be obtained with the additional reflective surface, the first photovoltaic concept modeling discussed in the next section uses north/south oriented arrays tilted at the latitude to maintain simplicity of installation.

Photovoltaic array packing fractions of 95% are quoted in Reference 10 and this value has been assumed for this study for nonconcentrating systems.

Tracking and/or concentrating arrays will be considered during the next report period when low temperature thermal collectors will be incorporated into the STES model for the photovoltaic concept.

*See List of Symbols

4.0 TASK 3 - CONCEPT APPLICATION EVALUATION

A small computer program has been written to evaluate the different STES concepts for commercial buildings (Reference 1). To obtain realistic definitions of the system performance, tradeoff studies of operating conditions have been made and constraints applied to the allowable collector area for the systems.

4.1 Land Utilization Constraints

Commercial buildings are normally located in high-cost land areas (1-5 \$/ft²) and consequently do not have a large parking area. Multi-tiered parking is common where land costs favor multistoried buildings. Preliminary data from Reference 21 indicates that parking areas are usually less than the total building floor area for shopping centers while the parking area is considerably smaller for office buildings (particularly true for high rise buildings).

Solar collector concepts vary in their ability to utilize the available land with nontracking collectors reported as utilizing 50% to 90% of the land surface and tracking collectors utilizing 15% to 50% of the land surface area with 25% utilization reported most of the designs in the literature.

Because of the land utilization factor and high land cost surrounding commercial buildings, the purchase of additional land for collector use only would add an incremental cost of \$40 to 120/m² to the capital investment for the additional collectors. Since the reference cost for concentrating collectors is \$100/m², the cost of these additional collectors would be doubled and hence unattractive economically.

This additional capital investment cost indicates that it is unlikely that tracking collector areas for commercial buildings can exceed the building total floor area (and may be limited to 50% of the floor area in some cases by building shadow problems) while nontracking

collectors are limited to less than twice the floor area. Since nontracking collectors are most likely candidates for retrofit systems, use of only the building roof limits the collector area to 50 to 90% of the floor area. With inefficient HVAC energy systems (as discussed earlier under Task 1) this means that the STES cannot furnish more than a small percentage of the building load. It is likely, therefore, that incorporation of the STES would be accompanied by conversion of the lighting and HVAC systems to the ASHRAE 90-75 standard conditions to accomplish a double saving with the potential to provide a larger fraction of the building energy requirement by solar energy.

4.2 Weather Effects

Although the parametric studies accomplished to date have been limited in scope, they illustrate a major problem area in the STES/utility interface. Because of the variability in weather conditions, the backup generation capability the utility must provide is 20-55% of the solar generation capability (Reference 10). Consequently, the utility will probably require a demand-based contract for purchased power since this excess capacity will be poorly utilized during most of the year.

Small STES (40%, or less, solar contribution) do not generate enough energy to cost effectively utilize either thermal or battery storage (as illustrated in Figure 25) for an average winter day assuming reasonable electric utility rates. It can be seen that the peak purchased power has not been reduced by the STES although a 30% reduction in total energy has been accomplished. Even with current utility contracts, the demand charge will significantly increase the cost of electricity to the user for the full ratchet period of one to twelve months. Table 21 illustrates that the problem applies to all STES concepts considered thus far and that period of clouds (low insolation) will occur every year with a high probability of requiring the STES to purchase all energy for several days a year. The control modes are discussed in Paragraph 4.5. A six- or twelve-month ratchet in the utility contract would, therefore, make the cost of energy prohibitive to the facility owner.

Figure 25. Typical Hourly Load Variation for Photovoltaic STES

77-J20-9-60

TABLE 21
IMPACT OF WEATHER CONDITIONS ON UTILITY INTERFACE (NO BUY BACK)

TYPE WEATHER	CONTROL MODE					
	ELECTRIC LOAD		THERMAL LOAD		SOLAR LOAD	
	NO STORAGE	STORAGE	NO STORAGE	STORAGE	NO STORAGE	STORAGE
CLEAR	NONE	NONE	BUY EVENING ENERGY	MINIMAL	BUY EVENING ENERGY	MINIMAL
INTERMITTANT CLOUDS	NONE	NONE	BUY PEAK POWER	MINIMAL	BUY PEAK POWER	MINIMAL
FULL CLOUDS ~1 DAY	NONE**	NONE**	BUY ALL ENERGY	BUY ALL ENERGY	BUY ALL ENERGY	BUY* ALL ENERGY
FULL CLOUDS ~1 WEEK	NONE**	NONE**	BUY ALL ENERGY	BUY ALL ENERGY	BUY ALL ENERGY	BUY* ALL ENERGY

*CAN BE REDUCED OR ELIMINATED BY LOAD LEVELING STORAGE IN CONJUNCTION WITH SOLAR SYSTEM

**AUXILIARY FUEL CONSUMPTION DRASTICALLY INCREASED

The solution to this problem appears to lie in the combination of a peak-shaving system with the STES so that purchased power in the evening and early morning can be stored for use during low insolation periods whether in the evening or during cloudy days. An alternate approach is to generate the energy on site with fossil fuel back-up. These approaches have not been considered in this study thus far but will be added to the analysis method. Table 22 presents typical breakdown of the commercial/industrial rate schedule (Southern California Edison Company, Schedule A-7) for a building demand rate of 1000 kW and monthly consumption rates of 200,000 and 400,000 kWh per month in 1975 and 1976.

To consider this type of combination system, a variable purchased electric power algorithm must be incorporated into the analysis. Since the cost of power varies considerably from site to site, the data from Reference 22 will be used to generate an empirical equation of the form

$$\frac{\$}{\text{kWh}} = C_1 \left(\frac{\text{kW}}{\text{kWh}} \right)^{C_2} / \text{kW}^{C_3}$$

This form approximates the data from a given rate schedule in Reference 21 within 1% and should be satisfactory for the studies made during the remainder of this contract with the three constants C_1 , C_2 , and C_3 derived directly from the Reference 22 data.

4.3 Solar Contribution

Besides the cost of the STES, an estimate of the solar energy contribution is desirable, to estimate both risk factors and fuel savings. However, to establish the relative worth of high grade energy (electricity) and low grade energy (cascaded heat) is a controversial task. The approach used during this study is to consider the cost of each type of energy and generate three contribution terms:

1. Solar Contribution = 1 - cost of purchased power divided by the cost to buy all energy.

TABLE 22
POWER COST BREAKDOWN
(SCE/SCHEDULE A-7)

BILLING DEMAND (kW)	1000			
MONTHLY CONSUMPTION (kWh/MONTH)	200,000		400,000	
YEAR	1975	1976	1975	1976
CHARGES (\$/kWh)				
DEMAND	0.550	0.550	0.275	0.275
USE CHARGE	1.726	1.926	1.460	1.660
FUEL ADJUSTMENT	0.949	0.949	0.949	0.949
STATE SURCHARGE	0.010	0.010	0.010	0.010
TOTAL	3.24	3.44	2.69	2.89
% INCREASE '75 → '76	6.2		7.4	

2. Fossil Contribution = cost of purchased fossil fuel divided by the cost to buy all energy.
3. Utility Contribution = cost of purchased electricity divided by the cost to buy all energy.

The sum of these contributions is unity and defines the reduction in cost of energy for the STES owner. Thus, at a site with a high cost of electricity, the system utilizing extra fossil fuel to reduce the electrical requirements would be favored by the owner even if more energy were actually used.

4.4 Concept Performance Evaluation

As discussed in the previous quarterly report (Reference 1), the system configuration yielding a minimum annualized cost to the user is determined by the Solar Total Energy Systems Evaluation Program (STESEP) for a particular building and site combination. Since modifications to the program are still being made, the analysis effort has been limited to one site (Washington, D.C.) and one type of building (shopping center) to illustrate the methodology that will be applied for evaluation of the concepts/site interrelationships. Storage costs have been included in the program for both oil and battery systems as discussed in the previous sections. Inclusion of these costs has decreased the size of the minimum annualized cost Rankine system considerably. Comparisons were made between the electrical, thermal, and solar load control concepts with variable turbine inlet and condenser temperatures to select the configuration shown in Figure 26 and Table 23 for the Rankine system.* For the assumed cost parameters, the selected systems use solar load control and a cascaded refrigeration system to provide the minimum cost to the user and were not limited by the available area.

A comparable photovoltaic system is shown in Figure 27 and Table 24. At \$100/m² assumed cost for the solar cells, this system was

*See List of Symbols

Figure 26. Shopping Center Solar Thermal STES Concept
[Rankine Cycle with Solar Load Control]

TABLE 23

SAMPLE COMPUTER PRINTOUT
(SOLAR THERMAL STES)

STES EQUIPMENT SIZES FOR A SHOPPING CENTER

LOCATED IN WASHINGTON, D.C.

~~WITH A FLOOR AREA OF 92900. SQ M AND 95061. KWHR/DAY OUTPUT~~

BASED ON INCIDENT INSOLATION OF 505. LANG./DAY, HDD/YR OF 4175. CDD/YR OF 1285.

--- RANKINE CYCLE STES CONCEPT WITH PCS CONTROL BY SOLAR LOAD WITH DISTRIBUTED COLLECTOR 1

SOLAR ENERGY FURNISHES 3.6 % OF ELECTRICAL LOAD, AND 30.0 % OF THERMAL LOAD

FOR A 1986 START OF OPERATION. COST PARAMETERS ARE

FCR=0.159 K=0.080 G=0.050 GF=0.080 N= 20 FUEL= 2.37 \$/GJ, ELECT=13.89 \$/GJ (1976 \$)

EQUIP	SIZE	EFF	TIN DEG C	TOUT DEG C	ENERGY KWH/DAY	INST'LD CST. \$/UNIT SZE.	CAP. INV. K\$	REC'G CST. K\$	CNPT. LIFE YEARS
COLL	8932. SM	0.295	191.	344.	15024.	100.	890.	0.	20.
STOR	9301. KW	0.722	0.	0.	2127.	76.	711.	21.	20.
HT EX	1491. SM	0.965	344.	191.	50117.	35.	53.	0.	20.
AUX HT	6033. KW	0.750	185.	338.	46791.	15.	88.	146.	20.
PCS	1068. KW	0.227	338.	60.	11390.	712.	761.	189.	20.
VC RFG	2720. TON	3.500	0.	0.	57495.	388.	1055.	0.	20.
AB RFG	1934. TON	0.652	105.	8.	48194.	443.	844.	0.	20.
PRO HT	3632. KW	1.000	60.	19.	0.	21.	74.	0.	20.
CL TWR	879. SM	0.700	60.	105.	2150.	11.	10.	0.	20.
CL STO	0. CM	1.000	8.	17.	0.	0.	0.	0.	20.
AUX EL	7936. KW	0.000	0.	0.	83671.	0.	0.	1527.	0.

TOTAL CAP. INV. IS \$ 0.44851E+07 WITH YEARLY REC'G. COSTS OF \$ 0.18838E+07

~~ANNUALIZED COST OF \$ 0.62260E+07 WITH A YEARLY SAVING OF \$ 0.17840E+06 R.O.I. = 4.0 %~~

FLOOR AREA = 93000 M²
 SITE: WASHINGTON, D.C.

Figure 27. Shopping Center Photovoltaic STES Concept

TABLE 24

SAMPLE COMPUTER PRINTOUT
(PHOTOVOLTAIC STES)

STES EQUIPMENT SIZES FOR A SHOPPING CENTER LOCATED IN WASHINGTON, D.C.
WITH A FLOOR AREA OF 92900. SQ M AND 131351. KWHR/DAY OUTPUT
BASED ON INCIDENT INSOLATION OF 454. LANG./DAY, HDD/YR OF 4175. CDD/YR OF 1285.

PHOTOVOLTAIC CONCEPT WITH MAX POWER CONTROL USING ARRAY 1

SOLAR ENERGY FURNISHES 35.9% OF LOAD IN AN ALL ELECTRIC BLDG.

FOR A 1986 START OF OPERATION. COST PARAMETERS ARE

PCR=0.159 K=0.080 G=0.050 GF=0.080 N= 20 FUEL= 2.37 \$/GJ, ELECT=13.89 \$/GJ(1976 \$)

EQUIP	SIZE	EFF	TIN DEG C	TOUT DEG C	ENERGY KWH/DAY	INST'LD CST. \$/UNIT SIZE.	CAP. INV. K\$	REC'G CST. K\$	CMPT. LIFE YEARS
ARRAY	83610. SM	0.128	0.	0.	54751.	100.	8361.	0.	20.
BATT	6428. KWH	0.722	0.	0.	11504.	50.	321.	64.	20.
AUX EL	10892. KW	1.000	0.	0.	82645.	0.	0.	1509.	20.
BLD HT	3044. KW	1.000	0.	0.	23878.	18.	56.	0.	20.
INVERT	7331. KW	0.900	0.	0.	76600.	65.	476.	134.	20.
VC RFG	2720. TON	3.500	0.	0.	57496.	388.	1055.	0.	20.
AB RFG	1904. TON	0.650	105.	8.	48193.	443.	844.	0.	20.
PRO HT	587. KW	1.000	0.	0.	12700.	8.	5.	0.	20.
TOTAL CAP. INV. IS \$ 0.11118E+08 WITH YEARLY REC'G. COSTS OF \$ 0.17066E+07									
ANNUALIZED COST OF \$ 0.67936E+07 WITH A YEARLY SAVING OF \$ 0.51867E+06 R.O.I.= 4.7 %									

limited by the available area and hence could be improved if the particular shopping center could provide additional "free" area for the arrays.

A sensitivity of these systems to the assumed cost parameters is discussed in the following sections of this report.

4.5 STES-Utility Grid Interfaces

Candidate approaches to the STES-utility grid interface include:

1. "Sale" of all of the STES output to the grid, when and as produced; "purchase" of power from the grid, as required.
2. Installation of STES on the building (utility customer's) site; customer is always a net user of power.
3. Stand-alone system with no electric utility interface.

The first option has the advantages of

- a) Potentially mitigating utility purchase of the expensive and scarce fuels (e.g., gas or oil) used for peak load shaving.
- b) Minimizing on-site energy storage requirements.
- c) The STES can be located "anywhere" within the system rather than at the customer's site, thus affording an additional degree of flexibility. The site would be selected as a function of insolation rate (where applicable), land cost and transmission cost trade-offs.

This approach will not necessarily result in a significant reduction in the investment for stand-by facilities required by the utilities (e.g., to back-up the STES on "rainy days"). Furthermore, in those cases where power may be generated at a customer's site using customer-owned equipment, development of an equitable formula for customer/utility credit assignments potentially represents a complex process. This approach is not considered within the scope of the present study.

The second option (i.e., installation of the STES on the customer's site where the customer always is a net user of electricity) may also serve to reduce utility peak power loads/costs but will not necessarily reduce capacity requirements. The ultimate selection and design of the system (e.g., type, solar contribution, control mode, storage mode, etc.,) will depend upon the availability and cost of off-peak power and the local demand charge base (e.g., 1-, 3-, 6-, or 12-month "ratchet").

The third option, a stand-alone system obviates the utility interface. The cost of a fossil fuel system to "back-up" the STES with its attendant investment and operating costs, however, is expensive.

4.6 Control Mode Selection

Candidate control modes are presented in Table 25. These include sizing the power conversion system to accommodate the total electrical, thermal, or insolation loads. A solar thermal STES can be designed for any of these modes, whereas, the solar control (insolation) mode is the only mode considered for the photovoltaic STES.

TABLE 25
CONTROL MODES FOR STES CONCEPTS

- **POWER CONVERSION SYSTEM (PCS) SUPPLIES TOTAL ELECTRICAL LOAD**
 - HOT THERMAL (600°F) STORAGE REQUIRED
 - NO UTILITY ELECTRICITY USED
 - COLD STORAGE OPTIONAL*(50°F)
 - AUXILIARY FUEL USED
 - TYPE OF CHILLER OPTIONAL*
 - NOT USED FOR PHOTOVOLTAIC STES
- **PCS SUPPLIES TOTAL THERMAL LOAD**
 - HOT THERMAL STORAGE REQUIRED
 - COLD THERMAL STORAGE OPTIONAL*
 - UTILITY ELECTRICITY USED
 - AUXILIARY FUEL USED
 - TYPE OF CHILLER OPTIONAL*
 - NOT USED FOR PHOTOVOLTAIC STES
- **PCS ACCOMMODATES AVAILABLE SOLAR INSOLATION**
 - APPLICABLE FOR PHOTOVOLTAIC AND STES SOLAR THERMAL
 - FOR PHOTOVOLTAIC SYSTEM WARM (200°F) THERMAL STORAGE OPTIONAL*
 - NO HOT THERMAL STORAGE NEEDED
 - COLD THERMAL STORAGE OPTIONAL*
 - BATTERY STORAGE REQUIRED (NO UTILITY BUY BACK)
 - NO PEAK SHAVING STORAGE CONSIDERED
 - TYPE OF CHILLER OPTIONAL*

*DETERMINED BY COST TRADE-OFF

Control mode selection criteria include cost, risk (e.g., weather/demand charge "ratchet" and sensitivity to escalation rates), flexibility, and fossil fuel displacement. The first three criteria are of primary concern to the owner/investor; the latter is of national interest.

With regard to costs, data on the minimum annualized costs and incremental return on solar equipment investment ($\Delta R0I$) are presented in Figures 28 and 29 for the three control modes for a shopping center* utilizing a solar thermal STES concept with distributive collectors. It can be seen that for the assumptions made, the electrical control mode results in the highest annualized costs and lowest (i.e., negative) incremental returns on investment over the range of collector sizes considered. Differences between the solar and thermal control modes are essentially nil. Furthermore, the electrical control mode is more sensitive to escalation rates than either the solar or thermal control modes.

The electrical control mode essentially provides for a stand-alone system and, therefore, the weather risks and electric utility dependency is minimal. This concept requires the largest heat rejection system to dissipate the excess thermal energy not required by the building. In the event of "bad weather," one would buy and burn more fossil fuel (if one chooses to pay the higher cost for this independence and flexibility). The solar control mode can be configured to employ battery storage, particularly if a favorable off-peak power rate were available, thus reducing the weather dependency and increasing flexibility of operations.

The thermal control mode uses a hot thermal storage system and requires a smaller heat rejection system than for the solar control mode. It is, therefore, more sensitive to weather and could require electric power to be purchased at times of peak demand. The larger heat rejection requirement would be due to mild day operations whereby the thermal storage capacity may be exceeded. Make or buy decisions on electricity would be a function of the local fuel/power cost ratio. This control mode is most dependent upon a utility back-up.

*See List of Symbols

Figure 28. Control Mode Cost Comparisons
(Distributive Collector)

Figure 29. Control Mode Cost Comparisons (Distributive Collector)

At this point in time, the solar control appears to be the preferred mode for distributive collector systems. (It is anticipated that an analogous rationale will prevail for the central receiver power tower concept.) The selection considerations are summarized in Table 26.

4.7 Concept Cost Comparisons

The solar output and unit costs of distributive (solar control) and solar photovoltaic STES concepts are presented in Figure 30. For a Washington, D.C. shopping center example, the solar output is approximately 45 W/m^2 for solar photovoltaic and $25\text{-}30 \text{ W/m}^2$ for a distributive collector. Figure 30(b) and (c) shows the effects of including the collector-related components (e.g., inverters, batteries, etc. for photovoltaic collectors and auxiliary heaters, storage, power conversion systems, etc. for distributive collectors) on the unit collector and net system costs, assuming collector costs of $\$50$ to $\$200/\text{m}^2$. In all cases, the solar photovoltaic unit costs are less sensitive to system size (i.e., collector area) because of the smaller numbers and cost of the related components. Typically, if a solar photovoltaic array were available at $\$200/\text{m}^2$ ($\approx \$2/\text{pW}$), then the net solar system cost would be on the order of $\$4,500/\text{kW}$. In the case of a distributive system, if collectors were available at $\$100/\text{m}^2$ ($\approx \$10/\text{ft}^2$), then the system size would have to exceed $65,000 \text{ m}^2$ to realize a system cost of $\$4,500/\text{kW}$.

The minimum annualized system cost and incremental return on investment ($\Delta \text{ROI} (\%) = \text{savings}/\text{solar investment} \times 100\%$) are compared in Figure 31 (a) and (b) for a solar photovoltaic and distributive system for the above example case. The data indicate that the minimum annualized cost of the distributive system is relatively insensitive to collector costs in the range of $\$50$ to $\$200/\text{m}^2$ and appear lower than similarly priced solar photovoltaic systems (i.e., $\$50$ to $\$200/\text{m}^2$). The $\$200/\text{m}^2$ distributive collector will break-even ($\Delta \text{ROI} \gtrsim 0$) at escalation rates greater than 8% in 1986; the $\$50$ and $\$100/\text{m}^2$ collectors will break-even at 6%. The solar photovoltaic break-even costs appear more sensitive to

TABLE 26
CONTROL MODE SELECTION

CRITERIA	CONTROL MODE		
	SOLAR	THERMAL	ELECTRICAL
COST*	APPROXIMATELY EQUAL		HIGHER
RISK (UNCERTAINTIES)			
ESCALATION RATE	APPROXIMATELY EQUAL		MORE SENSITIVE
WEATHER/DEMAND CHARGE (FLEXIBILITY)	<ul style="list-style-type: none"> • BATTERY STORAGE — COULD USE OFF-PEAK POWER (MINIMAL IMPACT) 	<ul style="list-style-type: none"> • REQUIRES HOT THERMAL STORAGE ON MILD DAYS, HIGH REJECT LOAD • MOST SENSITIVE TO WEATHER, BUY POWER AT PEAK DEMAND • MAKE/BUY FUNCTION OF FUEL/POWER COSTS 	<ul style="list-style-type: none"> • STAND ALONE SYSTEM/BUY MORE FUEL
ELECTRIC UTILITY DEPENDANCY/DEMAND	• NOMINAL	• MAXIMUM	• NONE

*AVERAGE ANNUAL COST EXCLUSIVE OF ANY DEMAND CHARGE PENALTIES

Figure 30. Solar Output and Unit Costs as a Function of Collector Area

Figure 31. Collector Concept Comparisons
(Distributive-Solar Control vs. Solar Photovoltaic)

inflation; the \$200/m² collector does not achieve break-even below escalation rates of ~11%, at \$100/m² break-even is achieved at ~7%, and at \$50/m² the break-even appears to be $\approx$ 5%. Although the solar photovoltaic system has a higher unit output and apparent lower unit costs than the distributive system for the assumed conditions, the overall thermal-distributive system, as configured, requires a smaller collector area because of cascading the waste thermal energy.

Figures 32, 33, and 34 show the effects of electricity costs on distributive collector STES, photovoltaic STES, and central receiver STES as a function of escalation rate. As can be seen, if power is available at 4 cents/kWh, an escalation rate of approximately 9% is needed for break-even in the distributive system and 0% for the photovoltaic and central receiver systems. At 5 cents/kWh, the break-even costs are approximately 6% for all three concepts. As would be expected, the solar contribution will increase as both the escalation rate and cost of power increase (Figures 32 and 33) until the limit of available area (e.g., rooftop and parking lot) for collectors is approached.

Figure 35 shows the effect of project start year on annualized cost, Δ ROI and solar contribution for distributive collector and photovoltaic STES systems. The data indicate that although the annualized costs increase with time, the Δ ROI also improves. Given an 8% escalation rate and 5 cent/kWh cost of purchased electricity, the percent solar contribution is of the order of 45% for photovoltaic and 20% for the distributive collector systems.

Figure 32. Effect of Electricity Costs (Distributive Systems-Solar Control)

Figure 33. Effect of Electricity Costs (Photovoltaic Systems)

Figure 34. Effect of Electricity Costs
(Central Receiver Systems-Solar Control)

Figure 35. Effect of Project Start Year

5.0 TASK 4 - COST AND MARKET PROJECTIONS

During this reporting period, data were developed on electric power cost trends, the effect of system amortization period, and system redundancy. Appendices C and D present the analyses for the effect of amortization period and system redundancy, respectively.

5.1 Electric Power Cost Trends

Trend data were presented in Appendix D of the last quarterly report (Reference 1) on the Bureau of Labor Statistics/Consumer Price Index and projected fuel costs. Federal Power Commission data (Reference 22) on the trends in the national average costs of electric power are presented in Figure 36. As can be seen from the upper graph, these costs remained essentially level throughout the 1960's before starting to increase in 1970. The lower curve shows the escalation rate to be on the order of 10 to 14%/year (compounded), depending upon the time period considered and the usage rate.

As would be anticipated, there is a significant variation in costs from region to region. Comparison of the Middle Atlantic States and the Pacific Coast (Figure 37) shows a two-fold rate variation. Rate variations also may be experienced within a given state as can be seen from Figure 38 wherein data are presented on the rates charged by several large California utilities.

State average monthly costs for commercial/industrial service in the U.S. are shown in Figure 39. As can be seen, the highest power costs are generally encountered in the Northeast. A tabulation of the costs by geographic division for 1976, 1975, and 1966 is also presented. The highest cost region (Middle Atlantic States) experienced a modest decline in costs from 1975 to 1976; whereas, the lowest cost regions (e.g., South Central, Mountain, and Pacific) experienced an average increase in rates of 16%. (On a national basis, the average increase in commercial/industrial rates was 7%.)

Figure 36. Electric Power Cost Trends

77-J17-9-9

Figure 37. Regional Variations in Power Costs

77-J17-9-11

Figure 38. Regional Cost Sensitivity - California

77-J17-9-12

Geographic Division	January 1, 1976			January 1, 1975			January 1, 1966		
	150 kW 30,000 kWh	300 kW 60,000 kWh	1,000 kW 200,000 kWh	150 kW 30,000 kWh	300 kW 60,000 kWh	1,000 kW 200,000 kWh	150 kW 30,000 kWh	300 kW 60,000 kWh	1,000 kW 200,000 kWh
New England	\$1,319	\$2,524	\$7,999	\$1,302	\$2,503	\$7,848	\$692	\$1,273	\$3,838
Middle Atlantic	1,836	3,558	11,581	1,899	3,685	11,991	788	1,445	4,320
East North Central	1,145	2,172	6,660	1,023	1,979	5,863	665	1,213	3,522
West North Central	1,016	1,971	6,106	879	1,704	5,195	611	1,151	3,430
South Atlantic	1,199	2,250	7,106	1,137	2,121	6,634	567	1,006	3,009
East South Central	883	1,698	5,099	819	1,577	4,704	447	833	2,442
West South Central	922	1,728	5,175	785	1,490	4,275	552	997	2,818
Mountain	1,033	1,953	5,900	880	1,648	5,054	565	1,057	3,048
Pacific	922	1,861	5,869	855	1,578	4,923	447	821	2,458
Noncontiguous	1,276	2,375	7,379	1,225	2,306	7,103	711	1,357	3,989
U. S. Average	1,231	2,348	7,395	1,157	2,199	6,888	631	1,154	3,407

Figure 39. State Average Monthly Costs

(Reference 22 Data)

5.2 Potential Market

Emphasis during the final quarter of the study for this task will be to refine estimates for defining potential market and the rate of penetration for the STES concept.

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APPENDIX A

AXCESS SIMULATION OF BUILDING HVAC SYSTEMS

The methodology employed in converting the AXCESS output to STES code input was required to be flexible and simple as well as yield reasonable accuracy. Flexibility was necessary to insure that HVAC system differences could be accommodated and compared on equivalent basis. The volume of the data to be reduced required a simple, rapid method of calculation. The required output of the method is a system-by-system hourly, monthly, and yearly electrical, heating, cooling, and hot water energy usage profile of each building.

The methodology considers the monthly and yearly electrical usage to be the total electrical meter reading less the sum of the primary heating system auxiliary, primary cooling refrigeration and primary cooling auxiliary meter readings on an appropriate monthly or yearly basis. A typical output for AXCESS is shown in Figures A-1 through A-3. The terminal systems usage is assumed to be included in the electrical usage. This assumption could introduce some error in calculating the usage of those systems employing reheat. However, this possibility was investigated and it was found that any error introduced by this method was small in comparison to the estimates of building energy usage inputs to AXCESS. This also implies that for a given building the electrical usages are essentially independent of the HVAC system employed in that building. This implication was also verified except in those cases previously noted.

The methodology considers monthly and yearly heating energy usage to be the sum of the primary heating system gas usage (equilibrated to electrical units of kWh) plus the primary heating system auxiliary usage. Similarly, monthly and yearly cooling usage is defined as primary cooling system refrigeration plus auxiliary usage.

TASK # 1 BUILDING LOADS ESTIMATE

HOURLY METERED ENERGY USAGE

DAY 1 HOUR 12

METER	SCHEME A	USAGE	SCHEME H	USAGE	SCHEME C	USAGE
1	TOTAL CUM.ELECT.	2827.	KWH	0.	0.	
2	INTERIOR LIGHTS	1060.	KWH	0.	0.	
3	COOKING EQUIP.	20.	KWH	0.	0.	
4	TOTAL CUM. GAS	6169.	CF	0.	0.	
5	P.S HEATING#1	5332.	CF	0.	0.	
6	P.S HEAT AUX.#1	9.	KWH	0.	0.	
7	P.S REF.#2	1143.	KWH	0.	0.	
8	P.S REF.#2 AUXIL	24.	KWH	0.	0.	
9	T.S MULTI ZONE	22.	KWH	0.	0.	
10	P.S HEATING #3	590.	CF	TOTAL CUM.ELECT.	3402.	KWH
11	P.S HEAT AUX.#3	1.	KWH	INTERIOR LIGHTS	1060.	KWH
12	P.S REFRIG.#4	349.	KWH	COOKING EQUIP.	20.	KWH
13	P.S REF #4 AUX.	2.	KWH	TOTAL CUM. GAS	67.	CF
14	T.S MULTI ZONE	75.	KWH	P.S HEATING#1	0.	CF
15		0.		P.S HEAT#1 AUX	0.	KWH
16		0.		P.S REFRIG.#2	1574.	KWH
17		0.		P.S REF.#2 AUX	33.	KWH
18		0.		T.S SINGLE ZN RT	22.	KWH
19		0.		P.S HEATING#3	0.	CF
20		0.		P.S HEAT#3 AUX	0.	KWH
21		0.		P.S REFRIG.#4	494.	KWH
22		0.		P.S REF.#4 AUX	3.	KWH
23		0.		T.S SINGLE ZN RT	75.	KWH
24		0.			0.	
25		0.			0.	
26		0.			0.	
27		0.			0.	
28		0.			0.	
29		0.			0.	
30		0.			0.	
31		0.			0.	
32		0.			0.	
33		0.			0.	
34		0.			0.	
35		0.			0.	
36		0.			0.	

FIGURE A-1 - ACCESS HOURLY SAMPLE OUTPUT - SMAL SHOPPING CENTER

HOURLY METERED ENERGY USAGE

DAY 1 HOUR 12

METER	SCHEME D	USAGE	SCHEME E	USAGE	SCHEME F	USAGE
1		0.				
2		0.				
3		0.				
4		0.				
5		0.				
6		0.				
7		0.				
8		0.				
9		0.				
10		0.				
11		0.				
12		0.				
13		0.				
14		0.				
15		0.				
16		0.				
17		0.				
18		0.				
19		0.				
20		0.				
21		0.				
22		0.				
23	T.S UNITAN #/H#1	75.	KWH			
24	P.S REFRIG.#4	0.	KWH			
25	P.S REFR.#4 AUX	0.	KWH			
26	P.S HEATING#3	333.	CF			
27	P.S HEAT#3 AUX	1.	KWH			
28	TOTAL CUM.SELECT.	1302.	KWH			
29	INTERIOR LIGHTS	1088.	KWH			
30	COOKING EQUIP.	20.	KWH			
31	TOTAL CUM. GAS	2024.	CF			
32	P.S HEATING#1	1624.	CF			
33	P.S HEAT#1 AUX	3.	KWH			
34	P.S REFRIG.#2	0.	KWH			
35	P.S REFR.#2 AUX	0.	KWH			
36	T.S UNITAN #/H#2	22.	KWH			

FIGURE A-1 - AXCESS HOURLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

TASK # 1 BUILDING LOADS ESTIMATE

JAN MONTHLY RESULTS

METER	SCHEME A	SCHEME H	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 1						
SERVES TOTAL CUM. ELECT.						
USAGE 889629. KWH		0.	0.	0.		
DEMAND 3119. KWD		0.	0.	0.		
HOUR 12		0	0	0		
DAY 13		0	0	0		
NO. 2						
SERVES INTERIOR LIGHTS						
USAGE 435081. KWH		0.	0.	0.		
DEMAND 1088. KWD		0.	0.	0.		
HOUR 10		0	0	0		
DAY 1		0	0	0		
NO. 3						
SERVES COOKING EQUIP.						
USAGE 5849. KWH		0.	0.	0.		
DEMAND 20. KWD		0.	0.	0.		
HOUR 11		0	0	0		
DAY 1		0	0	0		
NO. 4						
SERVES TOTAL CUM. GAS						
USAGE 2556667. CF		0.	0.	0.		
DEMAND 9826. CFH		0.	0.	0.		
HOUR 11		0	0	0		
DAY 27		0	0	0		
NO. 5						
SERVES P.S. HEATING#1						
USAGE 2229478. CF		0.	0.	0.		
DEMAND 9186. CFH		0.	0.	0.		
HOUR 11		0	0	0		
DAY 27		0	0	0		

FIGURE A-2 - ACCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER

JAN (CONT.)

METER	SCHEME A	SCHEME H	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 6 SERVES P.S. HEAT ALX. #1						
USAGE 3713. KWH		0.	0.	0.		
DEMAND 15. KWD		0.	0.	0.		
HOOR 11		0	0	0		
DAY 27		0	0	0		
NO. 7 SERVES P.S. REF. #2						
USAGE 240889. KWH		0.	0.	0.		
DEMAND 1362. KWD		0.	0.	0.		
HOOR 12		0	0	0		
DAY 13		0	0	0		
NO. 8 SERVES P.S. REF. #2 AUXIL						
USAGE 5014. KWH		0.	0.	0.		
DEMAND 28. KWD		0.	0.	0.		
HOOR 12		0	0	0		
DAY 13		0	0	0		
NO. 9 SERVES T.S. MULTI ZONE						
USAGE 7699. KWH		0.	0.	0.		
DEMAND 22. KWD		0.	0.	0.		
HOOR 9		0	0	0		
DAY 1		0	0	0		
NO. 10 SERVES P.S. HEATING #3						
USAGE 281054. CF 1332583. KWH			0.	0.		
DEMAND 590. CFH 3652. KWD			0.	0.		
HOOR 6			0	0		
DAY 1			0	0		

FIGURE A-2 - AXCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

JAN (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
<hr/>						
NO. 11						
SERVES P.S. HEAT AUX. #3 INTERIOR LIGHTS						
USAGE 47000 KWH 435681 KWH			00	00		
DEMAND 100 KWD 10660 KWD			00	00		
HOUR 8		10	0	0		
DAY 1		1	0	0		
NO. 12						
SERVES P.S. REFRIG. #4 COOKING EQUIP.						
USAGE 92553 KWH 56490 KWH			00	00		
DEMAND 4220 KWD 200 KWD			00	00		
HOUR 20		11	0	0		
DAY 12		1	0	0		
NO. 13						
SERVES P.S. REF. #4 AUX. TOTAL COM. GAS						
USAGE 6170 KWH 48471 CF			00	00		
DEMAND 700 KWD 300 CFH			00	00		
HOUR 20		19	0	0		
DAY 12		1	0	0		
NO. 14						
SERVES T.S. MULTI ZONE P.S. HEATING #1						
USAGE 36224 KWH 00 CF			00	00		
DEMAND 750 KWD 00 CFH			00	00		
HOUR 8		0	0	0		
DAY 1		0	0	0		
NO. 15						
SERVES P.S. HEAT #1 AUX						
USAGE 00 KWH 00 KWH			00	00		
DEMAND 00 KWD 00 KWD			00	00		
HOUR 0		0	0	0		
DAY 0		0	0	0		

FIGURE A-2 - ACCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

JAN (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 16 SERVES		P-5 REF#1#2				
USAGE	0.	543651. KWH	0.	0.		
DEMAND	0.	1764. KWD	0.	0.		
HOOR	0	12	0	0		
DAY	0	13	0	0		
NO. 17 SERVES		P-5 REF#2 AUX				
USAGE	0.	11221. KWH	0.	0.		
DEMAND	0.	37. KWD	0.	0.		
HOOR	0	12	0	0		
DAY	0	13	0	0		
NO. 18 SERVES		1-5 SINGLE ZN HT				
USAGE	0.	7699. KWH	0.	0.		
DEMAND	0.	22. KWD	0.	0.		
HOOR	0	9	0	0		
DAY	0	1	0	0		
NO. 19 SERVES		P-5 HEATING#3				
USAGE	0.	0. CF	0.	0.		
DEMAND	0.	0. CFH	0.	0.		
HOOR	0	0	0	0		
DAY	0	0	0	0		
NO. 20 SERVES		P-5 HEAT#3 AUX				
USAGE	0.	0. KWH	TOTAL CUM.ELECT.			
DEMAND	0.	0. KWD	1067728. KWH	0.		
HOOR	0	0	4918. KWD	0.		
DAY	0	0	10	0		
			28			

FIGURE A-2 - ACCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

TASK # 1 BUILDING LOADS ESTIMATE

JAN (CONT.)

METER	SCHEME A	SCHEME H	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 21 SERVES		P.S. REFRIG.#4	INTERIOR LIGHTS			
USAGE	0.	235692.	KWH 435881.	KWH	0.	
DEMAND	0.	554.	KWD 1088.	KWD	0.	
HOOR	0	11	10		0	
DAY	0	13	1		0	
NO. 22 SERVES		P.S. REF.#4 AUX	COOKING EQUIP.			
USAGE	0.	1572.	KWH 5849.	KWH	0.	
DEMAND	0.	4.	KWD 20.	KWD	0.	
HOOR	0	11	11		0	
DAY	0	13	1		0	
NO. 23 SERVES		T.S. SINGLE ZN RT	TOTAL CUM. GAS	T.S. UNITAR W/H#1		
USAGE	0.	36224.	KWH 48471.	KWH	36224.	KWH
DEMAND	0.	75.	KWD 301.	CFH	75.	KWD
HOOR	0	8	19		8	
DAY	0	1	1		1	
NO. 24 SERVES			P.S. HT & COIL #1	P.S. REFRIG.#4		
USAGE	0.	0.	359392.	KWH 6582.	KWH	
DEMAND	0.	0.	3028.	KWD 133.	KWD	
HOOR	0	0	9	15		
DAY	0	0	28	18		
NO. 25 SERVES			P.S. HT&COIL#1AUX	P.S. REF.#4 AUX		
USAGE	0.	0.	5250.	KWH 44.	KWH	
DEMAND	0.	0.	15.	KWD 1.	KWD	
HOOR	0	0	9	15		
DAY	0	0	1	18		

FIGURE A-2- ACCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

TASK # 1 BUILDING LOADS ESTIMATE

JAN (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 26 SERVES			T-S UNITARY HT P	P-S HEATING#2		
USAGE	0.	0.	7699. KWH	173257. CF		
DEMAND	0.	0.	22. KWD	590. CFH		
HOUR	0	0	9	8		
DAY	0	0	1	1		
NO. 27 SERVES			P-S HT&COUL#2	P-S HEAT#3 AUX		
USAGE	0.	0.	113741. KWH	294. KWH		
DEMAND	0.	0.	692. KWD	1. KWD		
HOUR	0	0	23	8		
DAY	0	0	27	1		
NO. 28 SERVES			P-S HT&CO #2 AUX	TOTAL CUM.ELECT.		
USAGE	0.	0.	3346. KWH	559298. KWH		
DEMAND	0.	0.	7. KWD	1611. KWD		
HOUR	0	0	8	15		
DAY	0	0	1	18		
NO. 29 SERVES			T-S UNITARY HT P	INTERIOR LIGHTS		
USAGE	0.	0.	35849. KWH	435881. KWH		
DEMAND	0.	0.	75. KWD	1088. KWD		
HOUR	0	0	8	10		
DAY	0	0	1	1		
NO. 30 SERVES				COOKING EQUIP.		
USAGE	0.	0.	0.	5849. KWH		
DEMAND	0.	0.	0.	20. KWD		
HOUR	0	0	0	11		
DAY	0	0	0	1		

FIGURE A-2 - ACCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

JAN (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 31 SERVES				TOTAL CUM. GAS		
USAGE	0.	0.	0.	978583.	CF	
DEMAND	0.	0.	0.	5776.	CFM	
HOUR	0	0	0	9		
DAY	0	0	0	28		
NO. 32 SERVES				P.S. HEATING#1		
USAGE	0.	0.	0.	756950.	CF	
DEMAND	0.	0.	0.	5153.	CFM	
HOUR	0	0	0	9		
DAY	0	0	0	28		
NO. 33 SERVES				P.S. HEAT#1 AUX		
USAGE	0.	0.	0.	1261.	KWH	
DEMAND	0.	0.	0.	9.	KWD	
HOUR	0	0	0	9		
DAY	0	0	0	28		
NO. 34 SERVES				P.S. REFRIG.#2		
USAGE	0.	0.	0.	4633.	KWH	
DEMAND	0.	0.	0.	199.	KWD	
HOUR	0	0	0	14		
DAY	0	0	0	17		
NO. 35 SERVES				P.S. REF.#2 AUX		
USAGE	0.	0.	0.	96.	KWH	
DEMAND	0.	0.	0.	4.	KWD	
HOUR	0	0	0	14		
DAY	0	0	0	17		

FIGURE A-2 - ACCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

JAN (CONT.)

METER	SCHEME A	SCHEME H	SCHEME C	SCHEME D	SCHEME E	SCHEME F
MJ, 36						
SERVES						
USAGE	0.	0.	0.	T.S. UNITAR W/H#2		
DEMAND	0.	0.	0.	7699.	KWH	
HOURLY	0	0	0	22.	KWD	
DAY	0	0	0	9		
				1		

FIGURE A-2 - AXCESS MONTHLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

YEARLY TOTAL CONSUMPTION

METER	SCHEME A	SCHEME H	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 1 SERVES TOTAL CUM. ELECT. USAGE 12009533 KWH DEMAND 3500 KWD MONTH 9.		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 2 SERVES INTERIOR LIGHTS USAGE 512443 KWH DEMAND 1088 KWD MONTH 1.		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 3 SERVES COOKING EQUIP. USAGE 68786 KWH DEMAND 20 KWD MONTH 1.		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 4 SERVES TOTAL CUM. GAS USAGE 19209328 CF DEMAND 920 CFH MONTH 1.		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 5 SERVES P.S. HEATING #1 USAGE 15437528 CF DEMAND 9186 CFH MONTH 1.		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 6 SERVES P.S. HEAT AUX #1 USAGE 20540 KWH DEMAND 15 KWD MONTH 1.		0. 0. 0.	0. 0. 0.	0. 0. 0.		

FIGURE A-3 - ACCESS YEARLY SAMPLE OUTPUT - SMALL SHOPPING CENTER

TASK # 1 BUILDING LOADS ESTIMATE

YR (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 7 SERVES P.S. REF.#2 USAGE 4260156 KWH DEMAND 1652 KWD MONTH 9		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 8 SERVES P.S. REF.#2 AUXIL USAGE 84679 KWH DEMAND 34 KWD MONTH 9		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 9 SERVES T.S. MULTI ZONE USAGE 90534 KWH DEMAND 22 KWD MONTH 1		0. 0. 0.	0. 0. 0.	0. 0. 0.		
NO. 10 SERVES P.S. HEATING #3 USAGE 2761052 CF TOTAL CUM.ELECT. DEMAND 590 CFH 16851360 KWH MONTH 1 4237 KWD			0. 0. 0.		0. 0. 0.	
NO. 11 SERVES P.S. HEAT AUX.#3 USAGE 4711 KWH INTERIOR LIGHTS DEMAND 1 KWD 5124443 KWH MONTH 1 1066 KWD			0. 0. 0.		0. 0. 0.	
NO. 12 SERVES P.S. REFRIG.#4 USAGE 1670675 KWH COOKING EQUIP. DEMAND 539 KWD 66986 KWH MONTH 8 20 KWD			0. 0. 0.		0. 0. 0.	

FIGURE A-3 - ACCESS YEARLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

YR (CONT.)

MLTR	SCHEM A	SCHEM B	SCHEM C	SCHEM D	SCHEM E	SCHEM F
NO. 13 SERVES P+S REF #4 AUX USAGE 12478. KWH TOTAL CUM. GAS 572257. CF DEMAND 4. KWD 301. CFH MONTH 8. 1. 0. 0.						
NO. 14 SERVES T+S MULTI ZONE P+S HEATING#1 USAGE 422290. KWH 0. CF DEMAND 75. KWD 0. CFH MONTH 1. 0. 0. 0.						
NO. 15 SERVES P+S HEATING#1 AUX USAGE 0. KWH 0. CF DEMAND 0. KWD 0. CFH MONTH 0. 0. 0. 0.						
NO. 16 SERVES P+S REFRIG #2 USAGE 0. KWH 7190513. KWH DEMAND 0. KWD 2217. KWD MONTH 0. 0. 0. 0.						
NO. 17 SERVES P+S REF #2 AUX USAGE 0. KWH 149675. KWH DEMAND 0. KWD 46. KWD MONTH 0. 6. 0. 0.						
NO. 18 SERVES T+S SINGLE ZN RT USAGE 0. KWH 90634. KWH DEMAND 0. KWD 22. KWD MONTH 0. 1. 0. 0.						

FIGURE A-3 - ACCESS YEARLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

YR (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 19 SERVES USAGE DEMAND MONTH	0. 0. 0.	P.S. HEATING#3 0. 0. 0.	CF CFH 0.	0. 0. 0.	0. 0. 0.	
NO. 20 SERVES USAGE DEMAND MONTH	0. 0. 0.	P.S. HEAT#3 AUX 0. 0. 0.	KWH KWD 1.	TOTAL CUM. ELECT. 9522073. 4918. 1.	KWH KWD 0.	0. 0. 0.
NO. 21 SERVES USAGE DEMAND MONTH	0. 0. 0.	P.S. REFRIG.#4 3069494. 676. 0.	KWH KWD 1.	INTERIOR LIGHTS 5124443. 1088. 1.	KWH KWD 0.	0. 0. 0.
NO. 22 SERVES USAGE DEMAND MONTH	0. 0. 0.	P.S. REF.#4 AUX 20475. 5. 8.	KWH KWD 1.	COOKING EQUIP. 68986. 20. 1.	KWH KWD 0.	0. 0. 0.
NO. 23 SERVES USAGE DEMAND MONTH	0. 0. 0.	T.S. SINGLE 2N RT 426290. 75. 1.	KWH KWD 1.	TOTAL CUM. GAS 572257. 301. 1.	CF CFH 1.	T.S. UNITAR W/H#1 426290. 75. 1. KWH KWD
NO. 24 SERVES USAGE DEMAND MONTH	0. 0. 0.	0. 0. 0.	P.S. HT & COOL #1 2153002. 3028. 1.	KWH KWD 1.	P.S. REFRIG.#4 482255. 391. 11.	KWH KWD

FIGURE A-3 - ACCESS YEARLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

VR (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 25 SERVES			F.S HT&COOL#1AUX	P.S REF.#4 AUX		
USAGE	0.	0.	1799. KWH	3217. KWH		
DEMAND	0.	0.	15. KWD	3. KWD		
MONTH	0.	0.	1.	11.		
NO. 26 SERVES			T.S UNITARY HT P	P.S HEATING#3		
USAGE	0.	0.	40634. KWH	737700. CF		
DEMAND	0.	0.	22. KWD	540. CFH		
MONTH	0.	0.	1.	1.		
NO. 27 SERVES			F.S HT&COOL#2	P.S HEAT#3 AUX		
USAGE	0.	0.	845803. KWH	1250. KWH		
DEMAND	0.	0.	642. KWD	1. KWD		
MONTH	0.	0.	1.	1.		
NO. 28 SERVES			F.S HT&CO #2 AUX	TOTAL CUM.ELECT.		
USAGE	0.	0.	39424. KWH	7660703. KWH		
DEMAND	0.	0.	7. KWD	2755. KWD		
MONTH	0.	0.	1.	5.		
NO. 29 SERVES			T.S UNITARY HT P	INTERIOR LIGHTS		
USAGE	0.	0.	422390. KWH	5124443. KWH		
DEMAND	0.	0.	75. KWD	1088. KWD		
MONTH	0.	0.	1.	1.		
NO. 30 SERVES				COOKING EQUIP.		
USAGE	0.	0.	0.	68486. KWH		
DEMAND	0.	0.	0.	20. KWD		
MONTH	0.	0.	0.	1.		

FIGURE A-3 - AXCESS YEARLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

TASK # 1 BUILDING LOADS ESTIMATE

YR (CONT.)

METER	SCHEME A	SCHEME B	SCHEME C	SCHEME D	SCHEME E	SCHEME F
NO. 31 SERVES				TOTAL CUM. GAS		
USAGE	0.	0.	0.	4632415.	CF	
DEMAND	0.	0.	0.	5776.	CFH	
MONTH	0.	0.	0.	1.		
NO. 32 SERVES				P.S. HEATING#1		
USAGE	0.	0.	0.	3322908.	CF	
DEMAND	0.	0.	0.	5153.	CFH	
MONTH	0.	0.	0.	1.		
NO. 33 SERVES				P.S. HEAT#1 AUX		
USAGE	0.	0.	0.	5535.	KWH	
DEMAND	0.	0.	0.	9.	KWD	
MONTH	0.	0.	0.	1.		
NO. 34 SERVES				P.S. REF#1G.#2		
USAGE	0.	0.	0.	727372.	KWH	
DEMAND	0.	0.	0.	1006.	KWD	
MONTH	0.	0.	0.	5.		
NO. 35 SERVES				P.S. REF.#2 AUX		
USAGE	0.	0.	0.	15141.	KWH	
DEMAND	0.	0.	0.	21.	KWD	
MONTH	0.	0.	0.	5.		
NO. 36 SERVES				T.S. UNITAR W/H#2		
USAGE	0.	0.	0.	90634.	KWH	
DEMAND	0.	0.	0.	22.	KWD	
MONTH	0.	0.	0.	1.		

FIGURE A-3 - ACCESS YEARLY SAMPLE OUTPUT - SMALL SHOPPING CENTER (CONT)

Monthly and yearly hot water energy usage profiles are determined by taking the difference between the total gas usage and the primary heating system gas usage and converting the result to electrical units of kWh.

As a result of the limitation on the availability of hourly data, the determination of representative hourly profiles was not straightforward. The method used in this case was to approach the problem from two directions. Hourly electrical and hot water energy usage profiles were synthesized from the AXCESS input usage profiles for each item of usage. The procedure was simply to determine, on an hourly basis, from the input, the sums of the usage of each item. The profiles utilized in this method were for work days. Consequently, the resulting hourly profiles represent the peak electrical and hot water usage, since the usage in these categories was considerably less than non-work days. Good agreement between the profiles obtained by this procedure and the appropriate profiles listed by AXCESS was obtained. This procedure was not applicable to the hourly heating and cooling profiles due to the non-availability of weather data in the input.

Consequently, a second procedure was developed to determine hourly heating and cooling profiles. The approach was to determine, by means similar to those used for monthly and yearly calculations, the mean hourly heating and cooling profiles averaged over the 8 days for which data were available. (The AXCESS hourly data were limited to eight representative days which consisted of six work days, a Saturday, and a Sunday/Holiday in order to avoid unnecessary data reduction.) Since these days occurred in January, it was postulated that the mean profiles obtained by this method were a good approximation of January's profile. The "January" profile was then modified by the ratio of the mean usage for one hour, averaged over the year, to the mean usage for one hour, averaged over January. The resulting profile is considered a fair representation of the hourly usage of a given system in a given building.

This procedure is, unfortunately, quite tedious, even with the help of a desk top programmable calculator, and requires considerable computational time. Also, this datum is of a low priority, being required only to check the validity of the STES code results. Consequently, this procedure has been applied only to the low- and high-rise office buildings. This method or a simplified version of it could be applied to the other buildings if required in the future.

RESULTS

The monthly energy usage profiles for each building are partially presented in the form of the total monthly usage profiles for each system in Figures A-4 through A-9. Also shown in these figures are the hot water, electrical, and minimum heating plus cooling usage. It should be noted that in all cases the hot water usage for a given building is independent of the HVAC system utilized. In almost all cases the electrical usage of a building is also independent of HVAC system utilization and in those cases where it is not, the variance is not significant. The difference between the total system energy usage and the electrical plus the minimum heating and cooling usage provides a qualitative measure of the inefficiency of the system, i.e., the greater the difference, the greater the inefficiency of that system.

The yearly energy usage data is summarized in Tables A1-A6. Also shown in these tables is the usage breakdown, as a percent of the total usage.

Figure A-4. Low Rise Office Building Energy Utilization for HVAC Internal Systems

Figure A-5. High Rise Office Building - Energy Utilization for HVAC Internal Systems

Figure A-6. Small Shopping Center Energy Usage

FIGURE A-7 - LARGE SHOPPING CENTER ENERGY USAGE

FIGURE A-8 - SMALL RETAIL STORE ENERGY USAGE

FIGURE A-9 - LARGE RETAIL STORE ENERGY USAGE

TABLE A-1
ENERGY USAGE BREAKDOWN (LOW RISE OFFICE BUILDING)

SCHEME	HOT WATER HEATING (%)	ELECTRICAL (%)	SPACE HEATING & COOLING (%)	TOTAL YEARLY USAGE (MWh)
DUAL DUCT	1.7	15.4	82.9	2092.6
MULTI-ZONE	2.2	19.4	78.4	1652.5
SINGLE ZONE REHEAT	1.7	14.6	83.7	2191.8
UNITARY HEAT PUMP	4.9	42.9	52.2	749.4
VAR. VOL. WITH REHEAT	3.1	24.8	72.1	1162.6
4-PIPE FAN COIL	5.7	50.4	43.9	638.1

TABLE A-2
ENERGY USAGE BREAKDOWN (HIGH RISE OFFICE BUILDING)

SCHEME	HOT WATER HEATING (%)	ELECTRICAL (%)	SPACE HEATING & COOLING (%)	TOTAL YEARLY USAGE (MWh)
DUAL DUCT.	8.4	18.4	73.2	20,424.5
VARIABLE VOLUME WITH REHEAT	12.5	29.1	58.4	13,699.2
SINGLE ZONE REHEAT	7.0	19.2	73.8	24,278.4
4-PIPE FAN COIL	14.6	40.0	45.4	11,681.9
4-PIPE INDUCTION	7.0	19.0	74.0	24,529.8

TABLE A-3
ENERGY USAGE BREAKDOWN (SMALL SHOPPING CENTER)

SCHEME	HOT WATER HEATING (%)	ELECTRICAL (%)	SPACE HEATING & COOLING (%)	TOTAL YEARLY USAGE (MWh)
MULTI-ZONE	0.9	35.0	64.1	18,340.7
SINGLE-ZONE REHEAT	1.0	37.7	61.3	17,019.1
UNITARY HEAT PUMPS	1.7	66.3	32.0	9,689.7
UNITARY COOLING SEPARATE REHEAT	1.9	71.2	26.9	9,017.9

TABLE A-4
ENERGY USAGE BREAKDOWN
(Large Shopping Center)

Scheme	Hot Water Heating (%)	Electrical (%)	Space Heating & Cooling (%)	Total Yearly Usage (MWh)
Multi-Zone	1.25	35.88	62.87	71,260
Unitary Heat Pumps	2.56	73.06	24.37	35,012
Single-Zone Reheat	1.13	32.25	66.62	79,265
Unitary Cooling Separate Reheat	2.66	75.75	21.59	33,770

TABLE A-5
ENERGY USAGE BREAKDOWN
(Small Retail Store)

Scheme	Hot Water Heating (%)	Electrical (%)	Space Heating & Cooling (%)	Total Yearly Usage (MWh)
Unitary Heat Pump	4.9	67.9	27.2	3,424
Unitary Cooling Separate Reheat	5.0	67.3	27.7	3,364
Single-Zone Reheat	4.3	59.3	36.4	3,920

TABLE A-6
ENERGY USAGE BREAKDOWN
(Large Retail Store)

Scheme	Hot Water Heating (%)	Electrical (%)	Space Heating & Cooling (%)	Total Yearly Usage (MWh)
Multi-Zone	0.2	59.0	40.8	14,132
Single-Zone Reheat	0.2	48.2	51.7	17,289

APPENDIX B - COST ALGORITHMS

B.1 ESTIMATED COST OF SMALL CENTRAL RECEIVERS AND TOWERS

In order to compare the performance of small central receivers with distributive collectors for STES commercial applications, algorithms for cost of the receiver and tower are required. In Reference B-1, it was suggested that $\$100/\text{m}^2$ should be used for the installed cost of distributed collectors and $\$65/\text{m}^2$ for the heliostats used in a central receiver system. The cost of the receiver/tower was not given.

Two references exist with cost estimates for central receivers towers. Reference B-2 gives estimates for three small systems designed at the University of Houston and refers to previous analyses of large systems (100-200 MWe). Reference B-3 describes one of these large systems in detail and has been used in conjunction with Reference B-2 as the basis for this cost estimate.

In Reference B-4, the height requirement for the central receiver tower is discussed. It is shown that the tower height will be approximately proportional to the square root of the heliostat area.

The cost of the tower itself will be proportional to the height of the tower raised to a power greater than unity. If the cost is assumed proportional to the square of the height, then the tower cost will be proportional to the heliostat area. Since the absorber area is also proportional to the heliostat area for a given concentration ratio, the total cost of the tower/receiver/plumbing should be related directly to the heliostat area.

Figure B-1 shows the unit costs ($\$/\text{m}^2$) presented in References B-2 and B-3 for six systems ranging in size from a heliostat area of 1,100 to 855,000 m^2 . These data indicate that 17 $\$/\text{m}^2$ is a reasonable cost estimate over this range. The central receiver costs can, therefore, be related to the heliostat area by the algorithm.

$$\text{Central Receiver Cost} = (65 + 17) \$/\text{m}^2$$

Figure B-1. Effect of System Size on Central Receiver Tower Cost

B.2 PHOTOVOLTAIC SYSTEM OPERATING COSTS

The operation and maintenance cost algorithm for photovoltaic STES is shown in Figure B-2 where the previously developed algorithm for thermal STES (Reference 1) are also shown. The data were developed by allocating supervision operations and maintenance labor as a function of plant size and operating hours for both the thermal and photovoltaic STES. The algorithm for photovoltaic STES is given by:

$$\text{Cost/yr} = 80,000 + 2.68 \times 10^{-3} (\text{kWh/yr})$$

B.3 CAPITAL EQUIPMENT COSTS

The installed cost algorithm for electric zone heater systems is assumed to be:

$$\text{Cost} = 63.5 (\text{kW})^{.846}$$

For electric water heaters, the installed cost algorithm is:

$$\text{Cost} = 33.4 (\text{kW})$$

Figure B-2. Cost Algorithms (Operations and Maintenance)

REFERENCE

- B-1 Letter dated August 4, 1976, R. W. Harrigen to S. Nalbandian
- B-2 The Utilization of Solar Energy for Feedmill and Irrigation Operations, University of Houston, Report Period June 18, 1975 - December 15, 1975
- B-3 MDC 66040, Central Receiver Solar Power Thermal System Final Report
- B-4 Comparative Performance of Solar Thermal Power Generating Concepts, LWen and 4Cwa Paper 769212, 11th Intersociety Energy Conversion Engineering Conference, September 1976
- B-5 Comparison of Solar Concentrators, A. Rabl, ANL/SOL-75-02, April 1975

APPENDIX C

EFFECT OF AMORTIZATION PERIOD

A 30-year lifetime was assumed initially for the system to conform with the precepts of "utility financing" described in Reference C-1. A 30-year life also was assumed for all the components in the preliminary calculations.

As the study progressed, it became apparent that the anticipated life of the collectors, the solar thermal power conversion system (i.e., "rotating equipment"), and air conditioning equipment would be on the order of 20 years. The impact of the amortization period on annualized cost, as a function of the assumed equipment lifetimes, therefore was assessed.

The data are presented in Table C-1 for component lifetimes of 20, 30, and 15/30 years, assuming escalation rates of 6 and 12%. As can be seen, replacing the collectors and rotating components at the end of 15 years will increase the annualized cost on the order of 5% for a plant with an assumed 30-year lifetime. On the other hand, if the amortization period is reduced to 20 years to conform with the assumed useful life of the rotating equipment (and a specific project such as a large regional shopping center), then the annualized costs will go down some 20 to 60%. The levelized busbar energy cost for $N = 20$ years, as compared to $N = 30$ years, will rise 23% at 6% escalation rates and decrease 6% if the escalation rate is 12%. (It should be noted that at the higher escalation rates the analyses indicate a higher investment in solar equipment; hence, a higher initial investment and lower recurring costs.)

An amortization period of 20 years was chosen as the basis for all comparisons.

TABLE C-1
EFFECT OF AMORTIZATION PERIOD (N)
(NO REDUNDANCY)

COMPONENTS	ASSUMED LIFE (YEARS)	INITIAL CAPITAL INVESTMENT (\$ X 10 ⁶)	ANNUAL RECURRING COST (\$ X 10 ⁶)	ANNUALIZED COST (\$ X 10 ⁶)	SOLAR CONTRIBUTION (%)
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G_F = 6%

1. ALL	30	3.006	1.929	4.744	11.75
2. COLLECTOR	15	3.006	1.929	4.951	11.75
PCS	15				
AIR CONDITIONING	15				
ALL OTHERS	30	3.006	1.929	4.062	11.75
3. ALL	20				

G_F = 12%

1. ALL	30	11.965	1.538	16.24	42.15
2. COLLECTOR	30	11.965	1.538	17.323	42.15
PCS	15				
AIR CONDITIONING	15				
ALL OTHERS	30	11.965	1.538	10.898	42.15
3. ALL	20				

PCS CONTROL BY SOLAR
COLLECTOR COST = 100/M²
FUEL COST = \$2.50/10⁶Btu
ELECTRICITY COST = 5.12¢/kWh
Y_{CO} = 1986
G_F = FUEL ESCALATION RATE

REFERENCES

- C-1. J. W. Doane, et al, "The Cost of Energy from Utility-Owned Solar Electric Systems," Jet Propulsion Laboratory, Pasadena, California," Report JPL 5040-29, ERDA/JPL-1012-76/3.

APPENDIX D
EFFECT OF REDUNDANCY OF SUBSYSTEM CAPITAL COSTS

A scaling relationship was developed and the effect of selected subsystem redundancy on cost was assessed.

The development of the generalized scaling relationship is presented in Figure D-1. Assuming that the cost of the subsystems of interest (e.g., air conditioning, power conversion, etc.) can be expressed as:

$$\text{Cost} \sim (\text{Size})^n$$

where n ranges between 0.5 and 0.7 as shown in Reference D-1, then the cost of N units is:

$$\text{Cost} \sim N (\text{Size})^n$$

Setting the required size of the given subsystem equal to unity, it may then be assumed that adequate redundancy can be achieved with two full-sized units, three half-sized units, four third-sized units, etc., as shown in the tabulation on Figure D-1. The graph presents the relative costs of a subsystem with N redundant units as a function of the exponent, n . As can be seen, providing for redundancy will approximately double the initial cost of a given subsystem.

The impact on the capital investment and annualized cost of providing for redundancy in the air conditioning and power conversion systems is presented in Table D-1. Redundancy will increase the capital investment by 15 to over 40%, depending on the assumed escalation rate; the increase in annualized cost will be on the order of 3 to 5%.

COST ~ (NO. UNITS) (SIZE)

OR

$$\frac{C_2}{C_1} \sim \frac{N_2}{N_1} \left(\frac{S_2}{S_1} \right)^n$$

WHERE:

	SIZE	N	
S = 100	1	N ₁	
S ₂	100	2	N ₂
	50	3	
	33	4	
	25	5	

AND $n = 0.5; 0.6; 0.7$

Figure D-1. Effect of Redundancy on Subsystem Capital Cost

TABLE D-1
EFFECT OF REDUNDANCY (N = 20 YEARS)

COMPONENTS	REDUNDANCY	CAPITAL INVESTMENT (\$ X 10 ⁶)	ANNUAL RECURRING COST (\$ X 10 ⁶)	ANNUALIZED COST (\$ X 10 ⁶)	SOLAR CONTRIBUTION (%)
G _F = 6%					
1. ALL	1	3.006	1.929	4.062	11.75
2. PCS	2	4.336	1.929	4.280	11.75
AIR CONDITIONING	2				
ALL OTHERS	1				
G _F = 12%					
1. ALL	1	11.965	1.538	10.898	42.15
2. PCS	2	13.866	1.538	11.209	42.15
AIR CONDITIONING	2				
ALL OTHERS	1				

N = 20
COLLECTOR COST = \$100/M²
FUEL COST = \$2.50/10⁶ Btu
ELECTRICITY COST = 5.12¢/kWh
Y_{CO} = 1986
G_F = FUEL ESCALATION RATE

REFERENCES

- D-1. Final Report on Total Energy Feasibility Criteria for the U.S. Army Engineers Power Group, Fort Belvoir, Virginia (Contract DAAK02-73-C-0370), by OES, Inc. (Envirodyne), December 1973

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