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of Solar Total-Energy Systems
Draft Final Report — Volume 2 (Appendixes)**

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Appendix A

DEVELOPING A REGIONAL-CLIMATE MODEL

Two general techniques can be applied to model regional climatic conditions. The first is to use actual weather tapes that contain measurements of insolation and temperature on an hour-by-hour basis for various cities throughout the country. An important advantage of this method is that an actual measured year of data is available for testing system performance. However, the method may not yield accurate results if the instrumentation (particularly that recording insolation) has not been calibrated properly, if the year is not "typical" for the region, or if the tapes contain errors, inconsistencies, or incomplete data (for which there are no generally agreed-upon correction techniques).

A second technique is to generate a "typical" year using long-term statistical measurements of insolation and temperature averages. Because the instruments are periodically replaced or recalibrated, this method reduces (but does not eliminate) inaccuracies resulting from instrumentation problems. In addition, it eliminates any problems stemming from incomplete or incorrect data.

In developing a regional-climate model for STE systems, we applied the second technique. The output of our model is a year-long simulation on an hour-by-hour basis of both insolation and temperature for each of the 12 solar regions. The simulation is based on regional temperature average and temperature-range data.

Average monthly data and statistical parameters were derived from actual measurements to generate the instantaneous solar-beam flux. The average daily insolation

on a horizontal surface ($\bar{H}$) for each month¹ was used to calculate the "clearness factors" ($\bar{K}_t$), or the fraction of the extraterrestrial solar radiation that reaches the ground. $\bar{K}_t$ was then used to define a statistical daily-insolation distribution function, which describes the fraction of time the total daily insolation is less than or equal to some specified value.² The form of this function depends primarily on $\bar{K}_t$ and is relatively insensitive to altitude or solar declination. Cumulative distribution functions were obtained from actual insolation data at 27 localities throughout the United States.

The hourly flux on a horizontal surface was then calculated assuming a daily cosine relationship. The $\bar{K}_t$ factor was used to split the flux into beam and diffuse components for each day. The insolation on the solar-collector plane was determined based on the solar altitude and the angle of incidence of beam radiation in the collector plane.

Hourly ambient temperatures were derived from average monthly temperatures and a random-number generator. The average monthly mean temperature ($\bar{T}$) and average monthly maximum and minimum temperatures ($\bar{T}_{\max}$, $\bar{T}_{\min}$) were obtained from the Climatic Atlas. Hourly temperatures were then calculated using the following equation:³

$$T_i = T_{\min} + (\Delta T \times F_i)$$

where:

T_i = Ambient temperature at the i^{th} hour

1. U.S. Department of Commerce, Environmental Science Service Administration, Climatic Atlas of the U.S. (1968).

2. B.Y.H. Liu and R.C. Jordan, "Availability of Solar Energy for Flat-Plate Solar Heat Collectors," Low Temperature Engineering Applications of Solar Energy, edited by R.C. Jordan, (New York ASHRAE, Inc., 1967).

3. V.M. Puri, "Domestic Solar Energy Systems for Delaware," M.S. thesis, Department of Mechanical & Aerospace Engineering, University of Delaware.

$$\Delta T = (\bar{T}_{\max} - \bar{T}_{\min}) \times \text{random number for each day}$$

$$T_{\min} = \bar{T} - (0.4457 \times \Delta T).$$

F_i = hourly factor for the i^{th} hour

$$= 0.113(1 - i/6) \quad 0 \leq i \leq 6$$

$$= 1 + \frac{i}{6.8}(i-12.8) \quad 6 \leq i \leq 12.8$$

$$= 1.0 \quad 12.8 \leq i \leq 15.23$$

$$= 0.35 - 0.1125(i-21) \quad 15.23 \leq i \leq 21.8$$

$$= 0.25 - \frac{0.147}{2.2}(i-21.8) \quad 21.8 \leq i \leq 24.$$

Appendix B

DEVELOPING A BUILDING- LOAD REQUIREMENTS MODEL

Once hourly temperatures and insolation are determined, building-load requirements for use in optimizing STE systems and evaluating their performance can be developed. Because hourly metered data for a similar building in each subsector in each region are not available, we developed estimates using typical buildings, and then adjusted those estimates to reflect regional differences in construction practices.

Institutional-building load profiles can be divided into HVAC loads, non-HVAC electric loads (primarily lighting and machinery), and hot-water requirements. HVAC and hot-water requirements are highly dependent on regional and seasonal climatic differences; non-HVAC electric profiles are essentially independent of region and season. All are dependent on the building type.

HVAC loads consist of internal loads (i.e., heat gains from body heat and electrical uses such as lighting or machinery) and external loads (i.e., heat gains from temperature differences between the indoors and outdoors, ventilation, and solar insolation). The data we used to develop these profiles were obtained from several sources: actual metered data, fuel-purchase records, estimates of energy requirements for actual building designs from architectural/engineering firms, and

estimates developed from generally accepted design standards.¹

Estimates of internal loads were based on occupancy and equipment-usage patterns provided by building owners or engineers. Estimates of solar-insolation effects were based on window area, construction materials, and regional insolation estimates (as discussed in the Carrier System Design Manual). These effects were then lagged to simulate a building's storage-load properties. Ventilation requirements (caused by mixing inside air with outside air) were taken into account. Transmission through the walls, roof, and windows was calculated by summing the $U \times A$ factors. In addition, the buildings were divided into six zones (the four outside wall regions, the top floor region, and the central core volume), and each zone's energy requirements were developed separately to ensure accurate estimates of actual energy use.

We then developed hourly HVAC profiles by calculating the hourly heat loss (or gain) from the internal and external loads, and thus the heating and cooling loads. Where cooling is required, we adjusted energy requirements to reflect regional humidity differences. Energy requirements for hot water, which depend on the water's source temperature and not necessarily the outside air temperature, were also determined.

To estimate hourly building-load profiles for an entire year, we used building-construction characteristics (see Exhibit B.a) and hourly temperature and insolation data. The hourly ambient temperatures (T_{amb}) were calculated

1. ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers (New York, 1974); ASHRAE Handbook and Product Directory-Systems, American Society of Heating, Refrigerating, and Air Conditioning Engineers (New York, 1976), Carrier System Design Manual, Part 1 - Load Estimating, Carrier Air Conditioning Company (New York, 1972).

* U is the average thermal transfer coefficient, which differs for walls, windows and roofs; A is the corresponding surface area.

Exhibit B.a

Building-Construction Characteristics

Building Type	Surface Area* (ft ²)		Total Floor Area (ft ²)	Glass/Wall Ratio	U-wall (Btu/hr/ft ² -°F)	U-roof (Btu/hr/ft ² -°F)	U-window (Btu/hr/ft ² -°F)	Ventilation (CFM**/ft ²)	Time Constant Wall (hr)	Time Constant Roof (hr)	Occupancy (day/night)
Hospital	N	12,400	136,000	0.15	0.18	0.09	1.13	0.33	3	5	1,710/720
	E	4,400									
	S	12,400									
	W	4,400									
	H	34,100									
College	N	19,000	760,000	0.15	0.18	0.09	1.13	0.09	3	5	9,000/4,000
	E	16,000									
	S	19,000									
	W	16,000									
	H	190,000									
Research & development	N	1,250	10,250	0.15	0.18	0.09	1.13	0.33	3	5	135/0
	E	820									
	S	1,250									
	W	820									
	H	10,250									
Office	N	910	7,000	0.15	0.18	0.09	1.13	0.20	3	5	90/0
	E	1,300									
	S	910									
	W	1,300									
	H	7,000									
School	N	1,640	24,500	0.15	0.18	0.09	1.13	0.09	3	5	325/0
	E	3,000									
	S	1,640									
	W	3,000									
	H	12,300									

SOURCE: InterTechnology/Solar Corporation

* N = North

E = East

S = South

W = West

H = Horizontal (roof)

**CFM = Cubic feet per minute

using the method developed by V.M. Puri.² Hourly insolation on the walls and roofs was calculated using equation 1:

Equation 1

$$Q_{\text{solar}} = Q_{\text{hourly}} \times \frac{(\alpha_w)(\bar{K}_t/0.75)}{(\alpha_g)(\tau)(440)(\cos \theta)}$$

where:

Q_{solar} = solar-heat gain absorbed by a building surface

Q_{hourly} = solar-heat gain through ordinary glass measured for each month, hour latitude, and surface orientation³

$\bar{K}_t$ = clearness factor, as a function of region and month⁴

θ = angle of incidence of solar radiation

α_w = wall absorptance

α_g = glass absorptance

τ = sash transmittance.

2. V.M. Puri, "The Domestic Solar Energy Systems for Delaware," M.S. thesis, Department of Mechanical & Aerospace Engineering, University of Delaware.

3. Carrier Air Conditioning Co., Carrier System Design Manual, Part 1 - Load Estimating (New York, 1972).

4. B.Y.H. Liu and R.C. Jordan, "Availability of Solar Energy for Flat Plate Collectors, Low Temperature Engineering Applications of Solar Energy, edited by R.C. Jordan, (New York ASHRAE, Inc., 1967).

Next, we determined the individual surface temperatures for each wall and roof using equation 2:

Equation 2

$$T(t) = T_{amb}(t) + \frac{(Q_T)(\alpha_w)}{\alpha_g h_o \tau} + \sum_{t'=1}^{t-24} \left[DF \left(T_{t'} - T_{t'-1} + \frac{(Q_{t'} - Q_{t'-1})\alpha_w}{\alpha_g \tau h_o} \right) \left(1 - e^{-\frac{t'-0.5}{TC}} \right) \right]$$

where:

$T(t)$ = wall temperature at time T

h_o = convective heat-transfer coefficient of outer-wall surface (Btu/hr/ft²/°F)

= $2 + 0.267V$ (V = average wind velocity in mph)

DF = damping factor to correct for wall capacitance (= 1)

TC = time constant to allow for transmission ambient temperature changes through surfaces (= 3 for walls, 5 for roofs).

Once the $T(t)$ profiles are determined, the actual profiles can be computed. Heat gains or losses through walls and roofs took the form presented in equation 3:

Equation 3

$$Q(t) = \frac{1}{1/U - 1/h_o} (A) \left[T(t) - T_m(t) \right] \left[1.0 - \frac{\text{glass area}}{\text{wall area}} \right]$$

where:

$Q(t)$ = heat loss or gain

U = overall surface conductance (Btu/ft²/°F/hr)

A = gross surface area (ft²)

T_m = indoor temperature.

Conductance through windows took the form presented in equation 4:

Equation 4

$$Q(t) = \left[\frac{\text{glass area}}{\text{wall area}} \right] (A)(U_g) \left[T_{\text{amb}}(t) - T_m(t) \right]$$

where:

U_g = window conductance.

Radiation through windows was determined using equation 5:

Equation 5

$$Q(t) = \left[\frac{\text{glass area}}{\text{wall area}} \right] (A) \left[Q_{\text{solar}}(t) \right]$$

where:

$Q_{\text{solar}}(t)$ = solar insolation at time t from equation 1.

Heat gain from building occupants was estimated using equation 6:

Equation 6

$$Q(t) = 450.0 \times OP(t)$$

where:

$$450.0 = \text{Btu/hr/person}$$

$$OP(t) = \text{occupation profile for the building at time } t, \\ \text{in number of people.}$$

Heat gain due to lights and equipment was computed using equation 7:

Equation 7

$$Q(t) = (WATLIT)(3.413)(AF)(EPROFL_t)$$

where:

$$WATLIT = \text{watts/ft}^2 \text{ for lights and equipment}$$

$$3.413 = \text{conversion of watts to Btu/hr}$$

$$AF = \text{floor area, ft}^2$$

$$EPROFL_t = \text{fraction of lights on hour } t.$$

Heat required for ventilation was calculated using equation 8:

Equation 8

$$Q(t) = 1.08(CFMP SF)(AF)(T(t) - T_{in}(t)[VPROFL(t)]$$

$$1.08 = \text{air constant, } \frac{\text{Btu} - \text{min}}{\text{hr} - \text{ft}^3 - ^\circ\text{F}}$$

CFMPSF = ventilation rate, CFM/ft²

VPROFL_t = fraction of ventilation required at hour t.

Heat required for dehumidification (included only if absolute humidity of ambient air is greater than interior-design absolute humidity) was calculated using equation 9:

Equation 9

$$A(t) = (.075)(60)(1080)(CFMPSF)(AF)(ABSHUM - 0.011)$$

where:

0.075 = lb/ft³ of air

1080 = latent heat (Btu/lb-water)

ABSHUM = absolute humidity of ambient air, (lb-water)/
(lb-dry air)

0.011 = interior-design humidity.

If ventilation can provide cooling, the cooling load is decreased correspondingly by admitting 100-percent outside air.

Exhibit B.b presents a typical hourly-demand profile for a large college in Los Angeles. Exhibit B.c presents typical monthly demands for large colleges in Boston, Phoenix, and Los Angeles. Exhibit B.d summarizes the total annual loads for the buildings analyzed in each region. Exhibit B.e presents the annual full-load-equivalent hours for air conditioning.

Exhibit B.b

Typical Hourly Demand Profiles

(Los Angeles college, $1.21 \times 10^6 \text{ft}^2$, 3 stories)

Hour	April		July		January		
	Heating (Btu/hr/ft ²)	Cooling (Btu/hr/ft ²)	Heating (Btu/hr/ft ²)	Cooling (Btu/hr/ft ²)	Heating (Btu/hr/ft ²)	Cooling (Btu/hr/ft ²)	Electricity (kWh/ft ²)
1	0.213	0	0	0	0.608	0	0.796
2	0.259	0	0	0	0.938	0	0.796
3	0.638	0	0	0	1.663	0	0.796
4	0.724	0	0.037	0	1.773	0	0.796
5	0.807	0	0.086	0	1.869	0	0.086
6	0.865	0	0.113	0	1.923	0	0.796
7	0.268	0	0	0	1.293	0	0.796
8	0	0	0	0	0	0	2.962
9	0	0	0	0	0.045	0	7.448
10	0.099	0	0	0.287	0.336	0	7.448
11	0.049	0	0	6.666	0.185	0	7.448
12	0.002	0	0	14.933	0.125	0	7.448
13	0	0	0	15.385	0.091	0	7.448
14	0	1.956	0	16.233	0.020	0	7.448
15	0	2.260	0	16.918	0.016	0	7.448
16	0	2.456	0	17.438	0.020	0	6.409
17	0	0.243	0	16.343	0	0	5.001
18	0	0	0	15.248	0	0	5.001
19	0	0	0	15.440	0	0	5.001
20	0	0	0	1.998	0	0	5.001
21	0.005	0	0	0	0.222	0	4.244
22	0.064	0	0	0	0.311	0	4.244
23	0.140	0	0	0	0.450	0	0.796
24	0.212	0	0	0	0.591	0	0.796
Daily	4.219	6.915	0.236	136.889	12.500	0	0.097

SOURCE: InterTechnology/Solar Corporation

Table B.c

Typical Monthly Demand Profiles*
 (Colleges, $1.21 \times 10^6 \text{ ft}^2$, stories)

Month	Boston			Phoenix			Los Angeles		
	Water (Btu/ day/ft ²)	Heating (Btu/ day/ft ²)	Cooling (Btu/ day/ft ²)	Water (Btu/ day/ft ²)	Heating (Btu/ day/ft ²)	Cooling (Btu/ day/ft ²)	Water (Btu/ day/ft ²)	Heating (Btu/ day/ft ²)	Cooling (Btu/ day/ft ²)
1	59.1	67.7	0	50.3	24.0	0	49.2	12.5	0
2	56.9	64.4	0	50.3	18.6	0.8	49.2	10.1	0
3	55.2	43.9	0	49.2	11.9	66.2	47.0	7.3	0.3
4	48.1	23.6	0	48.1	3.8	137.0	42.1	4.3	6.9
5	44.9	7.3	0	45.4	1.5	179.2	39.4	2.0	48.6
6	37.7	0.5	89.0	44.3	0	254.3	36.6	2.1	60.5
7	36.1	0	130.7	42.1	0	332.8	36.1	0.2	136.9
8	39.9	0.2	98.4	35.6	0	305.5	35.0	0.2	136.8
9	43.8	1.7	45.3	33.4	0	248.3	35.6	0.7	123.1
10	45.9	13.2	0	38.8	1.6	168.4	38.8	1.2	97.7
11	50.3	32.1	0	44.3	13.4	54.9	43.2	5.0	44.5
12	52.0	59.2	0	47.0	22.3	0	46.5	9.4	0.1

SOURCE: InterTechnology/Solar Corporation

* Electrical demand = 0.097 kWh/day/ft².

Exhibit B.d

Total Annual Loads of Institutional Buildings

		Schools		Colleges			Hospitals			Offices		
	Floor area (1,000 ft ²)	50	100	220	1,210	2,200	40	140	190	7	50	125
	Stories	1	1	3	3	3	1	3	3	3	3	3
Boston	Peak load											
	Electric (W/ft ²)*	6.66	6.65	7.45	7.45	7.45	10.0	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)**	2.04	2.01	3.20	3.30	3.01	1.8	2.0	2.0	3.0	2.6	2.5
	Annual load											
	Electric (kWh/ft ²)†	25.0	24.9	35.5	35.4	35.5	38.2	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)‡	15.2	12.8	28.0	26.8	27.0	42.8	38.6	37.1	42.1	16.4	11.2
	Cool (10 ³ Btu Clg/ft ²) §	5.5	5.4	11.5	11.1	11.2	10.3	11.2	11.1	19.7	17.2	16.6
Washington, D.C.	Peak load											
	Electric (W/ft ²)	6.66	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.34	2.30	3.94	3.58	3.68	—	2.7	2.7	3.5	3.1	2.9
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	11.1	9.3	23.5	22.7	22.9	—	27.9	26.8	31.3	12.3	8.4
	Cool (10 ³ Btu Clg/ft ²)	25.4	25.0	29.5	27.7	28.0	—	28.5	28.3	40.3	35.4	34.4
Madison	Peak load											
	Electric (W/ft ²)	6.66	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.16	2.12	3.30	3.10	3.09	—	21.4	2.12	3.1	2.6	2.6
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	20.0	17.0	34.9	33.0	33.4	—	56.9	54.7	59.6	23.6	16.1
	Cool (10 ³ Btu Clg/ft ²)	11.3	11.0	10.5	10.2	10.2	—	10.1	10.1	18.1	15.6	15.0

SOURCE: InterTechnology/Solar Corporation

*Peak non-HVAC electrical load per square foot of floor area.

**Peak electrical load for cooling per square foot of floor area. Calculated from the tons of cooling by using a COP of 3 and the formula:

$$\text{Power electric (kW)} = \frac{\text{tons of cooling} \times 12,000 \text{ Btu/hr/tons of cooling}}{3,412.2 \text{ Btu/hr/kW} \times \text{COP}}$$

†Total annual non-HVAC electrical load per square foot of floor area.

‡Total annual space and water heating load per square foot of floor area.

§ Total annual cooling load per square foot of floor area.

Exhibit B.d (continued)

Total Annual Loads of Institutional Buildings

		Schools		Colleges			Hospitals			Offices		
	Floor area (1,000 ft ²)	50	100	220	1,210	2,200	40	140	190	7	50	125
	Stories	1	1	3	3	3	1	3	3	3	3	3
Los Angeles	Peak load											
	Electric (W/ft ²)	6.66	6.65	7.45	7.45	7.45	10.0	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.18	2.13	3.46	3.20	3.25	2.0	2.2	2.1	3.2	2.7	2.6
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	38.2	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	5.14	4.0	17.0	16.8	16.9	9.5	8.7	8.2	17.1	6.76	4.5
	Cool (10 ³ Btu Clg/ft ²)	16.6	16.3	20.8	20.1	20.2	18.8	20.3	20.1	35.9	30.2	29.0
Charleston	Peak load											
	Electric (W/ft ²)	6.66	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.56	2.50	4.32	3.97	4.00	—	3.56	3.53	4.1	3.56	3.46
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	5.86	4.80	18.8	18.5	18.6	—	12.9	12.2	17.7	6.98	4.74
	Cool (10 ³ Btu Clg/ft ²)	46.0	45.3	56.9	52.9	53.6	—	68.4	67.9	77.9	70.4	68.6
Bismarck	Peak load											
	Electric (W/ft ²)	6.66	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.24	2.18	3.14	3.00	2.98	—	2.22	2.20	3.31	2.76	2.64
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	24.4	20.6	40.6	38.2	38.6	—	68.7	66.3	71.4	29.0	20.0
	Cool (10 ³ Btu Clg/ft ²)	11.3	11.0	10.7	10.4	10.4	—	10.8	10.7	19.0	15.8	15.1

SOURCE: InterTechnology/Solar Corporation

Exhibit B.d (continued)

Total Annual Loads of Institutional Buildings

		Schools		Colleges			Hospitals			Offices		
	Floor area (1,000 ft²)	50	100	220	1,210	2,200	40	140	190	7	50	125
	Stories	1	1	3	3	3	1	3	3	3	3	3
Mashville	Peak load											
	Electric (W/ft ²)	6.66	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.54	2.48	4.21	3.87	3.94	—	3.23	3.20	4.01	3.43	3.30
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	9.76	8.14	21.7	21.3	21.4	—	23.8	22.8	27.3	10.8	7.38
	Cool (10 ³ Btu Clg/ft ²)	34.4	33.8	41.3	38.6	39.1	—	44.0	43.7	56.9	49.8	48.2
Fort Worth	Peak load											
	Electric (W/ft ²)	6.66	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.68	2.60	4.32	4.07	4.05	—	3.33	3.29	4.26	3.54	3.40
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	6.22	5.12	18.1	17.8	17.9	—	14.4	13.7	18.9	7.46	5.06
	Cool (10 ³ Btu Clg/ft ²)	44.6	43.7	52.1	48.6	49.2	—	56.5	55.8	73.4	62.8	60.4
Omaha	Peak load											
	Electric (W/ft ²)	6.60	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.42	2.35	3.94	3.68	3.73	—	2.77	2.75	3.69	3.13	3.01
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.4	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	15.7	13.3	30.1	28.8	29.0	—	43.0	41.4	45.4	17.9	12.2
	Cool (10 ³ Btu Clg/ft ²)	24.0	23.6	26.3	24.8	25.1	—	25.9	25.6	38.6	33.2	32.1

SOURCE: InterTechnology/Solar Corporation

Exhibit B.d (continued)

Total Annual Loads of Institutional Buildings

		Schools		Colleges			Hospitals			Offices		
	Floor area (1,000 ft²)	50	100	220	1,210	2,200	40	140	190	7	50	125
	Stories	1	1	3	3	3	1	3	3	3	3	3
Seattle	Peak load											
	Electric (W/ft ²)	6.60	6.65	7.45	7.45	7.45	—	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.06	2.02	2.50	2.42	2.39	—	1.92	1.90	2.9	2.49	2.40
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	—	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	13.8	11.6	27.0	26.0	26.1	—	34.2	32.8	38.6	15.2	10.4
	Cool (10 ³ Btu Clg/ft ²)	5.00	4.89	4.55	4.44	4.46	—	4.53	4.47	8.6	7.1	6.8
Phoenix	Peak load											
	Electric (W/ft ²)	6.60	6.65	7.45	7.45	7.45	10.0	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.80	2.71	4.42	4.07	4.15	3.04	3.23	3.19	4.5	3.63	3.44
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	38.2	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	5.48	4.44	19.4	19.0	19.1	13.4	12.6	12.0	17.6	6.82	4.58
	Cool (10 ³ Btu Clg/ft ²)	48.6	47.2	56.9	53.5	54.1	55.0	58.2	57.4	86.3	69.8	66.3
Miami	Peak load											
	Electric (W/ft ²)	6.60	6.65	7.45	7.45	7.45	10.0	10.0	10.0	6.2	6.2	6.2
	Electric input to cooling (W/ft ²)	2.57	2.51	4.48	4.16	4.16	3.31	3.87	3.84	4.35	3.98	3.67
	Annual load											
	Electric (kWh/ft ²)	25.0	24.9	35.5	35.4	35.5	38.2	38.2	38.2	24.3	24.3	24.3
	Heat (10 ³ Btu/ft ²)	1.02	0.74	14.2	14.2	14.2	1.75	1.59	1.45	4.97	1.87	1.22
	Cool (10 ³ Btu Clg/ft ²)	74.2	73.1	95.5	88.7	89.9	100.5	119.3	118.4	133.4	119.2	116.0

SOURCE: InterTechnology/Solar Corporation

Exhibit B.e

**Annual Full-Load-Equivalent
Hours for Air Conditioning**

Region	Schools	Colleges	Hospitals	Offices
Boston	262	361	515	646
Washington, D.C.	1,060	740	1,020	1,120
Madison	510	320	465	570
Los Angeles	744	607	918	1,090
Charleston	1,760	1,300	1,880	1,930
Bismarck	493	339	475	559
Nashville	1,325	969	1,330	1,418
Fort Worth	1,633	1,178	1,669	1,733
Omaha	975	655	911	1,030
Seattle	236	179	230	278
Phoenix	1,698	1,270	1,760	1,880
Miami	2,830	2,080	3,010	2,990

SOURCE: InterTechnology/Solar Corporation

Appendix C

DEVELOPING FUEL-PRICE SCENARIOS

The economic viability of STE systems can be realistically assessed only in comparison with the costs of competing conventional (i.e., electric-utility and fossil-fuel) systems. Based on discussions with DOE personnel, we selected two regional fuel-price scenarios: the DOE Base Case scenario, which was developed using the PIES model; and an RPA scenario which adjusts this Base Case scenario to reflect the effects of an increase in the world oil price to \$20 per barrel (in 1975 dollars) by 1990.

The two fuel prices used were for commercial electricity and distillate oil. Natural gas, although presently a major fuel for the institutional sector, is expected to be either unavailable in the future (many facilities currently using it have already been curtailed or ordered to switch to other sources) or available at a deregulated price comparable to that of distillate oil.*

The DOE Base Case is an optimistic scenario: it assumes a stable real world oil price and continued regulation of natural gas. Specifically, it assumes that the price of crude delivered to New York remains constant at \$13 per barrel in 1975 dollars; that the ceiling price on new natural gas on the interstate market is held constant; that domestic controls on old oil remain in effect; and that the oil-entitlements program continues. The Base

* Coal and coal total-energy systems are expected to become serious competitors only in facilities with peak energy requirements of at least 50 MW, as a result of high costs of transportation, handling, storage, burning, and ash disposal; therefore, we did not specifically evaluate these systems.

Case also makes conservative assumptions regarding new oil and gas supplies from the North Slope and Outer Continental Shelf, new nuclear capacity scheduled to come on line, and the contributions of new energy technologies to supply and demand.

RPA has modified the DOE forecast to reflect an important different assumption: that the real price of oil will increase substantially between 1980 and 1990, from \$13 per barrel to \$20 per barrel. If the increase in oil prices is passed through directly to the delivered price of distillate oil, this \$7-per-barrel increase will be equal to an additional cost of \$1.21 per million Btu, which translates to a linear price increase of \$0.11 per million Btu per year.

We then adjusted the delivered price of commercial electricity to reflect the increase in oil prices. First, we multiplied the increased cost of oil by the inverse of an assumed overall generating efficiency, using 40 percent as the conversion-efficiency rate. Although this rate may be high for a national aggregate, it is probably reasonable for the future. We then multiplied this extra fuel cost by the percent of electricity generated in each region by distillate turbines or residual-oil steam plants, and added the product to the PIES price projection. We performed this procedure only for regions that obtain at least 10 percent of their electricity from oil-fired plants. (In 1980, six regions of the ten will obtain at least 10 percent of their electricity from the use of distillate or residual oil; the highest relative use will be 50 percent in Region 1, New England. By 1990, only three regions will use petroleum in significant amounts to generate electricity.)

Exhibit C.a presents the two scenarios: the DOE Base Case and RPA's alternative price projections. Both scenarios are presented in 1975 dollars; all prices were multiplied by 1.11 to determine the corresponding 1977 dollars for input into the market model.

The fuel-price scenarios were developed for the 10 DOE regions (see Exhibit C.b). The prices in each of the 12 solar regions were defined as those in the most closely associated DOE region.

Exhibit C.a

Regional Fuel-Price Scenarios

Region	Year	Commercial Electricity (\$/million Btu)	RPA Scenario	Commercial Distillate (\$/million Btu)	RPA Scenario
		DOE Base Case		DOE Base Case	
United States Average	1975	9.27	9.27	2.58	2.58
	1980	10.67	10.73	2.90	3.01
	1985	10.74	10.94	3.08	3.74
	1990	11.31	11.42	3.32	4.53
New England	1975	12.87	12.87	2.77	2.77
	1980	12.80	12.94	2.92	3.03
	1985	12.83	13.26	3.07	3.73
	1990	13.78	14.39	3.29	4.50
New Jersey/New York	1975	14.93	14.93	2.59	2.59
	1980	14.86	14.97	2.95	3.06
	1985	14.97	15.37	3.12	3.78
	1990	15.62	16.07	3.36	4.57
Middle Atlantic	1975	10.35	10.35	2.58	2.58
	1980	10.21	10.25	3.00	3.11
	1985	10.69	10.87	3.16	3.82
	1990	11.52	11.52	3.40	4.61
South Atlantic	1975	8.59	8.59	2.57	2.57
	1980	9.67	9.71	3.00	3.11
	1985	9.66	9.84	3.16	3.82
	1990	10.13	10.13	3.40	4.61
Midwest	1975	9.49	9.49	2.49	2.49
	1980	9.90	9.93	2.79	2.90
	1985	10.47	10.47	3.02	3.68
	1990	11.20	11.20	3.20	4.47
Southwest	1975	6.91	6.91	2.49	2.49
	1980	11.74	11.74	2.90	3.01
	1985	11.44	11.44	3.06	3.72
	1990	12.16	12.16	3.30	4.51
Central	1975	8.65	8.65	1.96	1.96
	1980	9.88	9.88	2.72	2.83
	1985	10.29	10.29	2.94	3.60
	1990	10.41	10.41	3.18	4.39
North Central	1975	6.90	6.90	2.68	2.68
	1980	7.29	7.29	2.85	2.96
	1985	7.46	7.46	3.06	3.72
	1990	8.41	8.41	3.30	4.51
West	1975	8.30	8.30	2.74	2.74
	1980	11.20	11.33	2.86	2.97
	1985	11.04	11.65	3.03	3.69
	1990	11.44	11.77	3.30	4.51
Northwest	1975	4.44	4.44	2.68	2.68
	1980	6.13	6.13	2.86	2.97
	1985	5.95	5.95	3.03	3.69
	1990	6.55	6.55	3.30	4.51

SOURCE: DOE PIES Base Case; Resource Planning Associates, Inc.

Exhibit C.b

Department of Energy – Regions

SOURCE: Department of Energy

Puerto Rico, Virgin Islands	Region 2
Canal Zone	Region 4
American Samoa, Guam	Region 9
Trust Territory of	
The Pacific Islands	

☆ National Office
● Regional Offices

Exhibit C.c shows the average United States prices for electricity and distillate oil. The significant regional variations in these prices (particularly electricity prices) are indicated in Exhibit C.d. In addition, average fossil and electricity prices can vary significantly within a single region, as indicated in Exhibits C.e and C.f.

The average electricity prices projected in these scenarios were not adequate for estimating the economic performance of the STE systems. Accordingly, we performed a more detailed examination of the actual pricing policies that will be implemented by the electric utilities to provide supplemental service to STE systems. Through personal and telephone interviews with representatives of utilities, state regulatory commissions, and federal agencies, we found that the trend in the development of electricity rates is toward time-of-day rates, which tie prices to peak-usage periods and provide an economic incentive to customers to shift usage patterns to the less expensive off-peak periods.

Time-of-day rates are established by first relating costs to demand and energy functions, and then developing cost and time distinctions between heavy and light periods of use. The demand charge generally reflects the capital costs of the generating mix used to serve a particular customer class. In some cases, the charge varies from month to month depending on the user's peak; however, the current trend is toward using a "ratchet charge" in which the user's demand charge is based on the highest peak during the previous 12 months. The peak-period charge usually represents the marginal cost of the fuel used to produce energy during the peak period as well as a major share of actual generation, transmission, distribution, and overhead costs. The off-peak charge usually reflects the fuel and operating and maintenance costs of operating the most efficient configuration of generating facilities.

Time-of-day rates will probably be more favorable to STE system economics than will current demand and energy rates. Because solar energy will be available during the peak hours, it will tend to displace the most expensive peaking capacity. Exhibit C.g lists actual conventional and time-of-day rates charged by representative utilities

Exhibit C.c

**Projected Fuel Prices
(1975 \$)**

SOURCE: DOE PIES model Base Case
Resource Planning Associates, Inc.

— RPA Scenario
- - DOE Base Case

Exhibit C.d

**Range of Fuel Prices, by Region
(1975-1990)**

SOURCE: DOE PIES model Base Case.

Exhibit C.e

Regional Electricity Prices
(1975 \$/10⁶ Btu)

DOE Region	Price Range		High/Low
	Low	High	
U.S.	3.07	22.36	7.28
I	8.52	17.11	2.01
II	11.54	22.36	1.94
III	9.78	19.37	1.98
IV	6.77	14.33	2.12
V	8.64	14.24	1.65
VI	6.97	13.68	1.96
VII	6.82	15.30	2.24
VIII	5.77	15.32	2.66
IX	5.27	15.76	2.99
X	3.07	7.20	2.35

SOURCE: U.S. Federal Power Commission.

Exhibit C.f

Fuel-Prices Variations, by Region
Distillate-Oil Prices
(1975 \$/10⁶ Btu)

DOE Region	Price Range		High/Low
	Low	High	
I	2.10	2.45	1.17
II	1.84	2.45	1.33
III	1.84	2.46	1.34
IV	1.67	2.53	1.51
V	1.96	2.51	1.28
VI	1.65	2.55	1.55
VII	2.12	2.43	1.15
VIII	2.08	2.51	1.21
IX	1.77	2.40	1.36
X	1.77	2.40	1.36

SOURCE: Platt's OILMANAC.

Exhibit C.g**Time-of-Day Electricity Rates**

Region/City	Peak Rate		Off-Peak Rate
	Demand (\$/kW/yr)	Usage (¢/kWh)	Usage (¢/kWh)
New England	72.00	3.18	1.53
New York/New Jersey	84.00	3.01	1.79
Middle Atlantic	63.00	1.40	1.12
South Atlantic	36.00	2.35	2.35
Midwest	61.20	2.00	1.00
Southwest	29.76	1.03	0.69
Central	28.80	1.10	1.10
North Central	43.44	1.09	0.45
Phoenix	40.20	2.00	2.00
Northwest	18.00	1.00	0.35
Los Angeles	24.84	4.54	0.50

SOURCE: Resource Planning Associates, Inc.

in each DOE region plus Los Angeles and Phoenix.* Although the utilities do not use any one formula to develop rates, we found, through a sensitivity analysis, that the rates generally reflect regional differences in capacity costs and fuel prices. In addition, some of the ratemakers we interviewed indicated that their rates are promotional; that is, they are designed to encourage users to shift to off-peak usage, and thus do not necessarily reflect the actual cost incurred. The Los Angeles off-peak rate of 0.5¢/kWh (\$1.47/MBtu) in the table is an example of a promotional rate.

* Several of the time-of-day rate schedules used by the utilities surveyed distinguish between the summer and winter seasons. For the purposes of our analysis, we averaged those rates to develop a representative rate. Also, different utilities define the time periods for peak and off-peak (in some case, mid-peak) differently. For this study, we defined the peak period to be from 8 a.m.-8 p.m., and the off-peak period to be from 8 p.m.-8 a.m.

Appendix D

COMPARING LIFE-CYCLE COSTS FOR CONVENTIONAL-UTILITY, TOTAL-ENERGY, AND STE SYSTEMS

The tables in this appendix summarize and compare the life-cycle costs for four institutional-building types in the regions in which STE systems are closest to being cost-effective: Los Angeles, Phoenix, Boston, and Madison.

Exhibit D.a

Life-Cycle Cost Comparison: Los Angeles

Application		Conventional-Utility System			Conventional Total-Energy System		Thermal STE System			Photovoltaic STE System	
Type	Size (1,000 ft ²)	First Cost (\$/ft ²)	Annual Energy Cost (\$/ft ²)	LCC (\$/ft ²)	Diesel (W/ft ²)	LCC	Area (ft ² /ft ²)	Generator (W/ft ²)	LCC (\$/ft ²)	PV Area (ft ² /ft ²)	LCC (\$/ft ²)
Office	7	3.607	1.786	35.96	6.686	30.61	0.277	1.83	47.65	0.451	28.97
	50	1.656	1.692	31.70	6.338	26.67	0.134	1.83	34.95	0.451	24.64
	125	1.216	1.672	30.75	6.263	26.00	0.103	1.83	32.41	0.451	23.91
Hospital	140	1.158	2.829	50.82	9.584	32.57	1.462	6.47	60.96	0.367	32.07
	190	1.034	2.824	50.57	9.585	32.43	1.454	6.47	59.48	0.368	31.87
School (10 month)	50	1.455	1.324	25.02	4.434	26.55	0.125	2.36	33.74	0.462	24.10
	100	1.135	1.316	24.45	2.217	25.85	0.112	2.36	31.49	0.462	23.64
College	220	0.973	2.103	37.93	4.967	29.37	0.233	2.91	37.74	0.356	27.89
	1,210	0.549	2.094	37.20	4.965	28.77	0.232	2.90	34.79	0.512	26.30
	2,220	0.451	2.096	37.10	4.967	28.66	0.232	2.91	34.16	0.512	26.19

SOURCE: InterTechnology/Solar Corporation

Exhibit D.b

Life-Cycle Cost Comparison: Phoenix

Application		Conventional-Utility System			Conventional Total-Energy System		Thermal STE System			Photovoltaic STE System	
Type	Size (1,000 ft ²)	First Cost (\$/ft ²)	Annual Energy Cost (\$/ft ²)	LCC (\$/ft ²)	Diesel (W/ft ²)	LCC	Area (ft ² /ft ²)	Generator (W/ft ²)	LCC (\$/ft ²)	PV Area (ft ² /ft ²)	LCC (\$/ft ²)
Office	7	4.324	1.414	30.46	3.757	34.85	0.225	1.83	43.61	0.375	34.91
	50	2.040	1.278	25.00	3.376	28.63	0.108	1.83	31.37	0.375	28.58
	125	1.474	1.250	23.75	3.292	27.32	0.084	1.83	28.48	0.375	27.40
Hospital	140	1.496	2.271	41.56	—	—	1.259	6.47	53.12	—	—
	190	1.337	2.264	41.23	—	—	1.252	6.47	51.62	—	—
School (10 month)	50	1.740	1.094	21.40	2.218	23.37	0.113	2.36	30.13	0.138	23.58
	100	1.351	1.081	20.65	2.217	22.43	0.102	2.36	27.81	0.138	22.65
College	220	1.155	1.596	29.35	3.574	32.83	0.210	2.91	31.78	0.426	32.84
	1,210	0.644	1.575	28.29	3.471	31.58	0.207	2.90	28.51	0.426	31.81
	2,200	0.522	1.578	28.19	—	—	0.207	2.91	27.90	—	—

SOURCE: InterTechnology/Sciar Corporation

Exhibit D.c

Life-Cycle Cost Comparison: Boston

Application		Conventional-Utility System			Conventional Total-Energy System		Thermal STE System			Photovoltaic STE System	
Type	Size (1,000 ft ²)	First Cost (\$/ft ²)	Annual Energy Cost (\$/ft ²)	LCC (\$/ft ²)	Diesel (W/ft ²)	LCC	Area (ft ² /ft ²)	Generator (W/ft ²)	LCC (\$/ft ²)	PV Area (ft ² /ft ²)	LCC (\$/ft ²)
Office	7	3.148	1.786	35.34	6.20	29.68	1.039	1.83	66.10	0.344	30.92
	50	1.610	1.616	30.31	4.39	26.40	0.453	1.83	37.89	0.251	27.58
	125	1.178	1.583	29.16	4.35	25.69	0.333	1.83	32.84	0.249	26.84
Hospital	140	1.146	2.906	52.14	—	—	3.429	6.47	105.61	—	—
	190	1.000	2.897	51.79	9.58	35.84	3.394	6.47	103.38	0.421	38.69
School (10 month)	50	1.422	1.420	26.64	2.218	25.75	0.453	2.36	39.09	0.127	26.32
	100	1.111	1.407	26.00	2.217	25.03	0.401	2.36	35.55	0.127	25.55
College	220	0.949	2.006	36.22	2.603	30.50	0.639	2.91	43.66	0.149	31.30
	1,210	0.513	1.989	35.32	2.589	29.86	0.613	2.90	40.05	0.148	30.61
	2,200	0.372	1.992	35.18	2.593	29.76	0.617	2.91	39.50	0.148	30.52

SOURCE: InterTechnology/Solar Corporation

Exhibit D.d

Life-Cycle Cost Comparison: Madison

Application		Conventional-Utility System			Conventional Total-Energy System		Thermal STE System			Photovoltaic STE System	
Type	Size (1,000 ft ²)	First Cost (\$/ft ²)	Annual Energy Cost (\$/ft ²)	LCC (\$/ft ²)	Diesel (W/ft ²)	LCC	Area (ft ² /ft ²)	Generator (W/ft ²)	LCC (\$/ft ²)	PV Area (ft ² /ft ²)	LCC (\$/ft ²)
Office	7	3.702	1.532	31.86	4.514	29.24	1.200	1.83	66.73	0.127	30.60
	50	1.687	1.336	25.54	2.440	24.00	0.517	1.83	35.25	0.122	24.85
	125	1.227	1.292	24.15	2.420	22.74	0.374	1.83	29.13	0.121	23.42
Hospital	140	1.197	2.546	46.19	—	—	3.317	6.47	99.71	—	—
	190	1.017	2.549	45.76	—	—	3.278	6.47	97.39	—	—
School (10 month)	50	1.570	1.306	24.86	2.380	23.45	0.492	2.36	36.16	0.119	24.22
	100	1.190	1.287	24.02	2.370	22.46	0.433	2.36	32.37	0.118	23.14
College	220	0.984	1.631	29.73	2.577	26.15	0.664	2.91	38.82	0.129	26.98
	1,210	0.505	1.611	28.74	2.565	25.41	0.628	2.90	34.99	0.128	26.21
	2,200	0.326	1.615	28.55	—	—	0.634	2.91	34.48	—	—

SOURCE: InterTechnology/Solar Corporation

Appendix E

PERFORMING THERMAL STE SYSTEM DESIGN TRADE-OFFS

In developing the detailed design of a thermal STE system, we performed trade-off analyses to select the most cost-effective collector system, storage system, and turbine working fluid.

COLLECTOR SYSTEM

The concentrating-collector systems we considered for incorporation into the thermal STE system design were the linear trough, parabolic dish, and central receiver. We compared the performances of the linear trough and the parabolic dish, and the parabolic dish and the central receiver.

Comparison of Linear Trough and Parabolic Dish

The efficiency of the linear-trough collector at solar noon is:

$$\eta_{PC} = 0.77 - 0.133 \frac{\Delta T}{I_d}$$

$$\Delta T = T_{\text{inlet}} - T_{\text{ambient}} (^{\circ}\text{F})$$

$$I_d = \text{direct solar intensity} \left[\frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2} \right]$$

Adjustments were made for end-effects and shadowing losses.

The efficiency of the parabolic-dish collector for all day is:

$$\eta_{PD} = 0.82 - 0.043 \frac{\Delta T}{I_d}$$

The amounts of solar energy collected by the linear-trough and parabolic-dish systems are respectively:

$$Q_{PC} = (\eta_{PC}) (I_d)$$

$$Q_{PD} = (\eta_{PD}) (I_d)$$

The outputs of the two systems under identical conditions are as follows:

I_d (Btu/ft ² /hr)	ΔT (°F)	Q_{PC} (Btu/ft ² /hr)	Q_{PD} (Btu/ft ² /hr)	$\frac{Q_{PD}}{Q_{PC}}$
100	500	10.5	75.5	7.2
150	500	49.0	101.5	2.1
200	500	87.5	157.5	1.8
300	500	164.5	239.5	1.46

At the sunniest places in the United States, the annual average beam insolation on the collector aperture will be about 200 Btu/ft² hr, and the ΔT for the STE system will be about 500°F. In this case, the parabolic dish will yield about twice as much useful energy as the linear trough. Unless the installed cost of the linear trough is less than half that of the parabolic dish, the parabolic dish will therefore be more cost-effective.

Comparison of Parabolic Dish and Central Receiver

Parabolic-dish and central-receiver systems were compared in terms of both their collection efficiencies and system costs. We developed the yearly optical collection efficiency for the central receiver using the Martin Marietta tower-performance estimate (see Exhibit E.a). We then calculated the ratio of the central-receiver input to the two-axis tracking collector input, and determined the yearly weighted average. To simulate the effects of shading on the parabolic-dish field, we calculated the ratio of the dish input with shading to the dish input without shading by including solar insolation only when the sun altitude was 15° or higher. The yearly collection efficiencies of the two systems, including piping losses, are approximately the same in most regions (see Exhibit E.b).

McDonnell-Douglas Astronautics Company developed a "point design" for a small oil-cooled central-receiver system consisting of 85 heliostats, each with an area

Exhibit E.a

Thermal Collector-System Performance*

SOURCE: Martin Marietta

* Includes losses due to cosine, shading, tower shadow, reflectivity, tracking, and optical losses, but not due to heliostat utilization or atmospheric absorption.

Exhibit E.b

**Collection Efficiencies of Central-Receiver
and Parabolic-Dish Systems***

Region	Central-Receiver System		Parabolic-Dish System	
	η_{OCR}	η_{CR}	η_{OPD}	PD
Boston	0.854	0.64	0.899	0.55
Washington, D.C.	0.860	0.66	0.917	0.59
Madison	0.852	0.65	0.899	0.58
Los Angeles	0.862	0.67	0.940	0.65
Charleston	0.860	0.67	0.938	0.63
Bismarck	0.842	0.66	0.871	0.59
Nashville	0.861	0.66	0.931	0.61
Fort Worth	0.860	0.67	0.938	0.65
Omaha	0.856	0.66	0.898	0.60
Seattle	0.841	0.63	0.879	0.54
Phoenix	0.860	0.68	0.938	0.68
Miami	0.850	0.66	0.951	0.65

SOURCE: Resource Planning Associates, Inc., and
InterTechnology/Solar Corporation.

*Ratio of Input (actual) to Input (ideal dish):

$$\eta_{CR} = (\eta_{OCR})(0.82) - 0.013 \Delta T/I$$

$\Delta T \approx 500^\circ\text{F}$ = temperature differential

$$I \approx \text{hourly insolation} \approx \frac{\text{MBtu/ft}^2/\text{yr}}{365 \times 12}$$

$$\eta_{PD} = (\eta_{OPD})(0.82) - 0.043 \Delta T/I$$

of 38 square meters (for a total area of 3,230 square meters, or 34,750 square feet), and a guyed central tower with a height of 53 meters (115 feet). Cost estimates for the system components (i.e., heliostat, tower, and receiver) for production rates of 15 and 100 plants per year are presented in Exhibit E.c).

The total system cost for the central receiver is \$23.88 per square foot of heliostat at a production rate of 15 systems per year, and \$12.49 per square foot of heliostat at a production rate of 100 systems per year.

The parabolic-dish costs should be similar to those of the heliostats, plus costs for the receiver and piping. Other factors (e.g., additional curved reflective area, heavier support structure, blockage by the receiver) may drive the costs up slightly. We estimate that these other factors will increase the costs of the dish by 15 percent over the heliostat. The receiver/absorber costs were estimated by Jet Propulsion Laboratory as \$1.42 per square foot of collecting aperture for a dish/steam system.

We estimated piping costs for the parabolic-dish system based on the General Electric designs for the Shenandoah large-scale experimental total-energy system. This system consists of 198 dishes, each 7 meters in diameter, for a total field aperture of 81,978 square feet. The field-piping length averages about 120 feet per heliostat, with an average diameter of 1 inch. The costs for the field's piping are estimated to be:

<u>Item</u>	<u>Cost</u>
Piping and welding	\$37,500
Insulation	\$109,500
Metal jacket	\$46,700
Installation	\$46,700
Valves	\$111,400
	<u>\$351,800</u>

Source: R.W. Harrigan, R. Hunke; Sandia Laboratories

Dividing this amount by the collector area yields a piping cost of \$4.30 per square foot of collector area. However, this field also uses a closely packed field

Exhibit E.c

Central-Receiver Cost Estimates
(\$/ft²)

Component	Component Cost	
	15 Plants Per Year	100 Plants Per Year
Heliostat	19.65	8.92
Receiver	2.28	1.63
Tower	1.94	1.94
Total	23.88	12.49

SOURCE: McDonnell-Douglas Astronautics
Company

geometry with a collector-area/collector-field area ratio of between 35 percent and 40 percent, which may have problems with shadowing at low sun angles. The optimal packing density will depend on land availability and costs, as well as piping costs and losses. The 40 percent we used is probably a maximum density; the \$4.30 per square foot piping cost is probably a lower limit.

In addition to the additional piping costs, the dish systems will require pumping power for the field. Assuming a 20-kW pump operating 8 hours per day, 365 days per year, this results in an additional energy requirement of 0.71 kWh/ft²/year. This amount can be capitalized using a 7-percent discount rate, a 25-year system life (for a capital recovery factor of 0.086), and a 4¢/kWh electricity cost, resulting in a \$0.47/ft² additional cost difference between the central-receiver and the parabolic-dish systems (see Exhibit E.d).*

We thus estimate that the parabolic-dish system will cost about \$4 more per square foot of collector than the central-receiver system. Coupling this with its equal (or slightly better) annual collection efficiency, we selected the central-receiver system for our thermal STE system design.

STORAGE SYSTEM AND TURBINE WORKING FLUID

Three different storage and working-fluid combinations were considered: oil/steam, oil/toluene, and water/steam. Therminol-66 was selected as the oil heat-transfer fluid because it is virtually the only commercial fluid that performs adequately over the temperature range required (0°F-600°F) without solidifying or generating significant vapor pressure. Water is an effective storage medium as a result of its high heat capacity and very low cost; however, it generates substantial vapor pressure at high temperatures, requiring the use of expensive high-pressure storage tanks.

* These numbers will not necessarily scale as the system collector area increases. However, the cost advantage of the central receiver over the parabolic dish becomes more pronounced as system size increases.

Exhibit E.d

**Parabolic-Dish
Cost Estimates
(\$/ft²)**

Component	Component Cost	
	15 Plants Per Year	100 Plants Per Year
Dish and support	22.60	10.26
Absorber	1.42	1.42
Piping	4.30	4.30
Capitalized energy cost	0.47	0.47
Total	28.97	16.45

SOURCE: Resource Planning Associates, Inc.

The cost comparison thus becomes high-pressure storage-tank costs vs. high-temperature heat-transfer oil costs.

For our analysis, the system was sized to handle a 25 kW_e average load for 24 hours; the collector field was sized to absorb enough energy in one day to operate the system for one 24-hour period, and storage was sized to contain one day's energy. Insulation and installation costs were assumed to be equal for water and oil storage. The cost for nonpressurized storage tanks (see Exhibit E.e) was based on prices obtained from Plant Design and Economics for Chemical Engineers,¹ adjusted to 1977 using the Chemical Equipment Cost Index. The cost of high-pressure (300 psig) vessels (see Exhibit E.f) was obtained from Buffalo Tank Division, Bethlehem Steel Corporation. The cost of pressure tanks at pressures other than 300 psig was determined based on the wall-thickness ratio. The equation for cylindrical shells was used to calculate the shell thickness of the 10-foot diameter tank.

The Rankine cycle efficiencies were calculated as 80 percent of the isentropic efficiencies. The Raytheon parabolic dish was selected as the collector to be used in this study, at an installed cost of \$22.00 per square foot. Therminol-66 properties were identified based on literature supplied by Monsanto. For calculation purposes, the heat capacity over the required temperature range was assumed to be 0.61 Btu per pound, and the density was assumed 6.6 pounds per gallon. The cost of this fluid* is \$6.95 per gallon. If rock and Therminol-66 are used in the storage tank, the cost of the storage fluid can be reduced from \$6.95 per gallon to approximately \$2.00 per gallon for equivalent storage capacity.

We performed a sample calculation for the oil/steam system operating at a steam-turbine inlet temperature of 500°F and an outlet temperature of 70°F. The isentropic cycle efficiency calculated from the steam tables is 27.3 percent. The actual efficiency (n turbine) was considered to be 80 percent of 27.3

1. Peters and Timmerhaus, Plant Design and Economics for Chemical Engineers (1968).

* June 1977

Exhibit E.e

Non-Pressurized Storage Tank Costs

SOURCE: *Plant Design and Economics for Chemical Engineers*, Peters and Timmerhaus, (1968).
(Dollars corrected to 1977 using *Chemical Equipment Cost Index*.)

— Ten-thousands of gallons
- - Thousands of gallons

Exhibit E.f

Pressurized Storage-Tank Costs*

SOURCE: InterTechnology/Solar Corporation

* High-pressure storage tanks, 300 psig @ 400°F, diameter 10 ft cylindrical, prices 9/76.

percent, or 22 percent. As the electrical load and the turbine efficiency are known, the total quantity of energy needed per day can be calculated as follows:

$$(25 \text{ kW}_e/\text{hr})(3413 \text{ kW}_e)(\frac{\text{Btu}}{24 \text{ hr}/n \text{ turbine}} = 9,308,180 \text{ Btu.}$$

With an oil-storage system operating in the range of 520° F, F-600° F, the heat capacity per pound of storage is:

$$(\Delta T) (C_p) = (80) (0.61) = (48.8) \text{ Btu/lb, or } 322 \text{ Btu/gal.}$$

Correspondingly, 28,907 (9,309 ÷ 322) gallons of storage are required. Using rock and oil, the cost is \$57,814 (\$2.00/gal x 28,907 gal). A 30,000-gallon unpressurized storage tank would thus cost \$15,700 (see Exhibit E.e).

The collector efficiency is based on an average oil temperature (T_{ave}) of 560° F. With $T_{amb} = 75° \text{F}$, $i_d = 135 \text{ Btu/ft}^2/\text{hr}$, and a 10-hour day:

$$n_{coll} = 0.82 - 0.013 (T_{ave} - T_{amb})/I_d = 0.77.$$

The collector field size is:

$$(9,308,180 \text{ Btu/day}) - (1,350 \text{ Btu/ft}^2\text{day}) (0.77) = 9,144 \text{ ft}^2.$$

At \$22 per square foot, a collector of this size costs \$201,168.

The total cost for the storage-related components is thus:

Component	Cost
Collector field	\$201,168
Oil/rock	56,814
Storage tank	15,700
	<u>\$274,682</u>

Exhibit E.g presents the component costs and sizes for the various systems considered. Total costs are plotted on Exhibit E.h.

Exhibit E.g

**Component Costs and Sizes for
Storage/Working Fluid Systems**

System	Exhaust Tempera- ture (°F)	Turbine Efficiency	Collector Efficiency	Required Storage (gal)	Oil Cost (\$)	Tank Cost (\$)	Collector Size (ft ²)	Collector Cost (\$)	Total Cost (\$)
Oil/steam*	70	0.22	0.77	28,907	57,814	15,700	9,144	201,168	274,682
	200	0.15	0.77	40,378	80,756	26,700	13,359	293,906	401,362
Oil/toluene*	70	0.24	0.77	26,384	52,768	15,700	8,350	183,691	252,159
	200	0.135	0.77	34,227	68,454	18,500	10,832	238,302	325,256
Water, steam*	70	0.13	0.785	17,915	—	107,360	10,386	228,484	335,844
	200	0.115	0.785	29,599	—	141,520	17,158	337,495	519,015

SOURCE: InterTechnology/Solar Corporation

*Turbine inlet conditions are 500°F and 400°F for the oil and water storage systems, respectively.

Exhibit E.h

Systems Costs as a Function of Operating Point*

SOURCE: InterTechnology/Solar Corporation

* Numbers within exhibit indicate usable thermal/electric ratio.

— Water/steam
 - - Oil/steam
 . . . Oil/toluene

For STE systems operating in a baseload mode, much of the time is spent condensing at 200° to provide energy for space-conditioning and hot water. Thus the oil/toluene system offers a significant advantage in life-cycle cost over the oil/steam or water/steam systems, and was used as our baseline design.

We also performed simulations to determine the usefulness of intermediate-temperature storage (ITS). The system performance results for a hospital with a parabolic-dish collector having an annual electric load of $3,512 \times 10^6$ kWh, an annual space-heating load of 1.05×10^9 Btu, and an annual space-cooling load of $1,0675 \times 10^9$ Btu, were as follows:

	<u>System with ITS</u>	<u>Systems without ITS</u>
Collector area (ft ²)	94,377	94,377
Portion of annual electrical load met by solar (Btu/year)	44.061%	44.054%

For all practical purposes, the performances of the two systems are identical. Because the addition of ITS would add considerably to overall system cost, it was eliminated from the system design.

Appendix F

DETERMINING THERMAL STE SYSTEM PERFORMANCE

We developed a simplified model for estimating thermal STE system performance in regions other than Los Angeles, Phoenix, Miami, and Boston (in those regions, we used the hour-by-hour simulation).

For any day of the year, three quantities that significantly influence STE system performances can be computed:

- Heat collected by the solar collector (Q_{in})
- Electrical demand (E_D)
- Thermal demand (Q_D).

If Q is the amount of thermal energy supplied by the solar system, the corresponding amount of electricity generated is $E_G = 0.14 Q / (1 - 0.14)$, since the turbine is 14-percent efficient when exhausting to the thermal system (using steam as the turbine working fluid). The amount of energy drawn from storage is $Q_S = Q / (1 - 0.14)$. If Q_{in} exceeds Q_S and more electricity is needed, $(Q_{in} - Q_S)$ can be converted to electricity at 24 percent efficiency and the exhaust heat discharged in a condenser. Hence, if E is the electrical energy supplied by solar:

$$Q = \min [Q_D; 0.86 Q_{in}]$$

$$\text{If } Q_D < 0.86 Q_{in} \quad E = 0.14Q/0.86 + 0.24(Q_{in} - Q_S)$$

$$\text{If } Q_D < 0.86 Q_{in} \quad E = 0.14Q/0.86.$$

Since the turbine is never bypassed, if $E > E_D$, these relations do not hold. Instead:

$$E = E_D$$

$$Q = \min [Q_D; 0.86 E_D/0.14].$$

All the conditions can be summarized:

$$Q = \min [Q_D; 0.86 Q_{\min}; 0.86 E_D/0.14]$$

$$E = \min [0.14 Q/0.86 + 0.24(Q_{\text{in}} - Q/0.86); E_D].$$

These quantities are calculated for one representative day per month.

A comparison between the approximate model and the full computer simulation is presented in Exhibit F.a. The approximate model's results are within 10 percent of the hour-by-hour simulation, and will be adequate to estimate STE performances.

A similar simplified model was developed for estimating photovoltaic STE system performance.

Appendix G

TESTING SENSITIVITY OF FUEL PRICES

After determining that STE systems will not be competitive in most regions of the country at an assumed level of conventional fuel prices, we developed estimates of the levels to which those prices would have to rise for STE systems to become economic. The resulting figures are not intended to be precise (inflation rates for electricity and fossil-fuel prices would have to be calculated separately and the system design would have to be reoptimized), but rather to provide reasonable estimates of the ratio of fuel costs to fuel savings that an STE system must offer to be adopted in a particular region.

For thermal systems, the simplest way to determine this ratio is to require the yearly fuel savings to equal the annualized system cost plus operating and maintenance expenses. We examined 1.21-million-square-foot² colleges in each region, using the system having the lowest life-cycle cost, but with a non-zero collector area (see Exhibit G.a).

We then calculated the ratio of the fuel costs to fuel savings using the equation:

$$\frac{(\text{STE Fuel Costs})}{(\text{Fuel Savings})} = \frac{(\text{Incremental STE Capital Cost}) \times (\text{Fixed-Charge Rate}) + (\text{Additional STE O\&M Costs})}{(\text{Fuel Savings})}$$

Exhibit G.b presents the ratio of fuel costs to fuel savings in the various regions, for several discount rates. A 3-percent discount rate was used in the system optimizations. The 7-percent rate is indicative of the level at which large colleges might purchase STE systems,

and the 10-percent rate is the level at which penetration might be expected in all subsectors.*

Values of the ratio less than 1.0 imply cost-effective systems. In general, with the exceptions of Los Angeles and Phoenix, 1990 regional fuel costs must be 50 percent to 100 percent higher than those postulated if the STE systems are to be competitive, even at relatively low discount rates.

In photovoltaic systems, the silicon cells act as "fuel savers" for the diesel systems. The annualized cost of the cells can be compared with the peak-usage charge imposed by the conventional utility (see Exhibit G.c). The usage charge must increase from 20 percent (in Phoenix and Miami) to 250 percent (in Seattle) before STE systems will begin to be competitive, even at a 3-percent discount rate.

* For the institutional sector, discount rates of 3 percent, 7 percent, and 10 percent imply fixed-charge rates of 0.060, 0.088, and 0.113, respectively.

Appendix H

SELECTING THE PHOTOVOLTAIC ARRAY

The use of independent arrays was first determined to be advantageous in the studies conducted by General Electric and Spectrolab.¹ Our analysis substantiated the results of those studies.

The solar absorptance of the silicon solar cell is 0.85 or less, and the emittance is 0.80 or greater. The corresponding values for a black-chrome coating are 0.93 and 0.10. Therefore, use of the solar cell reduces the absorption of a flat-plate thermal collector by:

$$450,000 \text{ Btu/yr/ft}^2 \text{ insolation} \times 0.90 \text{ transmission} \times (0.93 - 0.85) = 32,400 \text{ Btu/yr/ft}^2$$

and increases the losses by approximately:

$$50^\circ\text{F } T \times 1 \text{ Btu/hr/ft}^2/^\circ\text{F} \times 5 \text{ hr/day} \times 365 \text{ days/yr} \times (0.80 - 0.10) = 64,000 \text{ Btu/yr/ft}^2.$$

As a consequence, 100,000 fewer Btu are collected when the solar cells cover the thermal collector. We estimated the value of this thermal energy to be approximately \$0.37 per year. This value can be capitalized by dividing by the fixed-charge rate (0.0574 for a 3-percent discount rate, or 0.1102 for a 10-percent discount rate) to derive an additional cost of \$3.36 to \$6.45 per square foot for the combined array. Because this additional cost can be avoided by spending approximately \$2.50 for the additional structure needed to support a separate photovoltaic array, the separate flat-plate arrays are more cost-effective.

1. Photovoltaic Systems Concept Study, Spectrolab (April 1977).

For concentrating arrays, the thermal-collector losses are negligible, but the optical losses remain the same. With a black absorber ($\delta = 0.93$), the absorbed energy for the parabolic dish is $0.82 I$, where I is the beam (direct) insolation. For a cell-covered absorber, the absorbed energy is $0.82 I \times (0.85/0.93)$ or $0.75 I$. As a consequence, if I equals $800,000 \text{ Btu/yr/ft}^2$ (as in Boston), the optical loss amounts to $(0.82 - 0.75) I$, or $35,000 \text{ Btu/yr/ft}^2$, which is 8.6 percent of the energy absorbed by a black absorber. At $\$22/\text{ft}^2$, the cost of the collectors needed to offset this optical loss is $\$1.90/\text{ft}^2$, which is approximately the same as the cost of the structure required to support an independent photovoltaic array. Hence, in the case of concentrating photovoltaic arrays, a combined electrical and thermal array is marginally cost-advantageous over separate arrays. If annual performance is considered, and electricity needed only when heat is not (so cell cooling is parasitic), the combined array is less attractive. Concentrating systems would again use separate arrays.

Appendix I

ANALYZING INSTITUTIONAL-SECTOR DECISION PROCESSES

In the course of our investigation of the internal decision processes that lead to the selection of an energy system in the institutional sector, it became increasingly apparent that the decision processes, the types of decision-makers involved, and the decision criteria they consider are more a function of the level of government involved (i.e., federal, state, local, or private) than of any other variable (e.g., subsector, building type).

In general, two types of decision-makers participate in the process to select an energy system: those who review and approve the recommendations of others, and those who actually evaluate and choose among alternative systems. The approvers (usually legislators, boards of trustees, city councils, or high-level administrators) are responsible for financing projects, and are therefore interested primarily in ensuring that (1) sufficient need for a new facility or system exists to justify the expenditure involved, and (2) sufficient funds are available or can be raised. The evaluators (usually facility engineers, day-to-day business managers, or project architect/engineers), on the other hand, explore alternatives and make specific recommendations to the approvers, who usually accept and follow those recommendations. In the following sections, we discuss the roles played by the various decision-makers who participate in the selection of an energy system at each level of government.

Decision processes related to the selection of an energy system occur at the federal level for hospitals, public-administration buildings, military installations,

prisons, and post offices,* and do not vary significantly by type of building. The following major decision-makers are involved (see Exhibit I.a):

- Legislative committees. The major responsibility of legislative committees is to ensure that sufficient need exists to justify funding. This evaluation is usually based on preliminary cost studies that are performed before energy systems are specified; legislative committees are generally not concerned with the details of an energy-system choice. In actuality, they usually approve the recommendations of the Federal Office of Management and Budget (OMB).
- Office of Management and Budget. OMB is interested only in determining which type of facility or building system costs the least amount over time. All proposals for new facilities or major renovations are required to present a life-cycle cost comparison between constructing and leasing a building. OMB is also responsible for ensuring that executive orders concerning buildings and building systems are enforced. Currently, two executive orders may encourage the use of STE systems in federal institutions: one requires that energy use in new buildings be reduced by 45 percent of 1975 levels by 1985, and the second mandates that feasibility studies be conducted for solar-energy systems for all new buildings.
- General Services Administration (GSA). GSA's Public Building Service conducts preliminary cost studies for new facilities, and presents the results to OMB before funding is approved. Although these studies are performed on a life-cycle cost basis,

* Although post offices have not been under federal control since the Postal Reorganization Act of 1970, they are still subsidized by the federal government and abide by most federal policies.

Exhibit I.a
Federal Decision-Making Process

SOURCE: Resource Planning Associates, Inc.

Legend:

-
- Actively evaluates and selects energy-system alternatives
- Approves energy-system choice

they are usually performed before the proposed facility's energy system has been specified. Once funding is approved, GSA assumes responsibility for developing the detailed design of the facility and retains the services of a private architect/engineer. If the energy system has not yet been specified, GSA requires the project architect/engineer to submit life-cycle cost feasibility proposals for alternative energy systems. GSA then decides which system should be installed.

Historically, the initial cost of a building system has had to be within the previously approved budget. However, in recognition of rising energy costs and national conservation priorities, Congress is now likely to approve additional funds requested by GSA for initial investment in an energy system that is less expensive on a life-cycle cost basis.

- Federal Agency. When a federal agency needs additional space, it submits a request to GSA specifying the type of building, length of time, and location needed. GSA first searches its current inventory of buildings; if no suitable buildings are available, GSA then submits a request for a new facility to OMB. The federal agency requesting the facility generally has little interest in the type of energy system installed.
- Architect/engineers. Hired to develop specific designs for a new facility, these private professionals often initiate the idea to evaluate a new type of energy system. Although their technical recommendations and expertise play a major role in the choice of a particular system, GSA's Public Building Service actually decides which system is installed.

This general decision-making process varies somewhat by building type. Veterans Administration hospitals, for example, are required to conduct feasibility studies for both total-energy and solar-energy systems. Federal public-administration buildings are required by OMB to be located downtown to contribute to federal efforts to revitalize urban areas. Another internal procedure that could negatively affect STE potential in public-administration buildings is OMB's bias toward leasing rather than constructing buildings. OMB Circular A-104 presents a life-cycle cost comparison between leasing and constructing a building that

apparently leans heavily toward leasing. As a result, federal agencies often have no input into the types of energy systems installed in the buildings they occupy. GSA officials are currently working to have Circular A-104 revised.

Military installations have their own construction departments and do not require GSA approval. The Department of Defense (DOD) currently requires that feasibility studies of total-energy systems be conducted for all new facilities.

Without exception, federal institutions use life-cycle costing in comparing alternative energy systems. OMB's formula uses a 7-percent real discount rate, which represents an estimate of the internal rate of return on general-purpose real property leased from the private sector. DOD also requires that life-cycle costing be used in the feasibility studies conducted for total-energy systems, and generally uses a 10-percent real discount rate. However, as a result of recent changes, a portion of military construction funds is reserved for energy-conservation investments. The threshold criterion for projects approved to use these funds is annual savings of 22 million Btu per \$1,000 invested (implying a payback period of about 14 years).

STATE DECISION-MAKING PROCESS

Institutions under state control include hospitals, colleges, and universities, public-administration buildings, and prisons. Although each of the 50 state governments is organized somewhat differently, the basic decision process leading to the choice of an energy system is the same in most states and does not vary significantly by building type. The following major decision-makers participate in the process (see Exhibit I.b):

- Legislative Committees. As in the federal process, legislative committees usually approve funding based on preliminary cost studies performed before energy systems are specified, and are therefore generally not concerned with the details of an energy-system

Exhibit I.b
State Decision-Making Process

SOURCE: Resource Planning Associates, Inc.

Legend:

- Actively evaluates and selects energy-system alternatives
- Approves energy-system choice

choice. Instead, they act on the recommendations of the state budget office, which are based on an evaluation of the need for a facility. In recognition of the growing concern about energy conservation, however, state representatives are beginning to become involved in energy-related decisions. Some state legislatures have recently passed laws that establish guidelines concerning energy systems in state facilities. To date, however, state legislatures have been reluctant to appropriate additional funds when the energy system specified for a state building involves higher initial costs than were originally budgeted.

- State Budget Office. This central office (sometimes called the state finance or planning office) receives and reviews requests for new facilities from all state agencies. Requests are approved if need can be justified, without consideration of planned energy-systems. The state budget office compiles cost estimates and technical recommendations formulated by the state building commission, and presents its recommendations to the state legislature.

- State-agency. A state agency compiles and evaluates requests for funding by all state institutions under its jurisdiction. The agency may play a minor role in choosing the energy system for a new facility.

- Facility administrator. This individual initiates the request for a facility and presents it to the relevant state agency. The administrator has major input into decisions related to the facility's design and location (e.g., whether a new college laboratory will fit into the campus master plan), but is not usually involved in the choice of an energy system.

- State building commission. The state building commission (often called the public works department of the state architect's office) is staffed by professional engineers, architects, and planners. These officials have the major responsibility for evaluating and selecting energy systems. They perform general cost studies for submission to the legislature and, once funding is approved, appoint the project architect/engineers. The commission's staff then evaluates the feasibility studies of various energy

systems performed by the project architect/engineers and makes the final decision regarding the energy system to be installed.

- Facility engineer. The facility engineer approves the designs of the energy system selected to ensure that it will interface properly with the institution's existing systems.
- Architect/engineers. Hired to develop specific designs for the new facility, these private professionals often initiate the idea to evaluate a new type of energy system. Although architect/engineers conduct feasibility studies on different energy systems, the final choice is the responsibility of the state building commission.

The basic structure of this decision-making process applies to all state institutions; several subsectors, however, require the approval of additional agencies. For example, hospitals are required by the Health Planning Resources Development Act (PL 93-641) to justify the need for a new facility to a regional Health Systems Agency, which is required to grant a Certificate of Need for all new hospital services costing more than \$150,000 and equipment costing more than \$25,000. As one of their primary objectives is to control the cost of medical care, these agencies would have to be convinced that an STE system is sufficiently reliable and offers a high enough payback to reduce medical costs before they would approve its installation. Such agencies generally play a minor role in determining the type of energy system to be installed in state institutions.

Numerous internal institutional procedures may adversely affect STE market potential in state institutions. For example, the state of Texas prohibits new state facilities from generating electricity on-site, Pennsylvania and Ohio require that coal-fired systems be used in all state facilities unless proved infeasible, and Maine enforces historic-preservation regulations, which may preclude facilities from improving energy efficiency in some older buildings.

The numerous criteria used by state institutions to evaluate alternative energy systems vary from state to state. Currently, most states use a simple form of

payback analysis. State building commissions usually require a 5-year payback period, or an annual ROI of 20 percent.

Many states have recently begun to require that life-cycle costing techniques be applied in the evaluation of building and building-system designs. Effective January 1, 1977, the state of Colorado requires that all proposals for new facilities include a life-cycle cost analysis of alternative designs, using a discount rate of 10 percent. Florida has a similar requirement for state facilities. In addition, under the federal Energy Policy and Conservation Act of 1975, states are required to submit energy-conservation plans that include energy-efficient procurement policies to qualify for funding to meet federal energy-conservation mandates. Many states (e.g., New York, New Jersey) have submitted proposals to their legislatures to require the use of life-cycle costing in evaluating building-system designs for state facilities.

The sources and costs of capital funds for state institutions vary considerably by state (see Exhibit I.c). For state hospitals, the major sources of funding are state appropriations, tax-exempt bonds, accumulated funds, and federal loans under the Hill-Burton guarantee and subsidy program and a Federal Housing Administration (FHA) guarantee program. Gifts account for a small portion of hospital funds. State appropriations seem to be the major source of capital funds for state prisons.

Colleges and universities have traditionally financed their major construction programs through subsidized loans at 3-percent interest provided through two federal programs, the National Educational Facilities Act and the College Housing Act. These sources have recently been all but depleted; most college and university funds now come from state appropriations and tax-exempt bonds. Public-administration buildings receive funds from state appropriations.

As in the federal process, land availability is more a function of building type than of level of institutional control. State colleges and universities, state prisons, and state-controlled airports generally have

Exhibit I.c

**Sources and Costs of Capital Funds
for State Institutions**
(expressed as an interest rate)

Institutional Subsector				
Funding Source	Hospitals	Prisons	Colleges and Universities	Public Administration Buildings
Federal	Hill-Burton Loan Guarantee and Subsidy Program (8%)		National Educational Facilities Act	
	FHA-242 Mortgage Insurance Program with Government National Mortgage Association Guarantee (8%)		College Housing Act (3%)	
State	Accumulated funds	Appropriations	Accumulated funds	Appropriations
	Appropriations		Appropriations	
	Tax-exempt bonds (5-7%)		Tax-exempt bonds (5-7%)	
Local				
Private	Gifts		Endowments	
			Gifts	
			Fundraising	

SOURCE: Resource Planning Associates, Inc.

the amount of land needed and are willing to use it for solar collectors. State hospitals may also have sufficient land. Public-administration buildings, however, rarely have sufficient acreage.

LOCAL DECISION-MAKING PROCESS

Local governments build, fund, and exercise control over the construction of hospitals, primary and secondary schools, colleges, public-administration buildings, and airports. Although thousands of local governing units (e.g., city governments, school districts, special districts) are currently operating in the United States, the vast majority seems to follow a similar decision process in selecting an energy system for a major construction project. The following major decision-makers participate in the process (see Exhibit I.d).

- Local electorate. The local electorate must generally approve the construction-financing of a major institutional facility. By issuing general-obligation bonds, a local government can borrow money from investors in exchange for tax-free interest. Because bonds commit future taxpayers to repay the loan, their issue is strictly controlled by law, and must have voter approval in most states. Neither the voters nor the local electorate, however, play a role in the selection of an energy system.
- State agency. A number of states require that a state agency approve investments in local institutional facilities. Most such approvals, however, have little effect on the selection of an energy system.
- Local governing body. The local governing body approves investments for institutional facilities, generally relying on the technical recommendations of a facility administrator and/or architect/engineers.
- Facility administrator. The facility administrator develops the specific program requirements for a building, generally relying on the technical recommendations of the community's facility engineer or architect/engineers. The administrator presents and supports these recommendations to the local governing body.

Exhibit I.d
Local Decision-Making Process

SOURCE: Resource Planning Associates, Inc.

Legend:

- Actively evaluates and selects energy-system alternatives
- Approves energy-system choice

- Facility engineer. In larger communities with a sufficient budget to hire specialized staff, the facility engineer plays the major role in selecting an energy system, based on an evaluation of proposals submitted by architect/engineers.
- Architect/engineers. These private professionals are usually hired on a project basis to present detailed proposals for energy systems to the facility engineer or facility administrator, who then determines which systems to recommend to the local governing body.

In recent years, numerous local bond issues have failed as a result of voter resistance to higher taxes, communities' legal inability to support additional debt, or the bond market's demand for more interest than could legally be paid. Many local governing bodies, particularly school districts, have consequently begun to lease needed space. As a result, local governments have no input into the type of energy system installed in the buildings they occupy.

The criteria that local institutions use to evaluate the ROI generated by alternative energy systems vary by locality. In general, local institutions perform payback analysis, but with shorter payback periods than are used at the state level.

A few local institutional facilities use life-cycle costing, primarily when required by the state. For example, the state of Florida requires that local school districts perform life-cycle cost analysis using a 12-percent discount rate.

The sources and costs of capital funds for local governing bodies vary widely by institutional subsector (see Exhibit I.e).

- Local hospitals receive funds primarily through tax-exempt bonds and federal loan guarantee programs.
- Primary and secondary schools receive federal aid from only one federal program: the Department of Health, Education and Welfare's Aid to Federally Affected Areas program. School districts where growing student population includes children of federal

Exhibit I.e

**Sources and Costs of Capital Funds
for Local Institutions**
(expressed as an interest rate)

Funding Source	Institutional Subsector				Public Administration
	Hospitals	Airports	Colleges	Schools	
Federal	Hill-Burton Loan Guarantees (8%)	Airport Development Aid Program	National Educational Facilities Act	HEW's Aid to Federally Affected Areas	
	HUD (FHA) Section 242) Loan Guarantee (8%)		College Housing Act		
State	Appropriation		Appropriation	Appropriation	
			Tax-exempt bonds (5-7%)	Tax-exempt bonds (5-7%)	
Local	Accumulated funds	Accumulated funds	Accumulated funds	Accumulated funds	Accumulated funds
	Tax-exempt bonds (5-7%)	Tax-exempt bonds (5-7%)	Tax-exempt bonds (5-7%)	Tax-exempt bonds (5-7%)	Tax-exempt bonds (5-7%).
Private	Gifts				

SOURCE: Resource Planning Associates, Inc.

employees, military personnel, or families living on federal lands may qualify for grants-in-aid for new school construction. In 26 states, grant programs provide outright gifts for school construction; in 14 states, loan programs enable local governing bodies to borrow money from the state at low interest rates. School districts may also accumulate funds in a special fund or issue tax-exempt bonds for school construction. The average net interest cost for school bonds in 1975 was 6.27 percent.

- Local community colleges raise the majority of their capital funds by levying additional local property taxes. They also receive substantial aid through state appropriations; in some states, tax-exempt state bonds are available. However, the two major federal programs that have traditionally provided funds are currently all but depleted.
- Public-administration buildings obtain funds primarily by issuing bonds or from local taxes.
- Local airports receive FAA funds under the Airport Development Aid Program. These funds cover up to 50 percent of capital costs for non-revenue producing areas in terminal buildings. The remainder of airport funds come from state appropriations and bonds.

As noted, the availability of land is more a function of the type of institution and its location (i.e., urban, suburban, or rural) than of the level of governmental control. Most states however, recommend that new primary and secondary schools be built on large amounts of land. For example, the state of Maryland recommends that an elementary school have 10 acres of land, a junior high school, 20 acres, and a high school, 30 acres. Although schools generally do not have such large amounts of land, they usually do have enough land for an STE system. Local colleges and airports also usually have the 1-5 acres needed. Hospitals and public-administration buildings generally have the least land available.

Private Decision-Making Process

Privately controlled institutions include hospitals, primary and secondary schools, colleges and universities, and airports. The decision-making process in these

institutions generally involves less bureaucracy than is involved in choosing an energy system for comparable-sized institutions in the public sector.

The major decision-makers in private institutions are technicians and business managers. The following other decision-makers participate in the process (see Exhibit I.f):

- Board of trustees. The release of funds for any major building project must be approved by the institution's board of trustees. Primarily concerned with determining whether sufficient need exists to justify the investment, and whether sufficient funds are available or can be raised, the trustees do not become involved with details related to the choice of an energy system, but tend to accept the administrator's recommendations.
- Administrator. Responsible for ensuring that construction is completed satisfactorily, the administrator establishes the need for a building and formulates a general plan to meet space requirements. The administrator relies on the recommendations of the business manager regarding the choice of an energy system.
- Business manager. The business manager coordinates and evaluates proposed alternatives for building projects, working closely with the facility engineer and the architect/engineers retained to perform detailed planning. The business manager's primary concern is whether or not the energy system proposed is economically sound. Based on an economic analysis, the business manager presents a recommendation to the administrator.
- Facility engineer. The facility engineer's role is to evaluate the technical proposals submitted by architect/engineers. Once assured that a proposed energy system is reliable, the engineer presents a recommendation to the business manager.
- Architect/engineers. Almost all private institutions hire architect/engineers to prepare building designs, which are then evaluated by the facility engineer for technical reliability and the business manager for economic feasibility. Architect/engineers usually include a recommended energy system in the building designs they prepare.

Exhibit I.f
Private Decision-Making Process

SOURCE: Resource Planning Associates, Inc.

Legend:

-
- Actively evaluates and selects energy-system alternatives
 - Approves energy-system choice

With few exceptions, private institutions do not use sophisticated investment criteria for deciding among alternative energy systems. Hospitals and schools generally base their investment decisions on subjective criteria; that is, if the facility is needed and funds are available or can be raised, it will be purchased or built without further analysis. When objective criteria are employed, hospitals rely primarily on the payback method, using a payback period of 5-10 years. As private hospitals may receive a fee or profit based on a percentage of their operating costs, they have little incentive to incur higher initial costs (as would be required for an STE system) to save future operating costs.

Colleges and universities tend to be more concerned with the cost of a system over time, and therefore generally rely on simple payback analysis, using a payback period of 5-10 years and fuel-price increases of 5-15 percent annually. Private colleges and universities seem to be more innovative and flexible in their choice of an energy system than are public colleges and universities. This flexibility is probably largely attributable to their more streamlined decision-making process.

Airports typically are the most sophisticated in their investment analyses, primarily because of the detailed financial analyses performed before they approach the capital market for funds. Although their criteria vary depending on their capital structure, a 10-percent real rate of return is a reasonable estimate.

Private institutions generally obtain funds from private sources (see Exhibit I.g). Nonprofit hospitals receive construction funds from federal sources: the Hill-Burton loan guarantee and subsidy program and an FHA mortgage guarantee program. These hospitals also receive a significant portion of their funds through tax-exempt bonds and accumulated earnings. Investor-owned hospitals, on the other hand, must rely on accumulated earnings, loans, and investor equity.

The cost of borrowing is generally higher for private than for public institutions. Some states (e.g., Tennessee, Louisiana), however, allow private colleges

Exhibit I.g

**Sources and Costs of Capital Funds
for Private Institutions**
(expressed as an interest rate)

Funding Source	Institutional Subsector				
	Hospitals Profit	Non-profit	Colleges and Universities	Schools	Airports
Federal		Hill-Burton Loan Guarantee and Subsidy Program (8%)	National Educational Facilities Act (3%)		Airport Development Aid Program
		FHA-242 Mortgage Insurance Program with Government National Mortgage Association Guarantee	College Housing Act (3%)		
State	Tax-exempt bonds (8-10%)	Tax-exempt bonds (5-7%)			Appropriations
					Tax exempt bonds
Local		Tax-exempt bonds (5-7%)			Tax exempt bonds
Private	Accumulated funds	Accumulated funds	Tax-exempt bonds (5-7%)	Endowments	
	Investors equity	Loans and taxable bonds (8-10%)	Endowments	Gifts	
	Loans (8-10%)		Gifts	Fund raising	
			Fund raising	Loans and taxable bonds (8-10%)	
			Loans and taxable bonds (8-10%)		

SOURCE: Resource Planning Associates, Inc.

Appendix J

CALCULATING BACKUP RATES

To determine hypothetical regional backup rates for STE systems, we assumed that an electric utility would charge an STE system owner the full, or "true," cost of providing backup service. This true cost will equal the cost increment associated with the new generation, transmission, and distribution capacity the utility must add to provide backup electricity when needed, plus operations and maintenance (O&M) and fuel costs. The true cost thus represents a combination of the long-run marginal cost of service (i.e., the incremental cost of the capital required to provide service) and the short-run marginal cost of producing the electricity (i.e., the fuel cost incurred in producing the electricity).

We have assumed that an electric utility will install gas turbines (which are generally used to meet peak demands) to handle the intermittent load associated with STE system operation in its service area. We have assumed that all those STE systems will require backup service at the same time. The rates calculated thus reflect the maximum charges likely in the worst case of synchronous failure, or no "system diversity."

We computed the following regional backup rates based on the incremental costs associated with gas-turbine peaking units, assuming no system diversity:

<u>DOE Region</u>	<u>Demand Charge (\$/kW/year)</u>	<u>Energy Charge (¢/kWh)</u>
I - New England	\$58.39	3.00
II - New York/New Jersey	62.71	2.12
III- Middle Atlantic	58.91	1.56
IV - South Atlantic	56.27	1.24
V - Midwest	69.06	1.54
VI - Southwest	50.31	1.08
VII- Central	70.33	1.14

(RPA)

and universities to issue tax-exempt bonds. Private primary and secondary schools do not benefit from any government aid for facility construction, but must rely on endowments, gifts, fund-raising, and loans.

Private colleges and universities and primary and secondary schools generally have enough land available to accommodate an STE system. Private hospitals, however, especially those that are investor-owned, rarely have enough land.

4. Annual T&D operating expenses are \$5.63/kW/year (see Exhibit J.a).
5. The heat rate is 12,000 Btu/kWh.*
6. Generating fuel costs per 10⁶ Btu** are as follows:

<u>DOE Region</u>	<u>Cost</u>
I - New England	\$2.15
II - New York/New Jersey	1.51
III - Middle Atlantic	1.08
IV - South Atlantic	0.83
V - Midwest	1.07
VI - Southwest	0.71
VII - Central	0.75
VIII - North Central	0.60
IX - West	0.99
X - Northwest	1.03

T&D loss factors were calculated by region (see Exhibit J.b). We then computed demand (kW) and energy (kWh) charges (see Exhibit J.c for an example of the methodology we used). The O&M cost of T&D facilities is 1.5 mills⁺ per kWh.

To determine whether our computation of rates was reasonable, we surveyed a sample of 21 utilities across the country for their standby rates, and compared them with the calculated demand rates (see Exhibit J.d). Although rates vary significantly by utility, the calculated rates are generally consistent with existing rates.

* The heat rate is a measure of the gross heat content of the fuel used to produce 1 kWh of electricity. Estimate provided by General Electric Company.

** DOE PIES Model, 1975 dollars.

+ 1 mill = 0.1 cents.

VIII- North Central	57.16	0.97
IX - West	76.14	1.49
X - Northwest	85.83	1.56

The following equations were used to derive these rates:

Annualized Capital Cost, per kW =

$$[(\text{incremental generation cost/kW}) (\text{capital charge rate})] +$$

$$[(\text{incremental T\&D* cost/kW}) (\text{capital charge rate})] +$$

$$[\text{T\&D operation costs/kW}].$$

Annual Fuel Costs, per kWh =

$$\text{Fuel cost/kWh} + \text{O\&M cost/kWh} =$$

$$[(\text{heat rate}) (\text{fuel cost}) (\text{loss factor})] + [\text{O\&M cost/kWh}].$$

The kW cost represents a demand charge, and the kWh cost represents an energy, or commodity, charge.

The equations were applied using the following assumptions:

1. Utilities pay about 15 percent capital charge on their equipment, which covers interest, amortization, and taxes.
2. The cost of gas turbines is approximately \$145 per installed kW capacity.**
3. T\&D costs by region are as follows (see Exhibit J.a):

<u>DOE Region</u>	<u>\$/kW/yr</u>
I - New England	\$206.72
II - New York/New Jersey	235.52
III - Middle Atlantic	210.21
IV - South Atlantic	192.60
V - Midwest	277.86
VI - Southwest	152.85
VII - Central	286.30
VIII- North Central	198.54
IX - West	325.04
X - Northwest	389.67

* Transmission and distribution.

** Cost estimate provided by Power Systems Division, General Electric Company, Schenectady, New York.

Appendix K

CALCULATING ELECTRICAL-ENERGY COSTS

To determine whether the cost of the electrical energy generated by an STE system is comparable to the cost of the electrical energy generated by a conventional utility peaking system (e.g., gas turbine), we applied the ERDA/JPL methodology¹ to a 1.21-million-square-foot college. Because total energy systems supply both thermal and electrical energy, and substitute absorption for electrical refrigeration, that methodology had to be modified to reflect the STE system's direct displacement of electrical energy and indirect displacement of electrical usage. We determined the equivalent electrical energy by subtracting the kWh the STE system draws from the grid from the kWh a conventional facility uses.

The annual cost of the energy provided comprises (1) a fixed charge for the facility's capital costs, (2) operating and maintenance costs, and (3) fossil-fuel costs. The fixed charge is generally taken as a fraction of the facility's initial capital costs, and is calculated using the formula:

$$\text{FCR} = \text{fixed-charge rate} = \left(\frac{1}{1-\tau} \right) \left(\text{CRF} - \frac{\tau}{n} \right) + B$$

$$\text{Where CRF} = \text{capital-recovery factor} = \frac{K}{1 - (1+K)^{-n}}$$

K = after-tax cost of capital

$$= (1 - \tau) K_d D + K_e E$$

τ = tax rate

K_d = debt cost

D = debt portion of total capital

K_e = equity cost

E = equity portion of capital

N = system life

B = other costs (e.g., insurance, other taxes).

1. "The Cost of Energy from Utility Owned Solar Electrical Systems," ERDA/JPL - 1012-76/3 (Jet Propulsion Laboratory, Pasadena, California, June 1976).

Typical values for utility ownership and institutional ownership are as follows:

Variable	Ownership by	
	Utility	Institution
FCR	0.0126	0.088
CRF	0.082	.086
K	0.065*	0.07*
Z	0.50	0.0
K _d	0.03*	NA
D	0.50	NA
K _e	0.10*	NA
E	0.50	NA
N	20 years	25 years
B	0.0025	0.0025

NA not applicable

* net of inflation

Fossil-fuel costs were taken from the DOE Base Case scenario. Exhibits K.a and K.b present the equivalent electrical-energy costs to a utility for thermal and photovoltaic systems in various regions of the country.

Annual operating and maintenance costs were estimated to represent 4 percent of the turbine/generator costs and 2 percent of the remaining system costs. For the systems we analyzed, these costs average 2.3 of initial capital costs.

Recognizing that STE systems deliver their energy primarily during peak periods, we compared the STE electrical-energy costs with a utility's marginal peaking costs. Peaking costs, which are usually substantially higher than average costs, are difficult to calculate. In a study of 10 utilities,²

2. S. Feldman, et al, "Utility Pricing and Solar Energy Design" (Clark University, 1976).

Exhibit K.a**Equivalent Electrical-Energy Costs
for Thermal STE Systems**

Region	Building Type	Area (10 ⁶ ft ²)	Incremental STE Capital Cost (\$10 ⁶)	Equivalent kWh Delivered (10 ⁶)	Additional Fossil-Fuel Cost (credit) (\$10 ³)	STE Electricity Cost (¢/kWh)	
						Utility	Institutional
Los Angeles	College	1.21	12.0	23.0	230.0	8.6	6.8
	College	0.22	1.6	2.2	3.1	11.1	8.2
Phoenix	College	1.21	6.8	14.0	(52.0)	7.0	5.0
Boston	College	1.21	14.5	13.0	(75.0)	16.3	11.8

SOURCE: Resource Planning Associates, Inc.

Exhibit K.b

**Equivalent Electrical-Energy Costs
for Photovoltaic STE Energy Systems**

Region	Building Type	Area (10 ⁶ ft ²)	Incremental STE Capital Cost (\$10 ³)	Equivalent kWh Delivered (10 ⁶)	Additional Fossil-Fuel Cost (\$10 ³)	STE Electricity Cost (¢/kWh)	
						Utility	Institutional
Los Angeles	Hospital	0.19	0.97	5.3	142.4	5.5	4.8
	College	1.21	10.10	37.1	780.8	6.1	5.1
Phoenix	College	1.21	8.67	33.6	962.2	6.7	5.7
Bismarck	College	1.21	7.60	19.0	394.5	8.0	6.4

SOURCE: Resource Planning Associates, Inc.

the peak marginal costs were determined to range from less than 3¢/kWh to over 21¢/kWh. Adjusted to reflect DOE Base Case 190 fuel prices, some of these costs are as follows:

<u>Utility</u>	<u>1990 On-peak Marginal Costs (¢/kWh)</u>
Los Angeles	
Water & Power	10.0
Sacramento Municipal	2.9
New England Electric	5.9
Arizona Public Service	21.4*
New Mexico Public Service	9.4

* Arizona Public Service personnel have determined that 8.6-8.9 ¢/kWh is a more realistic estimate.

Finally, the standby charges in Appendix J can be used to estimate ranges for gas-turbine peaking costs. We divided the yearly demand charge by the hours per year the unit is used (generally 500-1,500 hours), and then added the usage charge (reflecting fuel and operating expenses) to develop a range of peaking costs:

<u>DOE Region</u>	<u>Demand Charge (\$/kW/yr)</u>	<u>1990 Energy Charges* (¢/kWh)</u>	<u>Marginal 1900 Peak Electrical-Energy Costs** (¢/kWh)</u>
I	58.39	5.38	8.3 - 17.1
II	62.71	4.38	8.6 - 16.9
III	58.91	4.08	8.0 - 15.9
IV	56.27	3.67	7.4 - 14.9
V	69.06	4.08	8.7 - 17.9
VI	50.31	3.66	7.0 - 13.7
VII	70.33	4.52	9.2 - 18.6
VIII	57.16	3.67	7.5 - 15.1
IX	76.14	4.54	9.6 - 19.8
X	85.83	5.39	11.1 - 22.6

Actual costs will vary significantly from utility to utility, depending on factors such as current and projected fuel costs, customer mix, generating mix, expansion plans, regulatory climate, and climatic conditions.

The resulting STE electrical-energy costs to the utility and to the institutional user are as follows:

COSTS TO UTILITY

<u>Region</u>	<u>STE Electrical-Energy Costs (ϕ/kWh)</u>		<u>Estimated Utility Peak Electrical Costs</u>	<u>Estimated Range of Regional Peak Electrical Costs</u>
	<u>Thermal</u>	<u>Photovoltaic</u>		
Los Angeles	8.6-11.1	5.5-6.1	10.0	9.6-19.8
Phoenix	7.0	6.7	8.6-8.9	9.6-19.8

COSTS TO INSTITUTIONAL USER

<u>Region</u>	<u>STE Electrical-Energy Costs (ϕ/kWh)</u>		<u>Average 1990 Electrical-Energy Costs (ϕ/kWh)</u>
	<u>Thermal</u>	<u>Photovoltaic</u>	
Los Angeles	6.8	4.8-5.1	5.3
Phoenix	5.0	5.7	3.6

Appendix L

OPERATING THE MARKET MODEL

To estimate potential STE system sales and the resultant energy savings in the institutional market, we developed a market model that integrates data on system performance and costs, fuel prices, financial decision criteria, and land availability. This appendix presents the algorithms and equations used in each of the four steps involved in operating the model.

STEP 1: DETERMINE THE TOTAL MARKET

The estimates of current inventory and new construction we developed (see Appendix M) are read into the model for the appropriate building type and size, region, new or retrofit application, and time interval. The resulting values indicate the total market for STE systems in each institutional subsector.

STEP 2: IDENTIFY THE POTENTIAL MARKET

The potential market is defined as that portion of the total market in which STE systems are economically feasible. To determine this, we first input our estimates of our collector field size and costs* other-component

* Using the following costs developed by McDonnell-Douglas for the central-receiver system (in which the major reductions occurred in discrete steps due to major government buys):

<u>Time Period</u>	<u>System Costs (\$/ft²)</u>
1980-1985	21.00
1985-1992	13.80
1992 +	9.50

capital costs, annual operating and maintenance costs, peak and off-peak electricity demand and usage requirements, and fossil-fuel requirements for both conventional and STE systems. Yearly cash flows are then determined. Using the institutional-sector discount rates (have determined to be 7%), the flows are discounted to determine the systems' life-cycle costs. If the STE sytem's life-cycle cost is less than the conventional system's life-cycle cost, the STE system is considered economic.

The difference in life-cycle costs between the systems is highly variable, as a result of fuel-price variations within a region and discount-rates variations. The variation in life-cycle costs can be calculated using the equation:

$$\sigma_T^2 \approx \sum \left(\frac{\partial (\Delta LCC)}{\partial x_i} \sigma_{x_i} \right)^2$$

The σ_{x_i} for electricity and fossil-fuel price variations is calculated by assuming that the high and low values within a region (see Appendix C) are the ± 3 points. These are divided by their mean value, and used to multiply the difference in annual electricity or fossil-fuel costs to determine the impact on relative life-cycle costs. Differences in the discount rates, which affect the present value of the net yearly cash flow, are determined by assuming the inverse of the high and low capital-recovery factors for the high and low expected discount rates. The values actually used are:

<u>VARIABLE (Xi)</u>	<u>$\sigma/(\text{mean value})$</u>	<u>ΔLCC</u>
Electricity	0.16	Yearly electricity costs
Fossil Fuel	0.05	Yearly fossil fuel costs
Discount Rate	0.15	Yearly net cash flow

Exhibit L.a shows the potential market as a function of difference in life-cycle costs.

Next, the portion of the market in which the STE systems are economically feasible is multiplied by estimates of the portion of the market that has

Exhibit L.a

Potential Market as Function
of Difference in Life-Cycle Costs

SOURCE: Resource Planning Associates, Inc.

NOTE:

$\Delta LCC = (\text{STE system LCC}) - (\text{Conventional system LCC})$

sufficient land available and is willing to use if for STE systems:

<u>Sector</u>	<u>Percentage having sufficient land</u>
Colleges and Universities	60
Military	80
Elementary and High Schools	60
Airports	50
Prisons	80
Post offices	20
Hospitals	20
Public-administration building	20

The result represents the "potential" market.

STEP 3: CALCULATE EXPECTED SALES

The expected sales of the STE systems are determined using a diffusion model, which simulates the process by which products come into use over time.

Studies have shown that the diffusion of both new goods and technical and social innovations generally follows an s-shaped curve. The proportion of adopters of the new product starts small, then grows rapidly up to a point. The rate of growth then falls off, and the number of actual users of the product gradually approaches the number of potential users.

To simulate the diffusion process for STE systems, we used a basic and fairly general model developed by Frank Bass.¹ Bass assumed that a small number of buyers, the "innovators," are not influenced by others in making an initial purchase. Most buyers, however, are "imitators," whose probability of purchasing the new good depends on the number of persons who have already made purchases.

1. Frank M. Bass, "A New Product Growth Model for Consumer Durables," Management Science, 15, January 1969.

Bass postulated that the probability that an initial purchase will be made at time t , $P(t)$, assuming that no purchase has been made previously, is linearly related to the cumulated number of previous buyers, $Y(t)$, or:

$$P(t) = y + \frac{q}{m} Y(t)$$

where m is the total number of persons expected to purchase the product.

Base refers to p , the probability of an initial purchase, as the "coefficient of innovation." The higher p is, the more important innovators are. Similarly, q is the "coefficient of imitation." The higher q is, the faster imitators will adopt a new product once it has been used by the innovators.

The fraction of the market captured by the innovation, $F(t)$, can be derived as:

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}}$$

where t represents the period since initial sales started.

Bass shows that this model provides a generally satisfactory explanation for the growth in sales of consumer durables ranging from home freezers to steam irons. Typically, p ranges from 0.001 to 9.50, and q ranges from 0.1 to 0.7. The correlation coefficient, R^2 , which indicates the fit of the regression coefficient to the data points, is generally above 0.8 (representing a reasonable fit). The variations of actual sales from the model's predictions can often be explained by periods of recession and expansion in the economy.

We computed regression estimates of p and q from time-series data on conventional total-energy systems, heat pumps, and air-conditioning systems (see Exhibit L.b). These were derived for penetration in both the initial years of sales and the total period for which sales data are available. The coefficients were not uniformly higher or lower than those Bass estimated for consumer durables. The coefficient estimates that STE systems are most likely to exhibit are those for conventional total-energy systems and heat pumps.

Exhibit L.b

Estimates of Energy-System Diffusion Coefficients

System	Time Period	Coefficients		
		Innovator p	Imitator q	Market Size m
Conventional total-energy systems	Total (1963-1972)	0.055	0.55	477
	Initial (1962-1967)	0.029	0.65	495
Heat pumps	Total (1957-1973)	0.013	0.16	1.7×10^6
	Initial (1957-1965)	0.029	0.40	6.7×10^5
Air conditioners	Total (1952-1974)	0.001	0.048	1.5×10^8
	Initial (1948-1963)	0.0004	0.17	3.1×10^8

SOURCE: Resource Planning Associates, Inc.

To bracket the probable ranges, we used three sets of coefficients, representing optimistic, neutral, and pessimistic estimates of probable market penetration rates (see Exhibit L.c).

We multiplied the potential market by $F(t)$ to determine the area of the facility actually purchasing the STE system. Actual collector sales were then determined by multiplying the square feet of the facility purchasing the system by the collector-area/floor-area ratio determined by the system design.

STEP 4: CALCULATE ENERGY SAVINGS

Finally, we multiplied the collector sales in each subsector by the electricity and fossil-energy savings per square foot of collector (determined in the conceptual design). Electrical conventional total-energy systems and heat pumps.

Exhibit L.c

Coefficient Estimates for STE Systems

SOURCE: Resource Planning Associates, Inc.

NOTE:

Optimistic: $p = .05$; $q = .55$; years to 90-percent market penetration = 7.8.

Neutral: $p = .025$; $q = .25$; years to 90-percent market penetration = 17.8.

Pessimistic: $p = .01$; $q = .15$; years to 90-percent market penetration = 31.1.

Appendix M

PROJECTING MARKET SIZE

We developed a general methodology for projecting the size of the market for STE systems and then applied that methodology to each of the eight institutional subsectors.

GENERAL METHODOLOGY

The general methodology we followed to project the size of the market for STE systems consisted of three major steps:

1. Determining total inventory
2. Calculating energy use
3. Distributing national data by region and building size.

Determining Total Inventory

To determine total inventory, we performed three steps for each subsector (see Exhibit M.a): (1) determine current (1975) inventory; (2) projected total inventory in 1990, 2000, 2010, and 2020; and (3) estimated new construction in each forecast interval (1975-1990, 1990-2000, 2000-2010, and 2010-2020).

For most of the subsectors, current inventory was not available in square feet. To determine current inventory, we therefore first obtained the number of users of a certain building type (e.g., employees for public-administration buildings, inmates for prison, students for schools and colleges), and applied a planning factor

Exhibit M.a

Methodology for Determining Total Inventory

SOURCE: Resource Planning Associates, Inc.

of square-foot-of-space per user. The number of users of certain building types was readily available from a variety of sources, and the planning factor for each type was obtained through surveys of selected buildings in various states.

We then projected total inventory in 1990, 2000, 2010, using one of three alternative methods. The most straightforward method we employed was to obtain projections from agencies involved in a particular subsector. For example, projections provided by the U.S. Postal Service were used to estimate post-office space.

The method applicable to the greatest number of subsectors was to compare historical growth in population or employment with historical growth in the number of users of a particular building type. For those subsectors in which a correlation was identified (e.g., hospital beds were determined to be related to population growth), growth rates for population (as forecast in the Bureau of the Census' Current Population Reports¹) or employment (as forecast in the U.S. Water Resources Council's OBERS Projections²) were applied to the number of users in 1975 to obtain the number of users in each projection year. The resulting figures were then converted to square feet of space by applying the appropriate planning factor. This growth-correlation methodology was used to estimate inventory in the elementary and high schools, colleges and universities, and public-administration subsectors.

The third method used involved a combination of the growth-correlation method and historical growth in the number of users. In cases where no correlation could be identified (e.g., hospital beds per thousand, prison incarcerations per thousand), historical growth rates were assumed to be indicators of future growth. However, historical growth rates alone were not used for any sector, as we considered it unrealistic to assume that

1. U.S. Department of Commerce, Bureau of the Census, Population Estimates and Projections: Current Population Reports (1971).

2. U.S. Water Resources Council, 1972 OBERS Projections: Regional Economic Activity in the U.S. (1974).

past trends will extend for 43 years, particularly in a period when population is expected to increase at a lower rate than it has over the past 25 years.

New construction was estimated for each forecast interval based on net new demand and replacement demand in each subsector. Net new demand was defined as the increased space needed as a result of increases in the number of users. In certain subsectors, it was not appropriate to forecast net new demand for all the intervals (e.g., total enrollment in colleges is expected to decline after 1990). Replacement demand, which represents increased demand resulting from the need to replace obsolete buildings, was determined based on estimated building life (as reported by agency personnel).

As with all projections beyond a 5-10 year horizon, our projections of space in certain building types involve a substantial degree of uncertainty. We have attempted to compensate for the unavailability of data by correlating growth in most subsectors with growth in population and employment forecasts from widely accepted sources. Assuming that the correlation of building users to population or employment continues and that the Census and OBERS projections are reliable, this methodology should provide a fairly accurate estimate of inventory in the projection years. However, some of the assumptions made do not take into account a variety of possible future occurrences (e.g., technological advances, reduction in demand for air-transport services resulting from high energy costs). The square-foot planning factor contains the greatest potential for error, as changes in space allocation per user over the next 43 years cannot be predicted.

In view of the number of variables involved in projecting inventory and new construction, and the substantial range of error associated with each, our projections should not be considered definitive. Rather, they are intended only to depict the magnitude of the maximum potential market for STE systems in the various subsectors. The results of our analysis are summarized in Exhibits M.b and M.c.

Exhibit M.b

**Current and Projected Inventory
in the Institutional Subsectors**
(millions of square feet)

Subsector	1975	1990	2000	2010	2020
Elementary and high schools	4,333	4,029	4,653	5,022	5,292
Colleges and universities	2,104	2,383	2,189	2,110	2,030
Hospitals	996	926	992	1,055	1,111
Military installations	1,147	1,147	1,147	1,147	1,147
Public administration	745	1,017	1,172	1,319	1,442
Post offices	175	196	200	200	200
Prisons	93	107	115	122	128
Airports	153	224	291	375	496
Total	9,746	10,029	10,759	11,350	11,846

SOURCE: Resource Planning Associates, Inc.

Exhibit M.c

**Projected New Construction in the
Institutional Subsectors**
(millions of square feet)

Subsector	Forecast Internal			
	1975-1990	1990-2000	2000-2010	2010-2020
Elementary and high schools	1,320	1,540	1,450	1,350
Colleges and universities	677	262	262	262
Hospitals	263	287	284	278
Military installations	229	153	153	153
Public administration	495	305	295	272
Post offices	87	49	44	44
Prisons	33	20	19	18
Airports	102	87	108	137

SOURCE: Resource Planning Associates, Inc.

Exhibit M.d presents projected building inventory for the various institutional-market subsectors to the year 2020. The compounded yearly growth rate is approximately 0.4 percent per year from 1975 to 2020. Although these estimates are based on analyses of past trends and the best judgments of professionals in both the public and private sectors, it must be emphasized that many of the variables (e.g., hospital beds per thousand, educational facilities per students, and the size of our military forces) are dependent on social and political choices, which change over time and thus cannot be forecast with a high degree of accuracy.

Exhibit M.e shows the regional distribution of this inventory. The Los Angeles and Phoenix areas, which have the highest potential for STE systems, together represent about 1.4 billion square feet of facility space, or about 14 percent of the institutional-sector total.

Exhibit M.f depicts the potential annual market for STE systems. This market includes the construction of new facilities to meet rising demand or to replace obsolete buildings, and retrofit applications, which are defined as that portion of the institutional sector that required replacement or extensive renovation of major HVAC systems.

Exhibit M.g presents estimates of the distribution of institutional-sector facility sizes. Because thermal STE systems appear to be cost-effective only in facilities greater than 500,000 square feet, this implies that the major markets will be limited to colleges and military installations, which often comprise several buildings.

Calculating Energy Use

Estimates of the amount of energy used in institutional buildings were developed to provide a basis for comparing the magnitude of energy use in the institutional sector to that in other major building sectors. To assess the relative magnitude of energy use within the institutional sector, we also estimated current and projected energy use for each subsector.

Exhibit M.d

Projected Building Inventory, by Market Segment

SOURCE: Resource Planning Associates, Inc.

Exhibit M.e

Projected Building Inventory, by Region

SOURCE: Resource Planning Associates, Inc.

Exhibit M.f

Projected New and Retrofit Markets

SOURCE: Resource Planning Associates, Inc.

Exhibit M.g

Facility Size Distribution

Facility Size Range (000 ft ²)	Total Floor Space (10 ⁶ ft ²)								Total
	Schools	Colleges	Hospitals	Military Installations	Public Administration	Airports	Post Offices	Prisons	
0- 50	1,473	13	107	—	306	18	122	—	2,039 (21%)
50-100	1,603	33	120	—	97	15	12	2	1,887 (19%)
100-500	1,257	410	769	11	342	120	41	38	2,988 (31%)
500 +	—	1,643	—	1,136	—	—	—	53	2,832 (29%)
Total	4,333	2,104	996	1,147	745	153	175	93	9,746

SOURCE: Resource Planning Associates, Inc.

For the purposes of describing national energy use, the institutional sector is usually considered part of the commercial sector. Estimates of total national energy use in 1975 developed by Oak Ridge National Laboratory and the Bureau of Mines attribute 12 percent of the total 71 quads of primary energy used in the United States to the commercial sector.³ If the institutional sector is defined to consist exclusively of the eight institutional subsectors, total 1975 energy use for the institutional sector equals 2.4 quads, which represents 3.5 percent of total 1975 energy use (see Exhibit M.h). Assuming that 2.4 quads is equivalent to 412 million barrels of imported crude oil, the value of 1975 institutional energy use is roughly \$5 billion in 1975 dollars. Exhibit M.i presents actual 1975 energy use by institutional subsector.

Two methodologies were followed to calculate 1975 energy use in each of the eight institutional subsectors (see Exhibit M.j). Under the first methodology, we estimated energy used in the subsector by applying a national average energy-use-per-square-foot factor to the current inventory of building stock in the subsector. The energy-use factors applied were derived either by conducting a small survey of buildings (e.g., in the case of airports) or obtaining national average energy figures for a comparable building type (e.g., energy-use factors were derived for all office buildings and then applied to the relevant square feet of public administration office buildings). Under the second methodology, the actual total amount of energy used in the subsector was obtained from agency files.

Projections of energy use were developed in two stages. We first calculated energy use for the 1975 inventory still in use in the projection year by applying the same energy-use-per-square-foot factor used to estimate total 1975 energy use. We then calculated energy use for buildings constructed after 1975 by adjusting the 1975 figures to reflect design changes required by the energy-efficient building codes currently being adopted

3. U.S. Department of the Interior, Bureau of Mines, Energy Perspectives 2 (June 1975), and Oak Ridge National Laboratory (unpublished data).

Exhibit M.h

Total National Primary Energy Use* (1975)

SOURCE: Bureau of Mines, Oak Ridge National Laboratory
Total national energy use = 72 Quads

*Electrical energy distributed to consuming sectors.

Exhibit M.i

Energy Use in the Institutional Sector (1975)

SOURCE: Resource Planning Associates, Inc.

Exhibit M.j

Methodology for Estimating Energy Use

in most states in compliance with the Energy Policy and Conservation Act of 1975. Total energy projections for each of the institutional subsectors (see Exhibit M.k) represent the sum of the energy use calculated in these two stages.

Distributing National Data
by Region and Building Size

Our final step in estimating market size was to distribute the national data for total inventory and new construction among the 12 climatic regions by building size (see Exhibit M.l). First, we distributed the national figures among the regions based on the measure (e.g., square feet, enrollment, beds) most appropriate for each subsector. Because most of the data were available by state, the quantities for each state were allocated among the appropriate regions according to the percent of a state's total 1970 population in each region (see Exhibit M.m), which was calculated by summing the populations of the BEA areas in each state. Where BEA areas cross state lines, the BEA areas were allocated among states based on the populations in the counties within each BEA area. The percent of the measured quantity was then applied to the national inventory to yield the inventory in each region.

The projections of total inventory and new construction were then disaggregated by region. In sectors where demand is a direct function of population (e.g., hospitals), the projections were disaggregated according to the projected percent of the continental U.S. population in each region. The percentages used were obtained by summing the projected populations of the BEA areas contained in each region (the 12 climatic regions follow BEA area boundaries) according to the 1972 OBERS projections (see Exhibit M.n).

In cases where demand is a function of a portion of the population (e.g., demand for elementary and high schools is a function of the school-age population), an adjustment factor reflecting the historical percent of the region in that population class was applied to the percent of total population. In sectors where the

Exhibit M.k

Current and Projected* Energy Use

SOURCE: Resource Planning Associates, Inc.

* Projections assume the adoption of energy-conserving designs in new buildings.

Exhibit M.I

Methodology for Projecting Market Size

Percent of State's Population in Each Region

SOURCE: Resource Planning Associates, Inc.

Exhibit M.n

**Percent of Continental U.S. Population
in Each Region (1970-2020)**

Region	1970	1975	1980	1990	2000	2010	2020	Compounded Yearly Population Growth Rate (percent)
I	30.1	29.9	29.7	29.3	29.3	29.2	29.1	0.7
II	11.7	11.8	11.9	12.1	12.2	12.3	12.4	0.9
III	8.5	8.4	8.3	8.1	8.0	7.9	7.8	0.6
IV	10.1	10.2	10.4	10.5	10.6	10.6	10.7	0.9
V	9.0	9.0	8.9	9.0	8.9	8.8	8.7	0.7
VI	4.5	4.4	4.3	4.2	4.1	4.1	4.0	0.5
VII	11.2	11.3	11.4	11.4	11.3	11.2	11.1	0.7
VIII	5.2	5.1	5.0	5.0	4.9	4.9	4.9	0.6
IX	4.2	4.2	4.1	3.9	3.0	3.8	3.7	0.5
X	2.0	1.9	1.9	1.9	1.9	1.9	1.9	0.6
XI	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.3
XII	2.1	2.4	2.6	3.0	3.3	3.6	3.9	2.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

SOURCE: Resource Planning Associates, Inc.

regional distribution does not reflect the distribution of population (e.g., public administration, airports, military bases), the projected distributions were assumed to follow the current distribution, based on the assumption that most institutional establishments are permanent.

In addition to distributing national inventory among climatic regions, we developed a building-size distribution to identify the percent of building floor space in various size ranges in each subsector. The purpose of this segmentation was to account for the different costs associated with the various sizes of STE systems.

We followed one of the three approaches in developing the building-size distributions. In some subsectors (e.g., post offices), the actual distribution of the entire building inventory was available from agency personnel. In other subsectors (e.g., prisons, public-administration buildings), we used a sample of the complete building inventory to determine a representative distribution. In others (e.g., hospitals, colleges and universities) where no size information was available, we combined the size distributions associated with other factors (e.g., beds, pupils) with square-foot-per-user factors to estimate building-size distributions.

APPLICATION OF METHODOLOGY TO INSTITUTIONAL SUBSECTORS

The following sectors present the results of our efforts to determine market size in each of the eight institutional subsectors. Our description of the specific methodology followed is supported by a detailed flow chart (Exhibit a for each subsector) delineating the data used and calculations performed in determining current (1975) inventory, energy use, and projected new construction. Each input box in the flow chart is keyed by a number referencing its source or method of derivation, which is listed on the page following the flowchart. The resulting figures for inventory, energy use, and new construction are then presented (Exhibits b and c for each subsector), and our approach to distributing the national data among the 12 climatic regions is explained.

In recognition that the economics of STE systems vary according to the size of the building in which they are installed, we also developed building-size distributions (Exhibit d for each subsector). These distributions enabled us to determine the percent of the market in each subsector that may be suited for STE systems at various levels of cost.

The eight subsectors of the institutional market are presented in the following order:

- Elementary and high schools
- Colleges and universities
- Hospitals
- Military installations
- Public-administration buildings
- Airports
- Post offices
- Prisons.

M.1. Elementary and High Schools

The elementary and high-schools subsector is defined as all public and private educational institutions that offer instruction in grades 1-12, including vocational-technical schools. Nursery schools, kindergartens, residential schools for exceptional children, sub-collegiate departments of colleges, federal schools for Indians, and federally operated schools on federal military installations are not included.

The methodology followed to project maximum market size for the elementary and high-schools subsector has three major components (see Exhibit M.1.a): 1975 inventory, projected inventory, and projected new construction. The figures for 1975 inventory were developed based on elementary and high-school enrollment and the average number of square feet of building per pupil. A similar method was used to project total inventory. The historical percentage of school-age population (i.e., 5-17 years) enrolled was applied to the projected school-age population to yield projected enrollments. These projected enrollments were then combined with a square-feet-per-pupil factor to derive total projected inventory. Projected new construction was estimated as a function of the demand resulting from increases in the school-age population and the need to replace obsolete buildings. The resulting figures for inventory, energy-use, and new construction are presented in Exhibits M.1.b and M.1.c.

The current inventory was distributed among the 12 climatic regions based on enrollment in each state. Projected inventory was distributed based on the projected percent of the total population in each region and the historical percent of that region enrolled in school (projected age distributions are not available on a regional or state basis). The same methodology was applied to distribute new construction among the regions.

To permit accurate assessment of the STE potential, a size distribution was developed for the elementary and high schools subsector (see Exhibit M.1.d). Although elementary and high school buildings vary widely in size, 71 percent are estimated to have less than 100,000 square feet of floor area.

Exhibit M.1.a

Methodology for Determining Market Size
Elementary and High Schools

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.1.b**Inventory and Energy Use
Elementary and High Schools**

Year	Inventory* (10 ⁶ /ft ²)	Energy Use (10 ¹² Btu)
1975	4,333	702
1990	4,029	550
2000	4,653	530
2010	5,022	477
2020	5,292	444

*Average annual growth rate equals 0.45 percent.

Exhibit M.1.c**New Construction
Elementary and High Schools**

Forecast Interval	New Construction (10 ⁶ ft ²)
1975-1990	1,320
1990-2000	1,540
2000-2010	1,450
2010-2020	1,350

Exhibit M.1.d**Building Size Distribution
Elementary and High Schools**

Building Size (ft ²)	Percent of Total Square Feet
0- 20,000	6
20,000- 50,000	28
50,000-100,000	37
100,000-200,000	20
200,000+	9

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods of Derivation:
Elementary and High Schools

1. U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States (1976), Table 182.
2. The estimate used was 90 square feet of building floor space per pupil (Robert Snow Means Company, Building Construction Cost Data, 1974).
3. Several sources were used to derive projected growth. First, 1975 enrollment figures and school-age population in 1975 were combined to estimate the percent of school-age children who are actually enrolled: 98 percent (Census, Statistical Abstract, Table 182). This figure was then combined with projections of school-age population (Census, Statistical Abstract, Table 3) to estimate the projected enrollment. Projected enrollment and the estimate of 90 square feet of floor space per pupil (Robert Snow Means Company, Building Construction Cost Data) yielded projected inventory.
4. Replacement demand was determined based on a 50-year building life (an RPA estimate based on discussions with school officials).
5. A building-size distribution was determined for elementary and high schools based on detailed school-enrollment data compiled for RPA by Market Data Retrieval, Inc., a textbook-marketing firm located in Westport, Connecticut, and the square-feet-per-pupil ratio of 90 square feet (Robert Snow Means Company, Building Construction Cost Data).
6. Regional distribution of national building inventory was estimated separately for current inventory and projected inventory. Current inventory was distributed based on 1975 enrollment in a region derived from state enrollments (Census, Statistical Abstract, Table 187) and the percent of each state's population in a region (see Exhibit M.m). Distributing projected inventory to each region was more complex. First, current and projected U.S. population in a region was derived from total current and projected U.S. population (U.S. Water Resources Council, 1972 OBERS Projections, IV, Table 1). The percent of total U.S. population in the region was

then combined with 1975 enrollment by region to yield the percent of the region's population that is enrolled. When combined with projected U.S. population in the region, this factor resulted in the percent of projected total U.S. enrollment in each region; that estimate was used to distribute projected inventory by region.

7. A national average of 162,000 Btu/square foot/year used to determine energy use in schools constructed prior to 1975 (Federal Energy Administration (FEA), National Survey of Public School District Energy Costs (1975) Table 3.

8. To account for the increased energy efficiency of new building designs, all projected new construction after 1975 was estimated to use only 51.8 percent of the energy per square foot that was used in previously constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs (FEA, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75 (undated), Table III-II).

M.2. Colleges and Universities

The colleges and universities subsector includes buildings owned or operated by all public and private institutions of higher education that grant degrees or offer work acceptable for degree credit (e.g., junior colleges, undergraduate institutions, graduate schools). Schools operated by the federal government (e.g., service academies) are not included.

The methodology followed to project maximum market size for the colleges and universities subsector has three major components (see Exhibit M.2.a): 1975 inventory, projected inventory, and projected new construction. Available data on the total floor space in institutions of higher education were first correlated with enrollment in these institutions. Projections of total floor space were then developed based on projected enrollment, which was derived from projections of the college-age population and the historical percent of that population enrolled in college. Projections of new construction were based on the demand resulting from expanded enrollment and the need to replace obsolete buildings. The resulting figures for inventory, energy use, and new construction are presented in Exhibits M.2.b and M.2.c.

Because the location of colleges and universities does not match the regional distribution of the population, the national data for current and projected inventory and projected new construction were distributed among the 12 climatic regions based on current enrollment in each state. Regional distributions were then developed for both projected inventory and projected new construction, as both represent separate potential markets in this subsector.

College and university buildings are usually arranged in complexes that cover a large aggregate floor area. More than 73 percent of all campuses comprise more than 600,000 square feet of building (see Exhibit M.2.d).

Exhibit M.2

Methodology for Determining Market Size
Colleges and Universities

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.2.b**Inventory and Energy Use
Colleges and Universities**

Year	Inventory* (10 ⁶ /ft ²)	Energy Use (10 ¹² Btu)
1975	2,104	604
1990	2,383	591
2000	2,189	499
2010	2,110	440
2020	2,030	380

*Average annual growth rate equals -.08 percent.

Exhibit M.2.c**New Construction
Colleges and Universities**

Forecast Interval	New Construction (10 ⁶ ft ²)
1975-1990	667
1990-2000	262
2000-2010	262
2010-2020	262

Exhibit M.2.d**Building Size Distribution
Colleges and Universities**

Building Size (ft ²)	Percent of Total Square Feet
0- 800,000	27
600,000-1,200,000	13
1,200,000-2,400,000	22
2,400,000-3,600,000	13
3,600,000-4,800,000	11
4,800,000 +	14

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods of Derivation:
Colleges and Universities

1. American Council on Education, Energy Costs and Energy Conservation Programs in Colleges and Universities 1972-73 and 1974-75 (April 1977), Table A-15.
2. U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States (1976), Table 233.
3. Projected enrollment was derived by combining projections of the college-age population with the historical percent of that population enrolled in college (Census, Statistical Abstract, Tables 3 and 233). These projections, when combined with the average square-foot-per-pupil estimate of 240 feet, resulted in projected inventory.
4. Replacement demand was determined based on an 80-year building life (an RPA estimate based on discussions with college and university officials).
5. A building-size distribution was determined for colleges and universities based on detailed college-enrollment data compiled for RPA for Market Data Retrieval, Inc., and the square-foot-per-student ratio of 240 square feet.
6. Regional distribution of current and projected national building inventory was estimated based on current enrollment in each region. Enrollment by region was calculated by combining figures for enrollment by state (Census, Statistical Abstract, Table 238) with the percent of each state's population in a region (see Exhibit M.m).
7. A national average estimate of 287,000 Btu/square foot/year was used to determine energy use in colleges and universities constructed prior to 1975 (Oak Ridge National Laboratory, unpublished data, June 1977).
8. To account for the increased energy efficiency of new building designs, all projected new construction after 1975 was estimated to use only 51.8 percent of the energy per square foot that was used in previously

constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs (FEA, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75 (undated), Table III-II).

M.3. Hospitals

All hospitals in the continental United States except military hospitals are included in the hospitals subsector; nursing homes and other special healthcare facilities are not included.

The methodology followed to project maximum market size in the hospitals subsector has three major components (see Exhibit M.3.a): 1975 inventory, projected inventory, and projected new construction. The figures for 1975 inventory were developed based on the number of hospitals and the estimated square feet per hospital. The inventory projections were developed by treating population growth as a determinant of demand for hospital beds. Projected new construction was estimated as a function of demand resulting from increased population and the need to replace obsolete buildings. The resulting figures for inventory, energy use, and new construction are presented in Exhibits M.3.b and M.3.c. The national inventory was distributed among the 12 climatic regions based on the percent of the continental United States population in each region (see Exhibit M.n.).

A size distribution of the buildings in the hospital subsector was developed from detailed enrollment data (see Exhibit M.3.d). Half of all space is in hospitals of over 200,000 square feet.

Exhibit M.3.a

Methodology for Determining Market Size Hospitals

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.3.b**Inventory and Energy Use
Hospitals**

Year	Inventory* (10 ⁶ /ft ²)	Energy Use (10 ¹² Btu)
1975	996	498
1990	926	400
2000	992	363
2010	1,055	327
2020	1,111	288

*Average annual growth rate equals 0.24 percent.

Exhibit M.3.c**New Construction
Hospitals**

Forecast Interval	New Construction (10 ⁶ ft ²)
1975-1990	263
1990-2000	287
2000-2010	284
2010-2020	278

Exhibit M.3.d**Building Size Distribution
Hospitals**

Building Size (ft ²)	Percent of Total Square Feet
0- 70,000	15
70,000-140,000	18
140,000-210,000	16
210,000-280,000	12
280,000-350,000	11
350,000 +	28

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods
of Derivation: Hospitals

1. The projected number of hospital beds was estimated from the projected U.S. population (U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States (1976), Table 3) and historical figures for beds per 1000 population (Census, Statistical Abstract, Table 125).
2. An estimate of 700 square feet was used on the average amount of building floor space per hospital bed (based on a survey of selected states conducted by ITC in August 1975).
3. Census, Statistical Abstract, Table 126.
4. An estimate of 135,000 square feet was used for the average-sized hospital.
5. Replacement demand was determined based on a 45-year building life (an RPA estimate based on discussions with hospital officials).
6. A building-size distribution was determined for hospitals based on the number of beds in the U.S. (American Hospital Association, Statistics, 1976) and the square-feet-per-bed ratio of 700 square feet (ITC survey).
7. Regional distribution of national building inventory was estimated based on the current and projected percent of continental U.S. population in each region (see Exhibit M.n).
8. A national average estimate of 500,000 Btu/square foot/year was used to determine energy use in schools constructed prior to 1975. (Oak Ridge National Laboratory, unpublished data, June 1977).
9. To account for the increased energy efficiency of new building designs, all projected new construction after 1975 was estimated to use only 51.8 percent of the energy per square foot that was used in previously constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs (FEA, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75 (undated), Table III-II).

M.4. Military Installations

The military installations subsector is defined to include all command or industrial installations owned or leased by the Army, Navy, or Air Force. Government-owned installations operated by private contractors are also included. All housing facilities are excluded.

The methodology followed to project maximum market size in the military installations subsector has two major components (see Exhibit M.4.a): 1975 inventory and projected inventory. The 1975 inventory figures were developed based on data available from the federal government, and the projected inventory figures were developed based on the projected relationship between base closures and new construction. (For the purpose of this analysis, we assumed a stable level of military activity; i.e., we did not consider possibilities such as war or severe cutback in real military spending.) New construction was calculated for this subsector based on new demand and replacement demand. The resulting figures for inventory, energy use, and new construction are presented in Exhibits M.4.b and M.4.c.

The national current inventory was distributed among the 12 climatic regions based on the locations of military bases by state. Although the distribution of military bases is likely to change by 2020, the factors affecting these shifts cannot reasonably be predicted. Accordingly, projected inventories will be assigned the same distribution as current inventory.

A building-size distribution was calculated based on an inventory of the non-housing portion of U.S. Army installations. This distribution was assumed for Navy and Air Force installations as well. Almost all (99 percent) military installations are larger than 500,000 square feet (see Exhibit M.4.d).

Exhibit M.4.a

Methodology for Determining Market Size
Military Installations

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.4.b**Inventory and Energy Use
Military Installations**

Year	Inventory 10⁶/ft²	Energy Use (10¹² Btu)
1975	1,147	300
1990	1,147	272
2000	1,147	252
2010	1,147	233
2020	1,147	214

Exhibit M.4.c**New Construction
Military Installations**

Forecast Interval	New Construction (10⁶ ft²)
1975-1990	229
1990-2000	153
2000-2010	153
2010-2020	153

Exhibit M.4.d**Building Size Distribution
Military Installations**

Building Size (ft²)	Percent of Total Square Feet
0- 500,000	1
500,000- 1,000,000	2
1,000,000- 5,000,000	35
5,000,000-10,000,000	41
10,000,000 +	21

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods of
Derivation: Military Installations

1. U.S. Water Resources Council, 1972 OBERS Projections, IV, Table 1.
2. General Services Administration (GSA), Government Building Statistics: Annual Report (June 30, 1976).
3. Replacement demand was determined based on a 75-year building life (an RPA estimate based on discussions with federal officials).
4. A building-size distribution was compiled from a 1976 inventory of the non-housing portions of U.S. Army installations (U.S. Department of the Army, Office of Chief of Engineers, Facilities Engineering: Annual Summary of Operations, 1976). Navy and Air Force installations were assumed to resemble these size patterns.
5. National inventory was regionally distributed based on the building floor space in each state (U.S. Department of Defense, State Maps of Major Military Installations and Industrial Facilities, June 1976) and the percent of a state's population in each region (see Exhibit M.m).
6. Current military inventory (GSA, Government Building Statistics) and total U.S. military energy use (as reported by Elmer Smith, Federal Energy Administration, in personal communication) were combined to determine a national average energy-use estimate of 262,000 Btu/square foot/year. This energy use figure was applied to current and projected inventory constructed prior to 1975.
7. To account for the increased energy efficiency of new building designs, all new construction after 1975 was estimated to use only 51.8 percent of the energy per square foot that was used in previously constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs (FEA, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75 (undated), Table III-II).

M.5. Public-Administration Buildings

The public-administration subsector comprises state government office buildings, federal government office buildings, and federal research and development (R&D) laboratories. Local government buildings are excluded because they encompass a wide variety of building types and energy-load profiles that cannot be meaningfully characterized (e.g., libraries, courthouses, fire stations).

The methodology followed to project maximum market size in the public-administration subsector has three major components (see Exhibit M.5.a): 1975 inventory, projected inventory, and projected new construction. The figures for 1975 state office inventory were developed based on the total number of state employees in public administration and an estimate of square-feet-per-employee. Estimates of 1975 federal building stock were obtained directly from government inventory records. Projections of federal and state office floor space were developed based on expected increases in the number of employees. New construction for the subsector was estimated as a function of new demand resulting from increases in government employees and the need to replace obsolete buildings. The resulting figures for inventory, energy use, and new construction are presented in Exhibits M.5.b and M.5.c.

The national data for state office buildings were distributed among the 12 climatic regions according to the locations of the state capitals. Federal floor space was allocated according to both present location and the percent of state's population in each region.

A size distribution for public-administration buildings (see Exhibit M.5.d) was calculated to permit accurate description of the potential market. This distribution was based exclusively on state government office buildings, but was assumed to apply to all public office buildings.

Exhibit M.5.a

**Methodology for Determining Market Size
Public-Administration Buildings.**

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.5.b**Inventory and Energy Use
Public Administration**

Year	Inventory* (10⁶/ft²)	Energy Use (10¹² Btu)
1975	745	238
1990	1,017	231
2000	1,172	222
2010	1,319	213
2020	1,442	200

*Average annual growth rate equals 1.48 percent.

Exhibit M.5.c**New Construction
Public Administration**

Forecast Interval	New Construction (10⁶ ft²)
1975-1990	495
1990-2000	305
2000-2010	295
2010-2020	272

Exhibit M.5.d**Building Size Distribution
Public Administration**

Building Size (ft²)	Percent of Total Square Feet
0- 10,000	10
10,000- 50,000	31
50,000-100,000	13
100,000-200,000	16
200,000 +	30

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods of Derivation:
Public-Administration Buildings

1. Current federal non-Department of Defense (DOD) office employment was derived from federal non-DOD employment (U.S. Department of Commerce (DOC), Bureau of the Census, Statistical Abstract of the United States (1976), Table 3) and the percent of federal non-DOE inventory used as office space (General Services Administration (GSA), Inventory Report on the Real Property Owned by the United States Throughout the World as of June 30, 1974, pp. 1376-1377).
2. Current federal office inventory was calculated from several sources. First, 1975 DOD inventory was subtracted from total 1975 federal inventory to derive 1975 non-DOD federal inventory (Census, Statistical Abstract, Table 339). Non-DOD federal inventory was then combined with the percent of federal non-DOD inventory used as office space (GSA, Inventory Report, pp. 1376-1377) to derive current federal office inventory.
3. DOC, Bureau of the Census, Public Employment in 1975 (GE-75, No. 1), Table 9.
4. Separate square-feet-per-employee estimates were used for state and local government employees. A 100-square-foot figure was used for local buildings, and a 150-square-foot figure was used for state office buildings. (These estimates were based on an RPA survey of selected states and counties.)
5. Projected federal non-DOD office employment was determined based on several factors: federal employment as a percent of total population historically (Census, Statistical Abstract, Table 3); projected continental U.S. population (Census, Statistical Abstract, Table 3); and office space as a percent of non-DOD inventory (GSA, Inventory Report, pp. 1376-1377).
6. Growth projections for state and local government employees were based on the projected earnings of state and local government employees divided by the projected earnings per worker (U.S. Water Resources Council, 1972 OBERS projections, IV, Table 1). This growth rate was then applied to the current state and local government inventory.

7. Replacement demand was determined for public-administration buildings based on a 40-year building life (an RPA estimate based on discussions with federal officials at GAS).

8. A building-size distribution was derived for public-administration buildings based on inventories of state office buildings requested from several state governments. This distribution was assumed to apply to federal and local government office buildings as well, although it appears that local buildings are generally smaller and and federal buildings are generally larger than state office buildings.

9. National inventory was distributed separately to regions for federal, state, and local buildings. To distribute federal buildings, the percent of DOD inventory in each state (Department of Defense, State Maps of Major Military Installations and Industrial Facilities, June 30, 1976) was combined with 1975 DOD office inventory (GSA, Government Building Statistics: Annual Report, 1976). This estimate was subtracted from total 1975 federal office inventory by state (GSA, Inventory Report, pp. 1376-1377) to determine 1975 non-DOD federal office inventory by state. The resulting figure was combined with the percent of each state's population in the region (see Exhibit M.m) to derive current non-DOD federal office inventory by region; this approach was used to determine regional distribution for both current and projected federal inventory. State inventory was distributed to the region in which each state capitol is located (see Exhibit M.a), and local inventory was distributed according to the amount of current inventory in each state (Census, Public Employment, Table 9) and the percent of each state's population in the region (see Exhibit M.m).

10. A national average estimate of 320,000 Btu/square foot/year was used to determine energy use in federal, state, and local government office buildings constructed prior to 1975 (Oak Ridge National Laboratory, unpublished data, June 1977).

11. To account for the increased energy efficiency of new buildings, all projected new construction after 1975 was estimated to use only 40.4 percent of the energy per square foot that was used in previously constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs (FEA, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE 90-75 (undated), Table III-II).

M.6 Airports

The airports subsector comprises all privately and publicly owned airports in the United States. Square feet of space in airports includes all terminal, cargo, and mail-handling facilities at each airport; hangar and other special-purpose areas are not included.

The methodology followed to project maximum market size for the airports subsector has three major components (see Exhibit M.6.a): 1975 inventory, projected inventory, and projected new construction. The 1975 and projected inventory figures were developed based on passenger embarkments and cargo loadings, and an estimate of square feet per ton or per passenger embarkment. The projections of passenger embarkments used were based on projected population growth rates, and the projections of cargo loadings were based on a combination of projected population growth rates and historical increases in cargo.* New construction was estimated for this subsector based on both new demand and replacement demand. The resulting figures for inventory, energy use, and new construction are presented in Exhibits M.6.b and M.6.c.

The national inventory data were distributed among the 12 climatic regions based on the location of 152 air traffic hubs. Some of these hubs comprise more than one airport (e.g., the Los Angeles hub includes Los Angeles International, Orange County, and Hollywood-Burbank airports). In total, these hubs account for 96 percent of all passenger embarkments.

A size distribution was calculated for the airport subsector based on FAA certificated airports. Almost 50 percent of total airport space is concentrated in airports over 250,000 square feet (see Exhibit M.6.d).

* The Federal Aviation Administration (FAA) projected air-traffic growth to 1988 at a compounded rate of 5 percent per year. This figure is based on optimistic assumptions regarding economic growth and new airport construction, and does not reflect recent experience.

Exhibit M.6.a

Methodology for Determining Market Size
Airports

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.6.b**Inventory and Energy Use
Airports**

Year	Inventory* (10 ⁶ /ft ²)	Energy Use (10 ¹² Btu)
1975	153	68
1990	224	77
2000	291	88
2010	379	104
2020	496	129

* Average annual growth rate equals 2.65 percent.

Exhibit M.6.c**New Construction
Airports**

Forecast Interval	New Construction (10 ⁶ ft ²)
1975-1990	102
1990-2000	87
2000-2010	108
2010-2020	137

Exhibit M.6.d**Building Size Distribution
Airports**

Building Size (ft ²)	Percent of Total Square Feet
0- 20,000	1
20,000- 50,000	11
50,000-100,000	10
100,000-260,000	31
260,000 +	47

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods
of Derivation: Airports

1. U.S. Department of Transportation, Federal Aviation Administration (FAA), Statistical Handbook of Aviation (1975), Tables 4.7, 4.8, and 4.9.
2. An estimate of 0.17 square-feet-per-passenger-embarked-per-year was used, based on FAA, Statistical Handbook, and personal communication with Edward Estep, General Services Administration (GSA).
3. FAA, Statistical Handbook, Tables 4.7, 4.8, and 4.9.
4. An estimate of 38 square feet per ton of cargo loaded per year was used, based on FAA, Statistical Handbook, and personal communication with Edward Estep, GSA.
5. Projected passenger embarkments were calculated based on projected population growth rates (U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States (1976), Table 3).
6. Projected cargo loadings were estimated (by RPA) to grow at the rate of 3 percent per year.
7. Replacement demand was calculated based on a 75-year building life (an RPA estimate based on discussions with airport officials).
8. A building-size distribution was determined for airports based on a summary of the 152 FAA hub airports, which account for 96 percent of total air traffic (Civil Aeronautics Board and Federal Aviation Administration, Airport Activity Statistics of Certified Route Air Carriers, 1976).
9. Current and projected national inventory were distributed by region, based on the location of air-traffic hubs in each state, weighted to reflect small, medium, and large airports (FAA, Statistical Handbook, Table 4.7, 4.8, and 4.9). State inventory was then distributed to regions based on population (see Exhibit M.m).
10. A national average estimate of 444,000 Btu/square foot/year was used to determine energy use in airport buildings constructed prior to 1975 (derived from Dulles International Airport, Controlling Energy Cost of Dulles International Airport: Report No. II (March 1977), and fuel-purchase reports, load profiles, and buildings inventory data supplied by the airport manager).

11. To account for the increased energy efficiency of new building designs, all projected new construction after 1975 was estimated to use only 51.8 percent of the energy per square foot that was used in previously constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs. (FEA, Energy Conservation in New Buildings Design: An Impact Assessment of ASHRAE Standard 90-75 (undated), Table III-II).

M.7 Post Offices

This subsector comprises all post offices owned or leased by the U.S. Postal Service.

The methodology for projecting maximum market size for the post-offices subsector has three major components (see Exhibit M.7.a): 1975 inventory, projected inventory, and projected new construction. The 1975 inventory figures were compiled from U.S. Postal Service records, and the projections of total stock were obtained through discussions with Postal Service personnel. New construction was estimated as a function of new demand resulting from increased population and the need to replace obsolete buildings. The resulting figures for inventory, energy use, and new construction are presented in Exhibits M.7.b and M.7.c. The national data were distributed among the 12 climatic regions according to the amount of floor space in the post offices in each state and the percent of a state's population in each region (see Exhibit M.m).

To permit accurate assessment of the potential market for STE systems, we calculated a building-size distribution for post offices (see Exhibit M.7.d). Approximately 68 percent of post office floor space is located in buildings of less than 25,000 square feet.

Exhibit M.7.a

Methodology for Determining Market Size
Post Offices

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.7.b**Inventory and Energy Use
Post Offices**

Year	Inventory* (10 ⁶ /ft ²)	Energy Use (10 ¹² Btu)
1975	175	44
1990	196	36
2000	201	30
2010	200	23
2020	200	20

*Average annual growth rate equals 0.30 percent.

Exhibit M.7.c**New Construction
Post Offices**

Forecast Interval	New Construction (10 ⁶ ft ²)
1975-1990	87
1990-2000	49
2000-2010	44
2010-2020	44

Exhibit M.7.d**Building Size Distribution
Post Offices**

Building Size (ft ²)	Percent of Total Square Feet
0- 5,000	30
5,000- 25,000	38
25,000- 50,000	9
50,000-150,000	13
150,000 +	10

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods of
Derivation: Post Offices

1. United States Postal Service (USPS), unpublished data (June 1977).
2. USPS, unpublished data (June 1977).
3. Replacement demand was determined based on a 40-year building life (an RPA estimate based on discussions with federal officials).
4. USPS, unpublished data (June 1977).
5. State data provided by USPS were combined with the percent of each state's population in a region (see Exhibit M.m) to distribute inventory regionally.
6. A national average estimate of 250,000 Btu/square foot/year was used to determine energy use in schools constructed prior to 1975 (derived from USPS unpublished data, and FEA, Federal Energy Management Program).
7. To account for the increased energy efficiency of new building designs, all projected new construction after 1975 was estimated to use only 40.4 percent of the energy per square foot that was used in previously constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs (FEA, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE 90-75 (undated), Table III-II).

M.8 Prisons

The prisons subsector includes all federal prisons and most state prisons. Road camps and forest camps are not included because they are found only in a few states, and community centers (e.g., halfway houses) are not included based on their small size and different load patterns. The prisons contain about 23 percent of all inmates in state prisons.

The methodology followed to project maximum market size for the prisons subsector has three major components (see Exhibit M.8.a): 1975 inventory, projected inventory, and projected new construction. The 1975 inventory figures represent the sum of the federal and state inventories of closed prisons and prison farms. The inventory of state prisons was projected based on historical incarceration rate and projected population. The inventory of federal prisons was projected by extending the historical growth rate in the number of federal inmates. New construction was estimated as a function of demand resulting from increased population and the need to replace obsolete facilities. The resulting figures for inventory, energy use, and new construction are presented in Exhibits M.8.b and M.8.c.

The national inventory data were distributed among the 12 climatic regions according to the square feet of prison space in each state and the percent of each state's population in the regions. The actual calculation of regional distribution will be the first output of the computerized market-penetration model.

A size distribution was calculated for the prisons subsector based on an actual size inventory of federal prisons. Approximately 92 percent of prison floor space is found in compounds greater in size than 250,000 square feet (see Exhibit M.8.d).

Exhibit M.8.a

Methodology for Determining Market Size
Prisons

SOURCE: Resource Planning Associates, Inc.

* See following page for data source or method of derivation.

Exhibit M.8.b**Inventory and Energy Use
Prisons**

Year	Inventory* (10 ⁶ /ft ²)	Energy Use (10 ¹² Btu)
1975	93	59
1990	107	57
2000	115	56
2010	122	55
2020	128	53

*Average annual growth rate equals 0.71 percent.

Exhibit M.8.c**New Construction
Prisons**

Forecast Interval	New Construction (10 ⁶ ft ²)
1975-1990	33
1990-2000	20
2000-2010	19
2010-2020	18

Exhibit M.8.d**Building Size Distribution
Prisons**

Building Size (ft ²)	Percent of Total Square Feet
0- 50,000	—
50,000- 250,000	8
250,000- 500,000	35
500,000-1,000,000	38
1,000,000 +	19

SOURCE: Resource Planning Associates, Inc.

Data Sources and Methods
of Derivation: Prisons

1. The projected growth of federal inmates was estimated from the historical incarceration rate (U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States (1976), Table 291) and projected U.S. population (Census, Statistical Abstract, Table 23).
2. U.S. Bureau of Prisons, Inventory of Real Property Owned by the United States, 1977.
3. Census, Statistical Abstract, Table 294.
4. The number of state inmates was derived from Census, Statistical Abstract, Table 294. Only state inmates in closed prisons and prisons farms were considered appropriate; those not housed in permanent prison facilities (e.g., prisoners in road camps) were excluded (Department of Justice, Census of State Correctional Facilities, No. SD-NPS-SR-1, July 1975, Table 1). This figure was combined with the average square feet per inmate for federal prisons of 514 square feet to determine current state inventory. The 514-square-foot figure was estimated from an actual inventory of federal inmates.
5. Projected growth of state inmates was determined from the historical incarceration rate (Census, Statistical Abstract, Table 291) and projected U.S. population (Census, Statistical Abstract, Table 3).
6. Replacement demand was determined for prisons based on a 75-year building life (an RPA estimate based on discussions with federal officials).
7. A building-size distribution was determined for prisons based on an actual size inventory of current federal prisons (Prisons, Inventory of Real Property, 1977). This size distribution was also assumed for state facilities.
8. Regional distribution of national inventory was estimated separately for federal and state facilities. Federal prisons were allocated to each region based on the actual federal inventory in each state (Prisons, Inventory of Real Property, 1977) and percent of a state's population in each region (see Exhibit M.m). State inventory was distributed based on the number of state inmates in each state (Census, Statistical Abstract, Table 294) and the percent of a state's population in each region (see Exhibit M.m).

9. A national average estimate of 630,000 Btu/square foot/year was used to determine energy use in prison buildings constructed prior to 1975. This estimate was based on energy use in federal prisons (Department of Justice, Summary of Form 63: Fuels Consumed by Federal Prisons, 1976).

10. To account for the increased energy efficiency of new building designs, all projected new construction after 1975 was estimated to use only 51.8 percent of the energy per square foot that was used in previously constructed buildings. This decrease in energy use is based on estimates of modified ASHRAE 90-75 designs (FEA, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE 90-75 (undated), Table III-II).

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