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January 1979

A Review of the Economics of Selected Passive and Hybrid Systems

Deborah L. Buchanan

Solar Energy Research Institute
A Division of Midwest Research Institute

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Golden, Colorado 80401

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ABSTRACT

Performance and economic information on passive and hybrid systems has been compiled as part of the solar commercial readiness activity at the Solar Energy Research Institute. This paper presents the results of selected performance simulation and cost estimate studies as well as actual cost and performance data from operating buildings. Systems representative of each major passive design concept are included: direct gain, indirect gain (thermal storage wall, thermal storage roof), and isolated gain (convective loop/thermosiphon, attached sunspace/greenhouse).

Results are presented in tables structured by major design concept. Data for simulated and actual systems are presented separately. Comparison of individual system design specifications, performance, incremental solar cost, and cost of delivered energy are made by major design concept and by simulated or actual data source. In addition, results are aggregated to derive cost and performance ranges over all data sources, by design concept and by simulated or actual system.

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SECTION 1.0

INTRODUCTION

The commercialization potential of passive solar heating has been recognized on a national level [1]. Understanding the economics of passive systems is necessary in order to remove obstacles to their widespread use. Economic information also comprises an integral part of a commercialization readiness assessment, supplementing technical and market readiness evaluations.

Economic information on passive systems has proven difficult to obtain and less information is available for hybrid than for passive systems. Initial passive solar work done at SERI included publication of generic and specific passive systems descriptions and cost and performance data available from engineering simulation and cost studies [2,3]. This database has been expanded and updated with additional information from simulation and cost studies as well as cost and performance data available from operating passive and hybrid buildings. This paper describes the methods and assumptions employed in data gathering and reports cost and performance results by generic design. System-specific information is presented in an appendix.

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SECTION 2.0

METHODS

Passive and hybrid systems information was compiled from previous solar energy conference proceedings, from other solar energy publications and from individuals and organizations involved in the design, construction and evaluation of such systems. Alternative technology organizations were consulted as well as energy commissions, scientific research organizations, builders, designers, engineers, building occupants, architectural firms, educational organizations, and economists. Data were updated and/or supplemented with additional information obtained by personal communication with authors or their associates. Information is presented for a total of 50 systems from 33 sources. The database, however, is small, and results should be regarded as tentative.

2.1 MATRIX

Information for each system is entered into a design/performance/cost matrix (see Appendix) for comparison among systems. The following descriptive information is provided for each system (where available):

- system type (direct, indirect, or isolated gain, or hybrid);
- number of glazing layers;
- type of storage;
- whether used for space heat, domestic hot water, or both;
- presence or absence of night insulation;
- building load in $Btu/ft^2/DD$;
- presence or absence of fans;
- collector area in square feet, and expressed as a percentage of heated floor area;
- estimated system lifetime;
- whether a new or retrofit system;
- type of design (tract or custom residential, commercial or institutional);
- number of locations; and
- whether simulated or actually built.

Systems having small circulating fans are included with passive systems. Hybrid systems represented are collections of active and passive collection and storage (brief descriptions of hybrid systems are given in footnotes to the data matrix). Collector areas are in most cases expressed in net figures rather than gross.

Cost and performance data presented are as follows:

- system yield, in annual millions of Btu and percent solar contribution to building load;
- total incremental capital cost;
- incremental capital cost per square foot of collector:
- dollar base year;
- operating and maintenance costs (expressed as a dollar figure, as an annual percentage of total incremental capital cost, or estimated as minimal or negligable); and
- cost of delivered energy in dollars per annual millions of Btu.

2.2 SYSTEM TYPE

Where systems are combinations of design types (e.g., a direct gain system combining other passive elements such as a thermal storage wall or a greenhouse) they are classified according to the design concept representing the largest area of the passive system. In some cases it is not possible to determine which element yields the most in terms of solar contribution. Hybrid systems are classified in one category even though they make use of all of the passive design concepts.

2.3 SIMULATED VERSUS ACTUAL

Cost and performance data presented are derived from mathematical simulation and cost estimation procedures and from actual building data. However, some structures are either under construction, not monitored, or monitored results are not available. Therefore data presented for actual systems include status of monitoring activity and performance verification. Number of systems by generic type and simulated or actual data are broken down in Table 2-1.

TABLE 2-1

	Sim.	Actual	Total
Direct Gain	6	10	16
Indirect Gain			
Thermal Storage Wall	7	8	15
Thermal Storage Roof	2	1	3
Isolated Gain			
Attached Sunspace	1	4	5
Convective Loop	2	0	2
Hybrid	0	9	9
TOTAL	18	32	50

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SECTION 3.0

RESULTS

3.1 DESIGN

In nearly all of the reported cases, systems are double-glazed. Only two systems provide domestic hot water alone. Both of these are direct gain systems. Three systems, one direct gain, one water wall and one hybrid convective loop system, provide both space heat and domestic hot water.

Less than half of the passive and hybrid systems make use of night insulation. One-third of the passive systems include small circulating fans.

Estimates of system lifetime vary widely from 10-15 years (where recycled components are employed) to 100 years or life expectancy of the building.

Most systems, both actual and simulated, are new, custom, residential passive and hybrid applications. Limited data are available for retrofit installations. Several simulation studies, however, report results for tract-type residences. In addition, data are reported for three commercial and four institutional systems.

Simulation studies generate data for a given passive system in as many as 48 different locations. All data for actual systems are based on one location per system only.

3.2 BUILDING LOAD RANGES

Building heating loads, expressed in Btu/ft^2/DD are in Table 3-1 by generic design.

TABLE 3-1

	Btu/ft^2/DD
Direct Gain	4 - 10.5
Indirect Gain	
Thermal Storage Wall	2.65 - 12.5
Thermal Storage Roof	9.36 - 12.5
Isolated Gain	
Attached Sunspace	4.31 - 21.0
Convective Loop	7 - 10
Hybrid	2.7 - 12.5

Loads for attached sunspaces vary most widely of all designs. In the indirect gain category, the building load range for the thermal storage roof design has a significantly higher lower bound than for the thermal storage wall. This may be due to the location of most thermal storage roof buildings in warmer climates where insulation requirements may be lower.

3.3 COLLECTOR AREA RANGES

Expressed as a percentage of building floor area, collector area ranges for each of the generic designs are in Table 3-2.

TABLE 3-2

Direct Gain	5 - 35%
Indirect Gain	
Thermal Storage Wall	15 - 75%
Thermal Storage Roof	38 - 100%
Isolated Gain	
Convective Loop	11 - 20%
Hybrid	9 - 25%

Thermal storage roof areas are largest and in some cases collection area is as large as floor area. Ranges for indirect gain systems vary more than for any other generic design. Data for attached sunspace systems are not available.

3.4 PERFORMANCE

System yields in annual (heating season) millions of Btu are reported by generic design and by simulated or actual system within each generic design. Actual systems are further divided into monitored and verified (M) or unmonitored (UM) systems. Results in Table 3-3 are as follows for residential systems only.

TABLE 3-3

	M Btu
Direct Gain	
simulated	14 - 121
actual, M	6.85 - 85.7
actual, UM	36 - 64.6
Indirect Gain	
Thermal Storage Wall	
simulated	.6 - 68
actual, M	10 - 95
actual, UM	53 - 80
Thermal Storage Roof	
simulated	6 - 30
actual, M	38
Isolated Gain	
Attached Sunspaces	
simulated	15 - 27
actual, UM	53 - 85
Convective Loop	
simulated	8 - 20
Hybrid	
actual, M	32 - 114
actual, UM	60 - 78

For direct gain, these yield figures include results for two domestic hot water systems and one system providing both space heat and hot water. In addition, two actual, monitored commercial installations provide 270 and 720 million Btu per heating season. One simulated institutional indirect gain system is expected to deliver 1090 million Btu annually and three distinct sections of an actual but unmonitored institutional indirect gain system should deliver from 55-195 million Btu annually. Data for only one actual thermal storage roof system are available. This system has been monitored, and this yield figure is given with confidence for heating and cooling. Limited data are available for isolated gain and hybrid systems.

System yields expressed as percent solar contribution to building heating load are in Table 3-4.

TABLE 3-4

	% Solar Contribution
Direct Gain	
simulated	26 - 95%
actual, M	35 - 100%
actual, UM	35 - 74%
Indirect Gain	
Thermal Storage Wall	
simulated	20 - 97%
actual, M	38 - 97%
actual, UM	65 - 91%
Thermal Storage Roof	
simulated	21 - 100%
actual, M	100%
Isolated Gain	
Attached Sunspace	
actual, UM	72%
Convective Loop	
simulated	33 - 61%
Hybrid	
actual, M	31 - 95%
actual, UM	59%

Actual data are available for only one thermal storage roof system and limited data are available for isolated gain and hybrid systems.

These numbers reveal that performance in delivered annual MBtu or percent solar contribution for actual systems matches or exceeds performance estimated for simulated systems (with the exception of a direct gain system supplying both space heat and hot water). Further, it was determined through personal communications that in some cases where performance was verified through solar system temperature and/or auxiliary heating system monitoring, performance exceeds previous prediction. If this is true for some actual, unmonitored systems it may help explain why performance figures for these systems are lower than for the monitored systems. However, the systems are not strictly comparable and differences in monitored and unmonitored system performance data may also be explained by design and climate variations.

3.5 COST

For most systems, operating and maintenance costs are estimated as minimal, or negligable, or as a small percentage of incremental capital cost per year, usually less than 1%.

Incremental capital costs associated with the addition of solar collection and storage elements are presented in Table 3-5 by generic design and by simulated or actual system (costs for systems still under construction, although not final, are not presented separately because their cost estimates are well within the range given for all actual systems).

TABLE 3-5

	Incremental Cost
Direct Gain	
simulated, residential	$1250 - 7560
actual, residential	$950 - 9969
actual, commercial	$8000 - 100,000
Indirect Gain	
Thermal Storage Wall	
simulated, residential	$124 - 47,930
simulated, institutional	$155,645
actual, residential	$1200 - 11,500
actual, institutional	$8600 - 22,000
Thermal Storage Roof	
simulated	$5410 - 9077
actual	$3168
Isolated Gain	
simulated	$891 - 2100
actual	$1040 - 14,160
Hybrid	
actual, residential	$3000 - 9307
actual, commercial	$10,000
actual, institutional	$18,463

3.6 COST EFFECTIVENESS

A more revealing measure than either system cost or performance (both of which often range widely by generic design) is cost of delivered energy, which is an indicator of cost effectiveness. Expressed in dollars per MBtu delivered per heating season (not over life cycle), ranges are in Table 3-6.

TABLE 3-6

	$/MBtu/yr.
Direct Gain	
simulated	$32 - 538
actual, M	$30 - 139
actual, UM	$33 - 127
Indirect Gain	
Thermal Storage Wall	
simulated	$85 - 887
actual, M	$36 - 244
actual, UM	$89 - 156
Thermal Storage Roof	
simulated	$179 - 1092
actual, M	$83
Isolated Gain	
Attached Sunspace	
simulated	$33 - 58
actual, UM	$12 - 120
Convective Loop	
simulated	$64 - 147
Hybrid	
actual, M, residential	$26 - 168
commercial	$278
actual, UM, residential	$120
institutional	$308

For direct and indirect gain systems, cost of delivered energy ranges appear more favorable for actual than for simulated systems. The very high upper bound on the simulated thermal storage roof range represents a system having no night insulation. The range for systems having night insulation is $179-469/MBtu/yr. Within the isolated gain category, cost of delivered energy ranges more widely for actual than for simulated attached sunspace designs. This range includes small, simple, low-cost and larger, custom, more expensive designs. Actual results for convective loop and simulated results for hybrid systems are not available. For hybrid systems, cost of delivered energy is much lower for residential than for commercial installations.

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SECTION 4.0

DISCUSSION

Several important factors must be kept in mind when attempting to interpret these data. The amount of data available is limited and in some cases (especially isolated gain and hybrid) results are given for very few systems. No attempt has been, or can be made to control for differences in design and climate. Passive solar is climate-, design-, and user-dependent and widely ranging cost and performance figures reflect this fact. Further, cost, performance and cost of delivered energy for each of the systems are moving targets. Separating costs associated with solar from those associated with conventional construction is not an easy task. Costs are not adjusted for location and year. Performance estimates are only as good as the techniques we have for computing them. More confidence can naturally be placed in data from actual, monitored buildings than from unmonitored or simulated systems. Variations in cost and performance may also be partly explained by the fact that some systems are optimized and others not, and that assumptions on which optimization procedures are based may vary.

The use of several systems for space heat and domestic hot water or for space heat and cooling complicates the attempt to compare systems. In addition, many systems combine direct, indirect and isolated gain elements but are classified by predominant generic design. Caution must therefore be exercised in comparing cost and performance of the various generic designs. Range differences may not be as significant as is apparent from the data reported here.

Some inaccuracy exists in incremental cost/ft^2 and collector area as percent of floor area figures due to unavailability of net collector area data for some systems. The variance in system lifetime data may be misleadingly large. Lifetime estimates range from as low as 20-30 years (or less) and some as high as 100 years and/or lifetime of building. Some of the low estimates may have been made in an attempt to conform to life cycle costing or mortgage financing time frames and may not be true estimates of system lifetime. Some engineers and designers hesitate to express system lifetime in accordance with a 20- or 30-year life cycle or mortgage period when it is felt that the system should have a much longer life.

Although it appears that the data reported here are "hard", they must be interpreted with a certain amount of flexibility. They represent state-of-the-art information and must not be regarded as absolute or as representative of all passive and hybrid systems. They reflect a maturing, progressively better understood technology for incorporating cost-effective passive and hybrid techniques into modern building, design and engineering practice.

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SECTION 5.0

SUMMARY

Design, cost and performance data have been presented for 50 passive and hybrid systems. Cost and performance for the various generic designs vary widely due to design and climate variations. The data show that performance of most actual systems matches or exceeds that of simulated systems. In some cases monitoring of actual systems has revealed that performance exceeds previous prediction. Most cost of delivered energy ranges (a measure of cost effectiveness) appear more favorable for actual than simulated systems.

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SECTION 6.0

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APPENDIX

DESICN, COST AND PERFORMANCE DATA BY SOURCE AND GENERIC TYPE

APPENDIX: DESIGN, COST AND PERFORMANCE DATA BY SOURCE AND GENERIC TYPE

DIRECT GAIN

	Design Parameters											Cost and Performance Data				
Source	# Glazing Layers	Storage	Space Heat or DHW	Night Insulation	Building Load (Btu/Ft²/DD)	Fans	Collector Area Sq. Ft. (% Floor Area)	Estimated Lifetime (Years)	New or Retrofit	Type of Design	Actual or Simulated System	Number of Locations	System Yield MBtu/yr (% Solar Contribution)	Incremental Capital $/Sq Ft (Base Year)	Incremental Capital Cost (Base Year)	Operating and Maintenance Costs	Incremental Cost ($/MBtu/Yr)
*ERCDC 1977	2	bldg. mass	both	no	n.a.	no	300 (15%)	20: DHW 30: space heat	new	tract	sim.	1	121[a] (50%)	$12.73 (1977)	$3820[a] (1977)	n.a.	$32
Golubov & Leffler 1978(2,3)	2	water tubes	DHW	yes	----	no	420 (-)	20	retro	----	sim.	1	51.66 (-)	$18 (1977)	$7560 (1977)	$20/yr	$146
Taff et al 1978(2, 3) (optimized)	var-iable	bldg. mass	space	var-iable	4 (base case)	yes	300 (18%)	20	new	n.a.	sim.	2	3-21.6 (39-55%)	$4.17 - 7.50 (1977)	$1250 - 2251 (1977)	n.a.	$104 - 538
Booz-Allen/ TEA 1977(2,3)	2	con-crete slab	space	no	7-10	no	232-371 (15-25%)	30	new	tract	sim.	8	11.4-15.8 (26-95%)	$14-22 (1977)	$4700-5990 (1977)	negligible	$313 - 450
Cole & Kinney 1978 (optimized) (2, 3)b	2	bldg. mass	space	variable	8.2 base case 3.9 well insulated case	no	variable variable to 29%)	20	new	tract	sim.	1	n.a. (n.a.)	n.a.	$4000 - 7100 (1977)	n.a.	$84 - 308
*Harris, et al 1976 (Illinois house) (optimized)	3	none	space	no	n.a.	no	122 (8%)	50	new	tract	sim.	1	14.3 (n.a.)	$16.39 (1976)	$2000 (1976)	negligible	$140
*Steel 1978 (Gannon house)	2	water in drums	space	yes	n.a.	yes	825 (n.a.)	50	new	custom	actual (under construc-tion)	1	61 (n.a.)	$7.27 (1978)	$6000 (1978)	1% of in-cremental capital cost/yr	$98
*Marier 1977 (Marier house)	2	concrete slab & bldg. mass	space	yes	6.6	no	272 (17%)	10-15[c]	new	custom	actual monitored aux.[d]	1	33 (35%)	$7.35[e] (1978)	$2000[e] (1978)	negligible	$61
*Starr & Melzer 1978a (Soldyne house)	2	concrete slab	space	no	n.a.	no	297 (n.a.)	30	new	custom	actual monitored verified	1	16.9 (90% heating 100% cooling)	$6.65[f] (1976)	$1975[f] (1976)	negligible	$117
*Starr & Melzer 1978b	1	water tanks	DHW	no	-----	no	31 (-)	20 +	new	custom bread-box	actual monitored verified	1	6.85 (45-55%DHW)	$31 (1976)	$950 (1976)	1% of in-cremental captal cost/yr	$139

DIRECT GAIN (con't)

	Design Parameters												Cost and Performance Data				
Source	# Glazing Layers	Storage	Space Heat or DHW	Night Insulation	Building Load (Btu/Ft²/DD)	Fans	Collector Area Sq. Ft. (% Floor Area)	Estimated Lifetime (Years)	New or Retrofit	Type of Design	Actual or Simulated System	Number of Locations	System Yield MBtu/yr (% Solar Contribution)	Incremental Capital $/Sq Ft (Base Year)	Incremental Capital Cost (Base Year)	Operating and Maintenance Costs	Incremental Cost ($/MBtu/Yr)
*W. & S. Nichols 1978 (Unit 4, First Village)	2	concrete and water	space	yes	6.6	no	434 (20%)	100	new	custom	actual monitored verified	1	85.7 (n.a.)	$23 (1977)	$9969 (1977)	negligible	$116
*Fraker 1978 (Geisel house)	2	water and stone	space	yes	6.1	no	684 (n.a.)	50	new	custom	actual will be monitored (this is 1st winter)	1	64.6 (74%)	$12 (1977)	$8200 (1977)	<1% of incremental capital cost/yr	$127
*Shippee 1977 (Linden house)	2	concrete slab	space	yes	5.6	no	160 (5%)	n.a.	new	custom	actual not monitored not verified	1	36 (35%)	$7.50 (1976)	$1200 (1976)	approx. 2% of incremental capital cost/yr	$33
*Shapiro 1977 (Crosley house)	2	masonry and concrete	space	yes	10.5	yes	450 (35%)	100: glazing system 8: awning fabric	new	custom	actual monitored aux. verified	1	27.3 (50%)	$5.56 ('75-'76)	$2500 ('75-'76)	<1% of incremental capital cost/yr	$91.60
*S. Keller 1978 (Plover Warehouse)	2	concrete slab & inventories	space	no	n.a.	yes	12,400 (10%)	30-40	new	commercial	actual monitored aux. verified	1	720 (95%)	$8.06 (1977)	$100,000 (1977)	negligible	$139
*B. Keller et al 1978 (Kalwall Corp. Warehouse)	2	concrete slab & inventories	space	no	7.5	yes	1750 (17.5%)	30-40	retro	commercial	actual monitored verified	1	270 (55%)	$4.57 (1977)	$8000 (1977)	negligible	$30

INDIRECT GAIN
(Thermal Storage Wall,
Thermal Storage Roof)

	Design Parameters												Cost and Performance Data				
Source	# Glazing Layers	Storage	Space Heat or DHW	Night Insulation	Building Load (Btu/Ft²/DD)	Fans	Collector Area Sq. Ft. (% Floor Area)	Estimated Lifetime (Years)	New or Retrofit	Type of Design	Actual or Simulated System	Number of Locations	System Yield MBtu/yr (% Solar Contribution)	Incremental Capital $/Sq Ft (Base Year)	Incremental Capital Cost (Base Year)	Operating and Maintenance Costs	Incremental Cost ($/MBtu/Yr)
Noll 1978 (optimized) (2,3)	variable	solid or Trombe wall 4"-20"	space	no	8	no	360-1121 (24-75%)	30	new	tract	sim.	1	(23-40) (45-80%)	$8-14 (1978)	$3057-8615 (1978)	1% of incremental capital cost/yr	$107-214
Noll, Roach & Ben-David 1978 a (2,3)	2	18" Trombe wall	space	no	9	no	10-3375 (n.a.)	30	new	tract	sim.	48	.6-68 (20-65%)	$10.75-16.61 (1978)	$124-47,930 (1978)	1% of incremental capital cost/yr	$111-887
Noll, Roach & Ben-David 1978 b[g] (optimized)	2	18" Trombe	space	yes	9	no	0-450 (0-30%)	30	new	tract	sim.	48	n.a.	$18 (1978)	n.a.	1%	$115-250
	2	18" Trombe	space	no	9	no	0-450 (0-30%)	30	new	tract	sim.	48	n.a.	$13.50 (1978)	n.a.	.5%	$123-268
	2	water	space	yes	9	no	0-450 (0-30%)	30	new	tract	sim.	48	n.a.	$16.50 (1978)	n.a.	1%	$105-228
	2	water	space	no	9	no	0-450 (0-30%)	30	new	tract	sim.	48	n.a.	$12.00 (1978)	n.a.	.5%	$120-277
Noll & Wray 1978[g] (optimized)	variable 1-3	4"-20" Trombe wall	space	none, R-5 or R-9	8.5	no	208-432 (14-29%)	30	new	tract	sim.	3	38.8-50 (n.a.)	$10-20 (1978)	$3300 - 5460 (1978)	.5 - 1%	$85-165
Booz-Allen/TEA 1977 (2, 3)	2	10" Trombe wall	space	no	7-10	no	295 (20%)	30	new	tract	sim.	3	8.9 - 13.2 (20-73%)	$8.48 - 9.33 (1977)	$2520 - 2920 (1977)	negligible	$151-324
Fraker & Glennie 1976 (2,3) (optimized)	variable	Trombe wall	space	variable	12.5	yes	640 (38%)	40	new	custom prototype	sim.	1	20.2-31.5 (62-97%)	$8-12 (1976)	$5291-7803 (1976)	n.a.	$229-262
*Fraker 1978 (Princeton School of Arch.)	2	brick & water	space	yes	10.9	yes	4278 (n.a.)	30-50	retro	institutional	sim.	1	1090 (n.a.)	$36.38 (1977)	$155,645 (1977)	<1%	$143
*Fraker 1978 (Parsons house)	2	water and concrete	space	yes	7.82	no	832 (59%)	20 (except H_2O storage tubes)	new	custom	actual (under const.)	1	53.1 (91%)	$9.44 (1977)	$7850 (1977)	<1%	$148
*Peckham 1978 (Meadows Townhouses)	3	Trombe wall	space	no	4.5-5.5	yes	146-225 (n.a.)	100	new	custom prototype	actual (under construction)	1 (4 town-houses)	55-78 (n.a.)	$40-44[h] (1978)	$5860 -[h] 9940 (1978)	minimal	$98-144

INDIRECT GAIN (con't)

Source	# Glazing Layers	Storage	Space Heat or DHW	Night Insulation	Building Load (Btu/Ft²/DD)	Fans	Collector Area Sq. Ft. (% Floor Area)	Estimated Lifetime (Years)	New or Retrofit	Type of Design	Actual or Simulated System	Number of Locations	System Yield MBtu/yr (% Solar Contribution)	Incremental Capital $/Sq Ft (Base Year)	Incremental Capital Cost (Base Year)	Operating and Maintenance Costs	Incremental Cost ($/MBtu/Yr)
Design Parameters													**Cost and Performance Data**				
*Fraker 1978 (Blairstown Center)	2	Trombe & water walls	space	yes	11.35 8.1 10.7	no	581 1738 1038 (n.a.)	50	new	institutional	actual (under const.) will be monitored	1	55 (73%) 195 (71%) 140 (65%)	$15 $13 $17 (1978)	$ 8600 22000 17400 (1978)	negligible	$156 $113 $124
*W. & S. Nichols 1978 (Unit 3, 1st Village)	2	16" Trombe wall & brick, concrete	space	no	6.8	no	337 (19%)	100	new	custom	actual not monitored	1	80 (n.a.)	$21 (1978)	$7148 (1978)	negligible	$89
*Converse 1978 (Cross School)	2	8" Trombe wall	space	no	n.a.	no	240 (n.a.)	n.a.	retro	institutional	actual monitored verified	1	33 (n.a.)	$5 (1978)	$1200 (1978)	n.a.	$36.36
*Towle 1978 (Milliken Houses)	2	Trombe wall	space	no	4.5	yes	140 (15%)	30	new	tract (low-income)	actual monitored verified	1	10 (38%)	$14 (1975)	$1950 (1975)	n.a.	$195
*Shippee 1977 (Sunearth house)	2	water in drums	both	yes	2.65	no	330 (16.5%)	n.a.	new	custom	actual monitored verified	1	27 (85%)	$20 (1977)	$6600 (1977)	1.5%	$244
*Sandia Lab 1977 (Kelbaugh House)	2	15" Trombe wall, concrete slab	space	partial	9.9	no	800 (38%)	50-100	new	custom	actual monitored verified	1	94.6[j] (84%)	$14.38 (1975)	$11,500 (1975)	negligible	$122
THERMAL STORAGE ROOF																	
Fraker & Glennie 1976 (2,3) (optimized)	variable	12" water ponds	space	yes	12.5	yes	640 (38%)	40	new	custom prototype	sim.	1	5.82 - 25.2 (21-91%)	$9.93 - $14.18 (1976)	$6356 - 9077 (1976)	n.a.	$336 - 1092
Kohler & Putnam (Booz-Allen /TEA) 1977 (2,3)	2	8" water ponds	space	yes	10	no	1500 (100%)	30	new	tract	sim.	3	13.4 - 30.3 (100%)	$3.61 - 4.19 (1977)	$5410 - 6280 (1977)	n.a.	$179 - 469
*Niles, Haggard & Hay 1976 (Atascadero House)	2	8" water ponds and concrete	space heat & cooling	yes	9.36	no	1100 (92%)	7: PVC bags 30-40: rest of system	new	custom	actual monitored verified	1	38 (100% heating & cooling)	$1.65[k] (1973)	$3168[k] (1973)	operating: negligible maintenance: n.a.	$83

ISOLATED GAIN
(Attached Sunspace/Greenhouse, Convective Loop/Thermosiphon)

		Design Parameters											Cost and Performance Data				
	Source	# Glazing Layers	Storage	Space Heat or DHW	Night Insulation	Building Load (Btu/Ft^2/DD)	Fans	Collector Area Sq. Ft. (% Floor Area)	Estimated Lifetime (Years)	New or Retrofit	Type of Design	Actual or Simulated System	Number of Locations	System Yield MBtu/yr (% Solar Contribution)	Incremental Capital $/Sq Ft (Base Year)	Incremental Capital Cost (Base Year)	Operating and Maintenance Costs	Incremental Cost ($/MBtu/Yr)
ATTACHED SUNSPACE/GREENHOUSE	Taff et al 1977 (2,3)	2	water	space	yes	n.a.	yes	98 (n.a.)	20	both	tract	sim.	12	15.27 - 26.94 (n.a.)	$9.09 (not varied with location) (1976)	$891 (not varied with location) (1976)	negligible	$33-58
	Yanda 1977 (2,3)	2	water	space	no	n.a.	no	160 variable	20	both	tract	actual not monitored	see footnote[b]	85[1] variable	$6.50[1] (1975)	$1040[1] (1975)	n.a.	$12
	*Steel 1978 (Conner House)	2	concrete and rock	space	no	n.a.	yes	368 (n.a.)	100: life of glazing system (same as house) 5-10: life of fans	new	custom	actual (under const.) not monitored	1	53 (n.a.)	$16.30 (1978)	$6,000 (1978)	<1% of incremental capital cost/year	$113
	*Fraker 1978 (Hamill Addition)	2	concrete and water	space	yes	21	no	520 (n.a.)	50	retro	custom	actual (under const) not monitored	1	74.3 (n.a.)	$12.50 (1977)	$6,500 (1977)	<1% of incremental capital cost/year	$87
	*Fraker 1978 (Jones Barn)	2	water and masonry	space	yes	variable 4.31-14.8	yes	1549 (n.a.)	50 (except fan)	retro	custom	actual not monitored	1	118 (72%)	$9.14 (1977)	$14,160 (1977)	<1% of incremental capital cost/year	$120
CONVECTIVE LOOP/THERMOSIPHON	Hurrle 1977	1	none	space	no	n.a.	no	262 (n.a.)	n.a.	retro	tract	sim.	1	15.7 (n.a.)	$3.82 (1977)	$1,000 (1977)	n.a.	$63.70
	Bocz-Allen TEA 1977 (2,3)	2	none	space	no	7-10	no	158-297 (11-20%)	30	new	tract	sim.	8	8.2-20.1 (33-61%)	$6.13-7.07 (1977)	$1,010-$2,100 (1977)	negligible	$86-$147

Source	# Glazing Layers	Storage	Space Heat or DHW	Night Insulation	Building Load (Btu/F^2/DD)	Fans	Collector Area Sq. Ft. (% Floor Area)	Estimated Lifetime (Years)	New or Retrofit	Type of Design	Actual or Simulated System	Number of Locations	System Yield MBtu/yr (% Solar Contribution)	Incremental Capital $/Sq Ft (Base Year)	Incremental Capital Cost (Base Year)	Operating and Maintenance Costs	Incremental Cost ($/MBtu/Yr)
	Design Parameters												**Cost and Performance Data**				
*Hayes 1978 (Marlboro, VT house)	variable[m]	masonry, concrete and water	space	no	4.5	yes	754 (23%)	30-40 (passive) 20 (hybrid)	new	custom	actual monitored verified	1	70 (63%)	$6.63 (1976)	$5,000 (1976)	negligible	$71
*Zwart[n] 1978 (Shankland house)	2	adobe, brick, concrete and rock	space	no	6.6	yes	500 (20%)	life of bldg. (exc. fans)	new	custom	actual monitored verified	1	114 (90-95%)	$6 (1976-1977)	$3,000 (1976-77)	minimal	$26
*Fraker[o] 1978 (Builder home)	2	water	space	yes	7.8	yes	380 (n.a.)	15-20	new	custom	actual not monitored not verified	1	77.7 (59%)	$24.50 (1977)	$9307 (1977)	2% of incremental capital cost/yr	$120
*Frerking[p] 1978 (Hull House)	2	concrete brick & rock	space	no	n.a.	yes	350 (25%)	20	new	custom	actual[q] monitored	1	37.8 (75%)	$9.83 (1977)	$3440 (1977)	negligible	$91
*Sandia Lab 1977 (Hunn house)	2	Trombe wall & rock	space	no	7.2	yes	250 (13%)	30	new	custom	actual monitored verified	1	32.4 (60%)	$18.12 (1976)	$5436[r] (1976)	negligible	$168
*W. & S. Nichols[p] 1978 (Unit 1, 1st Village)	2	rock & adobe	space	no	6.3	yes	400 (20%)	100	new	custom	actual monitored verified	1	80 (n.a.)	$17.25 (1976)	$6900 (1976)	negligible	$86
*Hunn & Jones[s] 1978 (Jones House)	1	rock	both	no	2.7	yes	532 (20%)	10-30 (depends on component)	new	custom	actual monitored partly verified	1	77.33 (84%)	$12.22 (1977)	$6500 (1977)	1-2% of incremental captial cost/year	$84
*Crowther[t] 1978 (Solar Offices)	2	bldg. mass	space	no	12.5	yes	388 (9%)	n.a.	new	commercial	actual monitored aux. verified	1	36 (31%)	$26 (1976)	$10,000 (1976)	n.a.	$278
*Banwell,[p] White & Arnold, Inc 1978 (White Mountain School)	2	rock	space	yes	n.a.	yes	2042 (n.a.)	40	new	institutional	actual monitored no results yet	1	60 (n.a.)	$9 (1978)	$18,463 (1978)	n.a.	$308

FOOTNOTES TO APPENDIX

a Cost and energy savings due to house orientation and insulation not included.

b System size optimized until 400 ft^2 area reached; then architectural constraint placed against larger sizes.

c Windows for direct gain system were recycled.

d Auxiliary heat use estimated (records not accurate) to be less than predicted by calculation.

e Estimate for current installed costs associated with solar if home were not owner-built.

f Includes $1200 cost if tile floor which may or may not be attributable to solar.

g Information obtained by personal communication with S. Noll, Los Alamos Scientific Laboratory, November-December, 1978.

h Construction delay may add 7-10% to incremental solar costs.

i Figures given for 3 district solar conditioned spaces within the Blairstown Center.

j Average gross solar gain. Fuel savings were $405 for winter of 1976-77.

k Costs associated with construction of prototype system.

l Cost is average of several New Mexico locations; yield is for Albuquerque area.

m Hybrid air collectors are double-glazed; greenhouse is single-glazed.

n Passive collection, passive and active storage.

o Greenhouse-assisted heat pump.

p Passive greenhouse with active rock storage.

q System has not been monitored through most severe part of heating season. It is anticipated that the 75% solar contribution estimated will prove conservative.

r Trombe wall with active storage has been operating in passive mode for two years. Direct gain from 140 ft^2 windows not included.

Cost of system not including active storage is $3617 ($14.47/ft^2 of collector), bringing cost of delivered energy down to $112/MBtu/yr. This, in turn, adjusts the cost of delivered energy range for actual, residential hybrid systems from $26-168/MBtu/yr to $26-120/MBtu/yr.

s Thermosiphon system with rock storage and forced-air distribution. Collector doubles as greenhouse glazing.

t Active collectors, passive direct gain with forced circulation.

* Indicates personal communication with source and/or associates.

n.a. = not available

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