DOE/NASA TECHNICAL MEMORANDUM

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COST ANALYSIS OF NEW AND RETROFIT HOT-AIR TYPE SOLAR ASSISTED HEATING SYSTEMS

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TECHNICAL MEMORANDUM

COST ANALYSIS OF NEW AND RETROFIT HOT-AIR TYPE SOLAR ASSISTED HEATING SYSTEMS

I. INTRODUCTION AND BACKGROUND

To effectively decide whether or not to install solar assisted heating (or cooling) systems into a structure, it is necessary to trade off the initial and recurring costs with projected cost savings. This analysis is called an economic analysis or "payback" analysis. It consists of two principal inputs: (a) the procurement, installation, integration, and maintenance costs, and (b) the yearly cost savings. The National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE) are installing instrumented solar assisted heating and cooling systems throughout the country to help answer some of the questions that arise in the difficult technical and economic decisions related to the desirability and the timing of conversion to solar assisted residential heating and hot water systems. The operational test sites, which are expected to yield data that can be used to project potential cost savings, are essentially "prototypes" or "engineering models" of later systems of the same type which would or could be used on a widespread basis to provide an auxiliary, augmented, or alternate source of energy for homes and commercial buildings. Since each operational test site is essentially a "one-of-a-kind" installation, its design, construction, installation, and integration costs are higher than would be expected in high rate production. These same types of systems, in quantity production, could be expected to be considerably less expensive because of (a) cost savings due to quantity buys, (b) employment of mass-production techniques, (c) design improvements and innovations directed toward lower costs, and (d) use of lower cost, newer materials and processes.

This report presents the results of a 6-month team effort which employed personnel of NASA, the University of Alabama in Huntsville's (UAH) Environmental and Energy Center, the American Institute of Architects (AIA), the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), and selected contractors and consultants. It provides preliminary cost estimates for hot-air type systems based on the first two operational test sites studied: Huntsville, Alabama, and Carlsbad, New Mexico.

Figure 1 shows a schematic of the basic type of solar domestic hot water and heating system installed in both operational test sites. Figure 2 shows the Huntsville Home Builders Association structure on Triana Boulevard in Huntsville, Alabama (a new structure). Figure 3 is a retrofit of the same type of solar hot water and heating system in a structure owned by the National Park Service near Carlsbad, New Mexico.

II. STUDY METHODOLOGY AND DEFINITIONS

The study approach for analyzing the costs of solar assisted systems based on NASA/DOE operational test sites is (a) to collect and analyze actual procurement, installation, and maintenance costs of selected operational test sites; (b) to perform production type cost estimates of these sites; and (c) to identify potential cost savings based on a cost reduction design study. Quantities of systems assumed for the production cost estimates are based on the nationally stated goal of "2.5 million solar heated homes by 1985," and it was assumed that any particular system being studied would account for 40 percent of that market.

During the cost analysis process, it became apparent that definitions were needed to distinguish between costs actually incurred in constructing the various NASA/DOE operational test sites and the costs which could be expected to be incurred if an average American homeowner were to install the same type of system at some future date. The former costs include nonrecurring costs encountered during initial design, development, and testing, while the latter are meaningful costs that could be used by a homeowner in the evaluation of whether or not a solar heating system will pay for itself in a reasonable period of time. Since the former (DDT&E) costs are available as actuals, it is desirable to use these costs as a basis for projecting the eventual cost to the average American homeowner.

To provide a correlation between the various cost categories and to identify specific content of cost estimates, it is necessary to precisely define what costs are included in each category. The cost categories exclude the cost of the backup, auxiliary, or standard heating system. All costs are in "1978 dollars" (no escalation/inflation is included).

Category I, Cost of Prototype (COP), is shown in two breakouts for the "new" system: "Actual Cost" and "Should Cost." The "Actual Cost" is the procurement, installation, and inspection cost of the prototype system hardware as installed in the operational test site as best as it can be isolated from the

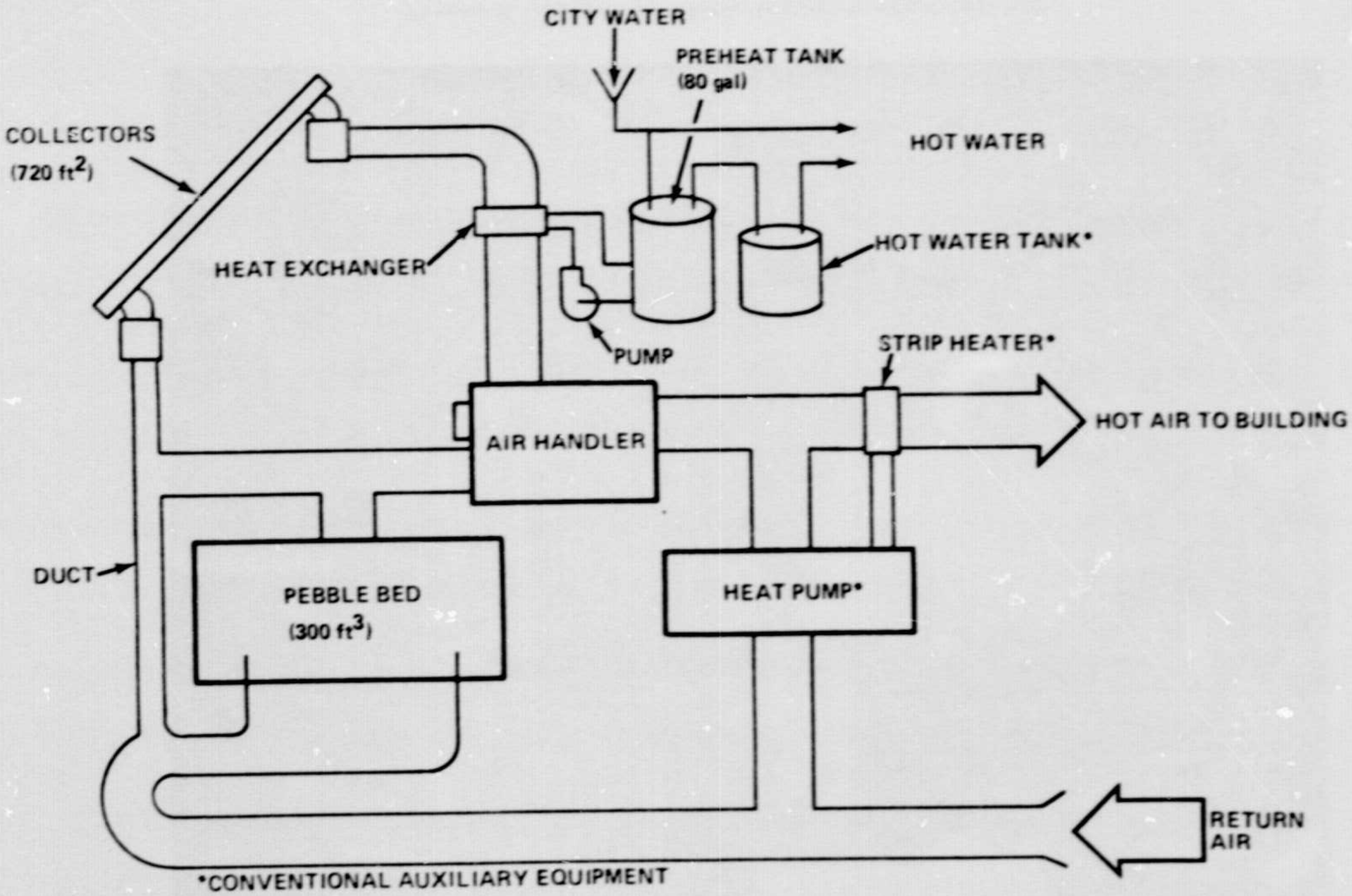


Figure 1. Solar assisted heat and domestic hot water system.

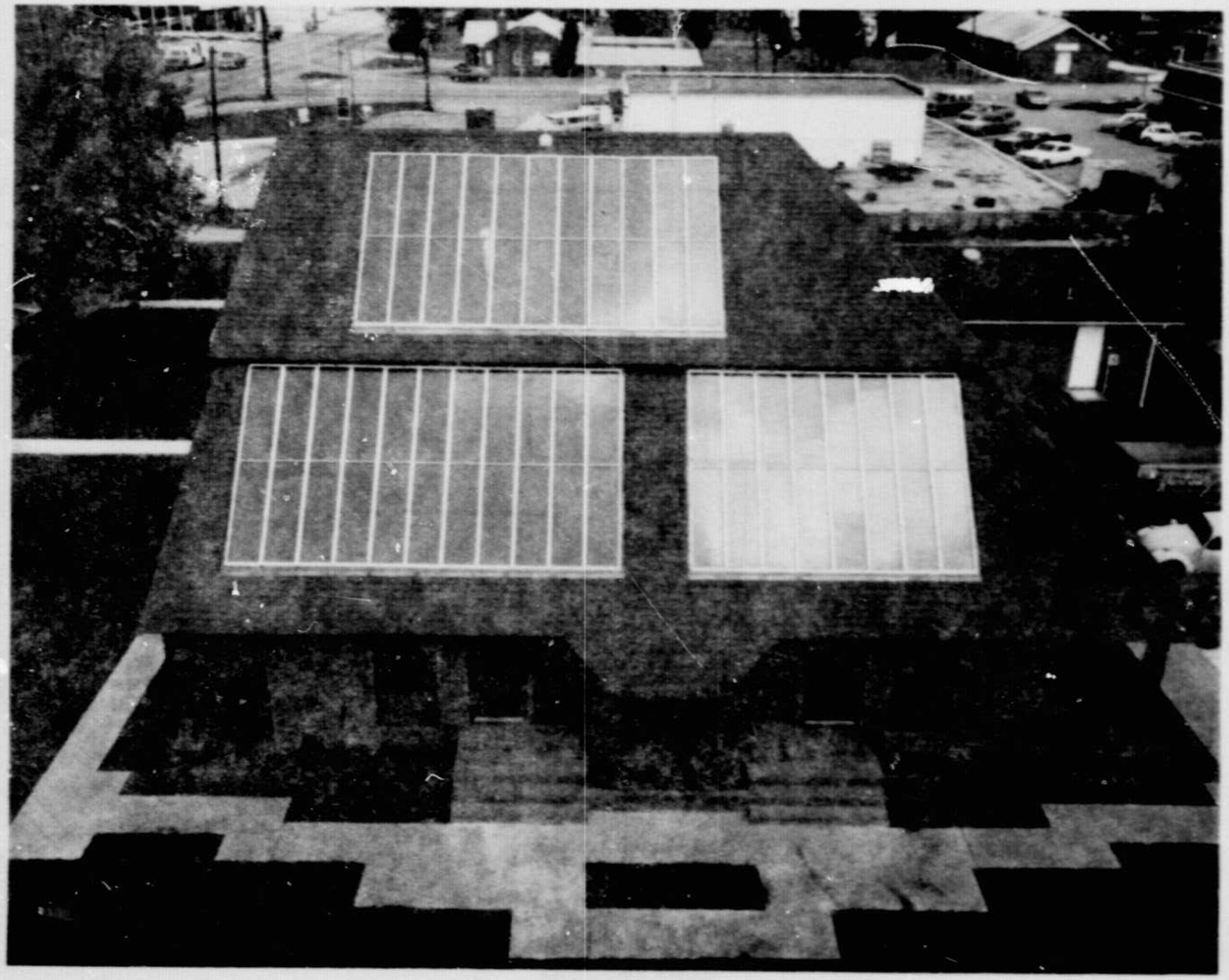
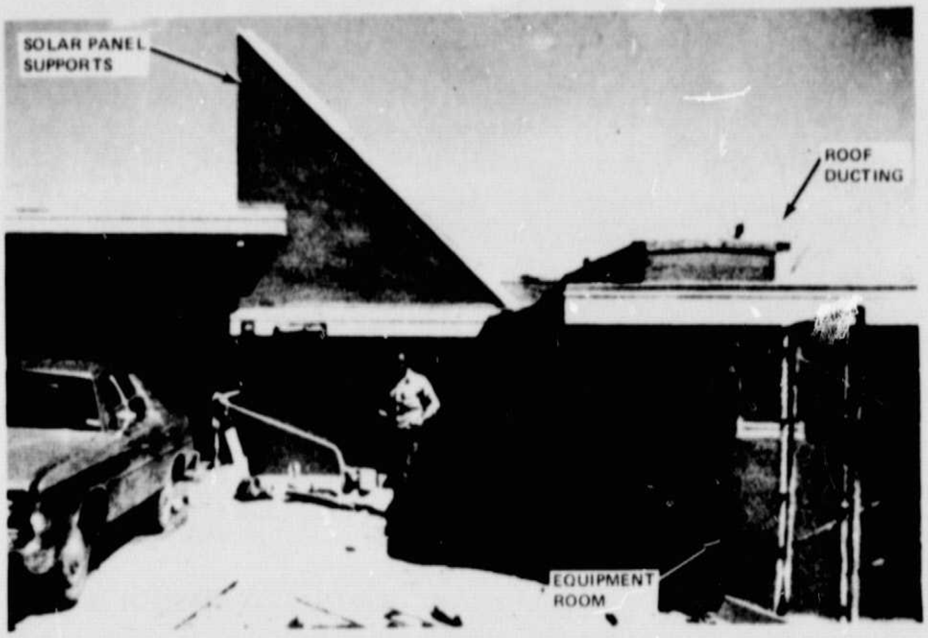
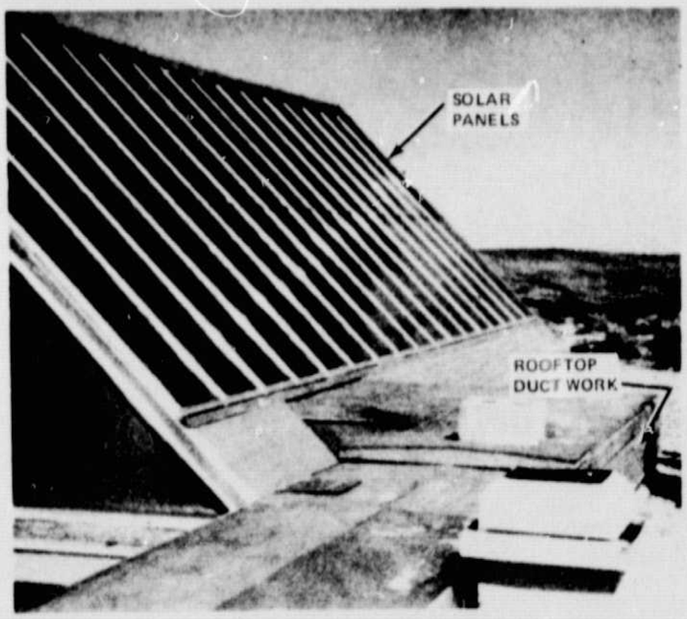


Figure 2. Huntsville Home Builders office building.

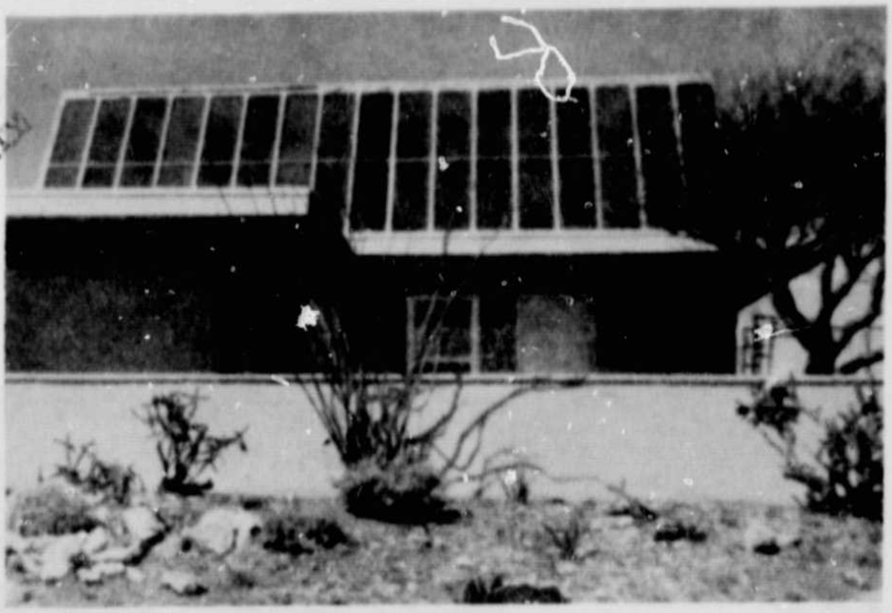


a. CARLSBAD SOLAR INSTALLATION, WEST SIDE OF CARLSBAD, NEW MEXICO, RETROFIT SOLAR INSTALLATION SHOWING NEWLY CONSTRUCTED (1) SOLAR PANEL SUPPORTS, (2) ROOF DUCTING, AND (3) EQUIPMENT ROOM.

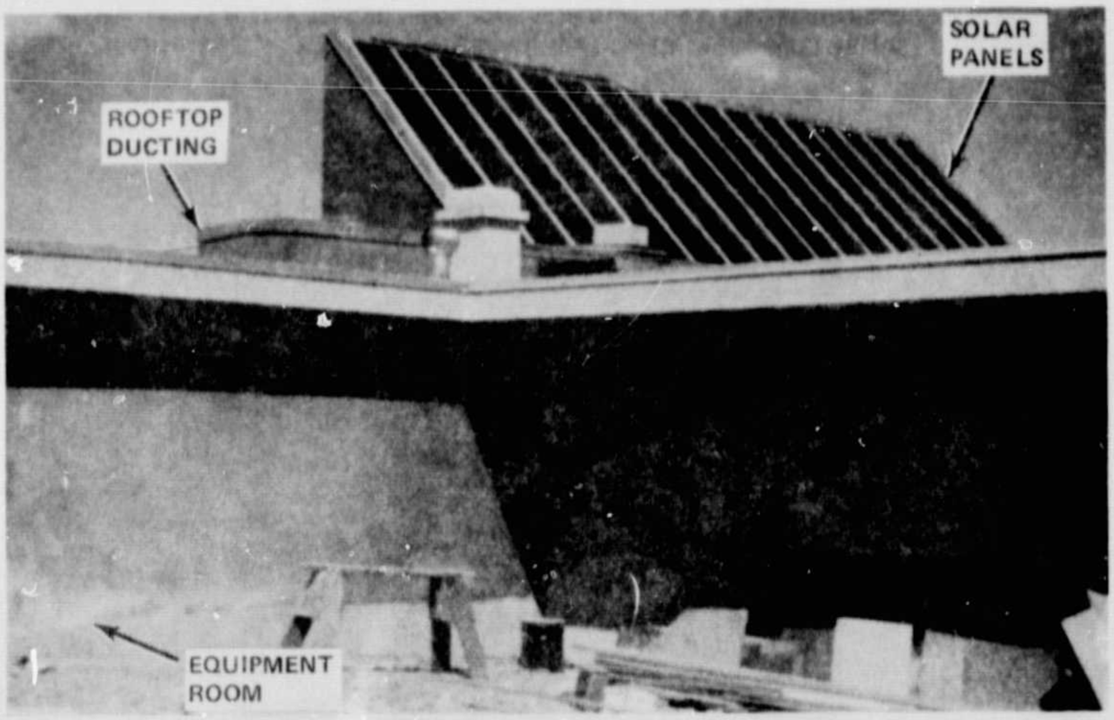


b. CARLSBAD SOLAR INSTALLATION, SOLAR PANEL AND ROOFTOP DUCTWORK.

Figure 3. Carlsbad, New Mexico retrofit installation.



c. CARLSBAD SOLAR INSTALLATION, FRONT (SOUTH) ELEVATION OF RETROFIT HOME.



d. CARLSBAD SOLAR INSTALLATION, SOUTHWEST VIEW SHOWING (1) SOLAR PANELS, (2) ROOFTOP DUCTING, AND (3) EQUIPMENT ROOM.

Figure 3. (Concluded).

total DDT&E cost. The "Should Cost" is the same procurement, installation, and inspection cost of the prototype system hardware as installed in the operational test site with actual costs and extras in the solar system as stated by the building contractor and the heating and cooling contractor.

Modifications in design to reduce cost (or learning due to high rate production) are not included in these cost numbers. The COP is merely a recorded cost figure of the actual prototype cost exclusive of instrumentation, design, consultation, architect fees, and other nonrecurring cost which would be expected to be omitted if an identical system were to be installed without the application of learning or cost improvement methods.

Category II, Mass Production Cost (MPC), is a projected cost of the prototype design if subjected to high rates of production/installation/utilization, but with no basic design changes made to achieve cost reductions (i.e., different materials or modified design of system or structure to permit factory or on-site labor reductions).

The MPC is the cost of the unmodified prototype design if produced in large quantities. The principal savings that would be expected would be due to (a) quantity-buys of materials, (b) learning of installation crews, and (c) mass production of components.

Category III, Mass Production-Improved Design (MPID), costs are defined as the costs in production of a modified, product-improved, production-engineered design. This cost would take into account cost reductions brought about by using different materials, construction methods, and design techniques to produce essentially the same system. This cost would include, for example, the types of innovations derived or disclosed from the current UAH/ASHRAE/AIA cost reduction study. The design and operation of the system would be the same as the prototype (operational test site), but cost reductions would be brought about by increased quantity production/utilization as well as by design innovations. (Design innovations are limited to subsystems improvements and specifically exclude total system concept changes.)

Category IV, Average American Home (AAH), is the cost equivalent which could be expected to be incurred by the average American homeowner at production/installation rates expected in 1985 if he were to install the type of system used in a specific operational test site. This cost includes considerations such as:

a) Deletion of special costs which have been incurred due to unconventional design.

b) Utilization in the more conventional type home construction.

c) Consideration of more optimum conditions such as location, orientation, and "do-it-yourself" aspects, and installation by a small general contractor.

d) Sizing of the system for the average size home. Reduced square footage (approximately 1500 ft^2 per home) is assumed by 1985 because:

1) Construction costs (nonrecurring costs) continue to increase

2) Cost of energy (recurring costs) continues to rise

3) Average family sizes are decreasing due to lower birth rates and longer life spans.

Category V, Innovative Design Concepts (IDC), is included to define reduced costs which may be encountered or made possible by innovative and imaginative design or construction concepts that (a) use the basic home structure as part of the collector, air transport, or storage systems; (b) employ "core modules" that can be mass produced and installed on site prior to construction of the home; and (c) rely upon auxiliary units installed externally to an existing or new home. Examples of these concepts are shown in Figures 4, 5, and 6, respectively.

These low cost design concepts were derived during the course of the study. Each of these concepts promises some improvement (reduction) in initial procurement and installation costs for a high utilization rate solar market. These three concepts are described in the following paragraphs.

A. Plenum Wall/Roof Concept

The plenum wall/roof concept was conceived and is being developed further by Sizemore and Associates, Architects, in Atlanta, Georgia, under overall cognizance of the American Institute of Architects. It involves the use of the basic home framing structure for transmitting and distributing the heated air. The roof framing (rafters) forms a plenum for holding the glass collector panels and for returning solar heated air to similarly constructed wall plenum chambers which replace the conventional ductwork needed in a hot-air type solar assisted system. Manifolding is completely eliminated since it is an integral part of the framing structure, and heat is transmitted at the periphery of the building where it can be effectively used for radiation heating or vented into selected rooms. The basic concept, along with some of its advantages and features, is shown in Figure 4.

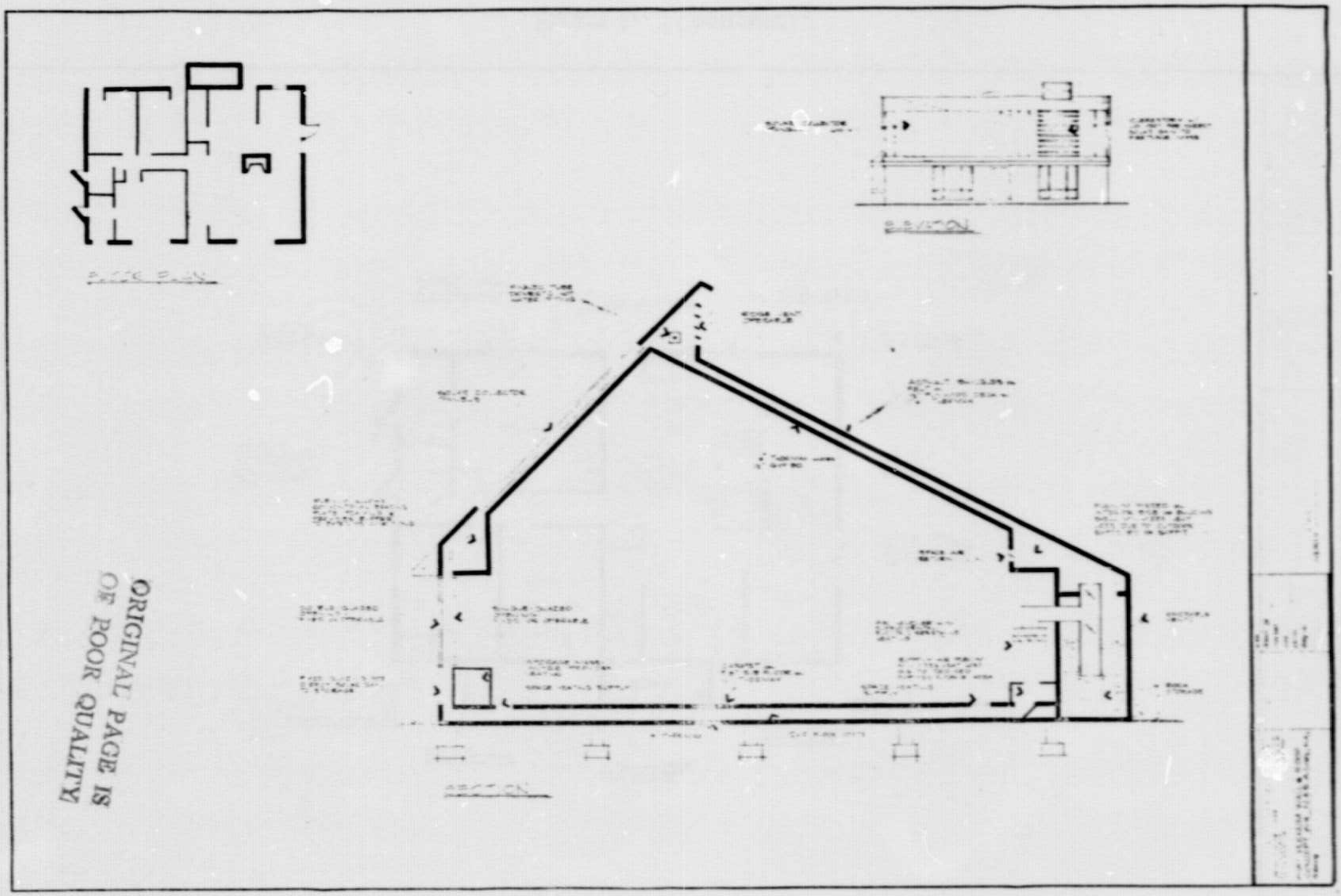


Figure 4. Plenum wall/ roof concept.

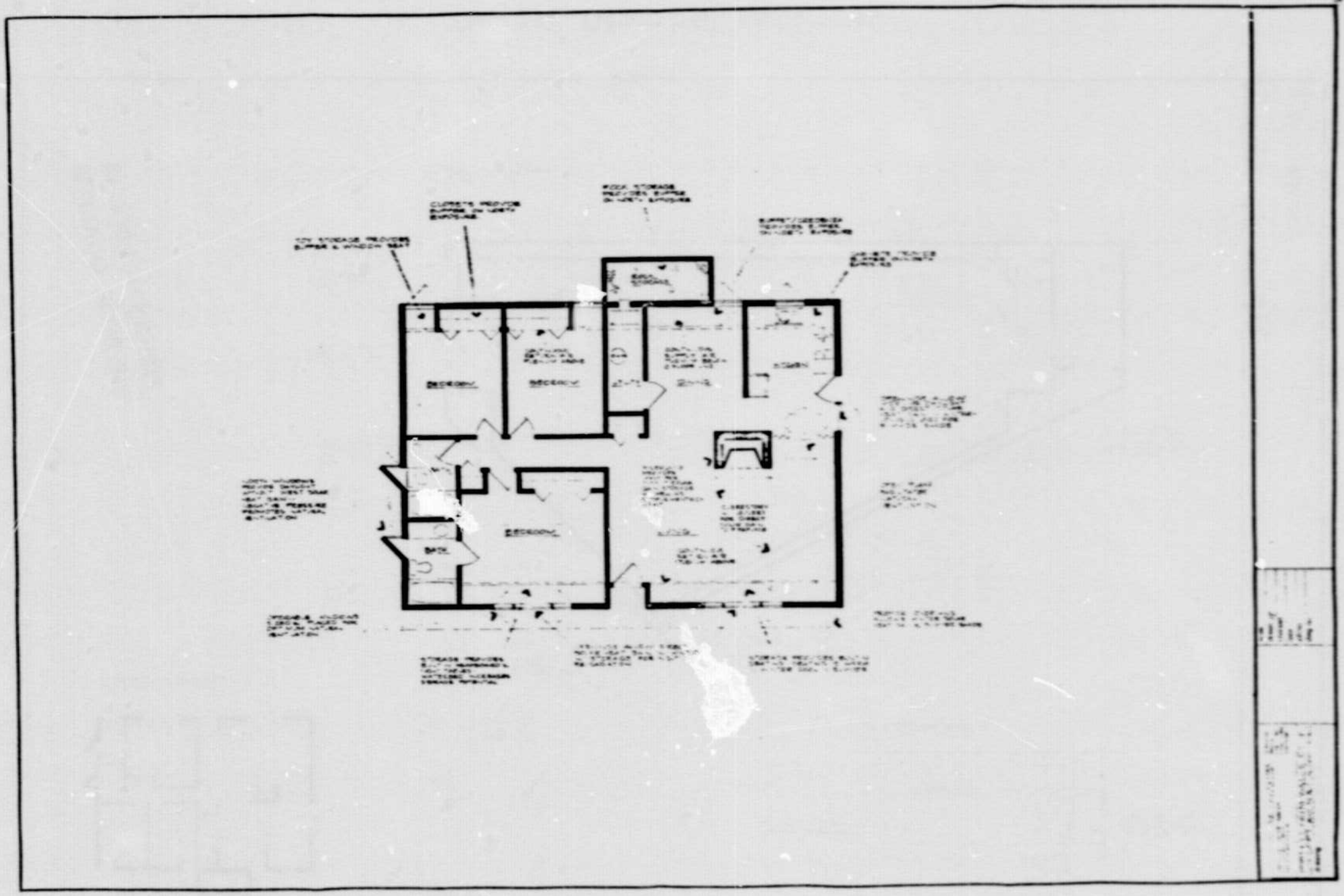


Figure 4. (Continued).

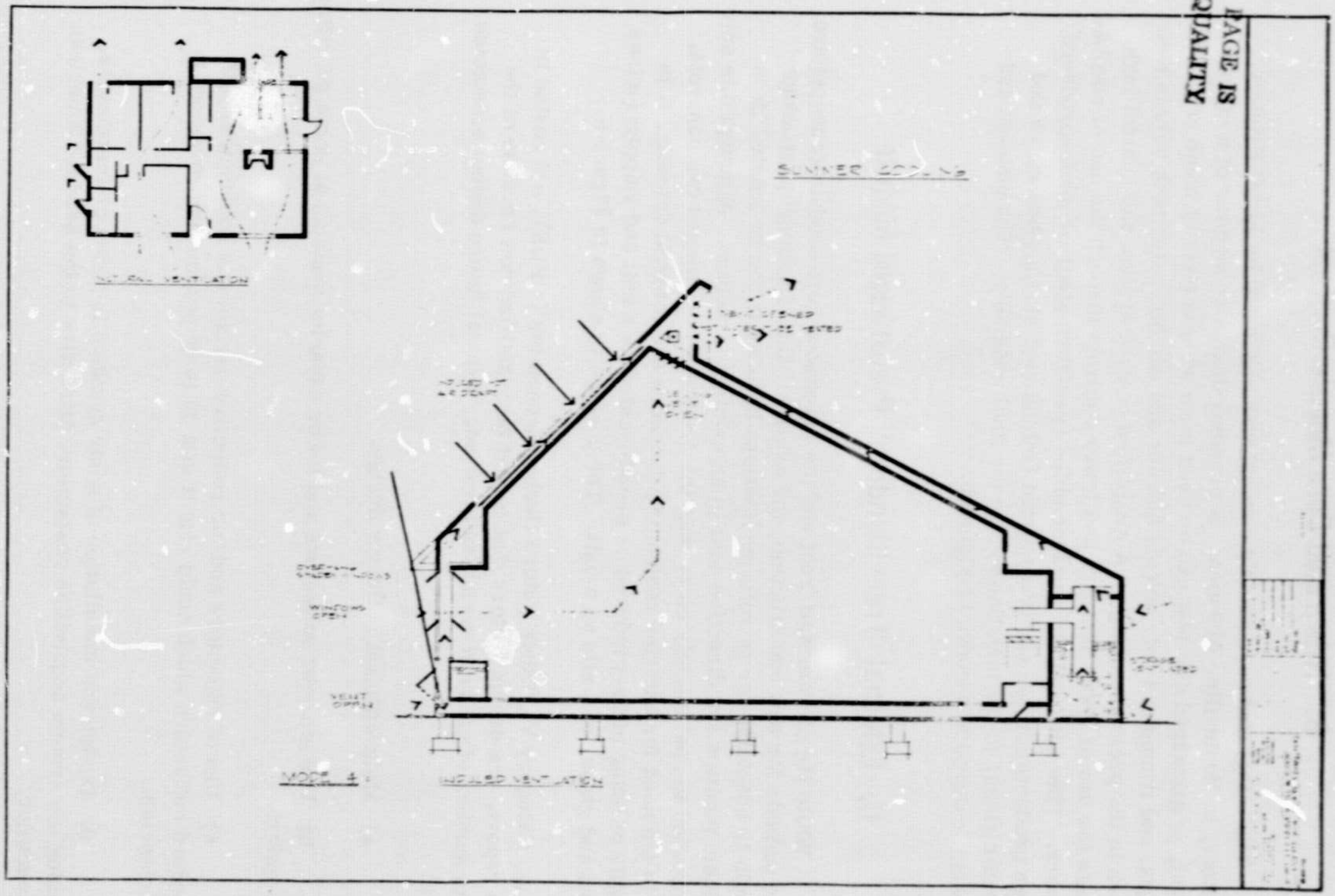


Figure 4. (Concluded).

B. Integrated Core Module Concept

The integrated core module concept was suggested by Lloyd Kranert, Architect, in Huntsville, Alabama. It provides design economies of a standardized, prepackaged unit that can be used for a wide variety of home structure designs, and it employs only one air handler and one hot water tank versus two of each in the prototype design. A simplified control system and control logic permits the use of fewer dampers and fewer controls through the use of coupled dampers. This unit could be preassembled (prefabricated) or mass-produced at high production rates and transported (minus heat storage bed rocks and collector glass) to the installation site for final assembly. The concept and its basic features are shown in Figure 5.

C. External "Free-Standing" Prepackaged Module

While the plenum wall/roof and the integrated core module concepts are most suitable for new construction, the external "full-standing" prepackaged module is adaptable for retrofit applications because it can be located in an optimum position and direction next to an existing structure. Although this unit is expected to cost slightly more than the previously mentioned two concepts, due to the need for exterior connecting ductwork and integral framing, it is capable of being mass-produced or prefabricated as a unit and shipped (minus rocks and glass) to a site as a unit. The concept is shown in Figure 6.

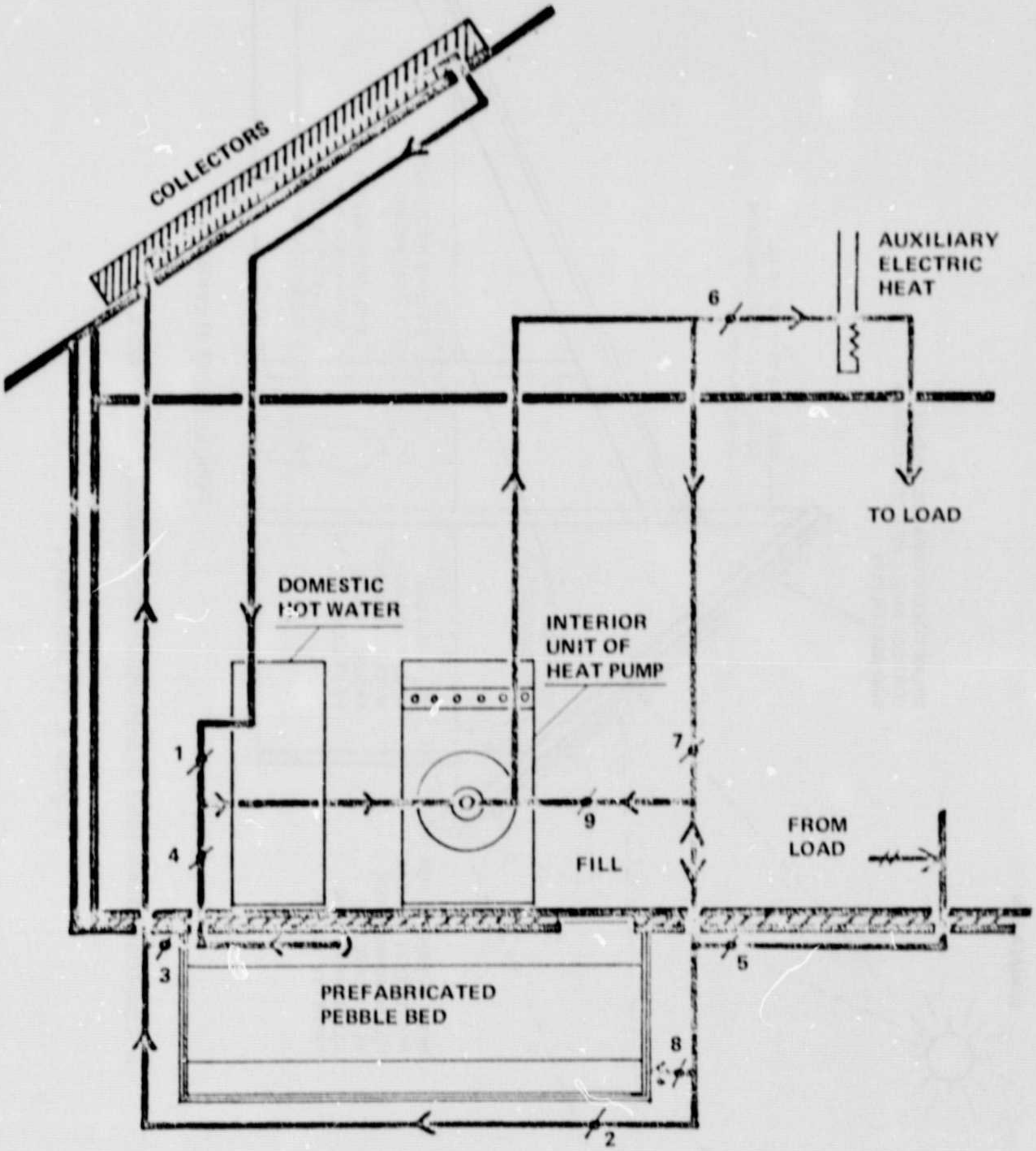
Category VI, Other Future Design Economies (OFDE), not costed in this report, are design factors that cannot be quantified now because of the large number of unknown variables involved. Typical future design economies are:

a) More efficient collector design.

b) Use of fewer collectors and lower capacity systems at some sacrifice in comfort.

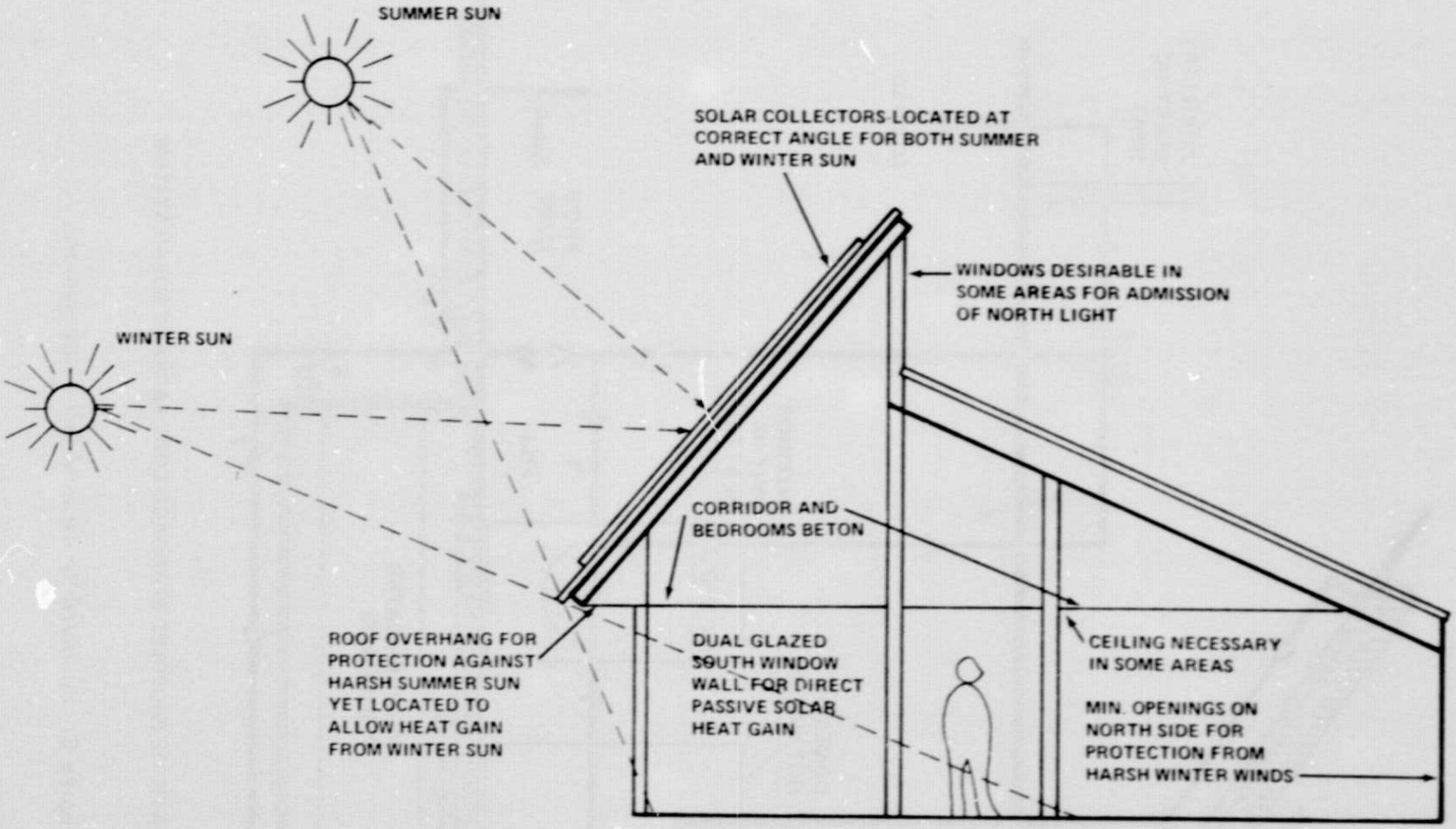
c) Use of reflectors and/or reflective surfaces in conjunction with standard collectors which could result in a 30 to 50 percent improvement in efficiencies.

d) Design and installation of solar systems in zones or increments, making the system acquisition costs more attractive to the average American homeowner.



a. SCHEMATIC OF PROPOSED STANDARD CORE PACKAGE SOLAR SYSTEM.

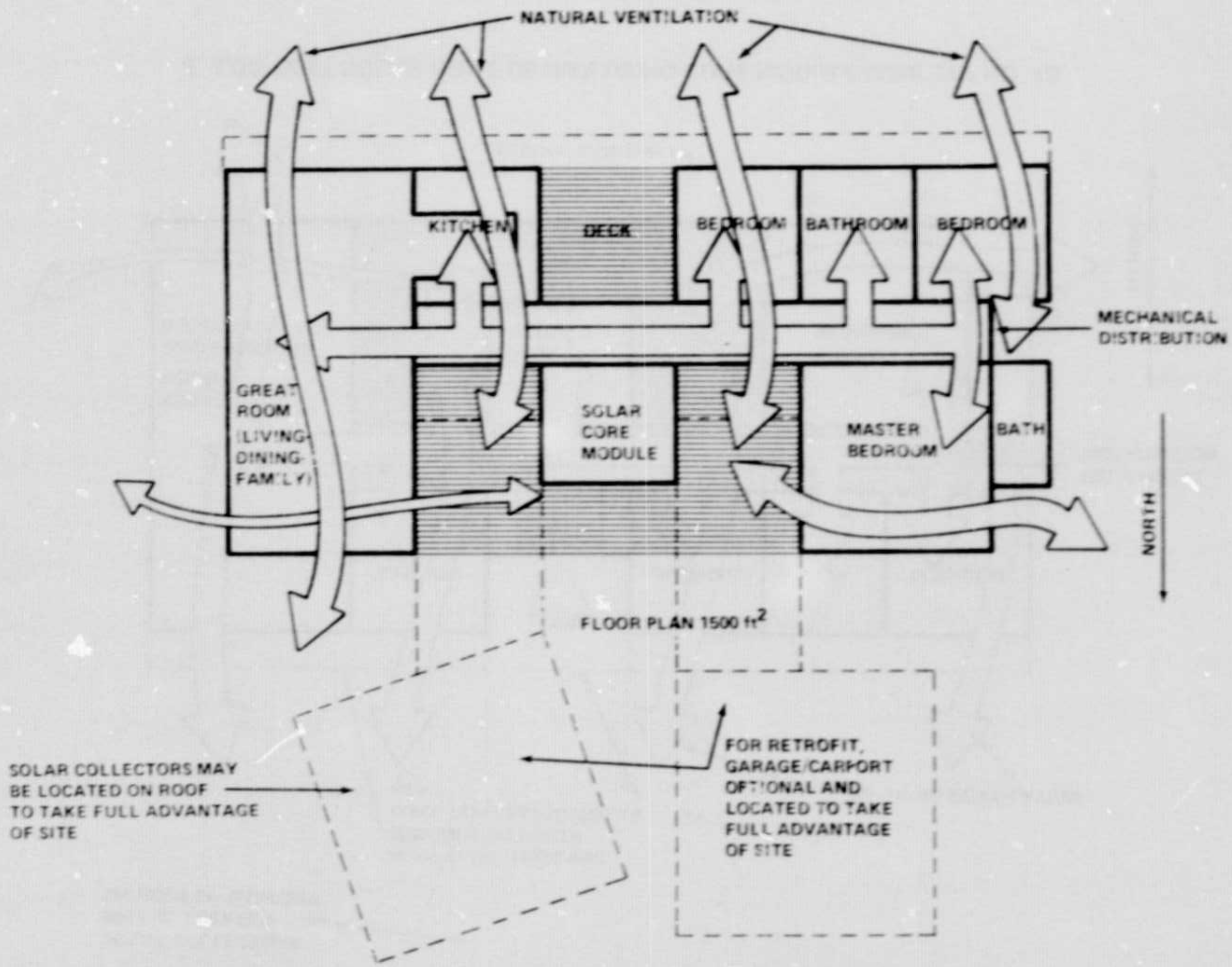
Figure 5. Standard "core module" solar system.



TYPICAL CROSS SECTION

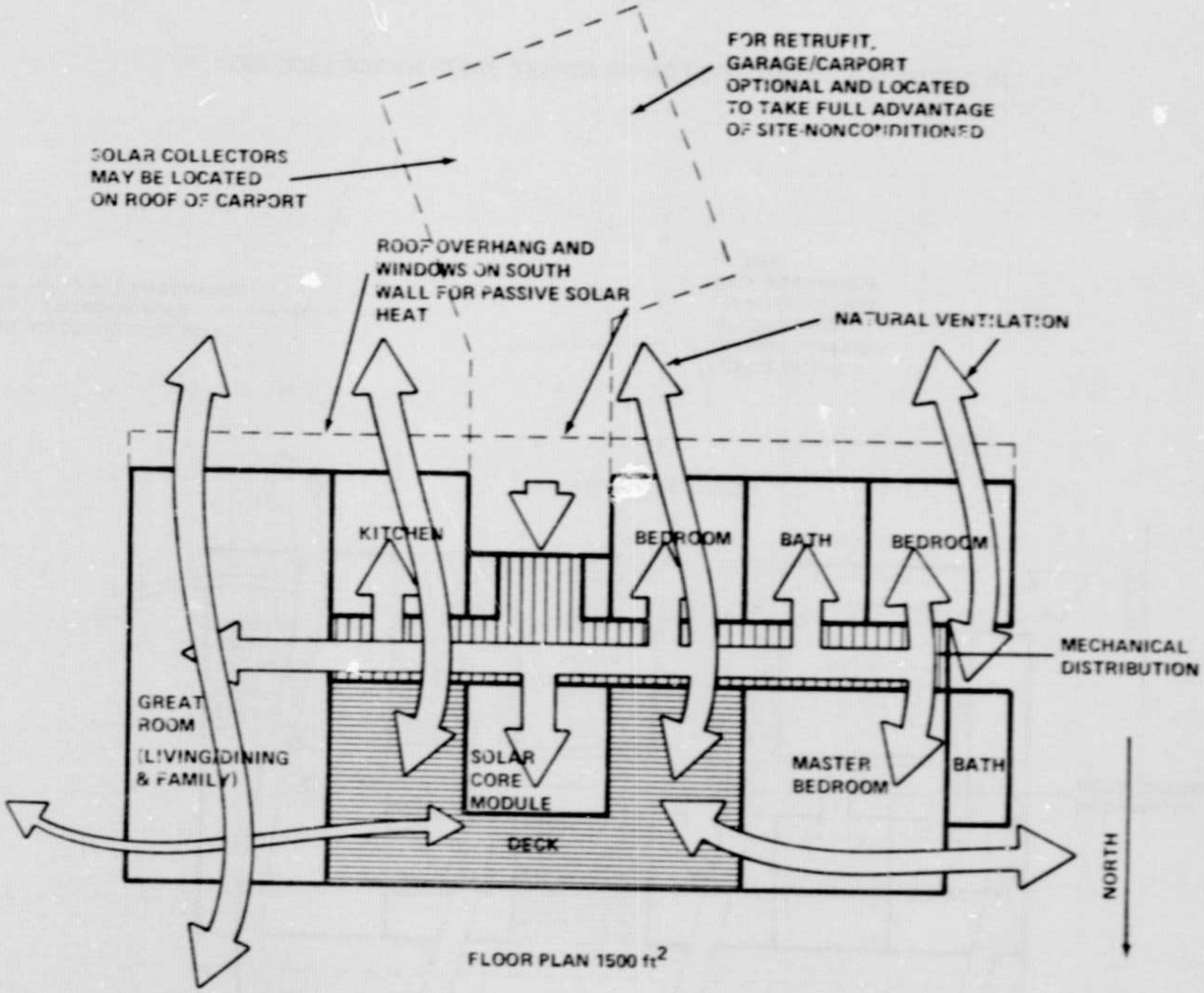
b. LOW-COST SOLAR HOME DESIGN USING CORE MODULE CONCEPT NO. 1.

Figure 5. (Continued).



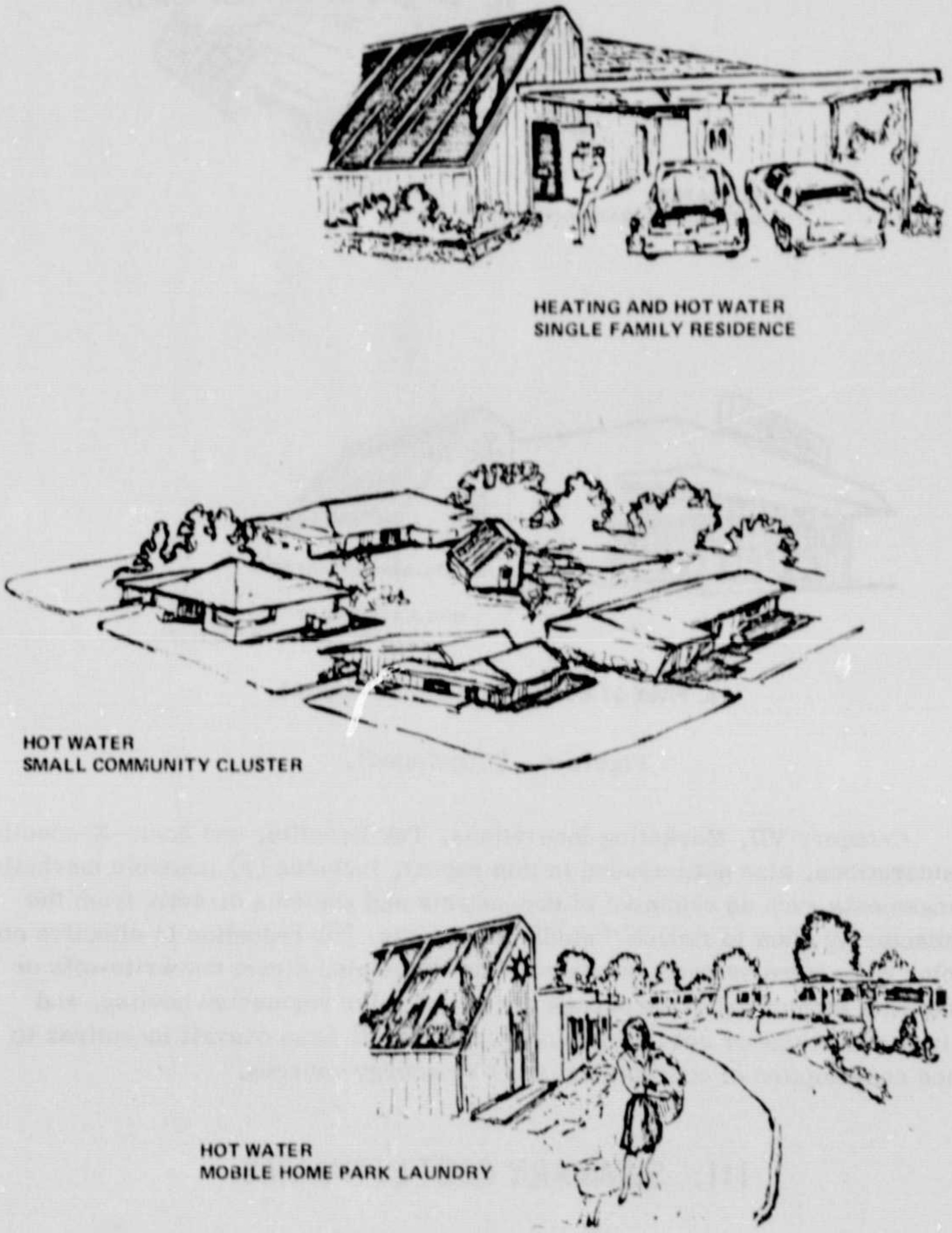
c. LOW-COST SOLAR HOME DESIGN USING CORE MODULE CONCEPT NO. 1A.

Figure 5. (Continued).



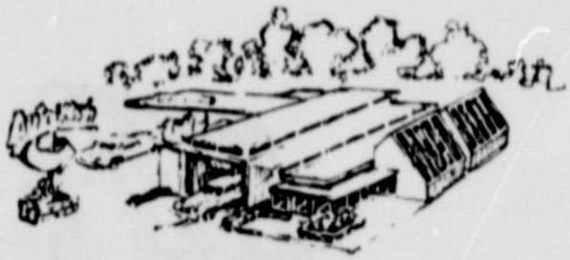
d. LOW-COST SOLAR HOME DESIGN USING CORE MODULE CONCEPT NO. 1B.

Figure 5. (Concluded).

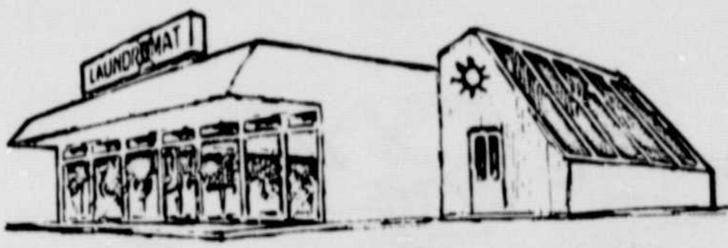


a. RESIDENTIAL AND COMMUNITY APPLICATIONS.

Figure 6. Free-standing auxiliary module.



HOT WATER
AUTOMOBILE WASHING FACILITY



HOT WATER-HEATING-DRYING
AUTOMATIC LAUNDRY FACILITY

b. FREE-STANDING AUXILIARY MODULE

Figure 6. (Concluded).

Category VII, Marketing Innovations, Tax Benefits, and Socio-Economic Considerations, also not included in this report, includes (a) possible marketing arrangements such as shipment of components and systems directly from the manufacturing plant to reduce "middleman" costs, (b) reduction in effective cost of solar augmented systems due to potential legislated direct tax write-offs or tax benefits authorized to encourage the use of solar augmented heating, and (c) cost reductions or cost avoidances which result from overall incentives to reduce consumption of conventional fuels or energy sources.

III. SUMMARY COST ESTIMATES

The "top level" summarized cost estimates derived in this study include a 20 percent markup for contractor overhead and profit and 10 percent markup for architect fee. These estimates, based on definitions contained in this report, are as follows:

Cost Definitions (Costs in 1978 Dollars)	Costs	
	New System (AL)	Retrofit (NM)
I. Cost of Prototype		
"Actual Cost"	$ 29 335	$ 41 245
"Should Cost"	34 009	-
II. Mass Production Costs	23 650	28 544
III. Mass Production-Improved Design	18 475	26 367
IV. Average American Home	14 381	21 680
V. Future Innovative Concepts	11 180	14 093

Tables 1 and 2 provide a breakout by Work Breakdown Structure (WBS) element of the costs under each definition. A general discussion of these costs and an item-by-item description of the overall rationale (and references) used in deriving the costs follows.

A. General Discussion

As might be expected, the costs estimated to retrofit a hot-air type residential solar heating and hot water system are somewhat higher than the costs to integrate a similar system into a new structure.

Although there is some disagreement among contractors on this point, the two example operational test sites bear out the conclusion that retrofit costs are higher for hot-air type system even when a more "ideal" type home with a ready-made basement and pitched roof facing south are assumed. (The point of disagreement lies in the statement by some heating and cooling contractors that time-phasing their work with new construction is more expensive than completing a retrofit job "all-at-one-time.") The cost estimates in this study also indicate that less is to be gained, percentage wise, when steps are taken to mass produce, simplify, or use "innovative concepts" for retrofit applications.

B. Rationale and References

1. <u>Cost of Prototype.</u>

a. "Actual Cost" (for "New" System). The cost estimate for the prototype new system (IBM System IA) installed in the Huntsville, Alabama, site

TABLE 1. SINGLE-FAMILY NEW, ACTIVE HOT-AIR-TYPE SOLAR HEATING SYSTEM COSTS[a] (IN 1978 DOLLARS)

WBS No.	Title	2200 ft² Home				1500 ft² Home	
		Cost of Prototype		Mass Production Cost ($)	Mass Production Improved Design Cost ($)	Average American Home Cost ($)	Plenum Wall/Roof Concept Cost ($)
		Actual Cost ($)	Should Cost ($)				
1.0	Solar Heating and Cooling System	22 224	25 764	17 917	13 996	10 895	8 470
1.1	Collector Subsystem	12 919	14 163	10 727	8 428	5 788	1 584
1.1.1	Collector	6 420	6 420	4 349	3 300	2 188	580
1.1.2	Installation and Flashing	1 338	1 763	875	725	1 004	1 004
1.1.3	Manifold and Duct Work	5 161	5 980	5 503	4 403	2 596	-
1.1.4	Duct Work Insulation	-	-	-	-	-	-
1.2	Air Transport Subsystem	1 565	1 565	1 115	1 115	575	575
1.2.1	Blower	456	456	325	325	253	253
1.2.2	Dampers	549	549	391	391	130	130
1.2.3	Cabinet	255	255	182	182	55	55
1.2.4	Assembly and Insulation	305	305	217	217	137	137
1.3	Storage Subsystem	2 484	3 035	2 131	1 406	715	715
1.3.1	Rock Bed Structure	1 425	1 877	1 359	811	312	312
1.3.2	Rocks	569	569	269	269	74	74
1.3.3	Ducts and Plenum	178	178	125	100	200	200
1.3.4	Insulation	312	411	378	226	129	129
1.4	Domestic Hot Water Subsystem	1 654	1 654	1 255	1 255	1 655	632
1.4.1	Heat Exchanger	103	103	54	54	103	125
1.4.2	Pump	94	94	49	49	94	94
1.4.3	Preheat Tank	100	100	53	53	100	100
1.4.4	Relief Valve	15	15	9	9	15	15
1.4.5	Assembly and Integration	1 342	1 342	1 090	1 090	1 343	188
1.5	Control Subsystem	767	954	293	268	389	389
1.5.1	Controller	279	368	168	168	279	279
1.5.2	Control Interface Unit	310	408	-	-	-	-
1.5.3	Control Sensors	178	178	125	125	110	110
1.6	Overall Integration	2 835	4 393	2 396	1 524	1 773	4 575
1.6.1	Mechanical Room Work	1 004	1 556	849	540	545	545
1.6.2	Interconnect Duct Work	485	752	410	260	233	980
1.6.3	Insulation	550	852	465	296	508	2 813
1.6.4	Control Integration	796	1 233	672	428	487	237
	Subtotal Cost	22 224	25 764	17 917	13 996	10 895	8 470
	Contractor O/H and Profit (20%)	4 444	5 153	3 583	2 799	2 179	1 694
	Architect Fee (10%)	2 667	3 092	2 150	1 680	1 307	1 016
	Total Cost	29 335	34 009	23 650	18 475	14 381	11 180

a. Based on New Construction — Estimating Basis: Huntsville Home Builders Structure on Triana Boulevard, Huntsville, Alabama.

TABLE 2. SINGLE-FAMILY RETROFIT, ACTIVE HOT-AIR-TYPE SOLAR HEATING SYSTEM COSTS[a] (IN 1978 DOLLARS)

WBS No.	Title	1400 ft² Home: Cost of Prototype ($)	1400 ft² Home: Mass Production Cost ($)	1400 ft² Home: Mass Produced Improved Design Cost ($)	1500 ft² Home: Average American Home Cost ($)	1500 ft² Home: Free-Standing Module Cost ($)
1.0	Solar Heating	31 247	21 624	19 975	16 424	10 677
1.1	Collector Subsystem	5 326	3 116	3 304	3 535	3 535
1.1.1	Collector	3 638	1 428	1 785	1 910	1 910
1.1.2	Installation and Flashing	989	989	989	1 058	1 058
1.1.3	Manifold and Duct Work	311	311	230	246	246
1.1.4	Duct Work Insulation	388	388	300	321	321
1.2	Air Transport Subsystem	1 077	1 077	724	724	724
1.2.1	Blower	314	3 314	314	314	314
1.2.2	Dampers	378	378	166	166	166
1.2.3	Cabinet	175	175	70	70	70
1.2.4	Assembly and Insulation	21	210	174	174	174
1.3	Storage Subsystem	4 436	3 654	3 192	3 415	1 842
1.3.1	Rock Bed Structure	3 212	2 451	2 451	2 623	1 050
1.3.2	Rocks	606	606	164	175	175
1.3.3	Ducts and Plenum	400	145	145	155	155
1.3.4	Insulation	218	432	432	462	462
1.4	Domestic Hot Water Subsystem	2 454	2 454	1 812	1 812	912
1.4.1	Heat Exchanger	103	103	103	103	103
1.4.2	Pump	94	94	94	94	94
1.4.3	Preheat Tank	100	100	100	100	100
1.4.4	Relief	15	15	15	15	15
1.4.5	Assembly and Integration	2 142	2 142	1 500	1 500	600
1.5	Control Subsystem	789	789	389	389	389
1.5.1	Controller	279	279	279	279	279
1.5.2	Control Interface Unit	310	310	-	-	-
1.5.3	Control Sensors	200	200	110	110	110
1.6	Overall Integration	10 298	3 687	3 687	3 687	1 475
1.6.1	Mechanical Room Work	1 388	1 040	1 040	1 040	-
1.6.2	Interconnect Duct Work	5 653	1 065	1 065	1 065	-
1.6.3	Insulation	1 200	788	788	788	-
1.6.4	Control Integration	2 057	794	794	794	-
1.7	Construction Add/Mods	6 867	6 867	6 867	2 862	1 800
1.7.1	Mechanical Equipment Room	2 393	2 343	2 343	-	-
1.7.2	Collector Support Structure	2 322	2 322	2 322	-	-
1.7.3	Duct Housing or Mods	1 587	1 587	1 587	1 440	-
1.7.4	Miscellaneous Modifications	615	615	615	493	493
1.7.4.1	Windows	417	417	417	417	417
1.7.4.2	Relocate Plumbing	61	61	61	61	61
1.7.4.3	Gutters/Downspouts	122	122	122	-	-
1.7.4.4	Miscellaneous: Nails, Caulking, etc.	15	15	15	15	15
	Total Direct Costs	31 247	21 624	19 975	16 424	10 677
	Markup:					
	Contractor O/H and Profit (20%)	6 249	4 325	3 995	3 285	2 135
	Architect Fee (10%)	3 749	2 595	2 397	1 971	1 281
	Cost to Average Homeowner	41 245	28 544	26 367	21 680	14 093

a. Based on Retrofit Construction — Estimating Basis: National Park Service Residence in Carlsbad, New Mexico.

includes the purchase cost of major items and installation cost as shown in IBM Report SIMS-77-0806, dated August 9, 1977. The collectors and differential thermostat which were GFE'd by MSFC have been priced at their cost and included in the estimate.

b. "Should Cost." This estimate is for the same system previously described. Cost overruns and extras which were incurred by the builder and heating and cooling contractor were not charged to the project but are included in the "Should Cost."

The cost estimate for the retrofit system prototype installed at Carlsbad, New Mexico, is based on a preliminary estimate of that site by James A. Evans, Consulting Engineers of Birmingham, Alabama, in a report dated February 18, 1977, entitled "Feasibility Report on Solar Energy Projects using IBM SIMS Prototype System I." Actual cost data were requested from the site manager, but has not been received as of the publication date of this report due to litigation and cost settlement of the final contract.

2. MPC. "Grounds-up" cost estimates for a solar installation of the same size as the prototype (Category II) were developed assuming large production quantities. This mass production assumption is based on wide acceptance of solar energy as a means of space heating and providing domestic hot water.

Some items in this estimate were considered to already be in mass production (all items but the collector) and do not reflect a reduction in cost throughout this exercise.

The mass production cost estimate was developed using the standardized WBS and is shown in cost analysis reports dated September 30, 1977, and March 1, 1978, for the new (Huntsville) and retrofit (Carlsbad) installations, respectively.

3. MPID Costs. These costs were based on minor design or construction improvements thought possible by the UAH/ASHRAE/AIA team that was employed to identify potential cost savings. The rationale for Category III costs indicated for the new (Huntsville) system are described as follows:

WBS

1.1 Collector panels with inlet and outlet manifolds integrated into the collector will increase cost of collectors by approximately 25 percent. However, the manifold and duct work will be reduced by approximately 26 percent, resulting in savings for the collector subsystem.

1.2 Moving the heat pump indoor unit out of the by-pass duct and into the supply air duct eliminates the need for the internal by-pass and two of the dampers inside the solar air handling unit. This move will reduce the cost of the dampers and the cabinet.

1.3 Loading the pebble bed could be improved and made less expensive by washing the rocks at the quarry in piles and loading into a prewashed cement truck from the top half of the washed pile and loading pebble bed from the truck. This eliminates hand loading which will reduce cost of the pebble bed.

1.4 No potential savings given.

1.5 If this system were to be mass produced, the necessary controls could be simplified and would require much less field labor. The need for the IBM supplied interface control unit could be eliminated, thereby reducing the cost of the control subsystem and in overall system integration.

1.6 Changing the custom metal duct work, wrapped with 5 in. of external insulation, to preinsulated rigid round fiberglass or duct board would result in an additional cost savings.

A similar rationale was used for the retrofit (Carlsbad) system; however, as can be seen from the estimate, not as much improvement is expected from the improved design features in a retrofit system as in a new system.

4. AAH Costs. The rationale for the cost estimate for a new hot-air type system for an average American home based on the type of system installed in the Huntsville structure is listed in the following WBS.

Assuming the average American home will be reduced in size to approximately 1500 ft^2, some items of the solar system will be reduced since the prototype was 2200 ft^2.

WBS

1.1 To reduce the collector square foot area based on reduced size of home, calculate as follows:

$$\frac{1500}{2200} = 68 \text{ percent of Category IV estimate}$$

1.2 The air transport subsystem would not reduce at the same rate since blower, dampers, cabinets, and assembly would be required regardless of size of collector area. However, some savings can be expected in reduced size of this equipment when the home size is reduced. It has been estimated that this savings would be approximately 21 percent.

1.3 The storage subsystem would require less area for the rock bed structure and the number of tons of rocks required would also be less for this reduced size home. It has been estimated that the reduction would be approximately 21 percent.

1.4 The domestic hot water subsystem is not expected to reduce significantly in installation cost. Although the family size is declining and hot water consumption is reduced, certain installation cost such as plumbing, insulation, wiring, etc., are required for any size system.

1.5 The control subsystem (already reduced by mass production) would not be expected to show a cost savings in the smaller home.

1.6 Overall integration could be expected to reflect a slight reduction due to the smaller pebble bed and its insulation, reduced size of ducts, and simpler interconnecting duct work. It has been estimated that approximately 5 percent cost savings could be realized.

The rationale for the retrofit system is similar. The principal savings in the retrofit system are brought about by the assumptions that (a) the average American home to be retrofitted will already have a basement or other suitable location for a pebble bed and equipment to be installed, and (b) the average American home to be retrofitted for solar energy will already have at least one sloping roof facing approximately south on which solar collector panels can be placed. Hence, the need to build an extra equipment room and a special roof support structure is eliminated. Also, some economies are assumed by using a more direct routing of collectors to storage to load ducts.

5. <u>IDC Costs.</u> Two distinctly different concepts were assumed under this cost category, one for the new construction category and one for the retrofit category. The new category assumed a plenum wall/ roof concept.

The cost estimate for the plenum wall/ roof concept is based on a conceptual design made by Sizemore & Associates of Atlanta, Georgia. The design is for a 1500 ft^2 residence which has been assumed to be an average American home.

These costs have been distributed to the standardized WBS as used in other categories of this exercise.

Some items in this estimate were considered to already be in mass production and do not reflect a reduction in cost.

The collector subsystem was reduced approximately 70 percent due to a decrease in collector square foot area and the elimination of manifold and duct work using the plenum wall/ roof concept for ducting.

The domestic hot water subsystem was reduced approximately 60 percent primarily in the assembly and integration of the system.

Overall integration was increased by approximately 60 percent. The major increase was in the insulation of the walls and roof area since these areas are used for plenum and ducting. Also, special storm windows are required on windows of the North and South walls since these double glazed windows are used as ducting. A set of sketches of the plenum wall/ roof concept are shown in Figures 4. An alternate low-cost approach, an integrated core-module concept, is shown in Figures 5.

The retrofit future innovative concept is based on a "free-standing hot-air module" (similar to an IBM "4-A" system module) illustrated in concept by Figure 6. Although a detailed cost estimate has not been completed by IBM, the Cost Analysis Office developed a preliminary estimate which is given in this report. Additional economies are anticipated if mass-utilization is achieved for industrial and commercial uses.

A similar liquid-type solar heating module concept is described in UAH's Kenneth E. Johnson Environmental and Energy Center report entitled "Solar Heating Module Program" dated November, 1977.

IV. COMMENTARY ON THE NEED FOR A SYSTEMS ENGINEERING AND INTEGRATION APPROACH

A very clear and strong indication in the UAH report and in the NASA study was that there is a need for a systems engineering and integration approach in the adaptation of solar energy to a residence. Rather than considering the solar equipment or system as a separate entity, it must be considered as an integral part of the home, with the proper interfaces, interactions, and possible design and construction economies considered. This could be accomplished by careful coordination of architectural plans and engineering drawings to simplify duct work, piping, controls, wiring, etc., and integrating the heat pump with the solar system. Another economic consideration is that the system, if mass produced, could be supplied by one company in a total package.

V. CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this report are as follows:

a) Analysis of the two hot-air systems installations indicates that the addition of an air-type solar heating and hot water system to a residential size structure adds from $6.36 to $8.14 per square foot to the initial cost of a new residence (based on mass-production/utilization).

b) Significant savings can be achieved through attention to design detail, use of local materials, and thorough coordination of architectural plans with heating and cooling system design.

c) The use of an overall systems engineering and integration approach would significantly decrease cost and improve system effectiveness.

The principal recommendation of this report is that costs be reduced for future systems by:

a) Use of locally available materials wherever possible.

b) Reduction of on-site labor and installation costs through factory manufacture and assembly of solar heating systems.

c) Careful and meticulous coordination of the building design with the solar heating system configuration and construction.

VI. ADDITIONAL ANALYSIS AND STUDY REQUIREMENTS

Since this cost analysis and cost reduction improvement assessment has been accomplished on two of the earliest operational test sites, the findings and conclusions are necessarily preliminary in nature. As analysis of subsequent test sites proceeds, the techniques and methods of analysis are expected to improve and more information will become available on the types of hot-air solar augmented heating systems installed in the first two sites. Additional and continuing study of the data presented herein will be required, and these data will be supplemented by the actual maintenance and operations cost data required to make the total "payback" or economic analysis complete. The following studies should be accomplished to achieve these end objectives:

a) Update of the estimates based on emerging subsystem configuration for hot-air solar assisted systems.

b) Incorporation of additional design, production, assembly, installation, or operational economies not addressed in this study.

c) Feedback of actual performance, maintenance, and operational data into the design of the hot-air type augmented heating and hot water system.

As other sites are analyzed, the data will be compiled to produce a data base that will allow the development of estimating relationships or factors that will take into account geographical, weather, solar insolation, and construction cost differences in the various locations to be considered.