The Economics of Solar Technology in the Carolinas

Editor's Note: These articles discuss the economic viability of two types of solar energy technology using cost and weather data from Piedmont, North Carolina. In Single Family Home Solar Heating and Cooling, *a simple system for the solar powered space conditioning of a single unit residence is compared to conventional methods of space conditioning. The conclusion that the solar alternative is lower in lifetime costs is underscored by the increases in the costs of electricity and fuel oil which have occurred since the cost data for this article were gathered in 1975. In* The Feasibility of a Multi-Residence Total Solar Energy System, *a solar powered electrical generation and space conditioning system for a twenty unit residential development is compared with and found to be of higher cost than conventional methods of servicing such a development.*

Solar heating and cooling for single family units is economically feasible

Photo by Bruce Stiftel

Single Family Home Solar Heating and Cooling

It is impossible to deny we are rapidly depleting the world's conventional energy supplies. In addition, the use of conventional energy results in billions of dollars in pollution costs each year.[1] Household and commercial requirements account for about one-third of United States energy use and over one half of electricity demand.[2] Over 70 per cent of the energy consumed in these sectors is for heating, cooling, and water heating.[3] All three of these usages can be provided by existing solar technology. Implementation of that technology in North Carolina would result in a monetary savings to the individual homeowner and environmental savings to the public.

Solar Technology

Solar heating is simple. It usually involves pumping water or air over a solar heat collector and then storing the heat in rocks or water for circulation through the house. A design which has been utilized for over 18 years in three Washington, D.C. homes involves pumping water to the rooftop, allowing it to flow over a black sheet metal roof heated by the sun and into the basement to a storage tank which is surrounded by fist-size stones. A small blower activated by a thermostat circulates air through the stones and into the house. The solar heated water on the way to the storage tank is used to give a pre-heat boost to the domestic hot water supply.[4]

Solar housing technology involves only conventional materials such as sheet metal, glass, tubing, and rock. Construction includes steps which are unusual (e.g. installing a 1500 gallon tank in a basement), but it involves no special knowledge or equipment not possessed by most builders.

Although it is technologically feasible, solar air conditioning probably will not be economical until after 1980. Until that time there exist two cooling methods which have been associated with solar heating and which utilize less energy than conventional air conditioning. One is rooftop cooling which involves pumping water to the roof on cool nights,

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allowing it to flow over the roof, and storing "cold" in the storage tank used in the heating process. This is effective only in areas with cool dry summer nights. The second method involves the use of a conventional central air conditioning unit which operates at night, drying and cooling outside air and blowing it over the stones.

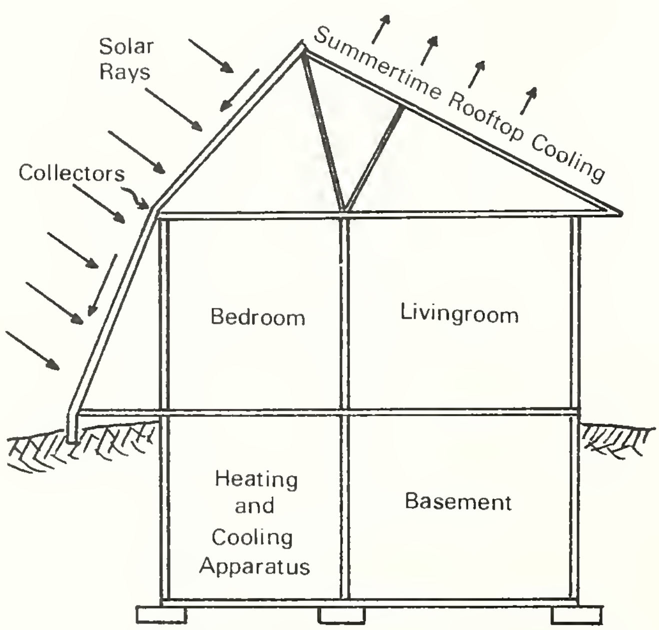
In both of these methods, during the day the same blower used during the winter heating cycle circulates the household air through the stones and thus cools and dehumidifies the house. Since the compressor only runs at night, when temperatures are lower, it should operate at higher efficiency than conventional central units.

Given this brief introduction to existing solar technology, we shall proceed to look at private sector feasibility of the solar heating and cooling alternative. First what are the parameters of construction costs, alternative fuel costs, discount rates, and system lifetime that will allow a solar system to "pay for itself" in fuel savings? Second, what are the implications of increasing energy costs with respect to solar desirability? Third, how adaptable is solar technology to different locations, housing patterns and design tastes?

A Framework for Cost Comparison

In order to determine with some precision both construction costs and energy use of a solar heating and cooling system, it was necessary to describe the size, design, location, and other details of a particular hypothetical house. Three builders were provided with an explanation of the principles of solar heating and cooling, and a plan similar to one circulated by Thomason,[5] including design specifications from "typical" houses used, by the North Carolina Oil Jobbers Association for energy cost comparisons, by Duke Power Company for insulation standards and energy savings estimates, and by the U.S. Environmental Protection Agency for energy conservation studies.

Figure 1
A cutaway view of the "typical" house using solar heating and preheating of household hot water with off-peak cooling.



Drawing by Dan Fleishman

The house was to be a wooden frame structure facing North on a unshaded lot, with 1500 square feet of finished space, a full unfinished basement, and an attached enclosed unheated garage on slab. A side cutaway view of the house is shown in Figure 1.[6] The back side is covered by a solar collector extending from the crest of the roof to the ground. The front roof is less slanted, and as shown, may be equipped for summertime rooftop cooling. About one third of the basement is reserved for the solar storage tank and apparatus. All insulation standards were those required for FHA homes. The house was to be equipped with central cooling.

Conventional heating capital costs vary with type and locale. An oil, forced air system costs up to 2000 dollars installed with a usual price of about 1500 dollars.[7] Of the 1500 dollars, about 650 dollars is furnace cost, and 850 dollars is the cost of ductwork.[8] Electric furnaces installed run about the same price. The cheapest heating system to install is electric ceiling or baseboard heat which costs around 500 dollars.[9]

The differences in capital costs disappear to a great extent when central cooling is used. Ductwork must be added to the electric ceiling or baseboard heated home. This adds another 850 dollars to cooling capital costs of about 300 dollars per ton of refrigeration. (1 ton refrigeration = 200 BTU/min). This raises the total heating-cooling (3 ton load) equipment and installation costs to at least 2300 dollars for our "typical" house.[10]

The estimated costs of the solar system varied considerably. A piedmont Virginia contractor gave an estimate of about 6550 dollars for the solar heating system with off-peak cooling which included an auxiliary oil furnace.[11] A Chapel Hill independent builder gave the lowest estimate at about 4400 dollars.[12] This incorporated a lower cost method for auxiliary heating. The third estimate was 5450 dollars.

If the cheaper booster idea is substituted for the complete auxiliary heating in each estimate, an initial capital cost reduction of 550 dollars is realized. Thus, the estimates stand at 4400 dollars, 4900 dollars, and 6000 dollars. A cost estimate of 7300 dollars, proposed by Doolittle of North Carolina State University for a completed solar heated housing system with auxiliary for Raleigh, North Carolina was used for the high cost extreme.[13]

Figures 2 and 3 depict fuel requirements of the solar house and ensuing costs under 1975 electric rates in the region. This includes Thomason's finding that the off-peak cooling permits the same amount of electricity to produce 45 percent more cooling due to

Figure 2

Energy Consumed by the Solar System

(KWH/yr = horsepower x 746 watts/hp x 1 KW/1000watts x days used/year x hours/day x 1/e)

	Heating		Cooling			
Variables	Warm Air Blower	Water Pump	3 Ton Compressor	Cooling Blower	Hot Water Heater	Misc. Electricity
power	.17 hp	.25 hp	3 hp	.5 hp	Solar elect.	——
daily use	20 h/d	3 h/d	9 h/d	9 h/d	——	——
duration of use	120 d/yr	120d/yr	150 d/yr	150 d/yr	——	——
efficiency	.75	.75	.85	.75	——	——
KWH/yr	406	90	3554	671	3400	9750

increase compressor efficiency at lower nighttime temperatures.[14] This is equivalent to getting the same cooling from about 68 percent of the amount of electricity required by conventional central cooling systems.

Assumptions necessary to the prototype situation are as follows: domestic hot water - 80 gallons per day; miscellaneous electrical use - 750 kwh per month; annual heating demand - 4380 degree days (at 65°F inside temperature); annual cooling demand - 900 hours. The last two estimates are based on a "typical" house studied by the N.C. Oil Jobbers Association in 1972.[15]

1975 electric rates plus the fuel escalator bring costs per kilowatt hour (KWH) to 4.06 cents for the first 250 KWH per month and 2.42 cents from then on.[16] For the total 17,871 KWH per year estimated for the solar house, the average cost is 2.44 cents per KWH. This yields a total annual cost of 481.68 dollars. By updating the oil costs in the 1972 Oil Jobbers study to the 1975 rate of 37 cents per gallon, operating costs for the oil heated "typical" home are 1115.18 dollars including electricity. Energy requirments for the all electric home comes to 60,044 KWH per year or an annual energy cost of 1274.72 dollars.[17]

Using these annual energy cost calculations, the solar alternative shows a yearly energy savings of 589 dollars over oil and 793 dollars over electricity. The critical question to be answered is whether the total lifetime costs of the solar alternative—capital and operational—will be competitive with electricity and oil.

Total Lifetime Cost Analysis

Lifetime cost comparisons can be figured on the basis of the following total cost equation:

$$TC = FC + pvac$$

The total cost (TC) of the system equals the fixed initial cost (FC) plus the present value of the annual average costs (pvac) of operation over the system lifetime. TC will vary depending on parameters for materials and construction costs in FC and with the cost of energy, discount rates, and system lifetime used to establish pvac. To discover how the solar alternative compares with oil or electricity, a sensitivity analysis was performed using different parameters for initial construction costs, conventional energy costs, and discount rates. System lifetime is estimated for conventional systems at 20 years. Since the solar system in question has proven to be at least as durable, there is no need to test lifetime.

The calculation for the present value of the annual costs (pvac) can be made using the following formula:

$$pvac = \sum_{i=1}^{n} \frac{\text{annual cost in year i}}{(1+r)^{i}}$$

where n = the number of years of the project, and r = the rate of discount. A sample calculation for the pvac of the oil heat system over 20 years at ten percent is performed as follows:

$$TC = FC + pvac$$

$$TC = \$2300 + \sum_{i=1}^{n} \frac{\$1115}{(1.1)^{i}}$$

$$TC = \$11{,}789$$

The remaining calculation for changes in discount rate or cost of energy are performed using the same method.

Figure 4 compares the full cost range of the solar estimates to the oil and gas alternatives. It applies the total cost equation for lifetime costs given different discount assumptions and constant energy prices. Calculations show the following: (1) At discount rates of six, eight, and ten percent, each solar estimate offers a lifetime savings over conventional alternatives. (TC for solar is less than TC for oil or elec-

Figure 3

Annual Costs of the Solar System Operation

Component	Power Used (KWH)	Cost ($)
Water pump	90	2.44
Blower (Heat)	406	10.95
Compressor	3554	95.79
Blower (Cool)	671	18.09
Water Heat	3400	91.64
Miscellaneous	9000	242.56
Aux. Heat	750	20.21
Total	17871	481.68

Power costs are based on rates in Chapel Hill, N.C. effective March, 1975.

Figure 4

Sensitivity of Total Costs (TC) to Discount Rate

Discount Rate		Low Solar Estimate	High Solar Estimate	Doolittle Solar	Oil House	Electric House
	FC	$4400	$6000	$7300	$2300	$2300
6%	Annual Cost	482	482	482	1115	1275
	pvac	5495	5495	5495	12713	14535
	TC	9895	11495	12795	15013	16835
8%	pvac	4733	4733	4733	10949	12521
	TC	9133	10733	12033	13249	14821
10%	pvac	4102	4102	4102	9489	10850
	TC	8502	10102	11402	11789	13150
15%	pvac	3003	3003	3003	6946	7943
	TC	7403	9003	10303	9246	10243

tric). (2) In only one case, the highest (Doolittle) estimate figured at the highest (15 percent) discount rate, was the solar alternative more costly than its oil or all-electric counterparts. The discount rates chosen represent the range generally used in this type of calculation.

Sensitivity of the Findings to Rising Energy Costs

As expected, the solar alternatives become even more desirable to homeowners if energy costs rise. Figure 5, also derived by present value calculations, shows that a five percent rise in energy costs every five years will cause the lifetime costs (TC) of the oil and electric alternatives to rise four percent. Solar lifetime costs, however, rise by only 1.7 to 2.3 percent. This results in a present value savings of 651 dollars, and 2073 dollars, in favor of even the highest solar estimate versus the oil and all electric systems respectively.

A rise of 10 percent in conventional energy costs every five years results in present value lifetime savings of 921 dollars for the high cost solar estimates versus oil and 2415 dollars versus electricity. If energy costs rise 20 percent every five years, the solar savings grow to 1513 dollars and 3148 dollars respectively. Energy price rises in the range of 50 percent every five years are not unlikely given recent trends. In such an event, savings to solar systems would be at least 3660 dollars versus oil and 5844 dollars versus electricity. Again it must be emphasized that these savings are for the *highest* cost solar estimate. The lower estimates and mass-produced estimates offer even larger savings; as much as 8744 dollars for the lowest solar estimate versus all-electric when electric rates rise 50 percent every five years.

Cost Comparison from the Homebuyers' Perspective

Another way to compare the costs of solar housing with conventional types is to calculate lifetime costs for both systems and compare average total annual costs for each. In other words, on the average, how much will it cost the consumer each year, in mortgage payments and energy costs to heat his water and heat and cool his home, by each method? The original base cost for constructing the four identical homes in the same location should be the same, excluding the costs for heating and cooling equipment. If homebuyer O relies on oil heat, homebuyer E on

Figure 5

Sensitivity of Total Costs to Rising Energy Costs at 10% Discount Rate

Change in Energy Cost in 5 Years		Low Solar Estimate	High Solar Estimate	Doolittle Solar	Oil House	Electric House	Present Value of Doolittle Solar over Oil	Elect.
	FC	$4400	$6000	$7300	$2300	$2300		
5%	pvac	4299	4299	4299	9950	11372		
	TC	8699	10299	11599	12250	13672	651	2073
10%	pvac	4508	4508	4508	10429	11923		
	TC	8908	10508	11808	12729	14223	921	2415
20%	pvac	4956	4956	4956	11469	13104		
	TC	9356	10956	12256	13769	15404	1513	3148
50%	pvac	6589	6589	6589	15249	17433		
	TC	10989	12589	13889	17549	19733	3660	5844

electricity, and homebuyers S^1 and S^2, on solar heating, cooling, and water heating, how will their yearly outlays differ over the twenty years of system lifetime?

The mortgage sought by O and E will include 2300 dollars over base cost to cover conventional heating and cooling equipment. Using a discount rate of 10 percent to represent interest, insurance and other finance cost, O and E will each pay a total of 5330 dollars over a twenty year mortgage. S^1 will pay 9200 dollars on a solar investment of 4400 dollars over 20 years. S^2 will pay a total of 16,910 dollars on his original solar investment of 7300 dollars. The annual cost of these mortgages will usually be one twentieth of the total cost. By adding the annual mortgage payments to the annual cost of electricity or fuel under each option, Figure 6 illustrates that even with a high 10 percent interest rate (which is less favorable to the solar alternatives than lower rates), the average annual costs will be lower for S^1 by 390 dollars compared to O, and 549 compared to E each year. Even solar homebuyer S^2, who paid 7300 dollars for his initial solar equipment will be better off each year than O and E by 54 dollars and 213 dollars respectively. If lower interest rates or a rising cost of electricity and fuel oil are used, the solar homebuyers would fare better still.

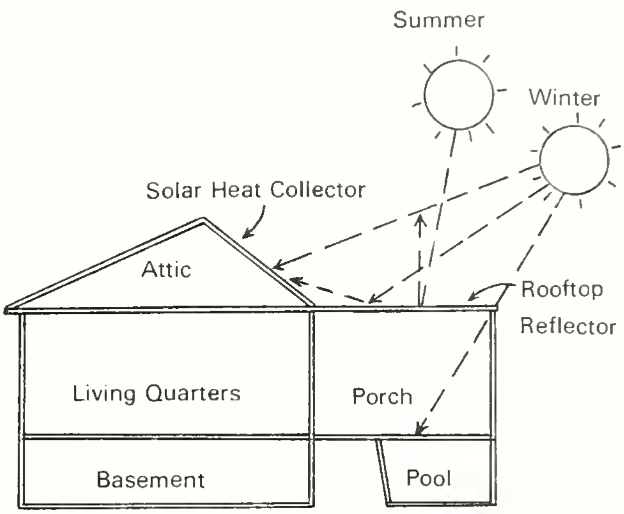
Limitations of Solar Housing

The probable economic advantage of single family solar housing is not a panacea. Much construction is not single unit dwellings. Further, many single family homes may not be able to be built facing North on unshaded lots. In addition, designers and consumers may doubt the aesthetic advantage of a building which has an odd slope to its roof and one side made of glass-covered sheet metal. Homebuyers may not be willing to take the risk that adjoining property owners might put up tall buildings, cutting off sunlight. Given these limitations and peculiarities of solar housing, are there ways to alter the technology or to adapt the surroundings to make the solar alternatives more attractive?

Overcoming the constraint of the need for proper orientation of the solar collector while maintaining a regard for aesthetics is a principal challenge to solar designers. Since sunlight is a very low density energy source, its margin of effectiveness is small. Slight variations in direction of collector orientation or slope can undermine a solar system's effectiveness.[18]

Figure 7

Rooftop Reflector System for Increasing Collector Efficiency



Drawing by Dan Fleishman

A homeowner or builder must answer the question of whether on a given lot there can be a southern exposure for one side of the house without 1) interrupting the symmetry of the property by placing the house at a skewed angle to the frontage; 2) prominently displaying the collector toward the frontage; 3) obstructing an important southerly view; or 4) being shaded by desirable trees or other existing or potential structures? The orientation of houses with respect to road frontage is purely a matter of taste. If consumers reject alternatives to direct parallel road orientation and wish to hide the collector, only lots with North frontage will be suitable for solar housing.

Recent designs in solar collectors are aimed at overcoming this limitation as well as to improving other aesthetic aspects of the system. In a recent Thomason solar house, the roof of the enclosed pool is a sun porch of light colored material which acts to reflect sunlight onto the collector, thereby boosting collector efficiency and eliminating the need for making the entire south wall a collector surface.[19] Figure 7 shows how the roof reflector system works.

Figure 6

Homebuyers Total Annual Cost
(at 10% mortgage and constant energy prices)

	O	E	S^1	S^2
Initial Capital Cost	$2300	$2300	$4400	$7300
Interest Cost (20 Years)	3030	3030	5800	9610
Total Capital Cost	5330	5330	10200	16910
Average Annual Capital Cost*	267	267	510	846
Average Annual Operating Cost**	1115	1274	482	482
Average Annual Total Cost	1382	1541	992	1328

* the part of yearly mortgage payment which goes for heating and cooling
** yearly energy costs

The threat that new construction on adjoining land might block sunlight is a realistic one, especially in urban areas. There has been a longstanding legal debate over a "right to light and air" which American courts, unlike their British counterparts, have refused to recognize.[20] Recently there has been talk of granting such a right by zoning or by legislation.[21] There is a fear among some policy makers that the courts might view such action as an unconstitutional taking of property without compensation. There is also a contention that a "right to light" would discourage construction and thereby slow economic growth. The concurrence of the environmental and energy dilemmas, and the prospects for Zero Population Growth and lower economic growth, may in the future prove to be convincing reasons for a "right to light". Of course, even without this right, residential housing patterns make a considerable amount of solar home construction possible.

Most of the limitations of the solar system boil down to conflicts of savings versus aesthetics or inconvenience. It is likely that many of the aesthetic drawbacks will be ameliorated as the mainstream of the design community begins to work on solar housing. As more solar homes are built, new homebuyers will find their appearances less peculiar, and as energy costs rise, it is going to become more and more expensive not to make the decision to go solar.

Conclusion

Public benefits of solar housing in terms of energy conservation and environmental protection have been recognized for some time. Claims that solar housing is not competitive at its current state of development with oil and electricity have biased many homebuyers. This study indicates that at 1975 energy costs, using any reasonable interest rate, existing solar heating and cooling is not only competitive, but is significantly cheaper over its lifetime than conventional alternatives. As energy costs continue to rise, solar systems will compare even more favorably.

The barriers to solar housing implementation are basically institutional.[22] They include the reluctance of lenders to finance "peculiar" homes, the decentralization of the construction industry, the inability of the 30,000 U.S. building code jurisdictions to standardize building requirements, and the misappropriation of government research efforts for the development of new solar methods rather than the full exploitation of existing solar technology. Perhaps as the savings to solar housing becomes more apparent, the public sector will be encouraged to deal with the remaining obstacles to solar development.

Footnotes

1. Estimates of the costs of pollution in the U.S. vary, but generally range from ten to twenty-five billion dollars annually. See Thomas E. Waddell, *The Economic Damages of Air Pollution,* U.S. Environmental Protection Agency, Washington, D.C., May 1974 and Gerald Garvey, *Energy, Ecology, Economy,* New York, Norton, 1974.
2. Seidel, Plotkin, and Reck, *Energy Conservation Strategies,* U.S. Environmental Protection Agency, May 1973, pp 12-40.
3. Ibid.
4. This is called the Solaris system. Further explanation can be found in Harry E. Thomason, *Solar House Plans,* Edmund Scientific Corp., Barrington, N.J., and Harry E. Thomason, *Solar Houses and Solar House Models,* Edmund Scientific Corp., Barrington, N.J.
5. Thomason, *Solar House Plans.*
6. Thomason, *Solar Houses and Solar Models,* p 9.
7. Holcomb Brothers Heating Co., Elkin, N.C., interview February, 1975.
8. Alan McGinigle, private contractor, Chapel Hill, North Carolina, interview, March 1975.
9. Ibid.
10. James D. Kanak, private contractor, Prince George, Virginia, interview, January, 1975.
11. Ibid.
12. McGinigle, interview.
13. J.S. Doolittle, *Our Future Energy Resources: Part I Solar Energy,* NCSU Energy Information Program, Raleigh, North Carolina, June 1974, p 10.
14. Thomason, *Solar Houses and Solar House Models,* p 13.
15. North Carolina Oil Jobbers Assoc., Gerald P. Mathews, study results, December 6, 1972.
16. University of North Carolina Service Plants, Chapel Hill, North Carlina, March 1975.
17. Ibid.
18. For a discussion of the design criteria essential for utilization of solar thermal energy see generally Farrington Daniels, *Direct Use of the Sun's Energy,* Yale University Press, New Haven, 1964.
19. Thomason, *Solar Houses and Solar House Models,* p 14-15.
20. A landmark decision to this effect is *Parker and Edgarton v. Foote,* 19 Wend. 309, N.Y. Sup. Ct. 1838.
21. See H.R. 11677, 94th Congress, 2d. Sess., introduced by Rep. Joe Moakley (D-Mass.) which stipulated that no state or local zoning or other actions could permit construction "which would obstruct or otherwise interfere with sunlight" necessary for the operation of existing solar structures.
22. For a general discussion regarding the institutional barriers to solar housing see Ernest Ambler, "A Discussion of a Research Program", *Solar Energy Research: A Multidisciplinary Approach,* Staff of the House Committee on Science and Astronautics, 92nd Congress, December 1972, series 2 pp 64-84.