THE ECONOMICS OF A RESIDENTIAL SOLAR SPACE HEATING SYSTEM

by

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ABSTRACT

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The application of a solar space heating system to a model residential home and the probable financial consequences are investigated. Beginning with fundamental solar insolation and climatic data, monthly estimations are made of the solar energy that is available to a collector array. A simple design of collection, storage, and distribution utilizes the solar energy for space and water preheating, thus displacing fossil fuel and electrical energy that would ordinarily be used for these purposes. Values can be assigned to the utilized solar energy that depend upon the displaced fuel prices. The model home and solar system are considered as thirty year investment. To determine the financial advantage or disadvantage of the solar home, a comparison is made to a home of like design but lacking the solar system option. Factors considered in the extra investment in the solar system option are available mortgage terms, inflation, and fuel price trends. The final analysis results in a single column of figures, labelled the financial position, which indicates the relative financial value of the solar home to that of the non-solar home. The financial position and the ratio of the solar system cost to the annual dollar savings produced aid in determining the relatively best collector array size and slope for the model

solar home. Moreover, a decision can be made upon the sign and magnitude of the financial position as to whether or not the additional investment in the solar system option is advisable under the assumed conditions of inflation and fuel costs.

ACKNOWLEDGEMENTS

I would like to express my deep and sincere thanks to Dr. Duane F. Rost for his guidance and patience throughout the development of this thesis from its conception to its final form. Also I would like to thank Gene Ameduri whose encouragement meant much over the many months of writing that culminated in this thesis.

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LIST OF SYMBOLS

SYMBOL	DEFINITION	UNITS OF REFERENCE
A	Ordinate intercept of the solar Panel efficiency plot	none
b	Angle of tilt of solar panel from the horizontal	degrees of arc
B	Extinction coefficient of atmosphere	none
C	Clearness factor of atmosphere	none
E_g, E_{in}	Energy density per day of solar radiation at the solar panel	Btu/ft^2
E_{g1}, E_{g2}	Direct and diffuse components of Energy density at solar panel	Btu/ft^2
E_{hor}, E_{hor1}, E_{hor2},	Total, direct and diffuse components of the mean daily solar radiation on a horizontal panel	Btu/ft^2
E_{out}	Energy output per day per square foot of solar panel	Btu/ft^2
H	Hour angle of the sun	hours
H_o	Hour angle of the sun at sunset	hours
H_{ob}	Hour angle of the sun at grazing incidence to the solar panel	hours
H*	Either H_o or H_{ob}, whichever applies	hours
i	Angle of incidence of direct solar radiation upon solar panel	degrees of arc
K	Thermal conductivity	Btu/ $(ft^2\text{-}hr/in)$
L	Latitude of the solar panel	degrees of arc
% Sun	Percent of mean daily sunshine expected	%

q_i, q_{in}	Intensity of solar radiation at the earth's and solar panel's surface	Btu/ $(ft^2\text{-}hr)$
q_{loss}	Thermal losses of solar panel to the environment	Btu/ $(ft^2\text{-}hr)$
q_{out}	Thermal output of solar panel	Btu/ $(ft^2\text{-}hr)$
q_{peak}	Intensity of solar radiation on upper atmosphere, i.e. at an air mass of 0.	Btu/ $(ft^2\text{-}hr)$
q_s	Solar radiation absorbed by the solar panel	Btu/ $(ft^2\text{-}hr)$
T	Mean daily high temperature	^oF
T_c	Temperature of absorber of solar panel	^oF
T_{in}	Inlet temperature of fluid to solar panel	^oF
u_l	Heat loss coefficient of solar panel	Btu/ $(ft^2\text{-}hr\text{-}^oF)$
U_l	Product of u_l and β	Btu/ $(ft^2\text{-}hr\text{-}^oF)$
z	Zenith distance of the sun	degrees of arc
α	Altitude of the Sun	degrees of arc
β	Ratio of actual thermal collection rate to that if the entire absorber were at the temperature of the inlet fluid, T_{in}.	none
γ	Absorption coefficient of absorber of solar panel	none
δ	Declination of the sun	degrees of arc
η	Instantaneous efficiency of the solar panel	none
η'	Effective efficiency of the solar panel	none
τ	Transmission coefficient of the glass cover plate of the solar panel	none

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CHAPTER I

INTRODUCTION

Present Status of Fossil Fuel Energies

Although seven hundred times the United States' energy consumption is incident upon its land area, less than two percent is ever captured by the photosynthetic processes of plants and subsequently stored chemically as carbon compounds. Geochemical evidence suggests that 28 million tons of carbon from these sources is converted annually into fossil sediments, which after millions of years become our fossil fuels. However, estimates show that over two hundred times the amount deposited is burned as fuel every year. On this basis, the fossil fuels, which today are so important as power sources for American society, are seen to be non-renewable and finite stockpiles of energy.[1]

Historically, America relied on fuel wood for eighty percent of its energy before 1850. Coal soon replaced wood and by the early 1900's supplied over seventy-five percent of the total consumption. Today, nearly three-quarters of the nation's demand is met by petroleum and natural gas, whereas only seventeen percent is supplied by coal. The remainder is met by hydro-electric and nuclear power installations. The evolution of the use of these power sources since 1850 is shown in Figure 1.

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[1]Energy Primer: Solar, Water, Wind, and Biofuels (Fremont, California: Fricke-Parks Press, Inc., 1974), p. 2.

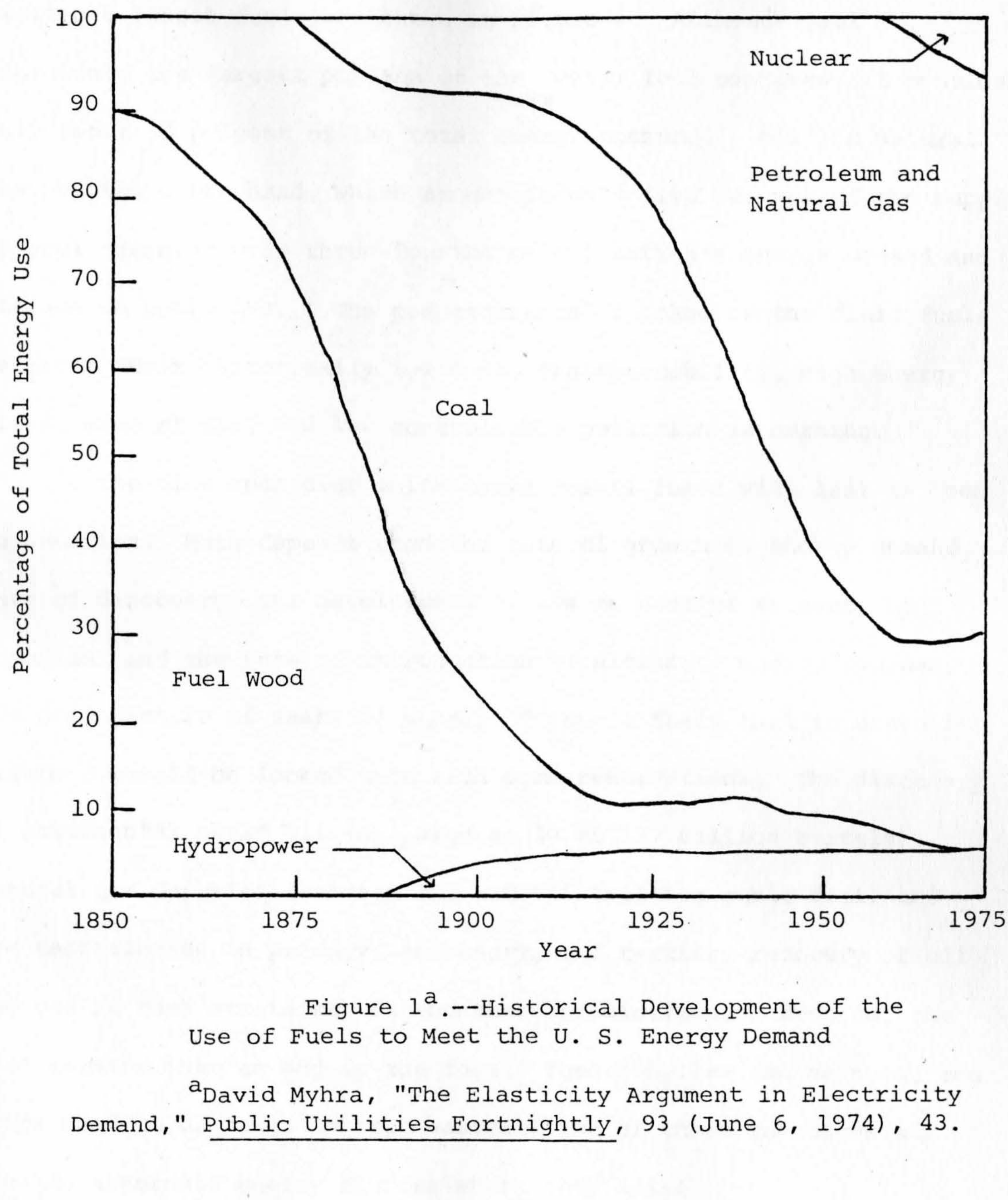

Figure 1[a].--Historical Development of the Use of Fuels to Meet the U. S. Energy Demand

[a]David Myhra, "The Elasticity Argument in Electricity Demand," Public Utilities Fortnightly, 93 (June 6, 1974), 43.

The relative amounts of known deposits of economically exploitable fossil fuels are shown in Figure 2. Although coal represents the largest portion of the fossil fuel energies, it provides only about 10 percent of the total energy consumed. Oil and natural gas, on the other hand, which amount to only five percent of the supply of coal, furnish over three-fourths of the nation's energy demand and will do so until 1990.[2] The preponderance of usage of the fluid fuels reflects their historically low cost, transportability, high energy yield, ease of use, and low controllable pollution in burning.

The time span over which these fossil fuels will last is open to question. Much depends upon the rate of growth of energy demand, rate of discovery, the development of new methods of recovery of deposits, and the rate of introduction of alternate energy sources. The grim picture of years of supply of fossil fuels that is drawn in Figure 3 should be looked upon with some reservations. The discovery of continental shelf oil (as large as 50 to 127 billion barrels), natural gas deposits (between 322 and 655 trillion cubic feet) and new technologies in primary, secondary, and tertiary recovery of oil and gas in rock strata may extend these predictions.[3] Even so, the fact remains that an end to the fossil fuel supplies can be seen, and steps need to be taken to stop wasteful use of these resources and provide alternate energy sources where they exist.

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[2]David Myrha, "The Elasticity Argument in Electricity Demand," Public Utilities Fortnightly, 93 (June 6, 1974), 45.

[3]Vincent E. McKelvey, "World Energy Reserves and Resources," Public Utilities Fortnightly, 96 (September 25, 1975), 29-31.

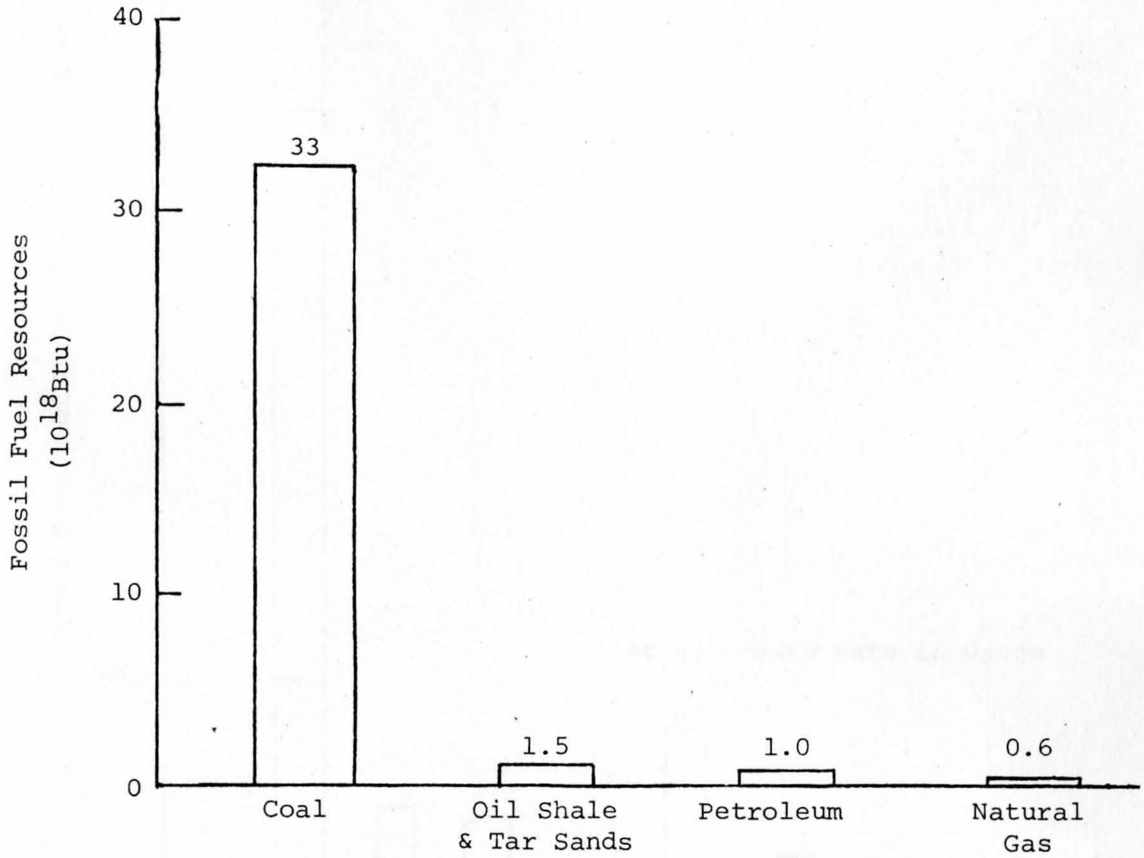

Figure 2[a].--United States' Resources of Fossil Fuels.

[a]David Myhra, "Elasticity Argument in Electricity Demand," Public Utilities Fortnightly, 93 (June 6, 1974), 43.

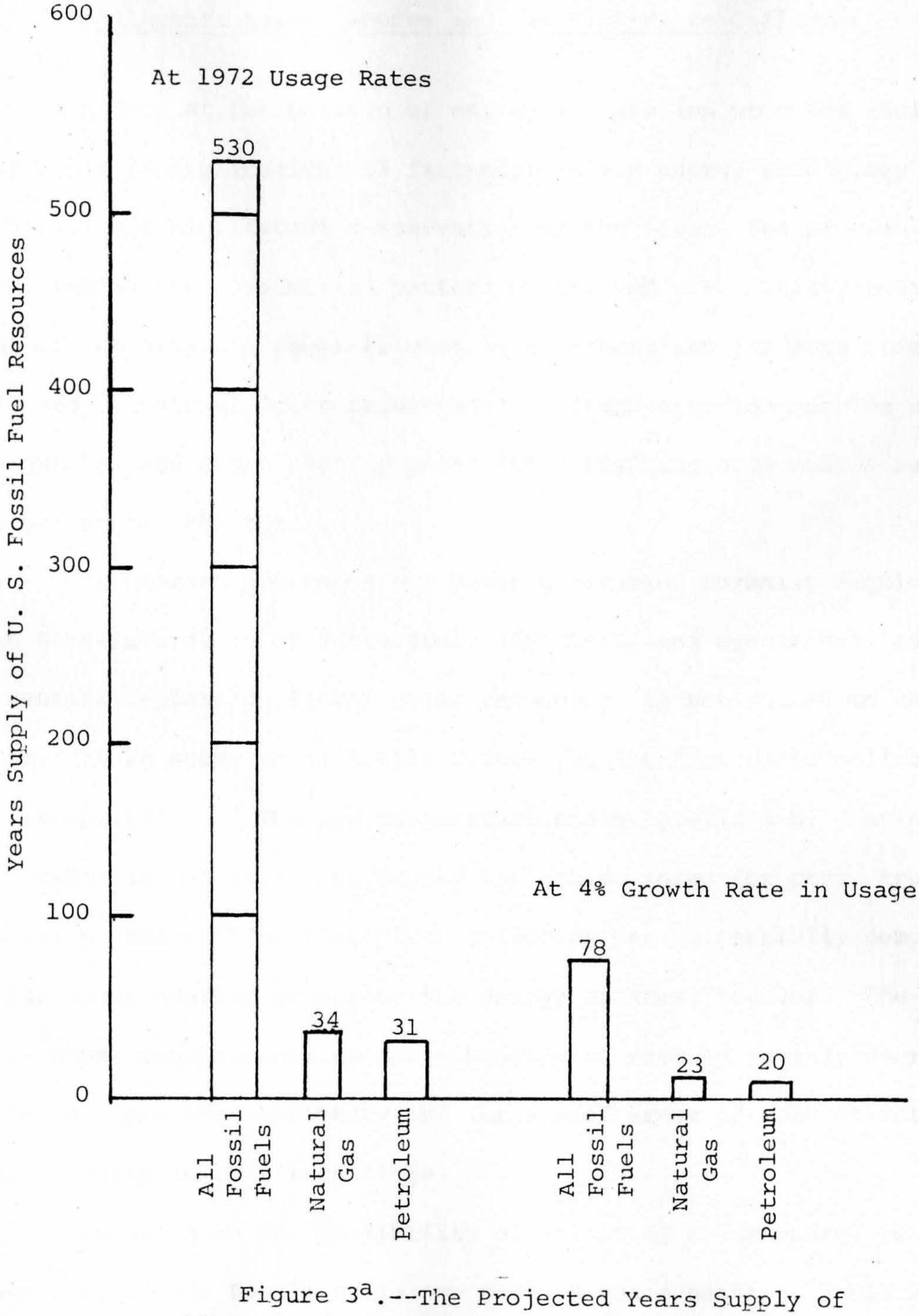

Figure 3[a].--The Projected Years Supply of Fossil Fuels for the U. S.

[a]David Myrha, "The Elasticity Argument in Electricity Demand," Public Utilities Fortnightly, 93 (June 6, 1974), 44.

Alternate Energy Source and the Flat-Plate Collector

A look at the pattern of energy consumption provides insight into possible applications of flat-plate solar energy technology that might allow a significant conservation of the fossil fuels. Table 1 shows the energy consumption pattern by its end use. Thirty-four percent of the nation's power is used by manufacturing for both process heat and industrial power requirements. Transportation gobbles up one-quarter and space heating one-fifth. Lighting uses only a meager two percent of the total.

Industrial processes and power generation normally require high temperatures to be successful, efficient, and economical, and current flat-plate collector solar technology is not suited to these needs. There seems to be little future for the flat-plate collector in transportation. The low temperature energy provided by flat-plate collectors is not suited to supply the motive force for cars, trucks, trains, or ships. The flat-plate collector can successfully compete in the space heating sector of the energy economy, however. The low temperature requirements of space heating of roughly seventy degrees Fahrenheit and the stationary and large roof areas of most structures adapt readily to this technology.

Focusing on the possibility of utilizing solar energy to displace some of the fossil fuels now used in space heating, Table 2 has been compiled to show the distribution of the consumption of fossil fuels and electricity over home, commercial, and industrial space heating use in 1968. The potential exists to reduce the amounts of oil and natural gas now consumed by twenty and twenty-five percent

TABLE 1[a]

1968 U. S. ENERGY CONSUMPTION PATTERNS BY END USE (%)

End Use	Natural Gas	Oil	Coal	Electricity	% of 1968 Total Energy Consumption
Trans-portation	3.1	53.7	0	0.4	24.9
Chemical Feedstock	2.3	10.2	1.1	0	5.5
Process Heat	40.7	9.7	37.3	2.5	26.2
Industrial Power	0	0	0	37.2	7.9
Lighting	0	0	0	9.3	2.0
Misc.	10.3	0.8	0	47.1	13.6
Space Heating	25.8	20.9	7.3	3.5	19.9
Electric Power Generation	17.8	4.7	54.3	-	-
% of Total Consumption by Fuel	26.5	42.1	10.1	21.2	-

[a]G.L. Hauser, "Future Trends in Energy Supply," Public Utilities Fortnightly, 92 (17 January 1974), 26-32.

respectively. Realistically, all of the fossil fuels used for space heating will not be displaced because of the need for auxiliary or back-up systems of conventional space heating when solar space heating is employed, but sizable reductions of fossil fuel use can occur. It is estimated that six million buildings, which amount to 8.8 percent of the total number, could be equipped with solar heating and cooling

TABLE 2[a]

1968 U. S. ENERGY CONSUMPTION PATTERNS

FOR SPACE HEATING (BTU x 10^{12})

	Space Heating Use		
	Home	Commercial	Industrial
Natural Gas	3236	1209	600
% of All Natural Gas Consumed	16.5%	6.2%	3.1%
Oil	2988	2405	200
% of All Oil Consumed	11.2%	9.0%	0.7%
Coal	0	568	400
% of All Coal Consumed	0	4.3%	3.0%
Electricity	451	0	0
% of All Electricity Consumed	3.5%	0	0

[a]G. L. Hauser, "Future Trends in Energy Supply," Public Utilities Fortnightly, 92 (January 17, 1974), 28-30.

systems by 1990 and sixteen million, 23.1 percent of the total number, by 2000. This could amount to a savings equivalency of ninety-eight million barrels of oil in 1990 and 233 million barrels of oil in 2000.[4] The National Science Foundation studies indicate that 1.5 trillion

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[4]Solar Energy Intelligence Report, November 15, 1975, p. 133.

kilowatt-hours of electricity, which amounts to the total generating capacity of the U. S. in 1970, could be saved annually by 2000. It is possible that a total of 5.9 quadrillion Btu's supplied by solar energy could be in use by 2000 to supply space heating and cooling.[5]

The Solar Energy Market

In operation in 1976 in the United States were roughly one hundred buildings that employed solar energy systems for space heating. Globally there are in excess of a million solar powered water heaters of various types. By the end of 1977, there could easily be one thousand structures incorporating solar energy for climate control of both heating and cooling, and by the year 2000, projections indicate the potential of forty million buildings utilizing the sun's energy. Considering only the residential domestic construction picture, it is estimated that over one-half of the homes built after 1985 will be equipped with solar heating and cooling capabilities. This amounts to some one million houses yearly.[6]

The economic consequences of the blossoming of the solar age are astounding. At the 1976 Solar Energy Press Conference of the Aluminum Association, Dr. Charles Alexander reported that the solar energy industry's marketing volume could reach $30 billion per year by 1980 and be at $40 billion per year by 2000.[7] The number of manufacturers of flat-plate collectors, for example, rose from 39 in

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[5] Solar Energy Intelligence Report, May 10, 1976, p. 77

[6] Solar Energy Intelligence Report, April 26, 1976, p. 66.

[7] Dr. Charles Alexander, Solar Energy Press Conference of the Aluminum Association, April 22, 1975.

1974 to 102 in 1975, which amounts to a near three-fold rise, and the total production during the second half of the year of 1975 was 44,794 square feet of collector.[8] Should the market grow as predicted, the demand for collectors and associated hardware would increase significantly which in turn could create 12,500 new companies and employ in excess of a quarter of a million workers.[9]

A Solar Heated Building

The term "solar heated building" is a general term that is often loosely applied to any structure designed with the sun in mind. Here it shall refer to a structure that employs a collector of solar radiation, reservoirs or storage facilities for the collected energy, and the controls and ducting or piping that allow for the required distribution of heat to the various places of need. Often when speaking of solar space heating, the additional word of cooling is heard. The technology of solar air conditioning is not many years away. The most intense sun occurs at the time of greatest need for air conditioning, whereas the opposite case of least sun and greatest need occurs for space heating. In the near future it is probable that solar units will be used that will both heat and cool the structure, thus utilizing the solar energy equipment throughout the year and improving the economic attractiveness.

The total system of solar heating and/or cooling is often referred to as "solar climate control" and consists of these basic

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[8] Solar Energy Intelligence Report, March 1, 1976, p. 34.

[9] Alexander, p. 1-2.

components: solar collectors, storage, back-up system, and auxiliary equipment. A solar collector is typically the flat-plate configuration: a glass enclosure that permits insolation on a blackened surface, transforms the incident radiation to thermal energy, and has a circulating fluid removing the accumulating heat. The thermal storage or reservoir is generally a material which has a high specific heat or heat of fusion or other capability to store thermal energy from the collectors and to release thermal energy upon demand. The back-up or supplementary energy systems is a conventional fossil fuel or electrical system that can meet the heating/cooling demands should the solar energy collection and storage system fail to do so. By its ability to supply added amounts of heat, the back-up system prevents the storage and collector designs from being unreasonably large. The auxiliary equipment includes the ductwork, piping, wiring, thermal sensors and assorted electronics, fluids, valves, motors, etc. that is required for interfacing and efficient operation of the system. In the future, a heat-actuated air conditioner may be added to this list in order that the solar energy collected during the summer months might be utilized for air conditioning.[10]

Solar Heating Systems Cost Factors and Incentives

The various components of a solar heating system need to be chosen wisely for the most economical utilization of solar energy so that it might be competitive with conventional heating systems. Such factors as geographical location, climate, building size and style,

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[10] Peter E. Glaser, "Solar Climate Control: Evaluating the Commercial Possibilities," ASTM Standardization News, 3 (August, 1975), 9.

and availability and cost of conventional fuels are considerations in choosing a particular system. No one design can be considered exclusively for all applications.

The economic push to solar heating systems is strongest where the cost of the thermal energy produced by these systems is low compared to the cost of conventional fuel energy it displaces. The cost of the solar system heat energy is minimized by low amortization rates, low capital costs, favorable climatic conditions, balanced continuous heating loads, and by sound design and construction of the system. The comparative costs of both fossil and electrical energies are determined by the local fuel prices and efficiencies of use. In January 1974, oil and natural gas were the most competitive cost energies overall. This has been changed by the price increases of oil, natural gas and electricity, and by the moratorium on natural gas service placed upon new residential consumers in northeastern Ohio since November 1975. The cost of heat energy from an operating solar system will become more and more competitive as the conventional fuel prices rise because its cost will not rise after installation. It is reasonable to expect the energy cost incentives for the consideration of investment in solar energy systems should grow stronger as the energy demand increases in the U. S. and as the prices for the dwindling conventional energy supplies rise.[11]

In addition to the dollar-and-cents incentives to move to solar energy are those concerning the environment: the equipment necessary for harnessing solar energy for space heating can be ecologically

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[11]Ibid., p. 9-10.

harmless in operation; there is no air, water, or thermal pollution; it produces no radioactive waste materials; it is an on-site energy form requiring no long distance transmission lines or fuel transportation equipment; it uses a renewable energy source of inexhaustible supply; it utilizes space existing overtop building roofs, not needing the land area necessary for other energy production methods; it can be adapted to satisfy the aesthetic considerations of architecture.[12]

With the establishment of the Energy Research and Development Administration (ERDA) in 1975, came the hope of large Federal grants to support solar technology development. Over one billion dollars will have been spent on solar energy research by the year 1980 if current plans are followed. Additional impetus is provided by the Solar Heating and Cooling Demonstration Act of 1974 and the Solar Energy Research, Development, and Demonstration Act of 1974. The total monies appropriated by these two bills amount to roughly 150 million dollars appropriated until 1980.[13] Both of these acts, as their names imply, have as their goal to demonstrate to the public and to the industrial sector of the economy the great potential that lies in the area of solar heating and cooling of buildings. A report commissioned by ERDA was written by the General Electric Company in 1976 which suggested that for demonstration purposes 625 residential dwellings and 175 commercial structures in various locations and of various designs should be constructed with the money allotted for such demonstrations.[14]

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[12] Ibid., p. 11.

[13] Heliotherm (unpublished EE 971 Class Project, Youngstown State University, 1975), p. 3-13 - 3-15.

[14] Solar Energy Intelligence Report, May 10, 1976, p. 77.

Efforts to stimulate the consumers of solar climate control systems have come in the form of proposed subsidies and tax credits and low interest, long-term loans for the buyer. Booz, Allen, and Hamilton, management consultants, have reported that the principal barrier presented to the potential consumer is the initial high cost and that this problem should be mitigated by direct subsidies to the buyer. Subsidies given to the manufacturers result in dilution of their effect and are subject to favoritism. Government regulation suffers from bureaucratic entanglement and political wrangling that affects the value of the subsidy presented to consumers. Subsidies given directly to the consumer have an immediate effect of encouraging investment, and industry yields much faster to a market pull of possible profit than a government push of a possible subsidy.[15]

The basic difference between the two proposed plans of incentives lies in the fact that the proposed loans deal with the front-end costs of providing capital at the time of purchase of solar equipment. Proposed tax credits on the other hand give relief at the year's end making them a more distant incentive. From the government's point of view, tax credits would be harder to control and would be more expensive since credits amount to gifts. Loans require repayment, but with the administration costs and the proposed low yield loan terms, it is somewhat cloudy as to their actual cost compared to the tax credits. In any event, Congress has seen the public's desire for incentives of various sorts, and soon legislation of the kind mentioned above might be passed into federal law.

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[15] Solar Energy Intelligence Report, April 26, 1976, p. 68.

State legislatures have also recognized the need for government assistance for the consumer of solar energy products. The Aluminum Association has compiled a list of 26 states that have significant solar legislation either pending or passed into law. The incentives are in the form of income tax deductions, property tax credits or exemptions for part of all of the solar energy system, income tax exemptions on the sale of solar energy products, state financed loans for solar energy systems, building code requirements of adaptability of new housing to solar heating systems, and various research and development monies for solar energy technology. Of the sixty-four bills proposed, sixteen have been signed into law as of May 1976.[16]

A Brief History of Solar Space Heating Applications

The application of solar energy to residential space heating and cooling has a recent history. The first well-documented design and study of a solar space heating system was done by G. L. Cabot of the Massachusetts Institute of Technology in 1939. The MIT Solar House No. 1, as it was called, was a one story, two room laboratory of roughly five hundred square feet of floor space. Mounted on the roof of thirty degree slope was 408 ft^2 of blackened copper sheet covered by three panes of glass, which served as the flat-plate collector. Water circulated through the collector and the sensible heat was stored in a 17,400 gallon tank insulated and buried below the laboratory. Tanks of this size were later proved far too large.

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[16]Report to AAMA Members, Aluminum Company of America, May 26, 1976.

This structure was demolished in 1941. MIT Solar Home Nos. 2, 3, and 4 were built, tested, and dismantled over the years 1945-7, 1949-53, and 1959-61 respectively. Each had incorporated improvements in design and technology. Though Solar Home No. 4 was abandoned because of maintenance problems, during its operation, it was reported to provide 57% of the home's heating needs over the second winter of operation. It had 1450 square feet of floor area, 640 square feet of collector, a 1500 gallon storage tank, and water was used as the circulating fluid.[17]

Over the span of years from 1940 to 1960, there were many attempts at constructing efficient and economical solar homes. In Dover, Massachusetts, the Telkes-Raymond-Peabody House had a reported 100% of its space heating requirements met by the solar heating system for the first heating season. Air was used as the circulating fluid. The collector consisted of 720 ft^2 of vertical wall of blackened galvanized plate with two glass covers. Storage was handled by latent heat of fusion of twenty-one tons of Glauber's Salt.[18]

The U. S. Forest Service Desert Grasslands Station was located 30 miles south of Tucson, Arizona. The solar space heating system was over designed and required no back-up system. Air was circulated through 315 square feet of collector and heat stored in 65 tons of 4-inch diameter rocks in a bin next to the house. The system provided a modicum of space cooling by using the cold night air and the

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[17]Richard C. Jordan, "Solar Energy Powered Systems--History and Current Status, "ASTM Standardization News,3 (August, 1975), 14-15.

[18]Phillip Steadman, Energy, Environment and Building (Cambridge: Cambridge University Press, 1975), p. 125.

night sky radiation to cool the air that nocturnally passed through the collectors. This house, however, proved to be uneconomical and aesthetically unacceptable and was razed in 1956.[19]

The feasibility of using air as the fluid in flat-plate collectors was shown by Dr. G. O. G. Löf in 1944 at Boulder, Colorado. Löf constructed a 1000 square foot, five room bungalow, mounted 463 square feet of collector at a pitch of 27 degrees, for storage used a bin with seven cubic yards of gravel, and managed to get twenty to twenty-five percent of the space heating needs from the sun. In 1958 he built a second house in Denver, which in addition to providing space heat, also permitted the pre-heating of the domestic hot water. Twenty-six percent of the space and water heating needs were gleaned from the sun, amounting to $80 per year of natural gas. The home is in current operation.[20]

H. E. Thomason has built four solar heated homes in the Washington, D.C. area during the period of 1959 to 1963. All utilize water to collect heat as it runs down the sloped roof over a blackened metal surface and is collected in a trough at the lower edge. Water is stored in a tank surrounded by stones. Air circulates through the rock bed, picking up heat, and distributing it to the home. His 1959 home received 95 percent of space heat from the sun.[21]

The idea of Jordan and Threlkeld of employing a heat pump to take advantage of the low temperature heat provided by solar energy

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[19]Jordan, p. 15.

[20]Steadman, pp. 126-7.

[21]Ibid., pp. 140-1.

was used in 1956 by Frank H. Bridgers. The Bridgers and Paxton office building in Albuquerque, New Mexico, had water pumped through flat-plate collectors on its roof then gathered in a 6000 gallon tank beneath. A water-to-water heat pump was able to operate with a coefficient of performance of 4.5 with a fifty degree temperature differential to supply space heating to the building. The system was discontinued in 1962 and now is being studied by Pennsylvania State University.[22]

One of the most advanced solar homes to date is the University of Delaware's Solar One, which was constructed by the University's Institute of Energy Conversion in 1973. It not only uses the solar thermal flat-plate collector technology but also experiments with solar photo-voltaic cells for electrical conversion in the collector design. Eutectic salts are used for primary and secondary storage. A heat pump connects the two bins to provide the thermal storage flow from one to the other. Lead acid batteries are the reservoir for any electrical energy collected. In this manner, the storage potentials amount to 1.2 million Btu and 20 kilowatt-hours respectively. The house is designed to obtain 80% of its power needs from the sun.[23]

There are new designs for solar homes being developed constantly. Many are submitted to ERDA in hopes of obtaining government funding. Others appear in the various popular magazines and journals. Needless to say, it is clear that solar energy is a viable energy source for residential use and that progress is accelerating in solar energy technology and design.

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[22]Jordan, pp. 15-16.

[23]Steadman, pp. 151-4.

Statement of the Problem

The analysis of the investment in a solar heating system is based upon the supposition that the buyer is to keep and operate the solar system for a period of thirty years. The financial standing of a solar home in comparison to a conventional home at the conclusion of these thirty years is the yardstick used to measure the advisability of the investment. The considerations that are included in the financial position are factors of economics, meteorology, and engineering design. The functional relationship of the financial position to the parameters of collector size and slope, system cost and design, thermal load of the home, system efficiency, levels of solar insolation, mortgage terms, fuel price increases, rates of inflation, and the year of use is complex.

Factors such as heat loss and thermal load of the home, collector efficiency, outside ambient temperatures, and solar insolation are able to be estimated from available data. Other factors are more uncertain. These include inflation and fuel prices over the course of thirty years. The opinions of economists vary about inflation rates even over the next five or ten years, and their opinions of fuel prices are rendered speculative by possible Arab oil embargoes and price hikes which would affect future fuel oil prices. Still other factors are influenced by the potential buyer himself. An example is the mortgage terms which for the same buyer would differ among mortgage institutions. These variable factors must be examined to determine which have the most effect on the financial position. If one should significantly overshadow the rest, it can be taken to be the most influential. The remaining factors can be given reasonable fixed values and the financial position be reckoned as depending upon only the one most significant factor thus determined.

The most favorable collector size and slope can be determined by consideration of two results. An indication of the proper configuration can be found by finding the minimum of the ratio of solar system cost to the annual expected fuel savings. The solar system cost is related to the array size. The more complex result is to examine the financial position of the various collector configurations after thirty years and locate the possible maximum value under the assumed conditions. This array size and slope in this case are a function of the most significant variables as noted before. In either case, extrema should exist due to the fact that ever larger array sizes reach a point when they can no longer return correspondingly larger amounts of energy savings. At this point the investment of more money produces less than offsetting returns in savings, and the ratio of cost to savings should rise and the financial position should decrease. If the two determined configurations differ, a judgment based upon financial and engineering considerations will be made to choose between them.

The potential investor must weigh many factors before making the investment in solar. For example: after thirty years, the solar home's financial distance ahead or behind the other possible investment of buying a conventional home; at what point, if any, the solar investment acts to provide out-of-the-pocket savings and not just aids in the reduction of the larger mortgage payment; the average amount of money that the system has saved or cost the investor over the course of thirty years; after thirty years, the total value of the solar system that if liquidated would be realized by the owner; and the length of time expected until the solar home value out paces the conventional rival home.

Such considerations affect the economic attractiveness of the solar home. The determination of dollar values provided by the solar system is carried out in the following pages. The final goal is to be able to look at one figure, called the financial position, and decide if, under the assumed circumstances, the investment in the solar system is advisable. This financial position is a measure of the dollar difference in investment that exists between the buyer of the solar home and a buyer of a conventional home of the same type. The inter-relationship of the factors is complex, but with reasonable and realistic assumptions the problem is made tractable.

Setting this analysis apart from others is the inclusion of items not heretofore considered: income tax credits on the interest paid toward the mortgage loan; calculations of annual dividends dependent upon size of mortgage payment, inflation rates and fuel prices; the inclusion of equity values of the investment in solar as the mortgage is amortized; the determination of the financial standing at the end of thirty years of the solar home owner and of the comparative position of the conventional home owner. This analysis with computer assistance enables one to input likely values for the variables, if different from the ones chosen here, and by looking at a single column of figures, to decide with a measure of certainty whether or not investment in solar is indicated. By this means, a prospective solar home buyer can select probable inflation rates and mortgage terms and see their consequences; this flexibility is important due to the differences of opinions of economists in their predictions of the economic future. The buyer, whose money is ultimately spent for the solar option, can obtain his own estimate of the financial future of his investment and make an informed decision.

CHAPTER II

METHOD

Model Home Investigated

The model home considered in this analysis is a two-story dwelling of approximately 1550 square feet of floor area. It can be assumed to be of similar construction and design as that of the Bryant Model Home of Stanjim Construction Company of Hubbard, Ohio. This model can be found in the Stanjim Meadowlands Development in Hubbard, Ohio.

A simple diagram of the basic components of the solar heating system is shown in Figure 4. The storage acts as a heat exchanger, storing the heat delivered by the collector array and releasing the stored energy to the home when needed. This particular design of thermal collection and storage of solar energy is planned to be both effective and simple. It demonstrates the extent to which a very basic and easily conceptualized solar heating design can be utilized to help meet the home space and water heating needs.

The peak of the house runs on an east-west line, and the south facing roof is available for the mounting of collector panels. The solar panels turn the sun's radiant energy into thermal energy by heating the panel's blackened surfaces called absorbers. The system is designed to use air as the circulating fluid to transport the heat energy. The individual collector panels are connected to the system in a thermal-parallel manner. This is to say a common input duct runs

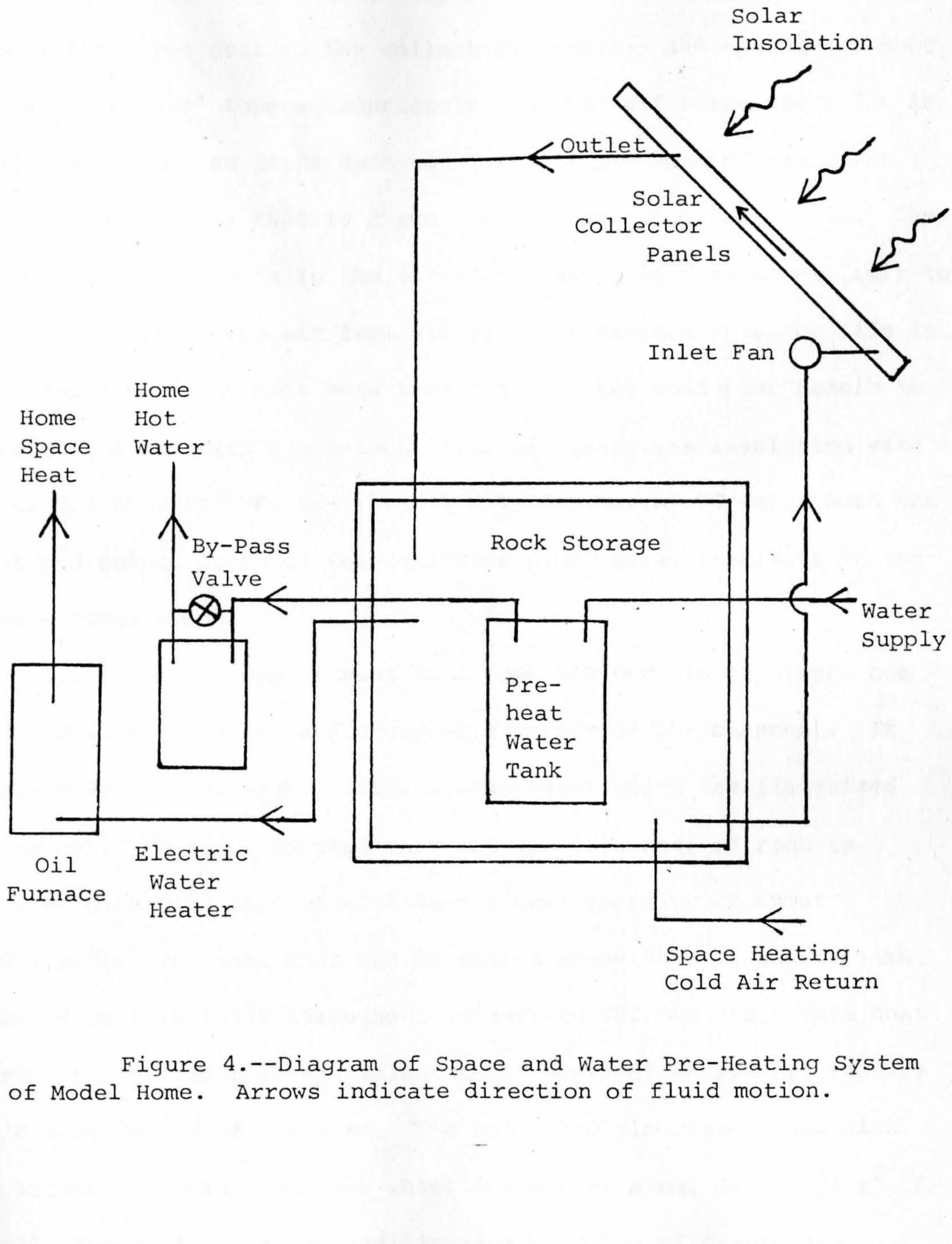

Figure 4.--Diagram of Space and Water Pre-Heating System of Model Home. Arrows indicate direction of fluid motion.

the length of the roof along the collectors' bottoms, and a common output duct along their tops. Flexible wire-reinforced plastic joints connect the input duct to the collectors' bottoms and the output duct to the collectors' tops appropriately. A one-half horse power fan is installed inside the input duct not far from the base of the first panel and forces air that is drawn from storage into the panels. The air cooled fan motor is in the air stream and places an upper limit to the temperature of the air from storage if a reasonable motor life is to be expected. The duct work that connects the collector panels to storage is lined with a one-inch layer of fiberglass insulation with a K of 0.2 Btu/(ft^2-^{o}F/inch) or 3.2 x 10^3Joules/(m^2-^{o}C/cm). Both the input and output ducts of the collector panel array terminate in the storage compartment.

The storage compartment is a cement block bin of dimensions 11 ft. x 11 ft. x 8 ft. and occupies a corner of the basement. It contains 23 tons of washed river bottom rocks which are fist-sized and smooth. If it is assumed that the specific heat of rock is 0.2 Btu/^{o}F, the 23 tons of rock have a heat capacity of about 9200 Btu/^{o}F. The heat that can be stored above 70^{o}F if the temperature of rock is 155^{o}F throughout amounts to 782,000 Btu. This heat energy is approximately equivalent to 27 hours of an average January day's heat demand of the home. The walls and floor are lined with two inches of styrofoam block which has a K of about 0.2 Btu/(ft^2-^{o}F/inch). The ceiling has an additional six inches of fiberglass batting. This insulated enclosure should not lose more than 5000 Btu/hr on the coldest days expected when its contents are charged to a temperature of 155^{o}F.

To pre-heat the domestic water supply, a 120 gallon galvanized steel tank is placed in the bin and surrounded by the loose rock. Water enters this tank at the temperature of ground water, about 50°F.[24] The walls of the tank in contact with the surrounding rock allow for adequate heat transfer from the rock to the water within. Hence the water is brought up to the ambient temperature of the rock of storage, that is to say pre-heated. The outlet pipe of the tank is connected to the water heater in the basement. The effects of pre-heating the water are two-fold. First, it saves energy by raising the water temperature somewhat, allowing the water heater to expend less fuel in heating the water the additional number of degrees to the desired temperature of use. Second, the hazards of thermal shock of cold water entering the hot water heater's tank resulting in sudden contraction and possible breakage of its glass liner are reduced. The fact that the water is pre-heated before it enters the hot water tank should prolong the life of the water heater that otherwise might suffer a glass liner break and failure. It is quite possible that in the summertime the temperature of the water in the pre-heating tank could reach 155°F. In this case, if this equals or exceeds the temperature of normal use of the hot water, the water heater may be avoided altogether by means of a valve that allows the pre-heated water to by-pass the water heater and go directly to the home.

The rocks of storage are heated by air that is warmed in the collectors and drawn through the output duct to the top of the storage bin. As this air passes down through the interstices of the rock pile,

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[24] Ground Water and Wells (St. Paul: Edward E. Johnson, Inc., 1966), p. 12.

the rocks are heated. From the bottom of storage, the air is cycled back to the collectors via the input duct. The fact that the warm air cools as it travels down through the storage bed means that temperature stratifications can occur in the rock. A temperature difference of 20 or 30 degrees may exist from the warmer top layers to the cooler bottom layers of storage rock. With this in mind, thermal sensors are placed at the bottom of the storage rock and on the back of the absorber of a collector panel. When the blackened absorber obtains a temperature of fifteen degrees Fahrenheit higher than the air at the bottom of storage, the input duct fan is actuated to circulate the air through the collectors and storage. When the temperature difference falls to $3^{O}F$, the fan turns off, thereby stopping the forced circulation of air. In this manner, the fan is allowed to run only until the temperature at storage bottom reaches a pre-set limit, whereupon the fan turns off. The top of storage may be at higher temperature due to stratification.

The temperature of the air at the bottom of storage is essentially the temperature of the air entering the collectors, and likewise, the air at the top of storage is the temperature of the air leaving the collectors. The probable maximum temperature delivered from the collectors is estimated at $175^{O}F$ under normal operating conditions. The storage wall insulation behind the plywood facing becomes unstable at $180^{O}F$, and the collector insulation at $250^{O}F$. The fan motor is air-cooled and puts an upper limit on the air of the input duct for a reasonable motor life. These constraints limit the temperature at the bottom of storage to $155^{O}F$ with the possibility of other upper layers of storage reaching a temperature of $175^{O}F$ or so.

The home space heating cycle is controlled by a thermostat located on the first floor of the home. If the house temperature as detected by the thermostat falls below $68^{o}F$ ($20^{o}C$), the blower of the furnace is actuated. The result is the circulation of the air from the top of storage, i.e., the warmest air available, through the furnace to the home and back to the bottom of storage. As the air passes upwards through the storage rock, it is heated. Upon reaching the top of storage, the air repeats the cycle. At this time, the burner of the furnace is still off. If the home reaches thermal equilibrium before the temperature falls below $66^{o}F$, this mode of operation continues. If the temperature rises to $68^{o}F$, the blower is turned off. However, if the temperature should drop below $66^{o}F$, the burner of the furnace is turned on in addition to the blower. The burner now heats the air an additional amount as it passes through the furnace. The furnace now operates in the conventional manner. The fact that the air entering the furnace is pre-heated by its passage through storage can ease the burden on the furnace burner, prolonging its efficient operation and saving fuel at the same time. The burner and blower remain on until the temperature sensed by the thermostat reaches $69^{o}F$, whereupon they both shut off. In this manner the home is kept near $68^{o}F$.

<u>Calculation of Available Energy from the Sun</u>

The following procedures can be simulated on the IBM 360 Computer at Youngstown State University. The Fortran IV program is in two parts which can be found in the Appendix. These programs incorporate some modifications in already existing programs used at Youngstown State University. The main program calculates the heat energy output of the solar system design, the expected fuel cost savings, and the ratio of the cost of the solar heating system to the amount of money that can be expected to be saved each year by its operation. The subroutine using the calculations made in the main program determines the buyer's financial position in regard to the investment in the solar heated home on a yearly basis. It makes a comparison between the solar home buyer and the conventional home buyer over the course of thirty years, and the difference in relative worth of their possible assets relating to their respective homes is calculated. The computer analysis was done at the Youngstown State University Computer Center.

Terrestrial Insolation

As the sun's rays penetrate the atmosphere of the earth, they are subject to many physical phenomena. The ultra-violet radiation lying below the 0.3 micron wave length is absorbed by the ozone of the upper atmosphere, and the infra-red radiation lying above the 2.6 micron wave length is absorbed by the water vapor in the lower atmosphere. Between these two cutoff points, there are many absorption bands characteristic of the other constituents of the atmosphere, carbon dioxide being a major one. A further development is the scattering of some of the incoming solar radiation by the dust particles and molecules of the atmosphere. This scattered radiation is primarily in the blue portion of the visible spectrum and results in the blueness of a clear sky. This is the diffuse component of the solar radiation. The portion of the sun's rays not scattered is referred to as the direct component of the solar radiation.

The collimated nature of the direct component permits straight forward calculation of the energy density it produces at ground level. The diffuse component as a result of its non-collimated nature presents a more difficult problem for its intensity is not uniform over the sky but depends upon the sun's position, the degree of cloudiness, the albedo of the surrounding terrain, and the atmospheric conditions. The separation of the ground level solar energy density into the direct and diffuse components is desired for the simple reason that the energy densities of the components at the panel are present to differing extents depending upon the panel's tilt from the horizontal.

The necessary data for the calculation of the direct and diffuse components include the mean daily solar radiation and the mean percentage of possible sunshine found in the Weather Atlas of the United States,[25] the mean monthly extra-terrestrial solar radiation intensities, atmospheric extinction coefficients and clarity factors found in the ASHRAE Handbook of Fundamentals.[26] Some of the pertinent data is reproduced in Harnessing the Sun by Keyes.[27] The bulk of the data is given in terms of mean monthly values. Therefore twelve data points that are mid-month values are used as representative of all the days of the month. The data of mean daily solar radiation energy densities are given in langleys or gram-calories/cm^2. The conversion

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[25] U. S. Department of Commerce, Weather Atlas of the United States (Washington: Government Printing Office, 1975), p. 198 and p. 217.

[26] American Society of Heating, Refrigeration, and Air-Conditioning Engineers, ASHRAE Handbook of Fundamentals, 1972 (New York: ASHRAE, Inc., 1972), pp. 387-394.

[27] John Keyes, Harnessing the Sun (New York: Morgan and Morgan, Publishers, 1974).

factor from langleys to Btu/ft^2 is 3.687 and to Joules /m^2 is 4.187 x 10^4. The analytic procedure for obtaining the amount of mean monthly solar energy available to the collectors is based upon that found in the ASHRAE Handbook of Fundamentals (pp 387-394), ASHRAE Handbook 1974 Applications (pp 59.1-59.20), and Harnessing the Sun.

The solar panel is assumed to be located in Youngstown, Ohio, which is adjacent to and south of Hubbard. There is no data available for the mean daily insolation and percentage of possible sunshine for Youngstown, however. The nearest and most similar larger city with recorded data is Cleveland, though its climate is affected somewhat by the presence of Lake Erie. The latitude of Youngstown is 41.27^o, which does not differ significantly from that of Cleveland, located about 60 miles to the northwest. Of the Cleveland data used, it should be mentioned the data of the mean percentage of possible sunshine is of questionable accuracy because of its manner of collection, which calls for an observer's estimation of cloud cover. Still it remains a necessary datum and is used in spite of this flaw.

To determine the sun's path in the sky for the mid-month date, the declination of the sun is needed. Declination is to the astronomer what latitude is to the geographer. If the parallels of latitude were projected outward upon the blackened inverted bowl of the night sky, the resulting celestial lines would be parallels of declination. The declination of the sun is the number of degrees of arc the sun is north or south of the equator, or the 0^o line. If the measurement is positive, the sun lies in the northern hemisphere; if negative, it is in the southern. The earth's axis is tipped about 23.5^o from the normal to the ecliptic, the plane of the earth's orbit. The earth's orbit is elliptical, though very nearly circular. As the earth revolves about the sun, the declination of the sun changes from a $+23.5^{\circ}$ on June 21 to a -23.5° on December 21. If the days are numbered consecutively from January 1, the following formula gives the declination of the sun (δ) for the days of the year to a good approximation.[28]

$$\delta = 23.5^{\circ} \cdot \sin \left[(\text{day number} - 80) \cdot 360^{\circ}/365 \right]$$

As for the mid-month data, the fifteenth of January would be numbered as 15; February 15 as 43; March fifteenth as 74; and so forth.

Figure 5 is a pictorial representation of a solar panel at latitude L tipped at an angle b with respect to the horizontal. The angle i is the angular measure of the arc between the normal of the surface of the panel and the straight line that joins the center of the sun's disk to the center of the panel's surface. The following trigonometric expression gives the value of the expression cos(i) in terms of known quantities for a south facing panel:[29]

$$\cos(i) = \cos(L-b) \cdot \cos(\delta) \cdot \cos(H) + \sin(L-b) \cdot \sin(\delta)$$

For a south facing panel, the angle of incidence of the sun's direct radiation is symmetrical about solar noon. Although considerations of cloudiness, geographical obstructions, and temperature variations over the day are factors in the orientation of the panel for

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[28] B. J. Brinkworth, Solar Energy for Man (Great Britain: The Compton Press, Ltd., 1972), p. 32.

[29] A. M. Zarem and Duane D. Erway, eds., Introduction to the Utilization of Solar Energy (New York: McGraw-Hill Book Co., 1963), p. 44.

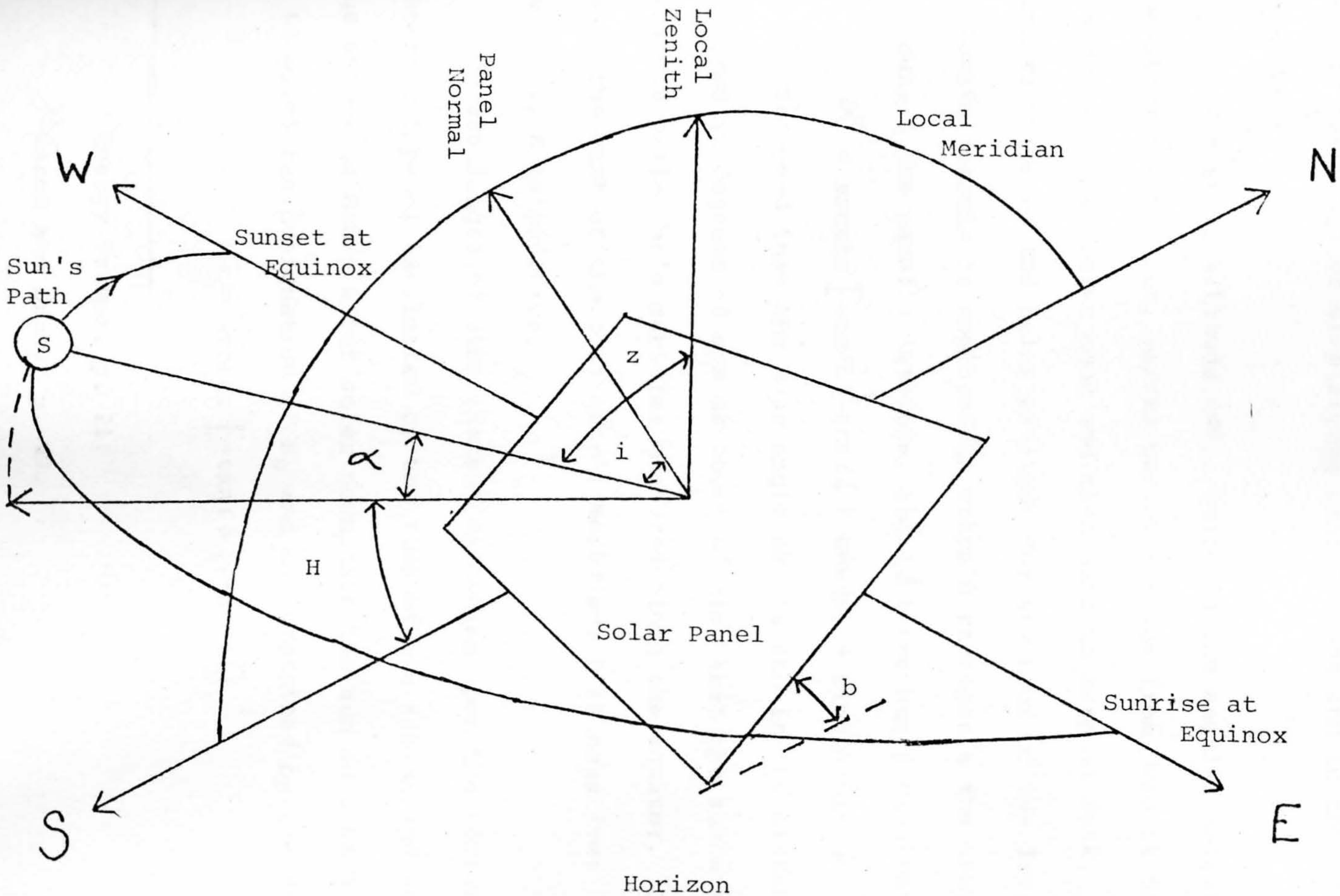

Figure 5.--The Orientation of the Solar Panel and Relative Position of the Sun at a Time After Solar Noon.

optimum operation, it seems that, in general, due south is the best direction to face the panel. It has been shown that at latitude 40° north, a departure of 30° from due south amounted to only an 8% degradation of day long insolation on January 21.[30] The choice of due south has the advantage of simplifying calculations and is the orientation considered.

The solar altitude (α), which is the angular measure of the sun above the horizon, varies during the day from zero at dawn to a maximum value at solar noon and then back to zero at dusk. For the determination of the solar altitude for any hour of the day, the following formula is employed in which H represents the hour angle of the sun, L the panel's latitude, and (δ) the sun's declination:[31]

$$\alpha = \arcsin\left[\cos(L)\cdot\cos(\delta)\cdot\cos(H) + \sin(L)\cdot\sin(\delta)\right]$$

It can be noted that the hour angle of the sun is the distance measured in degrees of arc or hours of time that the sun's meridian is from the collector's meridian measured along the equator. If the sun is to the east of the collector's meridian, H is negative; if it is to the west, H is positive.

The length of time the sun can shine upon the surface of a horizontal panel is limited by the time of its rising and setting. The number of hours after solar noon that the sun sets at a latitude L is given the designation of H_o and is determined by the formula:[32]

$$H_o = \arccos\left[-\tan(\delta)\cdot\tan(L)\right]$$

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[30] Energy Primer, p. 21.

[31] Zarem and Erway, p. 43.

[32] Ibid., p. 44.

However, for a panel that is tipped to the south by an angle b, the sun may be above the horizon and yet lie behind the panel's face. In this case, the time at which the sun's rays are at grazing incidence is the time limitation of the direct insolation. This condition occurs when the angle of incidence is 90°, or alternatively its cosine is zero. Using this fact and the formula for cos(i), the number of hours after solar noon at which it occurs for a south facing panel is called H_{ob} and is given by:[33]

$$H_{ob} = \arccos\left[-\tan(\delta)\cdot\tan(L-b)\right]$$

If H_{ob} is less than H_o, then the time of possible insolation over the day goes from $-H_{ob}$ to $+H_{ob}$, a total of $2H_{ob}$ hours. Otherwise the value of H_o is used in place of H_{ob}, and the total is $2H_o$ hours. It can be noted that for a horizontal panel, b = 0.0, and the expression for H_{ob} reduces to that for H_o as expected.

As the sun's rays penetrate the layers of atmosphere, they are attenuated to a degree dependent upon the path length through the atmosphere, and the clearness factor and extinction coefficient of the atmosphere. The path length of the sun's rays through the atmosphere is measured in terms of air masses, m. This is the ratio of the actual path length to the path length which would exist if the sun were directly overhead. This ratio depends upon the sun's altitude and can be approximated by the cosecant of sun's altitude, i.e. $\csc(\alpha)$. The extinction coefficient, B, of an air mass takes on different values depending upon the variations in water vapor, dustiness, and turbidity

[33]Ibid., p. 45.

of the atmosphere. The clearness coefficient, C, is a factor introduced to correct for constant differences in atmospheric clarity from the point of determination of the extinction coefficients. For example, the Minnesota region has a value of 1.0 for C. Variations range from 0.85 at the Gulf Coast to 1.15 in the Rocky Mountains. Northeast Ohio has a value of 0.98. If q_{peak} represents the direct extra-terrestrial solar radiation intensity incident upon the upper atmosphere and q_i the resulting intensity at ground level, the following formula is written:[34]

$$q_i = q_{peak} \cdot C \cdot \exp\left[-B \cdot \csc(\alpha)\right]$$

The energy density of insolation at a horizontal panel at the earth's surface is comprised of a direct and a diffuse component. The sum is a datum, and the direct component can be calculated. Thus the diffuse component is the difference of the two. The calculation of the direct component (E_{hor1}) including the percent of sunshine factor (% Sun) is given by:

$$E_{hor1} = (\%\ \text{Sun}) \cdot \int_{-H_o}^{H_o} q_i \cdot \cos(i) \cdot dH = (\%\ \text{Sun}) \cdot \int_{-H_o}^{H_o} q_i \cdot \sin(\alpha) \cdot dH$$

Since the panel is horizontal, b is 0. and cos(i) reduces to $\sin(\alpha)$ in this case. The diffuse component (E_{hor2}) is the following difference:

$$E_{hor2} = E_{hor} - E_{hor1}$$

E_{hor} is the mean daily solar radiation datum for each month. In this manner, the diffuse component is isolated from the total energy density.

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[34]ASHRAE Handbook of Fundamentals, p. 393.

In the more general case, the panel is not horizontal but is tipped to an angle b toward the south. The energy density at the panel surface is again the sum of a direct and diffuse component. The direct component, E_{g1}, is given by an integration over the day length having an identical form as the horizontal case, but b is no longer zero. The use of H_o or H_{ob}, whichever is applicable, is indicated by the notation H*.

$$E_{g1} = (\%\ Sun)\cdot\int_{-H^*}^{H^*} q_i\cdot\cos(i)\cdot dH$$

The diffuse component is more difficult to calculate because of the many factors that affect it. However, it is possible to approximate its value by using a factor of the square of the cosine of one-half the angle b, the angle of tilt of the panel.[35] If the diffuse component is known for a horizontal panel, the product of it and the factor just mentioned gives the energy density of the diffuse component at the tilted panel:

$$E_{g2} = E_{hor2}\cdot\cos(b/2)$$

The total energy density of the direct and diffuse components is their sum, E_g:

$$E_g = E_{g1} + E_{g2}$$

The calculated energy densities are on a per day basis, or more accurately, a per mean-day basis. To arrive at the monthly totals of the total energy density, E_g needs only to be multiplied by the number of days in the month. Of course there is a representative E_g for each of the 12 months, and thus there are twelve monthly totals for the energy density at the tilted solar panel.

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[35]N. Robinson, ed., Solar Radiation (Amsterdam: Elsevier Publishing Company, 1966), p. 44.

Collector Panel Efficiency

The solar collector panel is not a perfect radiative-to-thermal energy conversion device. There are losses present which reduce its efficiency below 100 percent. At thermal equilibrium, the power output of the collector is just the difference between the incident power of the solar radiation and the power drain of the losses to the environment. To put it into an equation:

$$q_{out} = q_s - q_{loss}$$

The power that is absorbed, q_s, is the product of the power of incident insolation, q_{in}, the transmission coefficient of the glass cover plate (τ), and the absorptivity coefficient of the absorber surface (γ). As an equation this can be written:

$$q_s = \tau \cdot \gamma \cdot q_{in}$$

The power loss, q_{loss}, is proportional to the temperature difference of the collector absorber surface (T_c), and the ambient temperature of the atmosphere, T:

$$q_{loss} = u_l \; (T_c - T)$$

This expression for q_{loss}, which includes conductive, convective, and radiative losses, is valid for small values of (T_c-T). For large values of (T_c-T), radiation losses, which vary as the quantity of $T_c^4-T^4$, become dominant and introduce significant departures from linearity into the q_{loss} curve. However, for small values of (T_c-T) which is the case here, the linear approximation is valid and useful. The constant of proportionality, u_l, can be determined experimentally by plotting q_{loss} versus T_c for various values of T.[36]

Combining the results of the above equations, the output power, q_{out}, can be written:

$$q_{out} = q_{in} \cdot \tau \cdot \gamma - u_l \cdot (T_c - T)$$

A further refinement is incorporated by NASA-Lewis Research Center and used in its reports of collector efficiencies. A factor, called β, is introduced that is the ratio of the actual collection rate of thermal energy to the thermal collection rate attainable if the entire collector absorber surface were at the temperature of the incoming fluid, T_{in}. By means of this factor, the following equation is written:

$$q_{out} = \beta \cdot \left[\tau \cdot \gamma \cdot q_{in} - u_l \cdot (T_{in} - T) \right]$$

This effectively places the dependency of the output power upon variables such as operating temperatures and wind velocities into the factor of β.[37]

The efficiency of the collector, η, is the ratio of the output power to the input power, i.e. q_{out}/q_{in}. An efficiency equation can be developed in the slope-intercept form of y = mx + b. By letting A equal the product of $\beta \cdot \tau \cdot \gamma$ and U_l the product of β and u_l, the equation for η is:

$$\eta = -U_l \cdot (T_{in} - T)/q_{in} + A$$

Comparing this equation with the slope-intercept form, m is identified with $-U_l$, x with $(T_{in} - T)/q_{in}$ and b with A. If a graph of η versus

[36]Zarem and Erway, p. 91-2.

[37]Ibid., p. 92

$(T_{in}-T)/q_{in}$ is drawn, the slope gives the value of U_1 and the η-intercept the value of A. Thus from the experimental data, a best-fitting straight line is drawn whose slope and intercept yield the necessary constants of the collector's performance efficiency.

To illustrate this technique, Figure 6 is presented. Here are the results of performance tests of four collectors. The three water-type collectors were evaluated by NASA. The Soloron Collector, which is an air-type panel, was evaluated by Solar Energy Products of Avon Lake, Ohio.[38] On the abscissa are the values of $(T_{in}-T)/q_{in}$ whose units are $(Btu/ft^2\text{-}hr\text{-}^{o}F)^{-1}$. On the ordinate are the values of collector efficiency, η, as a percent. Experimental data is collected under almost steady-state conditions during the test periods, including a constant flow rate of fluid, constant insolation, and constant temperature of the entering or inlet fluid, i.e. T_{in}. The data thus collected often shows some scatter, and best-fitting straight lines are drawn to fit the points. The resultant linear plots represent the steady-state performance of the collector tested.

The collector panel of the model home is the Soloron Collector, whose performance is plotted in Figure 6. The values of A and of U_1 can be determined from the graph: A is 0.69 and U_1 is 1.243. Though there are collectors of air-type whose steady-state performance exceeds that of the Soloron, they were judged not to be as cost-effective as the Soloron.

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[38]Personal Communications with Frank J. Rom, President of Solar Energy Products, Avon Lake, Ohio, 1976.

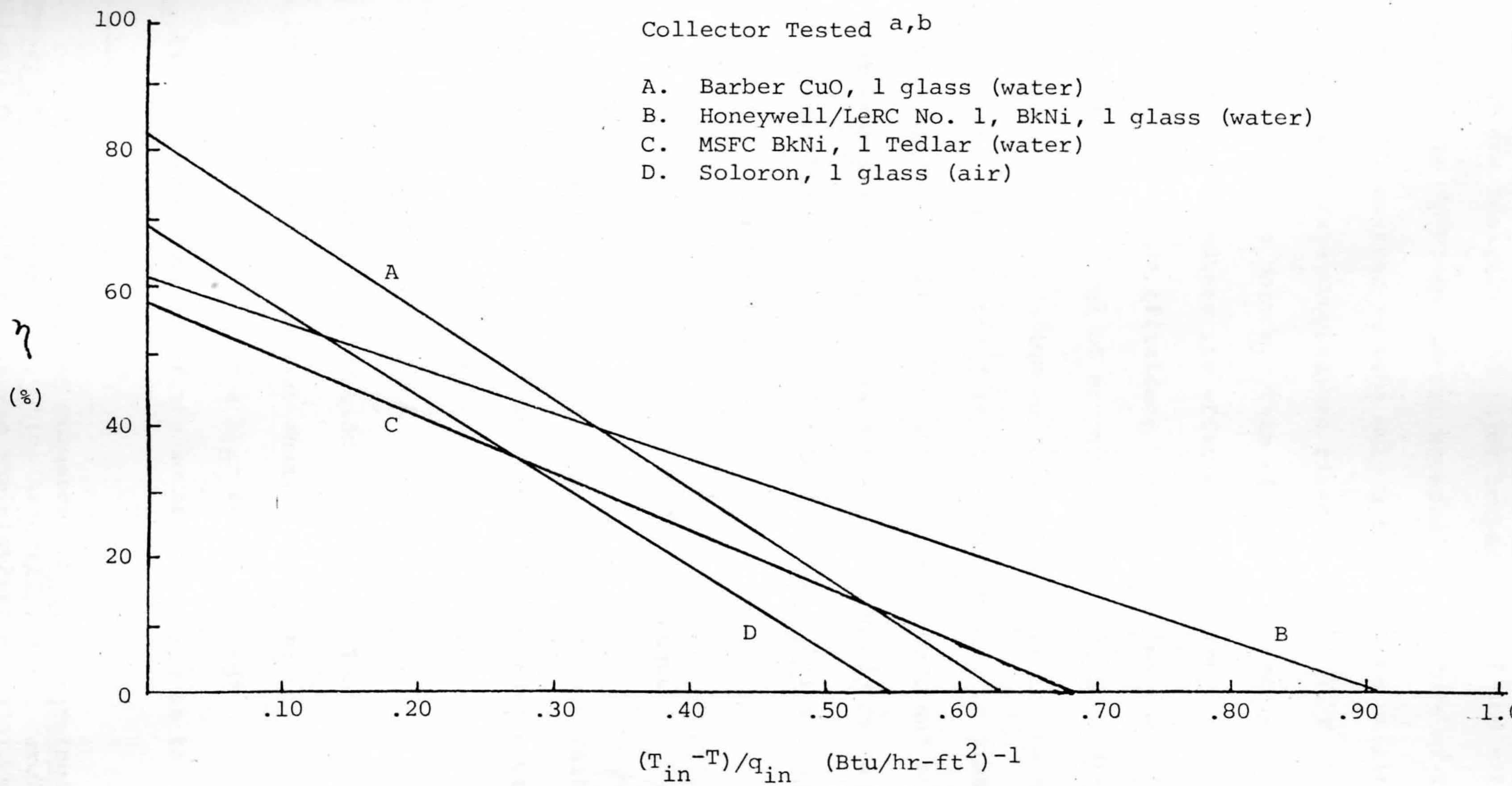

Figure 6.--Graph of Various Collector Performances

[a]Source for A,B, and C: NASA-Lewis Performance Test Report

[b]Source for D: Personal Communications with Frank J. Rom, President of Solar Energy Products, Avon Lake, Ohio.

In the analysis, the inlet temperature of the circulating air is taken to be 70°F, the lowest expected temperature of the air from storage. This however is true only until the home heating needs are met, and the storage temperature rises above the 70°F to the maximum of 155°F at storage bottom. This elevation of the inlet temperature to the collector reduces its efficiency since the losses are greater. But at this time, the efficiency becomes less important because it involves the last parcel of energy that is used for additional water pre-heating. This condition normally will occur in the summer time when the home heating demand is low, and sunshine is plentiful. The collector operates only during the daylight hours, and hence the mean ambient temperature, T, is taken to be the monthly average high temperature that is recorded in the 1974 Local Climatological Annual Data Summary for Youngstown.[39]

Collector Panel Energy Output

To obtain the amount of useful energy output daily, it is necessary to integrate the output power of the panel over the day length. Looking at the expression for q_{out}, namely,

$$q_{out} = A\, q_{in} - U_l \cdot (T_{in} - T)$$

it is noticed that an integration over the day length, which amounts to 2H* hours, gives the energy density equation:

$$E_{out} = A \cdot E_{in} - U_l \cdot (T_{in} - T) \cdot 2H^*$$

E_{in} is the energy density of the solar insolation at the tilted panel,

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[39]U. S. Department of Commerce, Local Climatological Data Summary of 1974, Youngstown, Ohio (Asheville, North Carolina: National Oceanic and Atmospheric Administration, 1974), p. 2.

or E_g. This result states that the daily energy output is equal to the difference between the amount of energy absorbed by the collector and the energy lost to the environment. In this way, an effective efficiency, η', of the collector may be defined thusly:

$$\eta' = E_{out}/E_{in} = 0.69 - 1.243 \cdot (T_{in} - T) \cdot 2H^*/E_{in}$$

The total amount of energy per square foot of collector, E_{out}, that can be used for thermal energy for the home becomes the simple product of the effective efficiency and E_g:

$$E_{out} = \eta' \cdot E_g$$

The energy lost is assumed to accrue over the entire 2H* hours of incident sunshine. This is a slight over-estimate since the absorber of the collector must reach a temperature of 15°F higher than the storage temperature for the input fan to operate. This over-estimate of loss should be offset by the assumption of the mean daily high temperature being used for T for the entire day, which provides an under-estimate of loss to the environment during the time of cooler temperatures of the normal day.

Utilization of Collected Solar Energy

The output per square foot of collector is the energy that is available for two purposes: space heating and water pre-heating. These two are intimately related since the hot water pre-heating tank is located in the rock storage bin. The space heating thermal load is the product of the number of degree days expected per month and the home's space heating rating in Btu/degree-day. The thermal load for the hot water pre-heating is based on 100 gallons of hot water per day for every day of the month.[40] The solar energy collected is used to fill these two demands according to a simple plan.

The storage rocks and the water in the pre-heating tank are assumed to be at 70°F (21°C) initially. The air circulation of the heating cycle in addition to the basement location of the well-insulated storage bin should keep the storage rock temperature near 70°F even during prolonged no-sun conditions. The water that enters the pre-heating tank is considered to be at a temperature of 50°F (10°C). This is the temperature of the surrounding ground water, and it is considered a constant throughout the year. To heat 100 gallons of water twenty degrees every day for an average month requires about 506,000 Btu. This expenditure of energy results in the water of the pre-heating tank being maintained at 70° F, the temperature of the surrounding rock. This initial parcel of solar energy displaces the more expensive electrical energy.

The next energy demand to be considered is for space heating. The model home has an expected thermal space heating demand of 18,274 Btu/degree-day.[41] The number of degree-days expected for each month of the year is taken to be a thirty year average that is found in the Local Climatological Summary of Youngstown, Ohio for 1974.[42]

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[40]American Society of Heating, Refrigeration and Air-Conditioning Engineers, ASHRAE Handbook and Product and Directory, 1973 Systems (New York: ASHRAE, Inc., 1973), p. 37.11.

[41]Evaluation of Bryant Model Home provided by Solar Energy Engineering, Poland, Ohio, 1976.

[42]Local Climatological Annual Data Summary of 1974, p. 2.

As the energy collected is being used for space heating, the temperature of the storage bin remains at 70°F. The thermal energy that enters the bin is used for home space heating and is not stored in the rock.

Should the space heating demand be met, additional energy collected is used to heat the storage rock and to preheat the water an additional 85°F (47.2°C). If enough energy is available for this, the result is a storage temperature of the rock and water in the preheating tank of 155°F (68.3°C). The monthly requirement of energy to raise the 100 gallons of water another 85 degrees is roughly 2.16 million Btu. Any additional energy available after this is accomplished is not utilized. The input duct fan is turned off when the bottom of storage reaches 155°F, and hot air input into storage ceases.

The two model homes used for comparison are identical with the exception of the solar system option that is incorporated into one of them. They both use an oil-fired furnace for space heating and an electric water heater. In this way, the effect of the year round operation of the solar system has upon displacing fossil and electrical fuel costs can be directly evaluated and compared to a similar home, and hence the advantage or disadvantage of opting for solar can be determined by subsequent analysis.

The solar energy system is considered to replace the conventional energy conversion devices of fossil fuel burners or electric immersion-resistance heating of electric water heaters. The value that is assigned to the solar energy collected depends upon the cost of the fuel displaced as well as the efficiency of its use.

The following table summarizes this and provides a reasonable value for the cost of a million Btu of oil and electrical energy. The use of natural gas has been curtailed by the imposition of a moratorium on new residential customers for Northeast Ohio as of November 1975.

TABLE 3

DISPLACED FUEL VALUES OF OIL AND ELECTRICITY

	Oil	Electricity
$/Unit	38¢/gal.	3.64¢/kwh
Btu/Unit	140,000 Btu/gal.	3414 Btu/kwh
Efficiency of use	55%	100%
$/million Btu	$4.92	$10.67

The cost per unit of fuel is a nominal figure for both. There are seasonal and geographical variations in both, but the figures shown are about average. The economy of operation of the electrical and fossil fuel devices depends upon their efficiency of operation. A fossil fuel burner is subject to fouling, incomplete combustion, and warm-up cycle times, all of which affect its efficiency. With the little or no maintenance provided by the average householder, a fossil fuel burner can be expected to operate between 50 to 60 percent efficiency.[43] As for electric water heaters, the heating elements are commonly the

[43]R. L. Dunning, "Fossil Fuel Losses Detailed," Electrical World, 192 (November 15, 1974), 117.

immersion-resistance type. These operate at nearly 100 percent efficiency.

The oil furnace is necessary in order to meet the space heating needs of the solar home under the worst case condition of no solar input and the depletion of storage. The size or capacity of the furnace is 120,000 Btu, and its installation cost is about $1800.[44] The electric water heater costs about $300 installed.[45] The quoted price for Soloron collector panels is $9.00 per square foot.[46] The cost for the duct work, storage, pre-heating tank, controls, and labor costs is given as $5900 for reasonable sized systems.[47] The additional labor and ducting cost of adding several panels to the array does not significantly affect this base cost. Storage, controls, and pre-heat tank costs are the same for any array size considered here. The total costs for the solar system is determined by the following formula:

$$\text{Total System Cost} = \$5900 + \$9.00/\text{ft}^2 * (\text{array size in ft}^2)$$

It can be noted that the difference in costs between the two homes lies only in the cost of the solar option. The conventional furnace and water heater are installed in both homes.

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[44]Quotation from Price Heating Company, Girard, Ohio, effective 1976.

[45]Quotation from Trumbull Supply Company, Youngstown, Ohio, effective 1976.

[46]Quotation from Solar Energy Products, Avon Lake, Ohio, December 1976.

[47]Quotation from Solar Energy Engineering, Poland, Ohio, December 1976.

Development of the Financial Analysis

To evaluate the financial desirability of investing in the solar heating system described here requires the examination of its projected operation over a time span of reasonable duration. The investment of ten or eleven thousand dollars in such a system is not thought to be made upon short run comparisons. The period of study is taken as thirty years. After thirty years have passed since the time of purchase, the investor should be approaching retirement. At this point, the solar system can be evaluated to determine its real estate value, the dividends provided, and the future financial benefits that could come to the owner.

Both the solar and non-solar home buyers are required to take out a mortgage on their home. What is important here is the added mortgage taken out by the solar home buyer to cover the additional cost for solar. This extra amount of mortgage, its payments, and the benefits of the solar option it is buying are the points of investigation.

The mortgage payment has its monthly payments determined by several factors: amount of down payment, interest rate charged, number of years for repayment. If these factors are known, the monthly payments can be calculated or found in prepared mortgage tables. Once the mortgage is let, the monthly payments are of a fixed amount over the length of the mortgage. Most mortgages are let on the basis of simple interest on the unpaid balance. In effect, the mortgagor is borrowing money one month at a time, at the end of which he is charged interest at one-twelfth the annual rate. His monthly payment is for two purposes: first, the amount of interest charged for a month's use is taken out; second, the rest of the payment is applied to reduce the principal. This new principal, or balance, is carried forward to the next month and the process is repeated. This continues until the balance is reduced to zero. Most of the initial payments go toward the large interest charges, and most of the final ones go toward reducing the balance since the interest charges become small. The computer subroutine does the mortgage accounting of the yearly amount of interest paid and the unpaid balance.

The additional mortgage of the solar home is a liability that must be met by an annual payment of twelve times the monthly mortgage payment. This annual figure is constant over the term of the mortgage. It is independent of fuel prices and inflation. This annual sum can be considered as a yearly cash outflow. This outflow is offset by two factors of cash inflow. In the first place, there is an annual expected fuel savings provided by the solar system. The savings represent money that does not go to the paying of fuel bills. This annual fuel savings is affected by inflation by means of a factor called the fuel escalator. The fuel escalator can be thought of as the percentage rate at which fuel prices increase faster than inflation. It is considered to always be greater than or equal to zero. This factor operates on the expected fuel savings every year, and once determined at the outset, remains constant throughout the thirty years. In the second place, there exists a Federal income tax deduction for the annual interest paid on the mortgage at the end of the tax year. This credit is deducted from the amount of taxable income of the mortgagor. As an illustration, the solar home buyer could be put into the 22% income tax bracket by virtue of his ability to afford the solar home.[48] The amount of the cash-back savings is the product of 0.22 and the amount of annual interest paid. The exact percentage is not critical but is used to point out that the deduction is a factor to be considered. Omitted is the personal property tax liability of the additional solar system value. Legislation for its exemption is probably forthcoming.

The difference between the cash inflow and outflow each year is called the annual dividend and is determined by the following:

annual dividend = (% rise of fuel prices) · (annual savings) + 0.22 · (annual interest paid) - (annual mortgage payment)

A running total of the annual dividends can be kept each year. This figure is called the total dividend.

A financial benefit is realized in the increasing equity that is being built up in the solar system as the mortgage is being paid off. The amount of equity consists of the product of the percent of principal that has been repaid and the concurrent real estate value of the system. The percentage of the system owned is increased initially by the down payment, and in each succeeding year by the annual payment made towards the principal. The real estate value is assumed to rise at the rate of inflation. The equity value can be expressed by the following formula:

equity value = (% of system owned)•(real estate value of the system).

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[48] The New Federal Income Tax Course (U.S.A.: Prentice Hall, Inc., 1974), p. 1124.

The total dividend and the equity value can be combined to form the sales position. The sales position is the amount of money that the solar system could mean to the buyer if he sold it at the conclusion of the year. It amounts to cash received by selling plus the total dividend it generated over the years of ownership. The annual dividend and the total dividend can have positive, negative, or zero values. The equity increase is always positive however. Hence the sales position can be positive, negative, or zero. In other words, the solar system might make or lose money depending upon the magnitudes and signs of the constituents of the sales position.

The conventional home buyer has at his disposal an amount of money equal to the solar home buyer's down payment of the solar option. This money is considered to be placed into a bank savings account which earns interest at 6% per annum. This is not a large return, but it is a safe one. In addition to earning interest upon this money, the conventional home buyer places into this account at the year's beginning an amount equal to the difference between the annual mortgage payment of the solar system and the annual fuel cost savings of the solar system. This takes into account that although the solar system does save fuel bills, it also means a larger mortgage payment for the solar home buyer. This difference can be put in the non-solar home's bank account. There may come a time when the fuel savings are greater than the mortgage payment. Here the deposit will be negative and will indicate a withdrawal from the bank account in order to meet the cost of fuel for the conventional home.

The financial position is the dollar difference between the solar system sales position and the value of the conventional home's bank account. Its value can be positive, negative or zero, and it is tabulated for each of the thirty years. Depending upon the financial position's sign and magnitude after thirty years, the investment in the proposed solar heating system is justifiable, dubious, or unadvisable.

The figures of annual dividends, total dividends, sales position, bank account balances, and the financial positions are tabulated at the end of each of the thirty years of expected operation. The year at which the financial position passes from a negative to a positive value, if ever, is regarded as the year of financial parity. The tabulation of the above figures for years one to thirty are provided in the computer subroutine.

Economic Trends for Inflation and Fuel Prices

The projection of the inflation rate of the economy over the time span of thirty years is open to question. The various estimates of inflation rate for only the next few years have ranged from the optimistic two to three percent yearly to an alarming ten to twelve percent. Some economists claim that the economy contains a built in five to six percent inflation rate.[49] A near decade of history of inflation from 1967 to 1976 is shown in Figure 7. It shows a rate of inflation averaging from four to five percent, with extremes of 2 to 12 percent. It seems reasonable to choose 4% as an average inflation rate for the next 30 years.

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[49]"Is Inflation Inevitable?" Newsweek, May 17, 1976, p. 78.

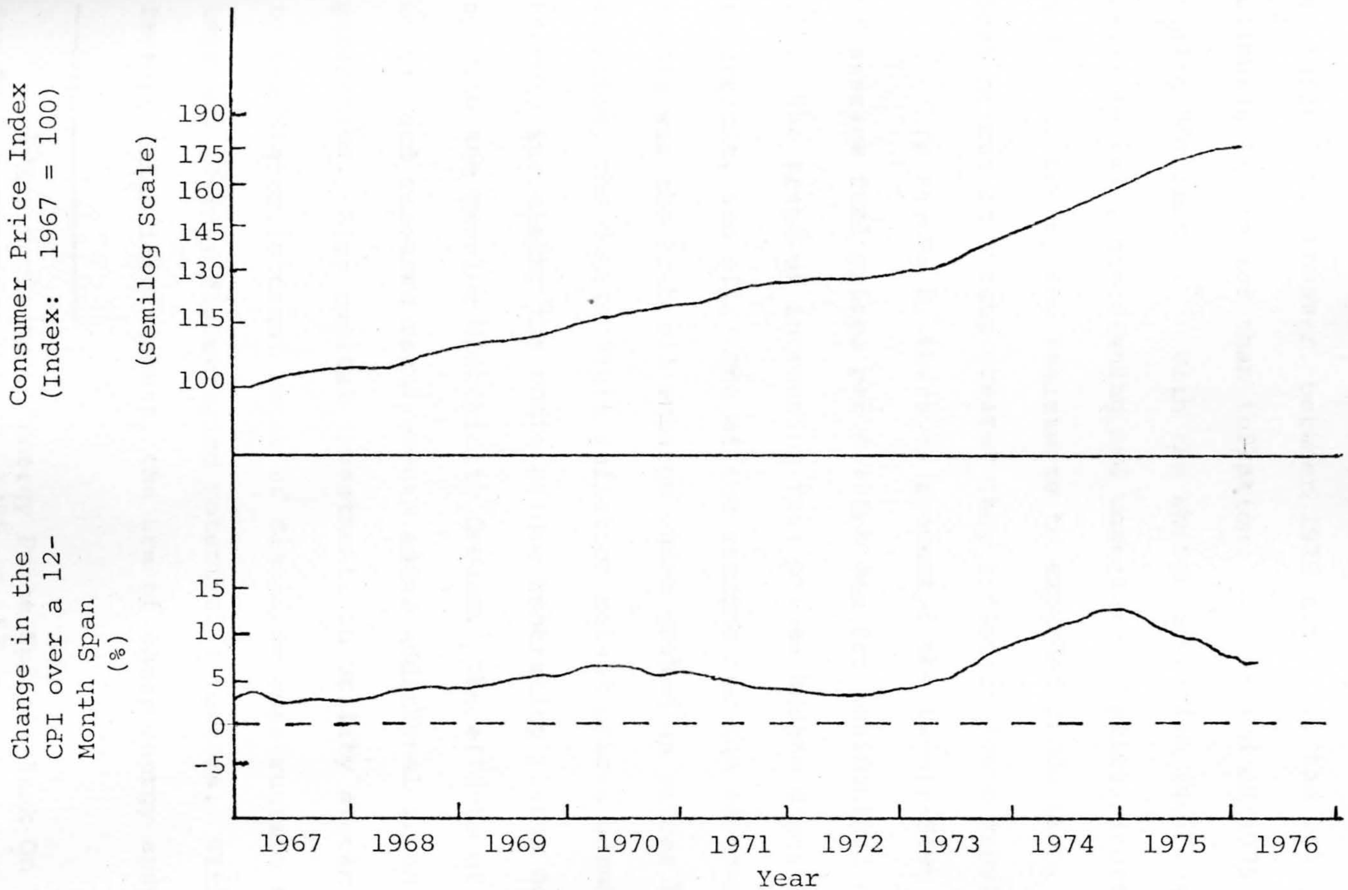

Figure 7[a].--The Consumer Price Index (CPI) 1967-76

[a]U. S. Department of Labor, Chartbook on Prices, Wages, and Productivity (Washington: Government Printing Office, 1976), p.9.

Fuel price increases present a slightly different picture. Until 1970, the prices of fuel and electricity were rising slower than inflation. Plentiful supplies, low labor and materials cost, and improving technology helped to keep the energy costs from rising as fast as inflation. However, between 1970 and 1973, the energy prices began climbing 11% faster than inflation. At the end of 1975, they were rising 50% faster.[50] With the energy companies facing shortages of raw materials, diminishing and uncertain supplies, increasing capital and labor costs, and resistance to expanded production, the rise of fuel prices at a rate greater than inflation seems inevitable.

In Figure 8, there is presented the twenty-five year record of average fuel prices per million Btu for residential consumers. In 1973, the trend of increasing fuel prices became dramatic in both electricity and oil. One of the reasons for the economic turn of events was the Arab oil embargo which pushed up prices by 89%. In addition, the double digit inflation raised prices across the board thereby increasing the costs of new generating plants needed to keep up with the growing electricity demand. The effects of the environmental and resource requirements added additional costs to power generation. Also capital investments in utility stocks decreased due to the higher interest rates of financing construction eroding earnings and thereby discouraging potential investors. With all these factors taken into account, the era of cheap energy appears ended.[51]

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[50]Ann Eggleston, "Energy Price Spiral: Bank On It and Plan for It," Purchasing, May 20, 1975, p. 57.

[51]"Why Utility Rates Will Keep Going Up," Changing Times, February 1977, p. 42.

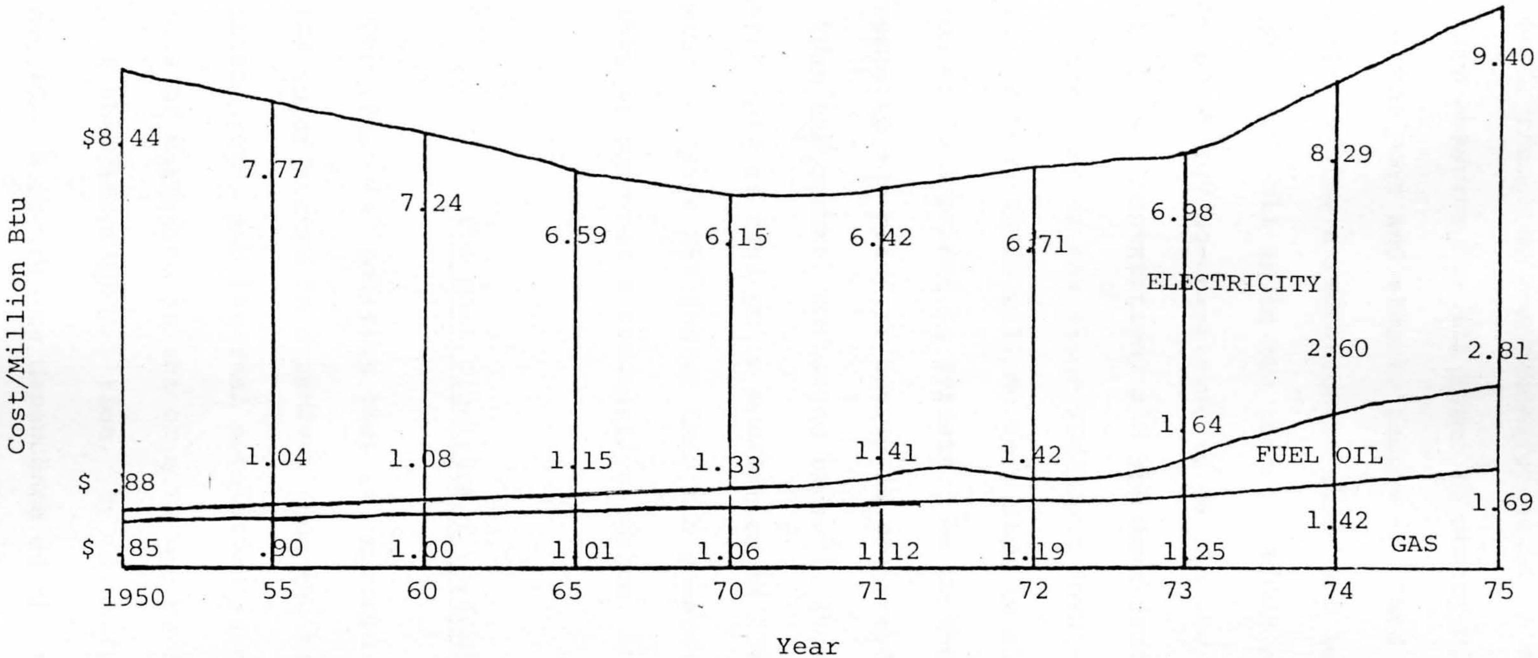

Figure 8[a].--The Average Cost to Residential Customers per Million Btu's of the Different Kinds of Energy Used in the Home from 1950 to 1975.

[a]"Why Utility Rates Will Keep Going Up," Changing Times, February 1977, p. 43.

To the end of keeping energy costs manageable, several ideas are proposed, though no comprehensive solution has been found. Extreme conservation measures for all forms of energy with government energy stamps for the poor and elderly people on fixed incomes, comprehensive utility rate reform, a reduction in state and local taxes on consumers' utility bills as well as on the gross receipts of utility companies, formation of energy co-operatives to obtain low interest financing for generating plant construction, and the development of alternate sources of energy are some of the major ideas put forward. Until a solution can be instituted, which will be very slow in all probability, the escalation of fuel prices is certain. As to the rate of escalation, the increase in the price of energy is predicted to be not too much greater than the general inflation rate.[52] Thus for this analysis, a suggested rate of fuel price escalation is 25%, i.e., prices of energy will increase 25% faster than the general inflation rate. Though this is somewhat a speculative choice, it remains a reasonable one.

The Most Significant Variables

The financial position that is expected after thirty years of use of the solar system is dependent upon the mortgage terms available, the inflation rate, and the fuel escalation rate. Of these factors, the effects of variation in one or more may be dominant in the determination of the financial position. By identifying the dominant factor, it is possible to reduce the dependence of the financial position

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[52]Ibid., p. 41-44.

effectively to only one variable. It is then possible to give the non-dominant factors reasonable fixed values and continue the analysis.

The collector sizes used in this analysis are 336 ft^2, 528 ft^2, and 720 ft^2. These sizes are equally spaced and cover the region of likely collector size. For each of these collector sizes, thirty year financial positions are generated wherein all but one of the variables are given fixed values. These fixed values are the most probable and reasonable ones: mortgage term of 25 years at 9% interest with 20% down payment; inflation rate of 4% and a fuel escalator of 25% over the thirty years. The variables in turn take excursions off this fixed point. The excursions allowed are: mortgage term of 15, 20, 25, 30, and 35 years; interest rates of 8, 8.5, 9, 9.5, and 10 percents; down payments of 0, 10, 20, 30, and 40 percents; inflation rates of 0, 2, 4, 6, and 8 percents; and fuel escalators of 0, 25, 50, 75 per cents.

The results of this analysis appear in Figures 9 to 13 inclusive, with inflation having been determined as being the dominant factor. Each graph is a plot of the financial position vs. the inflation rate. The vertical lines that appear inside the graphs are the range of the financial positions that the excursions of the variable produce at each inflation rate. Naturally, the largest financial positions are produced by the smallest term and interest rate and highest down payment and fuel escalator, and the smallest financial positions are produced by the opposite conditions. It is seen that in all cases except for the fuel escalator, the variations in financial position among the changing parameter are less than variations of inflation rates of a fixed value of the parameter. For example, the 15 to 35

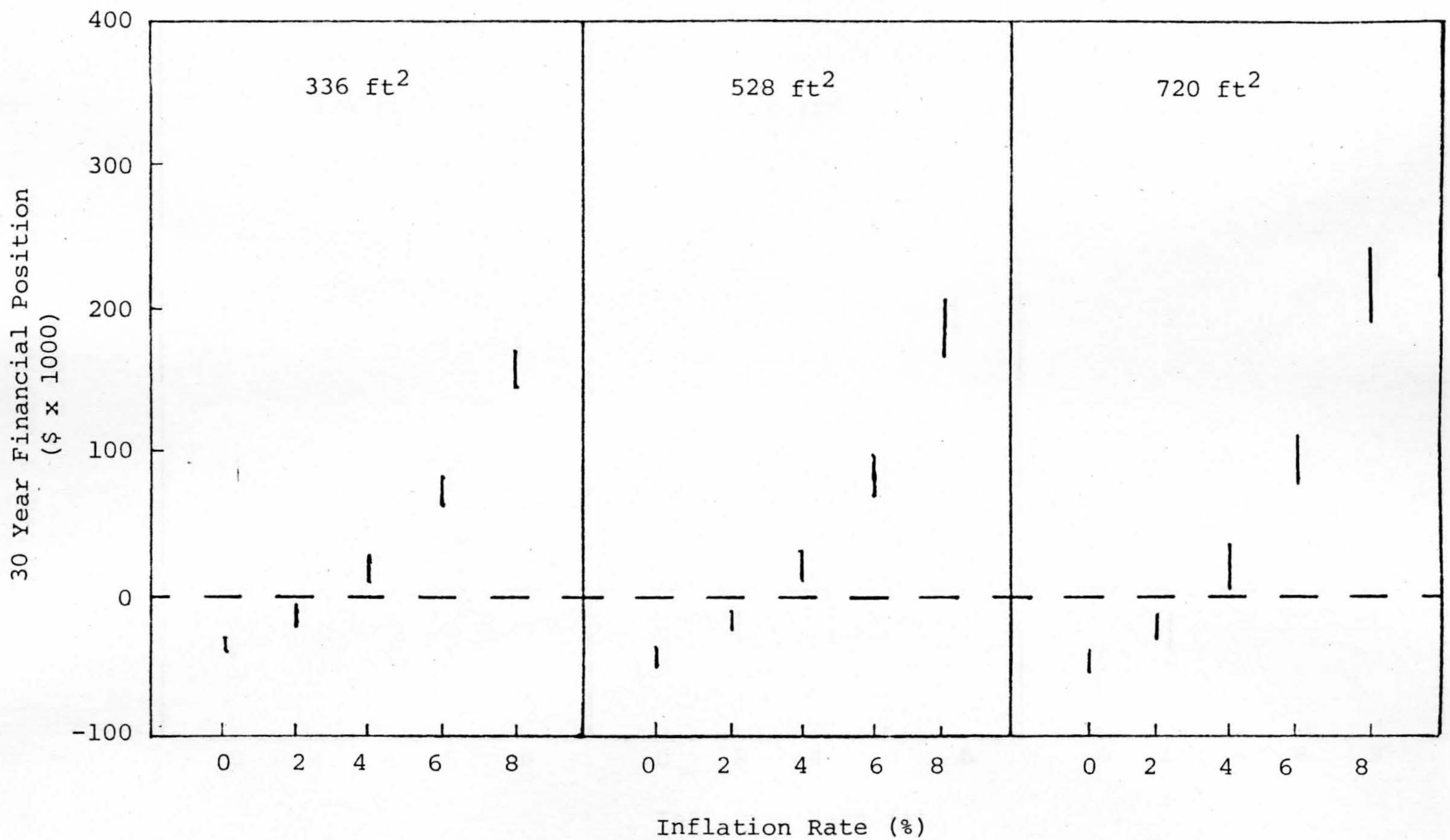

Figure 9.--The Range of 30 Year Financial Positions Produced by a Variation of Mortgage Term from 15 to 35 Years as a Function of Inflation Rate for Three Collector Array Sizes.

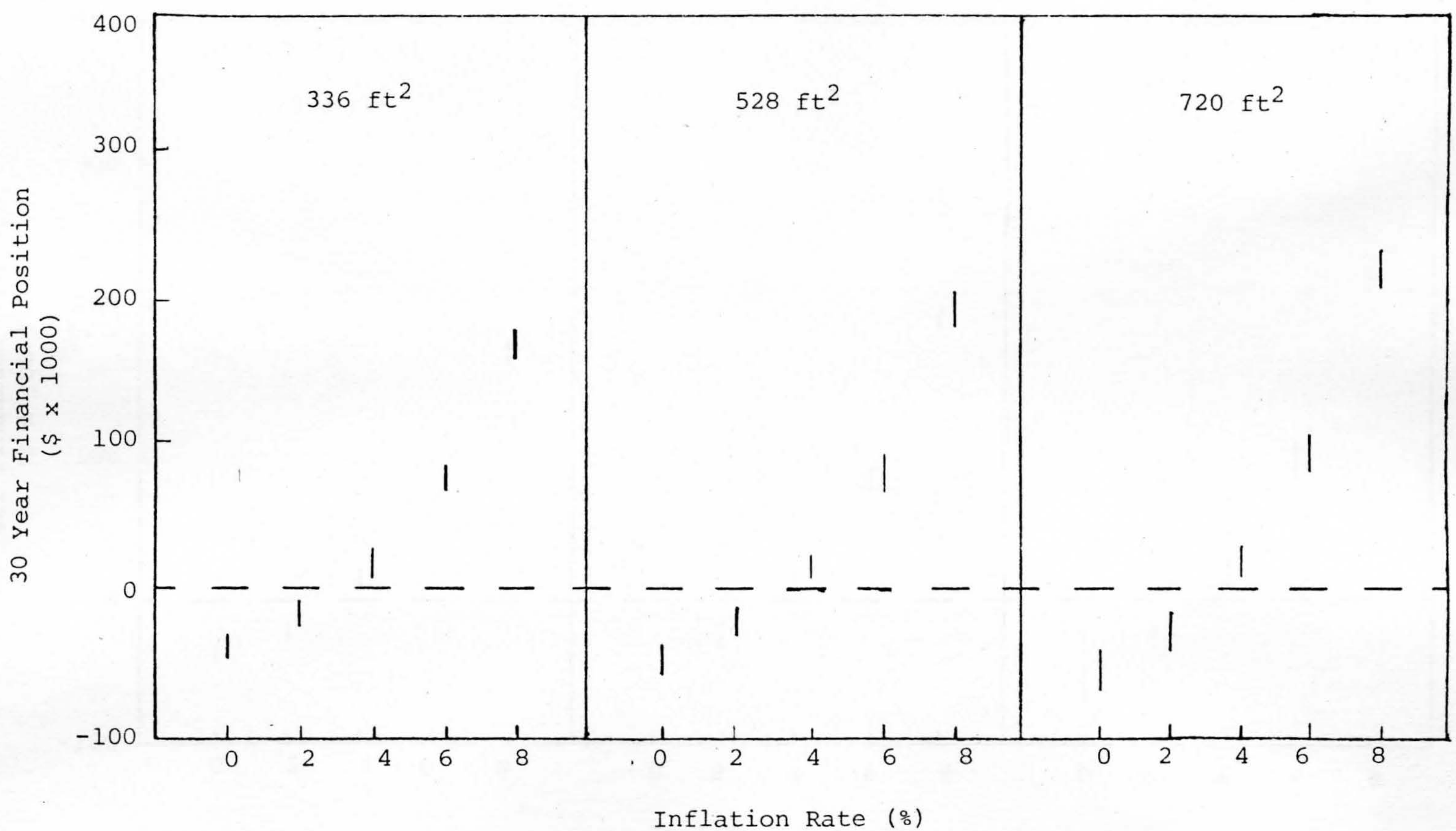

Figure 10.--The Range of 30 Year Financial Positions Produced by a Variation of Mortgage Downpayment from 0% to 40% as a Function of Inflation Rate for Three Collector Array Sizes.

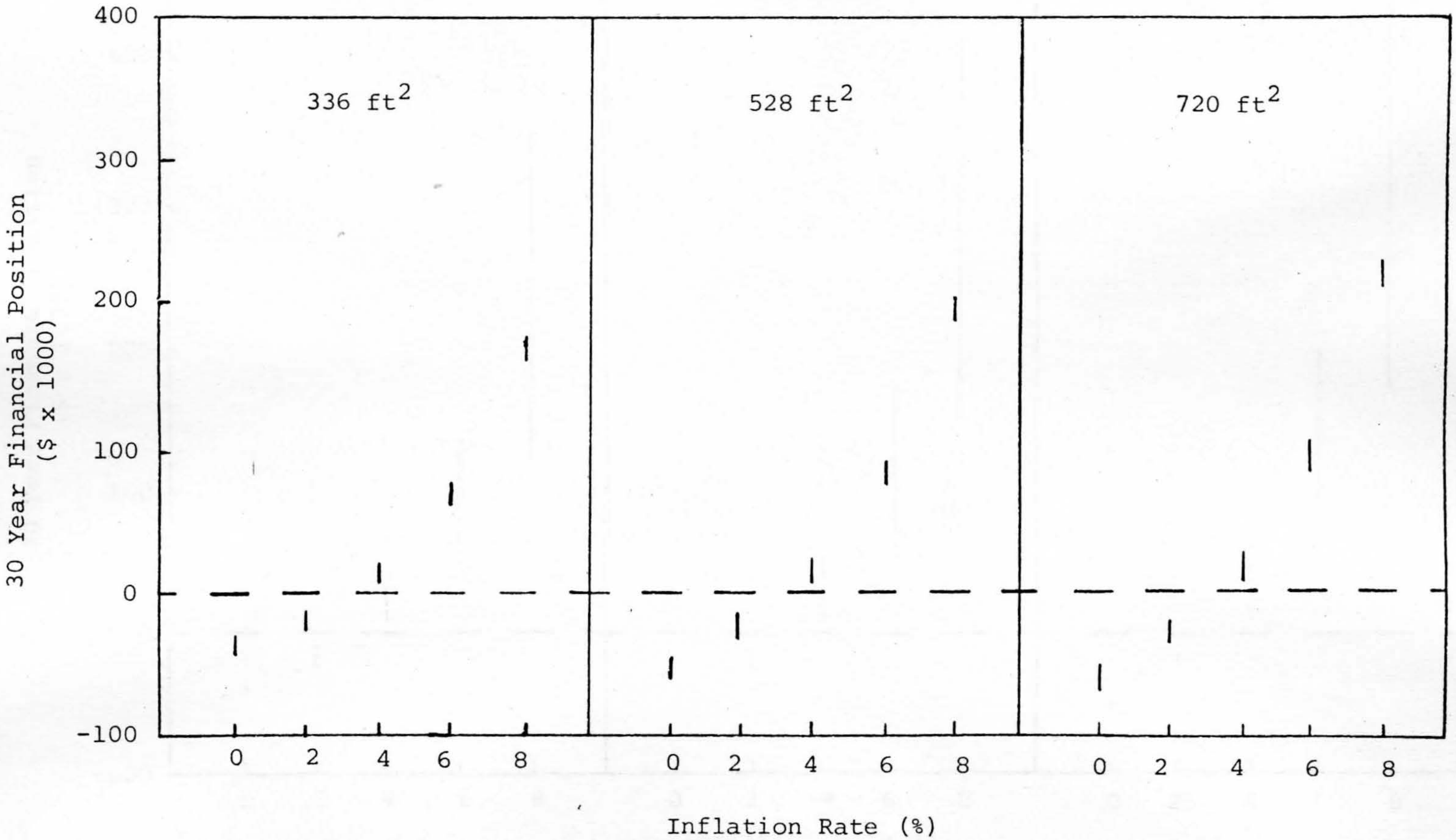

Figure 11.--The Range of 30 Year Financial Positions Produced by a Variation of Mortgage Interest Rate from 8% to 10% as a Function of Inflation Rate for Three Collector Array Sizes.

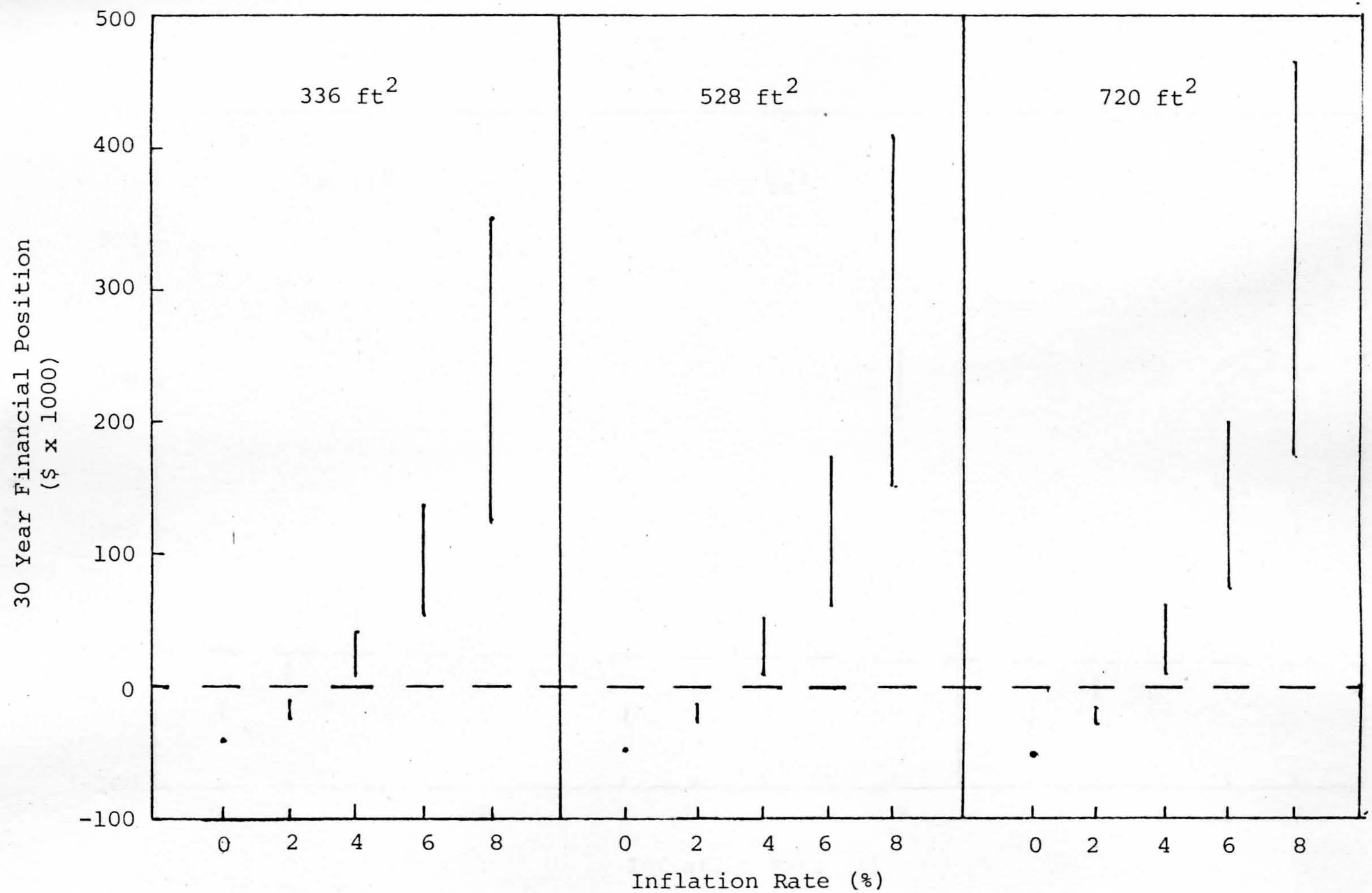

Figure 12.--The Range of 30 Year Financial Positions Produced by A Variation of the Fuel Escalator from 0% to 75% as a Function of Inflation Rate for Three Collector Array Sizes.

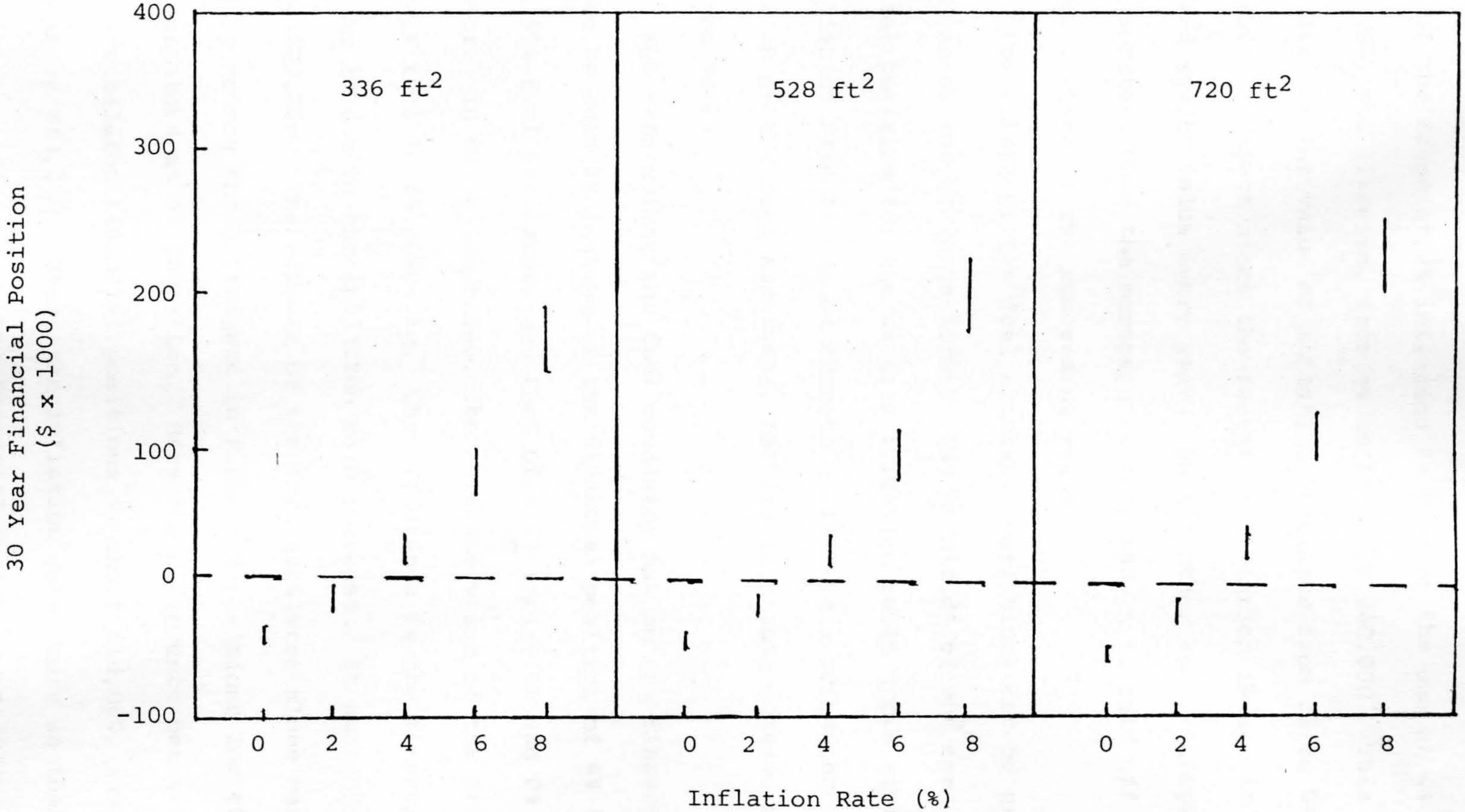

Figure 13.--The Range of 30 Year Financial Positions Produced by a Variation of Expected Annual Savings from -$50 to +$50 as a Function of Inflation Rate for Three Collector Array Sizes.

year mortgage term financial position spread for a 4% inflation rate of a 528 ft^2 collector is about \$20,000, whereas the change from the center of the range at 2% inflation to that of the one at 4% inflation is \$45,000, and likewise, from 4% to 6% it is \$60,000. This effect is accentuated as the value of inflation increases from 2% to 8%. This is reasonable to expect since the factor of inflation is applied to fuel costs and equity value every year. On the other hand, mortgage terms remain constant once the mortgage is let, and it is paid off in the inflated dollars of the succeeding years.

The effect of the fuel escalator variations can be greater than those of the mortgage terms. The magnitude of the spread of the financial position for the various inflation rates grows rapidly with the inflation rate as can be expected. This is a consequence of the definition of the fuel escalator, for its magnitude depends upon the inflation rate.

The effect that the fuel escalator has on the financial position can be seen by looking at the financial position of 4% inflation with a 50% fuel escalator, and that of a 6% inflation and 0% fuel escalator. In these two cases, the absolute value of the price increase of fuel is 6% annually. The difference in the financial positions is due to the inflation rate increase. It amounts to roughly \$27,000. The effects of the fuel escalator alone can be viewed by noting the difference in financial positions for the various fuel escalators at 4% inflation. Here the difference between 25% and 50% fuel escalator financial positions is about \$14,000, and from 50% to 75% about \$17,000. Thus, the inflation rate, more so than the fuel escalator rate, determines the financial position. Only one term of the financial position is influenced by the fuel escalator, that is the annual dividend. The inflation rate, however, affects not only the fuel escalator by definition, but also the equity value increase, giving it more impact on the financial position.

Another variable that might be considered is the amount of error expected in the annual dollar savings figure. A fifty dollar error on either side of the annual savings under the assumed fixed point conditions mentioned earlier is contemplated. The plot of Figure 13 of the plus-or-minus fifty dollar savings variation shows the results to be of similar effect as that of the 15-to-35 year mortgage term variation. The highest financial position is produced by a +$50 error in savings, and the smallest by a -$50 at each inflation rate.

From these considerations, inflation is identified as the dominant factor in the determination of the financial position. The fuel escalator, though it can have a great effect at larger inflation rates, plays an overall lesser role and is given a fixed value of 25%. The mortgage terms have a relatively minor effect. Thus as a reasonable and representative mortgage loan, a mortgage of 25 years, 9% interest, and 20% down payment, is assumed to be taken out by the prospective buyer.

CHAPTER III

SUMMARY

Findings

Array Size and Slope and Subsequent Financial Position

In order to establish a relationship between the collector array size and slope and its expected annual dollar savings return, the ratios of the cost of the array to the expected annual dollar savings of fuel for various sizes and slopes are formed. It is referred to as the cost-to-savings ratio. The plot of these ratios against the collector size and slope produces surfaces in three-space. For a fixed slope, as the array size increases so does the amount of energy it can collect and also its cost. However, the maximum amount of energy that can be displaced by solar is fixed by the total demand for space and water heating of the home. Any solar energy collected beyond this is of no value. Thus a point of diminishing returns in collector size occurs when the additional cost of more collector area does not bring about a correspondingly larger amount of total energy savings dollars. From this it seems reasonable to expect minima in the ratio plot.

To illustrate the way in which the cost-to-savings ratio is derived, Table 4 is presented. In this example, the array size is chosen as 528 ft^2. In this display, the slope angle is varied from 30^o to 60^o in steps of 5 degrees. Beneath each slope angle appear two columns: water and space. The figures in the water column indicate

TABLE 4

DISPLACED FUEL VALUES AND SUBSEQUENT COST-TO-SAVINGS RATIOS

FOR A COLLECTOR ARRAY AT SLOPES FROM 30° to 60°.

ARRAY SIZE= 528. SQ.FT. SYSTEM COST($9.00/SQ.FT. PLUS INITIAL COST OF $5900.)= $ 10652.00

SLOPE	30.		35.		40.		45.		50.		55.		60.	
	WATER	SPACE	WATER	SPACE	WATER	SPACE	WATER	SPACE	WATER	SPACE	WATER	SPACE	WATER	SPACE
JAN	0.2359	0.0	0.4385	0.0	0.5171	0.0781	0.5171	0.1879	0.5171	0.2497	0.5171	0.2633	0.5171	0.2284
FEB	0.4670	1.9365	0.4670	2.1281	0.4670	2.2600	0.4670	2.3312	0.4670	2.3409	0.4670	2.2893	0.4670	2.1767
MAR	0.5171	8.3231	0.5171	8.3953	0.5171	8.3724	0.5171	8.2546	0.5171	8.0429	0.5171	7.7388	0.5171	7.3446
APR	0.5004	9.4788	0.5004	9.3895	0.5004	9.2067	0.5004	8.9326	0.5004	8.5702	0.5004	8.1226	0.5004	7.5939
MAY	2.1976	4.7147	2.1976	4.7147	2.1976	4.7147	2.1976	4.7147	2.1976	4.7147	2.1976	4.7147	2.1976	4.7147
JUN	2.1267	0.7675	2.1267	0.7675	2.1267	0.7675	2.1267	0.7675	2.1267	0.7675	2.1267	0.7675	2.1267	0.7675
JUL	2.1976	0.1645	2.1976	0.1645	2.1976	0.1645	2.1976	0.1645	2.1976	0.1645	2.1976	0.1645	2.1976	0.1645
AUG	2.1976	0.4020	2.1976	0.4020	2.1976	0.4020	2.1976	0.4020	2.1976	0.4020	2.1976	0.4020	2.1976	0.4020
SEP	2.1267	2.1563	2.1267	2.1563	2.1267	2.1563	2.1267	2.1563	2.1267	2.1563	2.1267	2.1563	2.1267	2.1563
OCT	2.1975	7.0172	2.1976	7.0172	2.1976	7.0172	2.1976	7.0172	2.1975	7.0172	2.1976	7.0172	2.1976	7.0172
NOV	0.5004	3.1445	0.5004	3.3464	0.5004	3.4589	0.5004	3.6010	0.5004	3.6517	0.5004	3.6508	0.5004	3.5983
DEC	0.1594	0.0	0.3185	0.0	0.4390	0.0	0.5171	0.0028	0.5171	0.0434	0.5171	0.0435	0.5171	0.0032
TOTS	15.4240	38.1050	15.7857	38.4815	15.9847	38.6384	16.0628	38.5322	16.0628	38.1211	16.0628	37.3306	16.0628	36.1672
$SVD	164.57	187.48	168.43	189.33	170.56	190.10	171.39	189.58	171.39	187.56	171.39	183.67	171.39	177.94
MBTU SVD	53.5290		54.2672		54.6231		54.5950		54.1840		53.3935		52.2301	
$SAVED	352.05		357.76		360.66		360.97		358.95		355.06		349.33	
RATIO	30.2570		29.7740		29.5349		29.5095		29.6757		30.0008		30.4924	

the amount of energy in millions of Btu's that are displaced by the solar system for water pre-heating purposes as described before. Likewise, the space column indicated the millions of Btu's displaced for space heating purposes by the solar system. The water and space energy savings are tallied by the month and the yearly total appears at the bottom of each column. The millions of Btu's saved or displaced is changed into dollars and cents by multiplying the respective total by the dollar per million Btu factor of the energy displaced, i.e. \$4.92 per million Btu for space heating and \$10.67 per million Btu for water heating. This figure appears just under the yearly totals for each energy. The total annual amount of energy saved including space and water is just their sum and appears in the row labeled "MBTU SVD". The total annual dollar savings is the sum of the space and water yearly dollar totals and appears in the row labeled "\$SAVED". Finally the cost-to-savings ratio is formed by dividing the cost of the array which is given at the top of the display by the "\$SAVED" figure. The ratio is the last figure to appear in the display and appears in the row labeled "RATIO".

A plot of the cost-to-savings ratio for array sizes of 96 ft^2 to 960 ft^2 in steps of 48 ft^2 and slopes of 30, 40, 45, 50, and 60 degrees is shown in Figure 14. The two slopes of 35 and 55 degrees are omitted because of their close proximity to their neighbors adds little to the plot. As is expected, the graph shows both absolute and relative minima for each slope as the size varies. The lowest point of a corresponding three dimensional display would occur near the 336 ft^2 and 45^o point of the plot.

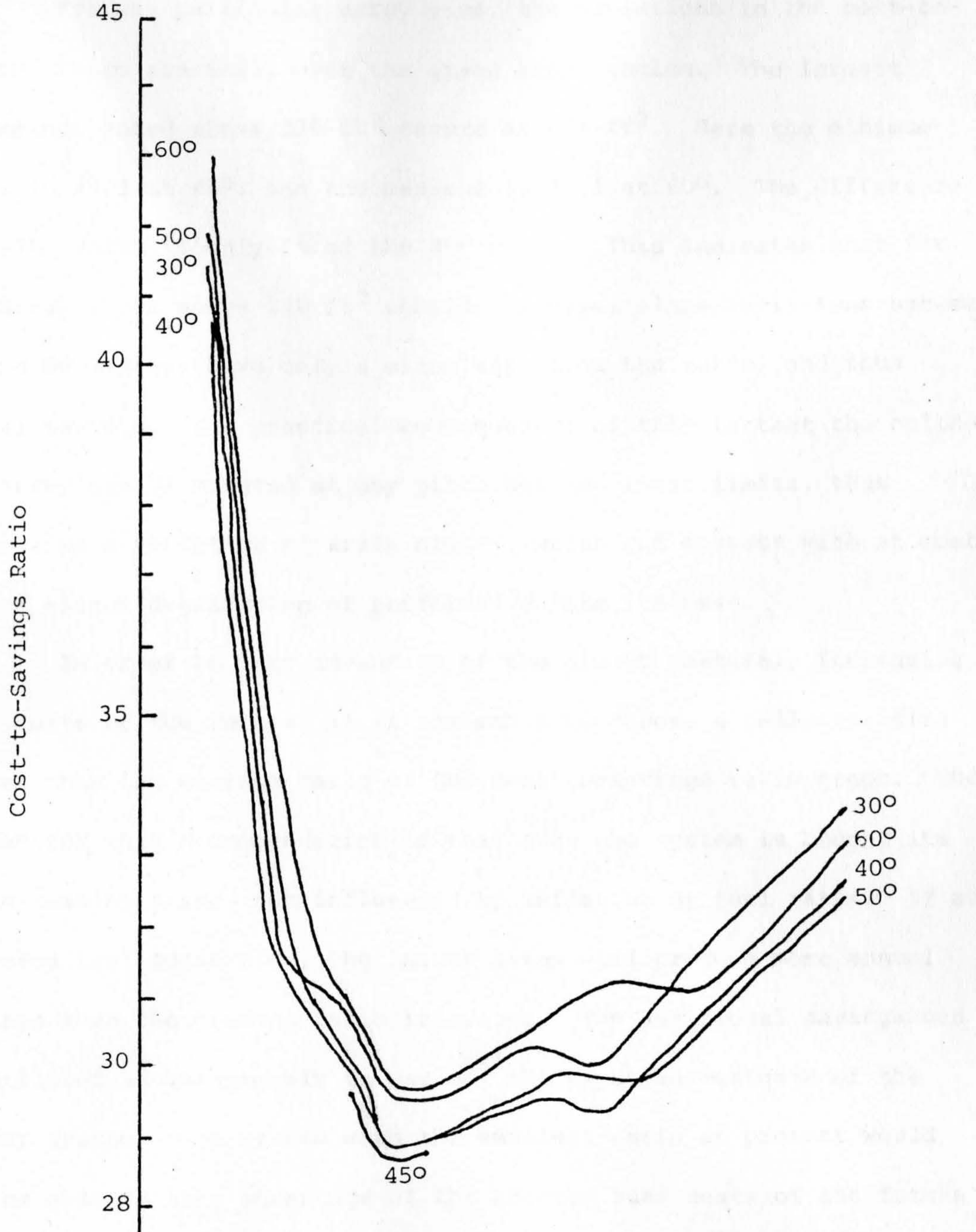

Figure 14.--The Cost-to-Savings Ratio for Various Collector Array Sizes from 96 ft^2 to 960 ft^2 at the Various Slope Angles from 30° to 60°.

For any particular array size, the variations in the cost-to-savings ratio are small over the given slope angles. The largest difference noted above 336 ft^2 occurs at 624 ft^2. Here the minimum value is 29.3 at 40^o, and the maximum is 31.1 at 60^o. The difference is 1.78, which is only 6% of the 40^o ratio. This indicates that for the array sizes above 240 ft^2 considered here, slope variations between 30 and 60 degrees have only a minor effect on the ratio, and thus annual savings. The practical consequences of this is that the collector array can be mounted at any pitch between these limits, thus permitting a variation of array slopes, which can operate with at most only a slight degradation of performance from its best.

In order to take advantage of the almost certainly increasing fuel costs of the future, it is advisable to choose a collector size larger than the minimum ratio of the cost-to-savings ratio graph. The reason for this recommendation is that once the system is bought its price remains fixed, not influenced by inflation or fuel rates. If as expected fuel costs rise, the larger array will produce more annual savings than the present ratio indicates. The additional savings can be utilized advantageously to pay off the expected mortgage of the larger system. The system with the smallest ratio at present would not be able to take advantage of the greater fuel costs of the future as well as the larger array could. The smaller array would then fall behind the larger array in benefits that could accrue in the future. This effect is pointed out in the financial analysis over a thirty year period of operation of a solar system. This consideration for the collector size can be examined by looking at the financial position of the various collector array sizes at the slope that produces the smallest ratio or the maximum expected savings of each size. The projected economic conditions are as determined before: 4% inflation, 25% fuel escalation, mortgage terms of 25 years, 9% interest, and 20% down payment. The plot of the financial position under these conditions appears in Figure 15. The maximum financial position occurs between 624 ft^2 and 672 ft^2. However, for array sizes from 384 ft^2 to 816 ft^2, the plot is relatively flat with not more than about $3000 difference, which amounts to about a 15% variation in the financial position after thirty years. The difference between the financial positions of a 528 ft^2 and 624 ft^2 array is about $2240, or approximately a 10% variation from the maximum.

The final consideration in determining the array size to be used is a very practical one: the amount of roof area available to mount the array. This is a structural limitation imposed by the use of the conventional home design that was popular in 1976. Homes of radically different designs are not considered here because it is thought that the buying public is not ready to accept these designs in 1977 to any great degree. The model home chosen to incorporate the solar system has a possible maximum roof area available for 22 collector panels or 528 ft^2.

Under these considerations, a collector array of 528 ft^2 (49.1 m^2) or 22 panels, at a slope of 45^o is a logical choice for the model home. The array size exceeds the point of minimum cost-to-savings ratio by 192 ft^2, or 8 panels. The slope chosen is that which yields the minimum ratio at 528 ft^2.

The development of the financial position for thirty years for the 528 ft^2 collector array is detailed in Table 5. The mortgage terms

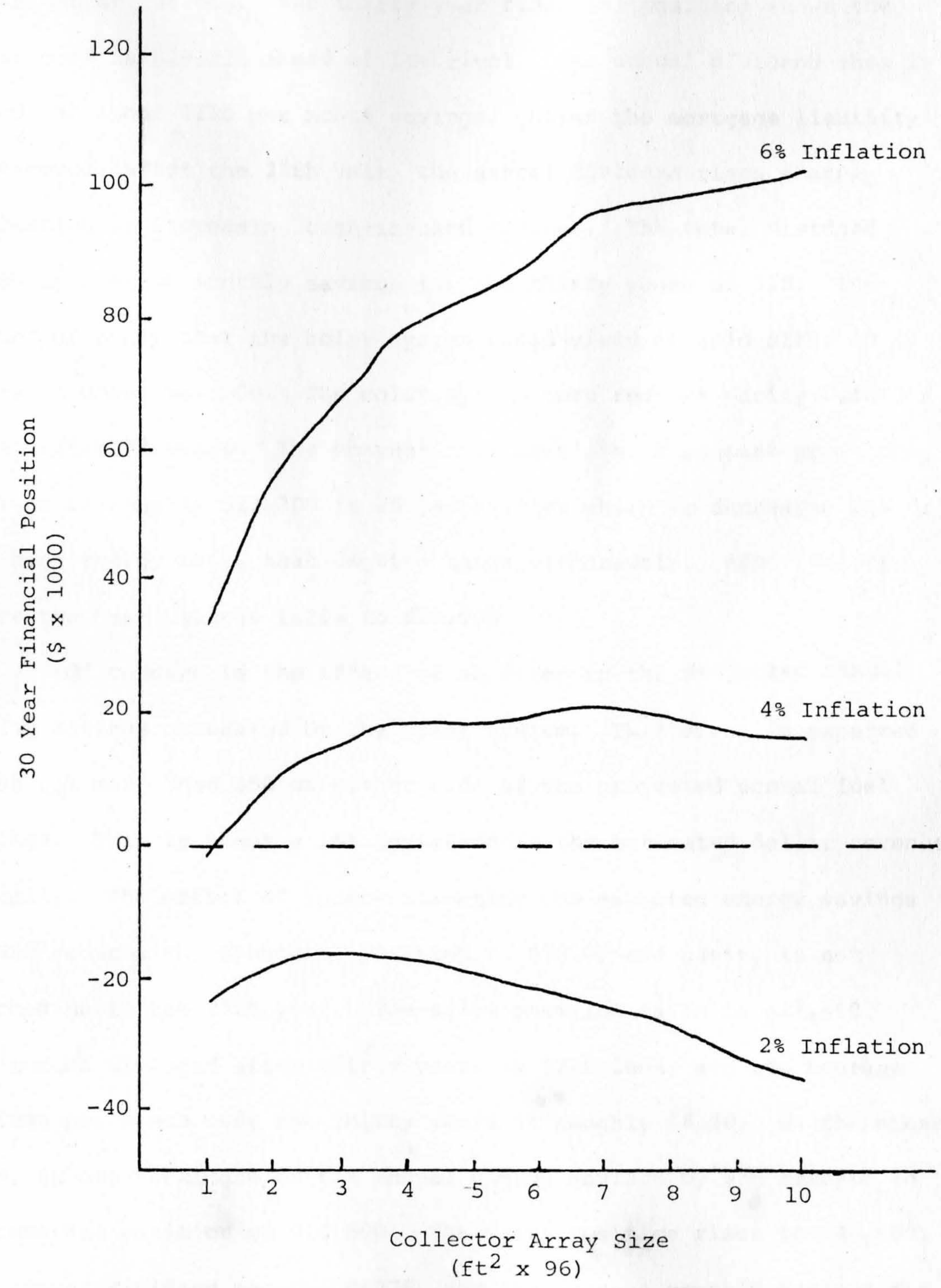

Figure 15.--The 30 Year Financial Position for Collector Array Sizes from 96 ft^2 to 960 ft^2 at the Inflation Rates of 2%, 4% and 6%.

are shown at the top. The thirty year financial position shows the solar home is $19,218 ahead of its rival. The annual dividend then is $1560, or about $130 per month savings. After the mortgage liability is removed, after the 25th year, the annual dividend rises sharply indicating an increasing cash-in-hand savings. The total dividend gives an average monthly savings for the thirty years of $18. The amount of money that the solar system would yield if sold after 30 years is about $41,000. The solar system home reaches parity with its rival after 23 years. The conventional home's bank account grows to a maximum of roughly $22,700 in 25 years after which it decreases due to the high energy bills that require large withdrawals. After thirty years the bank balance falls to $21,900.

Of concern is the effect of an error in the projected annual dollar savings generated by the solar system. This error is expected to be not more than $50 on either side of the projected annual fuel savings. This is about a 15% deviation in the estimated dollar revenue annually. The effect of under-estimating the expected energy savings by $50 reduces the financial position to $7820, and parity is not reached until the 27th year. The sales position falls to $37,600. The annual dividend after thirty years is $220 less, and the average savings per month over the thirty years is roughly $8.60. On the other hand, an over-estimate of the annual energy savings by $50 results in a financial position of $30,600. The sales position rises to $44,600. The annual dividend reaches $1776, and the average monthly savings for thirty years is $28. Parity is reached after 20 years. For an error of $50 in the projected annual fuel savings, the resulting change in financial position after thirty years is about $10,000.

TABLE 5

THE 30 YEAR FINANCIAL PROSPECTUS OF THE SOLAR HOME BUYER

TOTAL SYSTEM COST	DURATION OF MORTGAGE (YEARS)	DOWNPAYMENT	COLLECTOR SIZE(SQ.FT.)
10652.00	25	2130.40 (20.%)	528.

AMOUNT BORROWED	INTEREST RATE	MONTHLY PAYMENT	ANNUAL INFLATION RATE	ANNUAL SAVINGS	FUEL ESCALATOR(%)
8521.60	0.090	71.52	0.040	360.97*	25.00

ANNUAL INTEREST PAID	ANNUAL PRINCIPAL PAID	YEAR END BALANCE	ANNUAL DIVIDEND	TOTAL DIVIDEND	SALES POSITION TOTAL DIVIDEND + APPRECIATION INCLUDES DOWNPAYMENT AND EQUITY INCREASE	DOLLAR VALUE OF BANK ACCOUNT (6.0%)	FINANCIAL POSITION	YEAR OF USE
763.08	95.10	8426.47	-311.29	-311.29	2003.23	2766.14	-762.91	1
754.16	104.03	8322.42	-294.30	-605.60	1914.02	3419.94	-1505.92	2
744.40	113.79	8208.62	-276.55	-882.15	1866.25	4091.88	-2225.63	3
733.72	124.46	8084.13	-258.01	-1140.16	1863.77	4781.98	-2918.21	4
722.04	136.14	7947.96	-238.64	-1378.80	1910.93	5490.23	-3579.30	5
709.27	148.91	7799.04	-218.42	-1597.22	2012.52	6216.56	-4204.04	6
695.30	162.88	7636.14	-197.30	-1794.52	2173.94	6960.83	-4786.89	7
680.02	178.17	7457.95	-175.27	-1969.79	2401.24	7722.84	-5321.61	8
663.30	194.88	7263.05	-152.28	-2122.08	2701.17	8502.31	-5801.14	9
645.02	213.16	7049.87	-128.31	-2250.39	3081.32	9298.86	-6217.54	10
625.02	233.16	6816.68	-103.31	-2353.70	3550.22	10112.05	-6561.83	11
603.15	255.04	6561.62	-77.25	-2430.95	4117.43	10941.31	-6823.88	12
579.22	278.96	6282.64	-50.11	-2481.06	4793.74	11785.96	-6992.22	13
553.05	305.13	5977.48	-21.83	-2502.89	5591.29	12645.22	-7053.93	14
524.43	333.76	5643.70	7.60	-2495.28	6523.73	13518.16	-6994.43	15
493.12	365.07	5278.60	38.24	-2457.05	7606.48	14403.70	-6797.22	16
458.87	399.32	4879.26	70.10	-2386.95	8856.93	15300.62	-6443.68	17
421.41	436.78	4442.46	103.22	-2283.73	10294.74	16207.50	-5912.76	18
380.43	477.75	3964.69	137.64	-2146.09	11942.05	17122.75	-5180.70	19
335.61	522.57	3442.12	173.39	-1972.70	13823.95	18044.57	-4220.62	20
286.59	571.59	2870.52	210.49	-1762.21	15968.81	18970.95	-3002.14	21
232.97	625.21	2245.31	248.97	-1513.24	18408.68	19899.62	-1490.93	22
174.33	683.85	1561.45	288.86	-1224.33	21179.91	20823.04	351.87	23
110.17	748.01	813.43	330.18	-894.20	24323.59	21753.41	2570.18	24
40.01	818.18	-4.75	372.95	-521.24	27886.34	22672.60	5213.74	25
0.0	0.0	0.0	1283.45	762.21	30306.08	22672.48	7633.60	26
0.0	0.0	0.0	1347.62	2109.83	32835.45	22604.33	10231.12	27
0.0	0.0	0.0	1415.00	3524.84	35479.45	22460.68	13018.77	28
0.0	0.0	0.0	1485.75	5010.59	38243.36	22233.40	16009.96	29
0.0	0.0	0.0	1560.04	6570.62	41132.70	21913.75	19218.95	30

The effects of inflation rates from 0 to 8% upon the thirty year quantities of annual and total dividends, sales, financial positions and bank accounts are found in the following table:

TABLE 6

THIRTY YEAR VALUES OF FINANCIAL POSITION PARAMETERS

Rate of Inflation (%)	Annual Dividend ($)	Total Dividend ($)	Sales Position ($)	Bank Account ($)	Financial Position ($)	Years to Parity
0	360	-7781	2875	48774	-45899	>30
2	757	-2366	16935	38170	-21235	>30
4	1560	6570	41132	21913	19218	23
6	3160	21512	82715	-3553	86268	15
8	6298	46703	153932	-44145	198077	11

The average yearly dollars either saved or spent over the course of thirty years can be obtained by dividing the total dividend by 30.

Conclusions

The most significant factor that affects the financial position of the solar system investor is the expected inflation rate, and subsequently the magnitude of the fuel price increase year to year. If the fuel escalator is assumed fixed at 25%, an inflation rate of 4% or better is required to produce a financial position of a large positive value, i.e., in excess of $19,000. If inflation runs at a thirty year rate of less than 4%, the financial position after thirty years is negative by as much as $46,000 for a 0% inflation. Should inflation run at an 8% level resulting in a 10% yearly rise in fuel prices, the thirty year financial position reaches an astounding $198,000. This doubling of inflation rate, from four to eight percent produces a nearly ten-fold increase in financial position. In addition the years to parity are reduced from 23 to 11 by the same change in inflation rates. By the criterion of the financial position, inflation must run at a level of 4% or better to indicate an investment in solar is financially advisable. The higher the inflation above four percent that is assumed, the more attractive the investment becomes.

This study also finds that the potential solar home buyer should not expect to receive large dividends from the investment in solar in the first years. Rather the large dividends show up after the mortgage on the system is paid off in 25 years. The annual dividend of the first 15 years of operation attests to the fact that the larger mortgage payments necessary for solar are not offset by the expected fuel savings for those years. For example, at 4% inflation the annual dividend for the first year is -$311.29, that is, it cost $311.29 to have the system for the first year. However the annual dividend increases steadily by about $20 per year until after the 14th year, it becomes positive. This indicates that the solar system is providing a net savings in spite of the mortgage payment. It continues to increase at $30 to $35 per year until the mortgage is paid off in the 25th year. At this point the annual dividend jumps dramatically to $1283. This represents the cost of the displaced fuel since the other terms in the annual dividend are reduced to zero. It is at this point that the so-called large out-of-the-pocket savings are received from the solar system. This figure reaches a value of $1560 after thirty years and continues to rise. It is money that need not be spent upon fuel bills, money that can be budgeted for other purposes than to pay the utility company, money that is a virtual income as compared to the non-solar household. This is a major benefit provided by the solar home. It is probable that after thirty years has passed since the time of the purchase of the solar home, retirement is near. Living upon a fixed income is difficult, and the solar system can mitigate the problems by reducing the fuel bills significantly and providing a buffer against the increasing fuel prices expected.

Another benefit provided by the solar home lies in the fact that the solar system is an appreciating investment, which like the home can grow in value as does real estate. With every mortgage payment, the investor is buying a larger percentage of the solar system, that is, the investor is increasing his equity in the system. The equity has a value that follows the rest of the real estate market, which generally rises due to the effects of inflation. Hence this equity in the solar system acts as a long term hedge against inflation. At the end of the mortgage term, the equity reaches 100%, and the value of the system, which stood at the purchase price initially, now returns a value that reflects the action of thirty years of inflation.

The solar heating system presented here is not limited to installation only in the model chosen here. Rather it is feasible to adapt most any home plan to include a similar solar option. The same consideration can be given to the various home designs that are given to the model discussed here. For a home of similar characteristics, the slope of the collector panels and roof, in this case, can vary from 30 to 60 degrees with less than 4% change from the minimum in the cost-to-savings ratio. This fact allows for the consideration of ranch home styling of solar homes whose roof pitch is even less than 30 degrees, providing that the annual dollar revenue of energy savings is adequate to produce a positive financial position. The versatility of the solar system option is significant in that it allows for aesthetic variety in home design which is a concern of potential buyers, especially in housing developments. The door is opened for mass-produced solar housing developments of the same or comparable aesthetic quality of conventional housing developments extant in 1976. A solar home containing the solar system similar to that described could be available to any new home buyer in styles not futuristic or radical, a home that would fit into most any neighborhood without being out-of-place. These considerations should encourage new home builders to realize the solar home considered here as a viable and profitable alternative to a conventional housing unit.

In summary, the solar home described here can be a good investment if inflation runs at 4% or better over the next thirty years, or a poor one if inflation runs at less than 4% over the same period. It is assumed that the mortgage terms are reasonable by the 1976 market, and that fuel prices rise over the thirty years at a rate 25% greater than inflation. The benefits derived from solar are the annual dividend, which becomes a virtual income equal to the displaced fuel price after the mortgage is paid off, the investment in a piece of solar real estate whose value keeps pace with inflation, and the realization that the solar home buyer can be doing his financial best in the thirty year commitment to solar over the conventional choice. At four percent inflation over thirty years, the solar home buyer is projected to be about $19,200 ahead of his conventional rival, and the annual dividend expected after thirty years is $1560.

Recommendations

It is clear that encouragement and aid from government, both state and federal, would do much for the successful adoption of solar for residential use. In this study, it is assumed that no personal property tax is affixed to the additional solar system value that is added to the home. This is the case in a few states, and bills to the same effect are pending legislative action in many more. A significant improvement in the financial position of the solar home buyer is possible if the Federal government should allow an income tax deduction of 25% of the solar system's assessed value up to a maximum of $2000. If this subsidy or rebate check were to be received at the end of the first year of purchase and to be applied to the mortgage, it would reduce the time of parity to 12 years and result in a thirty year financial position more than twice that without the subsidy assuming 4% inflation. If instead of this, the rebate check were used to pay other bills, such as those incurred by the need of getting the initial down payment for the solar system, the financial position remains as if there were no rebate applied to the mortgage. In either case, the tax rebate would provide additional incentive in opting for solar by enhancing the financial position significantly or by easing the initial financial burden of solar.

Another development that would make the solar option more attractive would be a price reduction of future solar system components and labor charges for installation. The operation of the free enterprise market ought to be able to decrease prices of the solar components to a certain extent, but nothing as drastic as the transistor and semi-conductor products. The electronic devices initially high value was determined in part by the cost of research and initial difficulty and scarcity of production, and not by material and labor costs per se. As the problems of production were solved and the money returned for research, the price plummeted. Solar system components, on the other hand, consist mostly of bulk materials, such as aluminum and glass, and are labor intensive to fabricate. As skills are developed in the manufacturing process and as competition enters the market, prices might drop 25 to 50 percent, but nothing like the \$200-to-\$20 pocket calculator price drop can be expected. At the same time, the factor of inflation is acting to raise prices. It affects solar component costs and labor alike. These two upward pushes can be expected to offset somewhat the downward trend hoped for.

A prospective new home builder or owner who feels the inevitability of solar energy being applied to space heating should not hesitate to examine the financial merits and demerits that might result from a home equipped with a solar energy option as considered here. It is by no means certain that a solar energy option is a better financial investment than a conventional choice in all circumstances. For example, a ten year investment in the solar home mentioned here would have a financial position of -\$6217 at 4% inflation. This short term investor in the solar home could be further ahead if the money spent for the solar option was invested wisely elsewhere. Financial parity has not occured in the ten years of proposed ownership, and the negative financial position shows that the investment would not be indicated. Admittedly, this is a short sighted look at the solar option, for its benefits would transfer to the new owner in much the same way and with the same potential as given to the original owner. Yet for the investment minded buyer whose short term profits are requisite, it is a consideration that should not be neglected.

The financial position is the major criterion in the decision to invest in solar. It depends upon many different factors: local climate; geographical location; collector design, size and slope; system cost; fuel costs; mortgage terms; inflation and fuel price escalation rates to name a few. The analysis distills this information into one figure that measures the solar home value against a similar conventional home value under the conditions assumed by the potential buyer. Any further investigations that would improve the estimation or prediction of these and other factors would give the financial position even more credibility. In addition the effects of the various government legislation concerning possible subsidies and financial incentives in their various forms should be considered in order to find the most beneficial plans for the solar buyer.

In conclusion, the adoption of solar energy as a thermal source for residential homes as suggested here is shown to be a sound investment with certain reservations. The government at all levels could significantly improve the financial outlook of solar homes with the passage of legislation to provide the welcome incentives. The adoption of solar as a major thermal source for residential space and water heating can have the additional effect of creating new jobs and new markets, conserving on unrenewable fossil fuels, and helping to provide a cleaner environment. It is demonstrated that it is indeed possible to invest in solar homes in 1977 and to expect to fare better after 30 years than to invest in a conventional home for the same period. Hence solar energy for residential use is financially feasible in 1977, and its outlook should grow even more favorable in the years to come.

APPENDIX

Fortran IV Main Program and Subroutine

THIS PROGRAM CALCULATES THE AMOUNT OF FOSSIL FUEL SAVED BY USING A SOLAR HEATING SYSTEM. IN ADDITION IT TABULATES THE DOLLAR AMOUNTS OF THE DISPLACED FOSSIL FUEL COSTS. THE RATIO OF SYSTEM COST TO AMOUNT OF SAVINGS IS DETERMINED.

```
  DIMENSION ANG(7), COST(20), DELTA(12), EG(12,7),EG1(12,7),EG2(12,7),
  EHOR1(12), EHOR2(12), EO(12,7), HL(12), HO(12), RATIO(7),
  SHEAT(12,7), SSVNG(7), STOT(7), SVNT(7), TWS*7), WHEAT(12,7),
  WSVNG(7), WTOT(7)
  REAL M12(12)/'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG','SEP',
  'OCT','NOV','DEC'/
  REAL MONTH(12)/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,30.,31./
  REAL DD(12)/1218.,1072.,921.,519.,258.,42.,9.,22.,118.,384.,
  741.,1122./
  REAL L/41.27/
  REAL T(12)/33.,34.7,44.3,58.4,68.9,78.3,81.8,80.4,73.9,62.9,47.9,
  35.6/
  REAL EHOR(12)/125.,183.,303.,286.,502.,562.,562.,494.,278.,389.,
  141.,115./
  REAL PSUN(12)/.29,.26,.45,.52,.61,.67,.71,.68,.62,.54,.32,.25/
  REAL EXTN(12)/.142,.144,.153,.174,.192,.203,.206,.202,.183,.164,.152,
  .144/
  REAL QPEAK(12)/390.,386.,378.,364.,352.,346.,344.,349.,362.,375.,
  385.,390./
  DO 1 I=1,12
  EHOR(I)=EHOR(I)*3.687
1 CONTINUE
  OIL=4.92
  ELCTY=10.67
  PI=3.14159
  R=PI/180.
  C=0.98
  SLAT=SIN(L*R)
  CLAT=COS(L*R)
  D=15.
  DO 2 I=1,12
  DELTA(I)=23.5*R*SIN((D-80.)*2.*PI/365.)
  CDEL=COS(DELTA(I))
  SDEL=SIN(DELTA(I))
  TDEL=SDEL/CDEL
  HO(I)=ARCOS(-TAN(L*R)*TDEL)/.2618
  SUM=O.
  DH=2.*HO(I)/50.
  DO 3 N=1,50
  H=HO(I)=(2*N-1)/2.*DH
  S=CLAT*CDEL*COS(.2618*H)=SLAT*SDEL
  QI=O.
  IF(S.GT..017)QI=C*QPEAK(I)*EXP(-EXTN(I)/S)
```

```
      QQ=QI*S*DH
      SUM=SUM QQ
    3 CONTINUE
      EHOR1(I)=SUM*PSUN(I)
      EHOR2(I)=EHOR(I)-EHOR1(I)
      UL=1.243*(70.-T(I))
      SUM=0.
      M=0
      DO 4 K=30,60,5
      M=M+1
      ANG (M)=FLOAT(K)
      B=ANG(M)*R
      CB2=COS(B/2.)
      SB=SIN(B)
      CB=COS(B)
      HOB=ARCOS(-TAN(L*$-B)*TDEL/.2618
      IF(HOB.LT.HO(I))HO(I)=HOB
      IF(HOB.LT.HO(I)DH=2.*HOB/50.
      SUM=0.
      DO 5 N=1,50
      H=-HO(I)+(2*N-1)/2.*DH
      S=CLAT*CDEL*COS(.2618*H)+SLAT*SDEL
      QI=0.
      IF(S.GT.0.017)QI=C*QPEAK(L)*EXP(-EXTN(I)/S)
      SI=(SLAT*SB+CLAT*CB)*CDEL*COS(.2618*H)
      S2=(SLAT*CB-CLAT*SB)*SDEL
      QQ=(S1+S2)*QI*DH
      SUM=SUM+QQ
    5 CONTINUE
      EG1(I,J)=SUM*PSUN(I)
      EG2(I,J)=CB2*CB2*EHOR2(I)
      EG(I,J)=EG1(I,J)+EG2(I,J)
      EFF=o.69-UL*2.*HO(I)/EG(I,J)
      IF(EFF.LT.0.)EFF=0.0
      EO(I,J)=EFF*EG(I,J)*MONTH(I)
    4 CONTINUE
      D=D+MONTH(I)
    2 CONTINUE
      BTUDD=1.8274E+04
      DO 6 I=1,12
      HL(I)=BTUDD*DD(I)
    6 CONTINUE
      M=0
      DO 7 N=48,960,48
      M=M+1
      AREA=FLOAT(N)
      COST(M)=AREA*9.00+5900.
      CHK=0.
      DO 8 J=1,7
      DO 9 I=1,12
      WHEAT(I,J)=0.
      SHEAT(I,J)=0.
    9 CONTINUE
```

```
      WTOT(J)=0.
      STOT(J)=0.
      DO 10 I=1,12
      WW=100.*8.34*20.*MONTH(I)
      SW=100.*8.34*85.*MONTH(I)
      ETOT=EO(I,J)*AREA
      IF(ETOT.LT.WW) GO TO 83
      WHEAT(I,J)=WW
      WDIF=ETOT-WW
      IF(WDIF.LT.HL(I)) GO TO 81
      SHEAT(I,J)=HL(I)
      SDIF=WDIF-HL(I)
      IF(SDIF.LT.(SW-WW)) GO TO 82
      WHEAT(I,J)=SW
      GO TO 80
   81 SHEAT(I,J)=WDIF
      GO TO 80
   82 WHEAT(I,J)=WHEAT(I,J)+SDIF
      GO TO 80
   83 WHEAT(I,J)=ETOT
   80 CONTINUE
      WHEAT(I,J)=WHEAT(I,J)*1.E-06
      SHEAT(I,J)=SHEAT(I,J)*1.E-06
      WTOT(J)=WTOT(J)+WHEAT(I,J)
      STOT(J)=STOT(J)+SHEAT(I,J)
      TWS(J)=WTOT(J)+STOT(J)
   10 CONTINUE
      WSVNG(J)=WTOT(J)*ELCTY
      SSVNG(J)=STOT(J)*OIL
      SVNT(J)=SSVNG(J)+WSVNG(J)
      IF(SVNT(J).GT.CHK)CHK=SVNT(J)
      SVNT1=CHK
      COST1=COST(M)
      RATIO(J)=COST(M)/SVNT(J)
    8 CONTINUE
      GO TO 102
      WRITE(6,71)AREA,COST(M)
   71 FORMAT(//,T7,'ARRAY SIZE  'F5.0,' SQ.FT.',8X,'SYSTEM COST
      ($9.00/SQ.FT. PLUS INITIAL COST OF $5900.) = $',F9.2)
      WRITE(6,72)(ANG(J),J=1,7)
   72 FORMAT(//,1X,'SLOPE',7(7X,F4.0,7X))
      WRITE(6,72)
   73 FORMAT(T6,7(4X,'WATER',4X,'SPACE'))
      WRITE(6,74)(M12(I),(WHEAT(I,J,),SHEAT(I,J),J=1,7),I=1,12)
   74 FORMAT(1X,A3,1X,14F9.4)
      WRITE(6,75)(WTOT(J),STOT(J),J=1,7)
   75 FORMAT(/,'TOTS',14F9.4)
      WRITE(6,76)WSVNG(J),SSVNG(J),J=1,7)
   76 FORMAT('$SVD',14F9.2)
      WRITE(6,77)(TWS(J),J=1,7)
   77 FORMAT(/,'MBTU SVD'T10,6(F9.4,9X),F9.4)
      WRITE(6,78)(SVNT(J),J=1,7)
```

```
78 FORMAT('$SAVED',T10,6(F9.2,9X),F9.2)
   WRITE(6,79)(RATIO(J), J=1,7)
79 FORMAT(/,'RATIO',T10.6(F9.4,9X)F9.4)
   CALL ADVD(COST1,SVNT1,AREA)
 7 CONTINUE
   STOP
   END
```

```
      THIS IS A SUBROUTINE THAT CALCULATES THE FINANCIAL POSITION OF
      A POTENTIAL SOLAR HOME BUYER COMPARED TO A BUYER OF A CONVENTIONAL
      HOME.  THE SYSTEM COST AND ANNUAL EXPECTED SAVINGS ARE GIVEN BY
      THE MAIN PROGRAM.

      REAL IN,INFL,INP,INT,LOAN
      READ (5,1)TERM,DPMT,IN,INFL,FUEL
    1 FORMAT(5F10.3)
      BANK=6.0
      D=DPMT*100
      F=FUEL*100
      DWNP=DPMT*COST
      XX=DWNP
      LOAN=COST-DWNP
      N=IFIX(TERM)
      N2=N*12
      A1=IN/12.*(1.+IN/12.)**N2
      A2=(1.+IN/12.)**N2-1.
      PAY=LOAN*A1/A2
      WRITE(6,11)
   11 FORMAT(T3,'TOTAL SYSTEM COST',T25,'DURATION OF MORTGAGE(YEARS)',
      9X'DOWNPAYMENT',6X,'COLLECTOR SIZE(SQ.FT.)')
      WRITE(6,12)COST,N,DWNP,D,AREA
   12 FORMAT(F16.2,16X,I4,20X,F10.2,2X,'(',F3.0,'%)',6X,F12.0)
      BAL=COST-DWNP
      FF=(1+FUEL)*INFL
      DVDT=0.
      Y=0.
      PAYMT=PAY*12.
      WRITE(6,21)
   21 FORMAT(/,T2,'AMOUNT BORROWED',3X,'INTEREST RATE',3X,'MONTHLY
      PAYMENT',5X,'ANNUAL INFLATION RATE',5X, 'ANNUAL SAVINGS',5X,
      'FUEL ESCALATOR(%)')
      WRITE(6,22)BAL,IN,PAY,INFL,SVNG,F
   22 FORMAT(F12.2,F17.3,F15.2,F26.3,5X,F16.2,14X,F6.2)
      WRITE(6,31)
   31 FORMAT(/T1,2X,'ANNUAL',5X,'ANNUAL',3X,'YEAR',6X,'ANNUAL',5X,
      'TOTAL',9X,'SALES POSITION',12X,'DOLLAR VALUE',4X,'FINANCIAL
      POSITION',9X,'YEAR')
      WRITE(6,32)
   32 FORMAT(T2,'INTEREST',2X,'PRINCIPAL',3X,'END',5X,'DIVIDEND',2X,
      'DIVIDEND',2X,'TOTAL DIVIDEND APPRECIATION',8X,'OF',38X,'OF')
      WRITE(6,33)
   33 FORMAT(T3,'PAID',7X,'PAID',4X,'BALANCE',27X,'INCLUDES
      DOWNPAYMENT',8X,'BANK ACCOUNT',32X,'USE')
      WRITE(6,34)BANK
   34 FORMAT(56,'AND EQUITY INCREASE',12X,'(',F4.1,'%)')
      DO 4 I=1,30
      INT=0.
      PRNCT=0.
      DO 5 J=1,12
      INP=BAL*IN/12.
```

```
      PRNC=PAY-INP
      BAL=BAL-PRNC
      PRNCT=PRNCT+PRNC
      INT=INT+INP
    5 CONTINUE
      IF(BAL.GT.-10.) GO TO 6
      BAL=O.
      PRNCT=O.
      INT=O.
      PAYMT=O.
    6 CONTINUE
      DVD=SVNG*(1+FF)**I+O.22*INT-PAYMT
      DVDX=SVNG*(1+FF)**I-PAYMT
      DVDT=DVDT+DVD
      Y=Y+PRNCT
      P=(Y+DWNP)*(1+INFL)**I
      SPOS=DVDT+P
      XX=(XX-DVDX)*(1.+BANK/100.)
      FPOS=SPOS-XX
      WRITE(6,41)INT,PRNCT,BAL,DVD,DVDT,SPOS,XX,FPOS,I
   41 FORMAT(1X,F7.2,F10.2,3F10.2,7X,F14.2,5X,F19.2,6X,F12.2,16X,I2)
    4 CONTINUE
      RETURN
      END
```

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