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Economic Feasibility of Solar Water and Space Heating

Roger H. Bezdek, Alan S. Hirshberg, William H. Babcock

Summary. The economic feasibility in 1977 and 1978 of solar water and combined water and space heating is analyzed for single-family detached residences and multifamily apartment buildings in four representative U.S. cities: Boston, Massachusetts; Washington, D.C.; Grand Junction, Colorado; and Los Angeles, California. Three economic decision criteria are utilized: payback period, years to recovery of down payment, and years to net positive cash flow. The cost competitiveness of the solar systems compared to heating systems based on electricity, fuel oil, and natural gas is then discussed for each city, and the impact of the federal tax credit for solar energy systems is assessed. It is found that even without federal incentives some solar water and space heating systems are competitive. Enactment of the solar tax credit, however, greatly enhances their competitiveness. The implications of these findings for government tax and energy pricing policies are discussed.

Direct use of the sun's energy is of interest as a means of alleviating U.S. energy problems. The expected response of consumers to the financial incentives contained in the National Energy Conservation Policy Act (NECPA) of 1978 is of particular concern to energy policymakers. These incentives are primarily directed toward solar applications for supplying domestic hot water and for space heating, which together represent 20 percent of annual U.S. energy consumption.

The ability of solar energy systems to contribute to this large market depends on the current economic feasibility of solar water and space heating systems and the effectiveness of the financial incentives in enhancing their attractiveness. In this article we discuss the economic feasibility for 1977 and 1978 of solar water and combined water and space heating for single-family and multifamily dwellings for four representative U.S. cities. Three economic decision criteria are utilized to determine economic feasibility: payback period, years to recovery of down payment, and years to net positive cash flow. Solar system performance is compared in each city with the performance of heating systems based on electricity, fuel oil, and natural gas. The impact on solar economic feasibility of the federal tax credit in the NECPA is also assessed.

Solar System Description

Solar water heating refers to the use of solar radiation to heat water for domestic use—for showers, washing dishes, and so on. Solar space heating refers to the use of solar radiation to heat the building space. For technological as well as economic reasons, solar space heating systems are often designed to provide domestic hot water; thus the solar space heating systems analyzed here are in reality combined solar water and space heating systems. Typical systems of both types are shown in Figs. 1 and 2.

The solar domestic hot water system (Fig. 1) consists essentially of solar energy collectors, a water storage tank, a heat exchanger, a drain down tank, a circulating pump, a tempering valve, and a differential thermostat. In this example the backup system is a conventional electric resistance domestic water heater.

Whenever the temperature of the solar collectors is higher than the storage tank temperature, the differential thermostat energizes the circulating pump. Water is circulated between the solar collectors and the storage tank, thereby heating the storage water. Cold city water is introduced into the bottom of the storage tank, where it is heated by solar-heated water. Heated water is supplied to faucets after passing through the conventional water heater and a tempering valve. The tempering valve mixes solar-heated water with cold city water, if necessary, to provide the desired water temperature. However, if solar-heated water is not available, the conventional water heater is energized. Whenever solar energy is not available and the solar collector temperature is lower than the storage tank temperature, the differential thermostat de-energizes the circulating pump and causes the water contained in the collectors to drain into the drain down tank, thus preventing energy losses from the collectors and freezing of components.

The combined solar water and space heating system (Fig. 2) consists essentially of solar energy collectors, a water storage tank, a heat exchanger, two circulating pumps, a water heating coil, and a differential thermostat. The backup systems are an electric resistance do-

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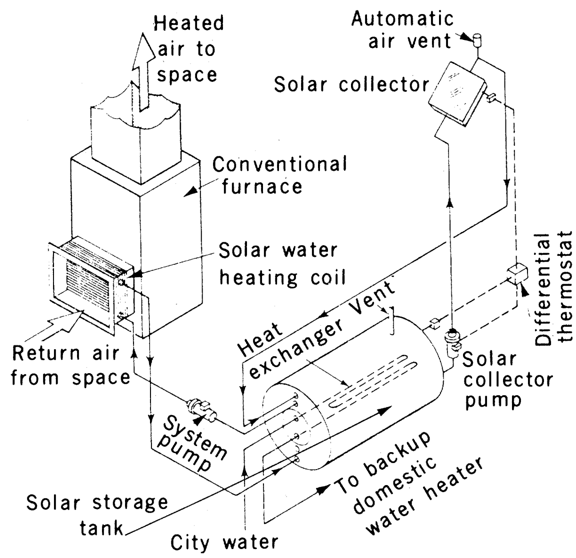

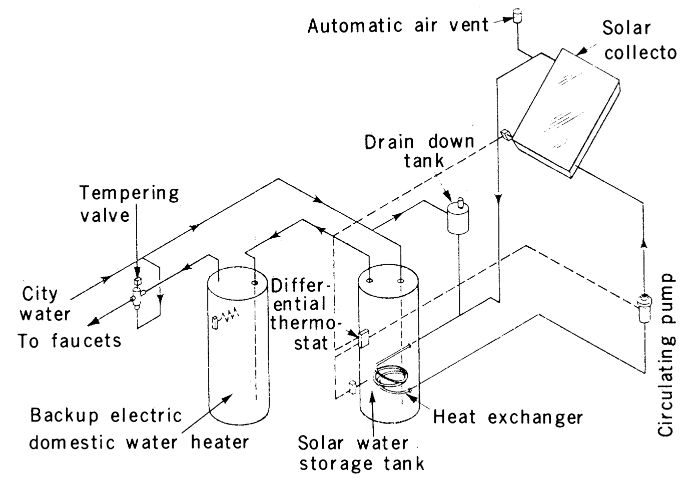

Fig. 1 (left). Solar domestic hot water system. Fig. 2 (right). Solar domestic hot water and space heating system.

mestic water heater and an electric resistance forced-air furnace.

As in the case of the solar water heating system, whenever the temperature of the solar collectors is higher than the storage tank temperature, the differential thermostat energizes the solar collector loop pump, thereby heating the storage tank. Cold city water is introduced into the heat exchanger located in the storage tank, where it is heated by the storage tank water. Heated water is supplied to faucets after passing through a conventional solar water heater and a tempering valve. If solar-heated water is not available, the backup solar water heater is energized.

Space heating is accomplished by means of a solar water heating coil located in the return airstream of the backup electric furnace. Whenever the space calls for heat, the system pump is energized, causing solar-heated tank water to circulate through the solar water heating coil. However, if the space calls for heating and solar-heated water is not available, the system pump is automatically de-energized and backup heating is provided by the electric resistance furnace.

Methodology and Data Base

The economic feasibility of solar water and space heating has been the subject of a number of studies, which have often arrived at conflicting results (*1*). Conclusions that are national in scope are difficult to reach and support for several reasons: (i) important cost and performance factors vary among published studies; (ii) system performance varies with local climates, weather, and solar insolation; (iii) the economics of solar heating systems are strongly affected by the unique thermal characteristics of each type of building; (iv) today's fuel prices and electric rates, which determine immediate cost savings, vary across the nation; (v) vital solar system characteristics, such as useful lifetime and operating costs, are not known with certainty; (vi) the specification of fuel price escalation rates has a substantial effect on economic results (*2*); (vii) the method of financing the solar investment varies between users; and (viii) the criteria by which investors judge solar system economics are inadequately understood today and will undoubtedly change over time.

Even though there is much uncertainty associated with analyzing the economic feasibility of solar water and space heating systems, our analysis does illuminate the potential effects of the solar tax credit and other government incentives.

In this analysis, we deal with the feasibility of solar water and space heating on strictly economic grounds. However, it is important to note that there are strong motivations other than financial ones to induce consumers to purchase solar energy systems. These motivations range from environmental concerns and a desire to attain a degree of individual energy independence to the desire to be the "first on the block" to acquire a new technology. It is difficult to assess the importance of these types of nonfinancial motivations in influencing consumers' decisions to purchase solar energy systems. There is strong evidence, however, that nonfinancial considerations have been of paramount importance in influencing such decisions (*3*). In one study it was even reported that nearly one-third of the solar heating systems purchased are being installed in residences where natural gas hookups are available (*4*). Thus, the importance of nonfinancial considerations as a stimulus to the solar energy industry cannot be overemphasized.

Nevertheless, in the long run, the cost competitiveness of solar heating systems compared to other energy systems will determine the rate of market penetration of solar systems, and the economics of solar heating and cooling depend critically on the relative prices of conventional fuels. Any policies such as taxes on fuel, deregulation, or marginal cost pricing that increase fuel costs will make solar energy applications more cost competitive. Such policies will also provide a strong incentive for a variety of energy conservation practices.

In this study actual data were used whenever possible and estimates were based on the most current information available to us. A modified version of the residential solar economic performance model developed for the Department of Housing and Urban Development (HUD) by Booz, Allen & Hamilton provided a well-documented methodology for the study (*5*). We assessed the economic feasibility of solar water heating systems and combined solar water and space heating systems compared to systems based on oil, natural gas, and electricity for two types of buildings—single-family detached homes and multifamily garden apartments—in four locations representative of most U.S. regions: Boston, Massachusetts; Washington, D.C.; Grand Junction, Colorado; and Los Angeles, California.

Solar collector sizes for this analysis were predetermined. Specifically, we fixed the collector size in each city to be capable of providing 70 percent of the hot water or 50 percent of the space heating (or both) needed annually for the building. This assumption was made to keep the financially optimum system size from becoming unrealistically small. The systems analyzed here are based on conventional flat-plate collector technology, which is presently available in the marketplace in all geographic regions (*6*).

The basic assumptions used in the analysis are listed in Table 1. They were derived from several standard sources. The number of occupants, hot water usage, and supply temperature were adopted from the book of fundamentals of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). The building thermal factor represents the heat loss rate of a typical building insulated to a level consistent with the 1977 HUD minimum property standards. Collector parameters were obtained by averaging the collector parameters of ten currently available solar collectors.

Fixed and variable components of system cost were determined from a regression analysis of cost and collector area for 37 HUD residential solar demonstration projects. Solar systems were assumed to be exempt from property taxes. Maintenance cost was assumed to be $1^1/_2$ percent per year of the system cost, which is similar to the maintenance cost of a typical house during a year. The building owner's financial parameters include the tax bracket for a homeowner earning about $25,000 per year. Mortgage rates of 20 percent down and $8^1/_2$ percent for a 30-year loan period were used. Fuel escalation rates for oil and electricity were assumed to be 2 percent above the 5 percent average yearly rate of inflation, and natural gas was assumed to escalate at the inflation rate plus 5 percent, reflecting partial deregulation. The discount rate of 10 percent is the official rate used by the Office of Management and Budget. The coefficients of performance for heat pumps were obtained from the Department of Energy. The four cities considered were chosen on the basis of the availability of data, their use in previous analyses, and their geographic distribution. Fuel prices used are

Table 1. Basic assumptions.

Parameter	Single family	Multifamily
	Building energy use parameters	
Number of occupants	4	100
Hot water usage, gallons per day	80	2000
Supply temperature, degrees Fahrenheit	140	140
Temperature	Average ambient	Average ambient
Building thermal factor, Btu's per square foot per degree-day Fahrenheit	8.42	8.42
Building floor area, square feet	1500	32,000
	Collector parameters	
$F'_R U_L$*	0.83	0.83
$F'_R \alpha$*	0.7	0.7
Glazing	Double	Double
Collector area	Fixed to meet 70 percent of DHW demand and (or) 50 percent of SH demand†	Fixed to meet 70 percent of DHW demand and (or) 50 percent of SH demand†
Tilt	Latitude	Latitude
	System cost parameters	
Hot water system cost		
Fixed component, dollars	400	500
Variable component, dollars per square foot	22	25
Hot water and space heating cost		
Fixed component, dollars	1300	1500
Variable component, dollars per square foot	22	30
Additional property tax	0	0
Maintenance (solar) as fraction of installed cost		
Hot water, per year	0.015	0.015
Hot water and space heating, per year	0.015	0.015
Depreciation (system life, 20 years)	NA‡	Straight line
System life, years	20	20
	Owner financial parameters	
Tax bracket, percent	30	50
Financing		
Period, years	30	25
Interest rate, percent	$8^1/_2$	8
Down payment, percent	20	30
Discount rate, percent	10	10
Fuel price escalation, percent		
Electric and oil	7	7
Gas	10	10
Inflation rate, percent	5	5
Utility rate discrimination	No	No
Tax credit	30 percent of $2000, 20 percent of next $8000	10 percent
Heat pump coefficient of performance§		
Boston	2.0	2.0
Washington, D.C.	2.1	2.1
Grand Junction	1.9	1.9
Los Angeles	2.5	2.5

*$F'_R U_L$ is a measure of heat transmission losses from the collector; $F'_R \alpha$ is a measure of the transmissivity and absorptivity of the collector. †DHW, domestic hot water; SH, space heating. ‡NA, not applicable. §Amount of usable energy out divided by amount of energy in.

1977–1978 prices for the cities included in the analysis (*7*).

The incentive package utilized is the federal income tax credit as proposed in the House version of the National Energy Act (H.R. 8444). The Act provides for a residential tax credit of 30 percent of the first $1500 and 20 percent of the next $8500 of expenditures for solar equipment, up to a total maximum credit of $2150. The business tax credit provides for a 10 percent investment tax credit (ITC) over and above the 10 percent conventional ITC for approved solar expenditures in commercial applications (*8*).

Economic feasibility is usually understood to represent the achievement of a certain level of consumer acceptance. Therefore, feasibility is dependent not only on the quantitative economic performance data provided by the model, but also on the decision criteria utilized by the consumer. For individual homeowners, market analysts have found that cash flow measures are paramount (*9*). Three measures are particularly important. Years to positive cash flow is the number of years elapsed until fuel cost savings become greater than the extra expenses of the solar system, after taxes. The criterion assumed is 3 years because most homeowners expect rapid savings for an "energy conserving" investment. Years to recover down payment is the number of years required for accumulated savings to offset initial cash payments and early cash flow losses, after taxes. The criterion assumed is 5 years, based on today's average housing turnover rate of 5 years. Payback period is the number of years required for accumulated savings to repay the full cost of the system (or equal the remaining principal on a loan, if financed). The criterion assumed is 10 years. Actual purchase criteria and their relative importance will, of course, be unique to each individual. However, we believe that these are representative of the criteria which must be satisfied before most American homeowners will purchase solar equipment.

For owners of multifamily buildings, the decision criteria are quite different. Most apartments are owned by limited partnerships, which are formed to utilize tax deductions from depreciation-generated tax losses. For this reason, the internal rate of return (IRR) is the key performance measure. Typically, before-tax IRR's range from 10 to 20 percent. As the criterion for the solar investment, we assumed that a minimum IRR of 15 percent was required.

Current Cost Economic Assessment

Some solar water heating and combined water and space heating systems are economically viable in some regions of the United States today, even without a federal tax credit incentive. The most economically viable systems are primarily solar water heating systems that have electricity as the alternative energy source. In addition, solar water and space heating systems are competitive against electricity-based systems in certain parts of the country, and they become more competitive with the federal income tax credits.

We define a solar system in a single-family detached residence as being economically feasible when any two of the three criteria discussed above are satisfied: (i) a positive cash flow is realized in 3 years or less; (ii) down payment is recovered in 5 years or less; and (iii) payback is achieved in 10 years or less. If

Table 2. Economic measures for solar hot water systems for single-family homes with and without the federal tax credit.

City and criterion	Alternative: Electricity		Alternative: Fuel oil		Alternative: Natural gas		Assumed criterion
	Without	With	Without	With	Without	With	
Boston							
Payback period, years	15	13	23	21	21	20	10
Years to recover down payment	8	1	18	12	18	14	5
Years to positive cash flow	1	1	8	8	9	9	3
Washington, D.C.							
Payback period, years	15	13	22	20	24	22	10
Years to recover down payment	8	1	16	1	21	18	5
Years to positive cash flow	1	1	7	7	12	12	3
Grand Junction							
Payback period, years	11	9	14	12	23	21	10
Years to recover down payment	4	1	7	1	20	15	5
Years to positive cash flow	1	1	1	1	11	11	3
Los Angeles							
Payback period, years	11	9	NU*	NU	24	23	10
Years to recover down payment	4	1	NU	NU	22	18	5
Years to positive cash flow	1	1	NU	NU	12	12	3

*NU, not utilized (fuel oil is not utilized for water or space heating in Los Angeles).

Table 3. Internal rates of return (percentages) for solar water heating and combined water and space heating for multifamily garden apartments with and without the federal solar income tax credit.

City and type of heating	Electricity		Electric heat pump		Fuel oil		Natural gas	
	Without	With	Without	With	Without	With	Without	With
Boston								
Water	<0	<0	NA*	NA	<0	<0	<0	<0
Water and space	0	3	<0	<0	<0	<0	<0	<0
Grand Junction								
Water	13	18	NA	NA	13	18	<0	<0
Water and space	8	13	0	2	8	13	<0	<0
Los Angeles								
Water	13	16	NA	NA	NU†	NU	<0	<0
Water and space	20	27	3	7	NU	NU	0	2
Washington, D.C.								
Water	<0	0	NA	NA	<0	<0	<0	<0
Water and space	3	7	<0	<0	<0	<0	<0	<0

*NA, not applicable. †NU, not utilized (fuel oil is not utilized for water or space heating in Los Angeles).

only one of the three criteria is satisfied, the system is considered marginally competitive. The specific results of our economic analysis are discussed below.

The economic feasibility of solar water heating in single-family detached residences in each of the four cities, in comparison to the three conventional fuels, with and without the federal tax credit, is summarized in Table 2. Even without the federal tax credit, solar water heating is economically viable when electricity is the alternative in some parts of the nation today. Table 2 shows that solar water heating is economically feasible in Grand Junction and Los Angeles and marginally economic in Boston and Washington, D.C. In the former two cities, two of the three feasibility criteria (years to down payment recovery and years to positive cash flow) are satisfied, and in the latter two cities the criterion of years to positive cash flow is satisfied.

When compared to fuel oil and natural gas systems, however, solar water heating is not economically viable in any of the four cities. Solar versus fuel oil for water heating is marginally competitive in Grand Junction. Solar water heating is not economically competitive with natural gas in any city.

As shown in Table 2, the tax credit makes solar water heating clearly economic in every location compared to electric water heating. However, the results shown in Table 2 also indicate that although the economic feasibility of solar water heating improves compared to oil and natural gas, the tax credit is not large enough to make it cost-competitive with either fuel.

Table 3 shows the IRR's achievable for garden apartments in the four locations. At best, it can be said that solar water heating can be economically justified when compared to the alternative of electricity, depending on location. In Los Angeles and Grand Junction, solar water heating is marginally feasible (IRR's of 13 percent), whereas in Boston and Washington, D.C., a solar water heating system would not be economically competitive. When compared to fuel oil or natural gas, solar water heating is not economically viable. The proposed 10 percent tax credit for commercial buildings does significantly affect the feasibility of solar water heating compared to electric water heating in Los Angeles and Grand Junction, where it results in an IRR greater than 15 percent. However, in Boston and Washington, D.C., against electricity and in all cities against fuel oil and natural gas, solar water heating is not economically feasible, even with the federal investment tax credit (*10*).

Table 4 shows the economic feasibility of combined solar water and space heating systems for single-family detached residences in each city, with and without the federal tax credit. Without the tax credit, combined solar water and space heating is at best marginally competitive with electric resistance heating in Los Angeles and Grand Junction. Los Angeles is the best location (hot water accounts for a large fraction of total heating needs), followed closely by Grand Junction (there is a high correlation between heating season and solar insolation), and finally Boston and Washington, D.C. Combined solar water and space heating systems are not economically justified in any of the four locations when compared to the electric heat pump, fuel oil, or natural gas.

The federal tax credit again has a significant impact on the economic feasibil-

Table 4. Economic measures for solar space and hot water systems for single-family detached homes with and without the federal tax credit.

City and criterion	Electricity		Electric heat pump		Fuel oil		Natural gas		Assumed criterion
	Without	With	Without	With	Without	With	Without	With	
Boston									
Payback period, years	18	17	25	23	27	25	24	23	10
Years to recover down payment	11	1	22	19	24	21	21	19	5
Years to positive cash flow	3	3	11	11	13	13	12	12	3
Washington, D.C.									
Payback period, years	19	17	24	23	25	24	26	25	10
Years to recover down payment	12	1	21	19	22	18	25	23	5
Years to positive cash flow	3	3	10	10	11	11	14	14	3
Grand Junction									
Payback period, years	13	12	18	16	17	15	25	24	10
Years to recover down payment	6	1	11	1	10	1	23	21	5
Years to positive cash flow	1	1	2	2	1	1	13	13	3
Los Angeles									
Payback period, years	13	11	27	26	NU*	NU	27	25	10
Years to recover down payment	6	1	26	22	NU	NU	25	23	5
Years to positive cash flow	1	1	14	14	NU	NU	14	14	3

*NU, not utilized.

Table 5. Internal rates of return (percentages) for solar water heating and combined water and space heating for multifamily garden apartments assuming that no income tax write-off for fuel expenses is allowed.

City and type of heating	Electricity		Electric heat pump		Fuel oil		Natural gas	
	Without	With	Without	With	Without	With	Without	With
Boston								
Water	14	18	NA*	NA	6	9	7	10
Water and space	14	19	9	15	8	13	9	12
Grand Junction								
Water	31	44	NA	NA	30	42	7	10
Water and space	23	32	16	21	22	31	4	7
Los Angeles								
Water	36	49	NA	NA	NU†	NU	10	14
Water and space	41	48	26	36	NU	NU	11	16
Washington, D.C.								
Water	17	23	NA	NA	9	13	3	6
Water and space	17	28	10	14	11	16	6	10

*NA, not applicable. †NU, not utilized (fuel oil is not utilized for water or space heating in Los Angeles).

ity of solar water and space heating systems compared to electric systems. With the tax credit the solar systems become economically competitive with electricity in Los Angeles and Grand Junction and marginally competitive in Washington, D.C., and Boston. However, the federal tax credit is not likely to have significant impact on the use of fuel oil or natural gas by homeowners. The economics of solar versus electricity are improved to the point where many more systems may be installed when the all-electric home is the only alternative. However, when fuel oil or natural gas is available, solar is a choice that is difficult to justify for single-family homes on strictly economic grounds.

For multi-unit apartment buildings, combined solar water and space heating systems are economic in some locations when compared to electric resistance systems, as shown in Table 3, but they are clearly viable only in Los Angeles. In Los Angeles (against electricity) the IRR is 20 percent without the credit and 27 percent with the credit. In each of the other areas without the credit the expected returns are in the IRR range 0 to 10 percent, which is likely to be inadequate for most apartment building investors. When compared to oil and natural gas, as before, solar systems are not economically feasible. Contributing greatly to the advantage of conventional systems is the fact that fuel and electricity costs are tax-deductible to apartment owners, which reduces the effective savings with solar by substantial amounts.

The additional 10 percent tax credit improves the economic feasibility of solar water and space heating systems compared to electric resistance systems for multifamily buildings to the point where the combined systems are viable in Los Angeles (by a clear margin, with an IRR of 25 to 30 percent) and Grand Junction, and nearly so in Boston and Washington, D.C. The credit does little to affect solar economics when compared to oil, the electric heat pump, or natural gas.

Homeowner investments in solar hot water systems can be expected to increase substantially because of the federal tax credit incentive. Installations may be limited to cases in which electric water heating is the only alternative to solar water heating. At present, nearly 15 percent of residential water heaters are electric. However, nearly 50 percent of new installations are electric and the percentage is growing rapidly (*11*). For this reason, the principal impact of solar water heating is likely to be on housing with electric water heating. There is also likely to be accelerated market penetration of solar space heating, but to a lower degree than hot water systems. Again, solar systems will be installed primarily in cases where electric space heating is the only alternative.

The impact of the tax credit on residential use of oil and natural gas is likely to be low. Although economic measures for solar water heating systems and combined systems compared to oil and natural gas are improved, a substantial market response is not expected until the investment criteria are met, or at least nearly met.

Perhaps the most interesting implication of this analysis is that although the residential tax credit will not significantly affect the payback period or the years to positive cash flow, it will dramatically reduce the time required to recover the down payment. This result is a logical consequence of our definition of economic feasibility and the administrative structure of a tax credit. For an individual to claim a tax credit for a solar installation on his 1978 income tax returns, for example, he must have incurred the expenditures during calendar year 1978. He is thus required to obtain financing for the system (with approximately a 20 percent down payment) and have it installed during 1978. In April 1979 he applies for the solar tax credit, which he may expect to receive in May or June 1979. This tax rebate will usually equal or exceed the down payment he had to provide for the solar system. However, it has no effect on years to positive cash flow and little effect on years to payback. This explains why the federal tax credit, or any program similar to it, will dramatically reduce the number of years to recovery of down payment but leave the other two economic decision criteria relatively unchanged.

Conclusions and Policy Implications

At present, solar water heating is economically competitive with electric water heating in some regions of the United States. In our analysis, we found solar water heating to be competitive with electricity in Grand Junction and Los Angeles, but not in Boston or Washington, D.C. Solar water heating does not compete in any of the four cities against fuel oil or natural gas. The effect of the tax credit is to make solar water heating economically competitive with electricity in all four cities and competitive with fuel oil in Grand Junction. Even with the tax credit, solar water heating for single-family residences is still not competitive with natural gas. For multifamily apartments, solar water heating is competitive with electricity in Los Angeles and with both electricity and fuel oil in Grand Junction.

Combined solar water and space heating is only marginally feasible in the four cities for single-family residences. The tax credit makes combined solar water and space heating competitive with electricity in all four cities and with the heat pump and fuel oil in Grand Junction. The outlook for combined solar water and space heating for multifamily apartments is unclear. At present, solar water and space heating is competitive only with electricity in Los Angeles, and the tax credit does not change this.

Additional incentives may therefore be needed before solar energy can penetrate the residential market to a degree where it makes a significant contribution to national energy supplies. As expected, solar heating may reach widespread use only in single-family homes and only when electricity is the alternative. The rationale for additional government action is embodied in the national cost of increased consumption of oil and natural gas. For example, when the costs of the solar systems discussed here are compared to the marginal cost of new oil ($15 per barrel or $0.75 per gallon—approximately the present price of imported oil) and gas ($4 to $6 per million cubic feet) supplies, solar energy becomes cost-competitive (*12*). With the federal tax credit applied, and at marginal fossil fuel costs, solar water heating is economic in most U.S. locations and solar space heating is economic in many locations. As a general rule, for most regions of the country, the cost of an alternative energy source must be in the range of $8 to $12 per million Btu's to make solar water heating economic and $15 to $30 per million Btu's to make solar space heating economic at 1978 solar equipment costs.

Solar energy is not currently competitive with the average residential price of natural gas in any region. Even the federal tax credit does not make it attractive compared to the average price of gas. However, utilities purchasing new supplies of natural gas must pay the incremental cost of the new gas supply, which is typically much higher than the average price paid by consumers. Current utility pricing policy insulates the consumer from the true costs of new supplies by "rolling in" the price of the new supply with the price based on existing gas supply contracts. An example should help clarify this point.

Natural gas from some new sources, such as coal gasification, is estimated to cost $4 per thousand cubic feet. Assuming a cost of $1 per thousand cubic feet for distribution charges and 50 percent efficient usage, the final cost of heat delivered to the consumer would be about $10 per million Btu's. The cost of solar water heating delivered to the consumer is about $8 per million Btu's, assuming an 8 percent loan and a 20-year term. A hypothetical rational consumer will choose to purchase the solar energy system since it will save him about $2 per million Btu's. However, under current regulatory pricing practice, the cost of the new gas supply will be rolled in with that of the existing supply, which currently costs about $1.50 per million Btu's. Assuming that the new gas supplies about 5 percent of the total energy (not an unreasonable amount for a coal gasification plant), the result of this pricing practice will be that the gas will cost about $1.70 per thousand cubic feet, or $3.40 per million Btu's delivered, assuming 50 percent efficiency. (Combining 100 million cubic feet at $1.15 and 5 million cubic feet at $5 gives 105 million cubic feet at a total value of $175,000 or about $1.70 per thousand cubic feet.) The rational consumer will find the $3.40 per million Btu's a bargain, even though the cost of the new gas alone exceeds the cost of the solar energy system. Thus, the rolled in pricing method used by regulatory bodies in effect insulates the consumer from the true cost of the new fuel supply. This pricing method is a substantial institutional barrier to the use of solar energy.

Another serious barrier to solar penetration of the commercial market is the present federal income tax provisions that permit full expensing of fuel and utility costs. These provisions discriminate against capital-intensive as opposed to fuel-intensive hot water and heating systems, primarily because tax deductions that are allowable for capital expenses are usually less valuable than fuel expenses, which are 100 percent tax deductible. The net effect of these tax code provisions is to discriminate against the more capital-intensive solar energy technologies. The dramatic impact of changing this policy can be seen by comparing the IRR for multifamily apartments, assuming no tax deductions for fuel expenditures, as shown in Table 5, to the IRR assuming tax deductions for fuel expenditures as shown in Table 3. With the elimination of fuel expense deductions, the IRR's for solar systems are dramatically increased for all competing fuels. Solar water heating and combined solar water and space heating systems would then be generally competitive in all four cities against both electricity and fuel oil.

In terms of direct economic incentives, the preceding analysis has an additional implication. Because many existing apartments and most new apartments are owned by limited partnerships that are formed specifically to take advantage of tax losses, the tax credit may not be usable by most owners. Special provisions by the Internal Revenue Service may allow the credit to be passed on to limited partners, but the policy question remains unresolved. More importantly, apartment owners are likely to be more responsive to accelerated depreciation incentives.

References and Notes

1. The studies reviewed include G. O. G. Löf and R. A. Tybout, "Cost of house heating with solar energy," *Sol. Energy* **14**, 253 (1973); A. E. McGarity, *Solar Heating and Cooling: An Economic Assessment* (National Science Foundation, Washington, D.C., 1976); *An Economic Analysis of Solar Water and Space Heating* (Energy Research and Development Administration, Washington, D.C., 1976); W. D. Schulze, S. Ben-David, J. D. Balcomb, "Solar home heating," report prepared for the Joint Economic Committee, U.S. Congress, 1977; *Application of Solar Technology to Today's Energy Needs* (Office of Technology Assessment, U.S. Congress, 1977). A detailed review of the assumptions and findings of these studies is available from the authors on request.
2. The sensitivity of economic performance indicators to changes in these critical variables is assessed in W. H. Babcock and E. M. Zampelli, in *Proceedings of the 1978 National Conference on Technology for Energy Conservation* (Information Transfer Inc., Rockville, Md., 1978), pp. 254–259.
3. J. E. Scott, "Consumer demand analysis: Solar heating and cooling of buildings," final report to the Energy Research and Development Administration, 1976; "Solar water heating: Economic feasibility, capture potential, and incentives," final report to the Department of Housing and Urban Development, 1977; OR/MS Dialogue, Inc., Cambridge, Mass., "A socio-economic and marketing study for a standard fomento factory in Puerto Rico," final report to the Department of Natural Resources, Commonwealth of Puerto Rico, 1977.
4. *The SHAC (Solar Heating and Cooling) Evaluation Study* (Booz, Allen & Hamilton Inc., Bethesda, Md., 1979).
5. *HUD Residential Solar Economic Performance Model* (Booz, Allen & Hamilton Inc., Bethesda, Md., 1977).
6. Evacuated tube, concentration, and other types of collector systems may produce more Btu's per dollar of cost than existing flat-plate systems. These advanced collectors are not expected to be available until the early 1980's. In addition, on-site fabrication of collectors may offer cost reduction advantages. The extent of these cost reductions is a subject of much debate.
7. In this analysis, fuel prices per million Btu's in each city were computed. This allowed measures of the economic feasibility of solar energy systems to be converted, mathematically, to a proxy in the form of the cost of natural gas per million cubic feet or the cost of crude oil per barrel, or the cost of either fuel in dollars per million Btu's. Obtaining an average price per gallon for fuel oil was straightforward, because the cost of fuel oil varies relatively little with region of the country or volume of consumption. Estimating an average price for electricity and natural gas, however, was extremely difficult. The costs of both of these latter fuels vary widely with region and with the type of rate structure used. The price paid for electricity, for example, depends on the region, utility services, level of fixed charges, specific application, season of use, absolute volume of use, specific type of rate structure involved, and level of fuel adjustment charges. Similar, although somewhat less complex, difficulties are encountered in estimating average natural gas prices. We chose average prices that were representative of the actual fuel prices in each of the four cities. For all cities we used a fuel oil price of $0.50 per gallon. For electricity we used the following costs per kilowatt hour for single-family and multifamily residences, respectively: Boston, $0.05, $0.04; Grand Junction, $0.04, $0.03; Los Angeles, $0.045, $0.045; and Washington, D.C., $0.045, $0.04. For gas we used the following costs per therm for single-family and multifamily residences, respectively: Boston, $0.40, $0.35; Grand Junction, $0.20, $0.15; Los Angeles, $0.20, $0.20; and Washington, D.C., $0.30 and $0.30.
8. The solar energy tax measure passed by Congress in October 1978 provided for a residential tax credit of 30 percent of the first $2000 and 20 percent of the next $8000 of expenditures up to a maximum credit of $2200. For the purpose of this analysis the two tax credits can be considered virtually identical. It should be noted that many states have also provided income tax credits and other incentives for solar energy which will tend to make solar energy systems more cost-competitive.
9. Recent studies have shown that consumers use multiple choice criteria when making purchase decisions [J. Scott, R. W. Melicher, D. M. Sciglimphelia, *Demand Analysis: Solar Heating and Cooling of Buildings. Phase I Report. Solar Water Heating in Southern Florida 1973–1974* (Government Printing Office, Washington, D.C., 1974); A. S. Hirshberg, R. Shoen, J. M. Weingart, "New energy technologies for buildings," report to the Energy Policy Project of the Ford Foundation, Cambridge, Mass., 1975; TRW Inc., *Solar Heating and Cooling of Buildings. Phase 0 Report* (NSF-RANN 74-0228, National Science Foundation, Washington, D.C., 1974)]. Studies at the University of Delaware and Booz, Allen & Hamilton indicated that consumers use a complex combination of cash flow, present value, and total cost criteria. We therefore chose three economic criteria to estimate consumer purchasing behavior.
10. However, in many areas of the country natural gas hookups are not available for new buildings.
11. According to the Commerce Department, 46 percent of all new single-family houses built in 1975 used electricity for water and space heating [*Annual Housing Survey: 1975. United States and Regions* (Department of Commerce, Washington, D.C., 1975)].
12. A. S. Hirshberg and E. S. Davis, *Solar Energy in Buildings: Implications for California Energy Policy* (Report 5040-42, Jet Propulsion Laboratory, Pasadena, Calif., 1977).

13. The authors are grateful to W. Shurcliff for helpful comments on an earlier draft of this article.