Conf-780808--7

LA-UR -78-1631

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SUBMITTED TO: 1978 Annual Meeting of the International Solar Energy Society, August 28-31, Denver, Colorado

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St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

THE COMPARATIVE ECONOMICS OF PASSIVE AND ACTIVE SYSTEMS: RESIDENTIAL SPACE HEATING APPLICATIONS[+]

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ABSTRACT

As the interest in solar energy applications for residential space heating grows, it becomes imperative to evaluate the economic performance of alternative designs. We concentrate on one passive design--the thermal mass storage wall. The economic performance of this design is examined and subsequently contrasted with one active design--the air collector/rock storage system. Architectural design criteria, solar performance characteristics, and the incremental solar cost of each design is briefly reviewed. Projections of conventional energy prices are discussed, along with the optimal sizing/feasibility criterion employed in the economic performance analysis. In addition, the effects of two incentive proposal--income tax credits and low interest loans--upon each design are examined. Results are reported on a state-by-state basis, with major conclusions summarized for each design. It is generally the case that incentives greatly enhance the economics of both system designs, although the contrast is greater for the passive design. Also, against the less expensive conventional fuels (natural gas and heating oil) the passive design was shown to offer a more cost effective alternative than the active system for most states.

1. INTRODUCTION

As the interest in passive solar energy heating applications grows, so does the need for consistent economic and technical analysis of alternative designs. In this paper we concentrate on one generic passive design, thermal storage walls, and contrast its performance with an air collector/rock storage system. One representative site from each state is chosen to measure the relative sensitivity of each solar design to changes in climate, cost factors, and regional variations in the price of conventional heating fuel alternatives. In the sections below we briefly discuss the components of our methodology which include design, performance, incremental costs, assumed energy futures, optimal sizing, and comparative financial analysis. For a more thorough discussion of detailed methodologies one should refer to the specific references listed throughout the paper. We conclude by summarizing the results and pointing out the key highlights of the analysis.

2. METHODOLOGY

We employ five basic steps in our evaluation of the economic performance of solar designs. First, architectural design parameters for a standard home and solar space heating system are established. Using these design parameters, physical performance of the individual systems in various locales is estimated using a computer simulation code based upon a solar load ratio (SLR) correlation [1,2]. The solar performance characteristics (e.g. glazing area and storage volume) obtained from the simulation model are combined with consistent estimates of unit incremental costs--collector independent (fixed) and dependent (variable) costs--to calculate costs of providing alternative quantities of heat (solar fraction) for each locale. Fourth, the costs of providing heat through conventional means (natural gas, heating oil, and electricity--both resistance and heat pumps) are projected for each locale in the analysis. And finally, the potential for solar installations is evaluated through our economic analysis which combines optimal system sizing, evaluation of proposed or potential legislative actions, and financial performance measured by several alternative criteria.

A standard home design of approximately 139.4m^2 (1500 ft^2) is being used throughout the analysis to allow interregional comparisons. Figure 1 contains a schematic for the Trombe wall design. Moreover, a 'tract' home concept and common building materials are assumed. This makes possible our examination for the potential of solar energy in residential space heating applications for a majority of new home buyers in the United States.

The modified solar-load ratio (SLR) correlation procedures developed by Los Alamos Scientific Laboratory [1,2] were utilized to estimate solar performance given the parameters of the above solar system designs. This procedure is capable of treating several design parameters as variables: i.e., nominal building heat loads, glazing type, number of glazings, glazing area, storage volume, and storage type. Regional variability in weather patterns are taken into account in the performance

[+]This work was supported by the Los Alamos Scientific Laboratory under contract to the US Department of Energy.

Fig. 1. Schematic for Trombe wall.

computations. The modified SLR performance correlations are used to determine the glazing (collector) area required to achieve given solar fractions for the specific solar design under analysis. The ratio of glazing (collector) area to storage volume was held constant for each of the solar systems to ease the computational burden and limit the almost infinite construction design possibilities.

Every effort was made to construct realistic cost estimates for each solar design. In all cases we isolate the add-on solar components so that they may be priced independent of traditional home costs. In the active system, solar add-on components included collectors, roof supports, insulated ducts, an air handling system (fans, dampers, and controls), and a rock storage bin. For the passive design the solar add-on components included the wall, glazing, and framing requirements [3,4]. Credit was given for a portion of a normal wall replaced by the south-facing thermal mass storage unit.

In many solar system concepts, there are two cost components: a fixed cost which is essentially independent of system sizes; and a variable cost associated with collector or glazing area requirements. However, no substantial fixed cost component was identified in the passive designs. This means that all costs associated with each passive system can be stated strictly in $\$/m^2$ ($\$/ft^2$) of glazing area once a storage to glazing area ratio is fixed. A credit for the wall is included in the cost estimates. Costs for passive systems were developed by solar engineers and architects associated with the study [3,4]. Using Mean's 1978 construction cost indices, we subsequently adjust these materials and labor costs for each locale to account for regional variability in construction price indices and practices.

For the air collector/rock storage system, we separate the system into a fixed collector-independent component and a variable collector-dependent component. The major portion of the rock storage bins, as well as the incremental insulated duct work and air handling system are treated as a fixed cost component -- i.e., their size and therefore installed dollar amount are assumed not to vary with changes in collector size [5,6,7]. The variable cost component included the collectors, support requirements, and the collector area dependent portion of rock storage. These incremental solar costs were developed after a careful survey of manufactures, a preliminary look at the HUD, ERDA, and EPRI Solar Demonstration Programs, and detailed discussions with solar engineering consultants and installers.

Although we are examining many alternative energy futures, we utilize the proposed National Energy Plan (NEP) as modified by the recent natural gas compromise in Congress to construct projected fuel costs. A 1977 state-by-state energy data base for natural gas ($\$/m^3$ [$/MCF]), heating oil ($¢/m^3$ [¢/gal]), and electricity (¢/J [¢/Kwh]) prices has been constructed previously [6,7,8]. We then develop future price projections at the wellhead for natural gas and oil, at the meter for electricity, and add in a transportation, distribution, and marketing cost adjustment component (natural gas and heating oil only) to arrive at delivered or metered cost. To construct equivalent delivered heating costs we transform the above fuel prices into a $\$/1.055 \cdot 10^9 J$ ($\$/10^6$ Btu) measure for each year. These figures are subsequently adjusted for furnace or heating equipment conversion efficiency.

We employ an equivalent set of criteria for our economic analysis of all solar energy system/designs [3,5,6,7,8,9]. Reduced to its simplest form we evaluate a series of home heating systems that include a solar component, providing anywhere from 0 to 100 percent of the required heat, to determine the economically optimal mix of solar and conventional back-up systems. The net present value (NPV) of a solar addition in concert with the fuel cost from a conventional furnace over the heating system life is maximized. This is exactly equivalent to minimizing the cost of delivered heat to the home over a specified life time.

3. RESULTS

For the air collector/rock storage active system in only one state--Maine-- does it prove economic to install solar when natural gas is the alternative fuel. The price of natural gas remains below the cost of solar through 1990, despite its (natural gas) rather rapid rate of increase under the recent compromise. Without the proposed NEP tax credits, there would be no states included in the feasible set.

If the Trombe wall without night insulation design is contrasted with natural gas, only in two states does it appear economic to install such a design in a new home: Maine in 1978 and Idaho in 1983. By the addition of night insulation to the Trombe wall concept some additional states join the feasibility set when natural gas is the alternative fuel (Map 1). Except for North Carolina, the additional states are located in New England.

THE NATIONAL [illegible] FOR [illegible]
RESEARCH, DEVELOPMENT AND [illegible]*

by

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[illegible]

The National [illegible] and Development in Solar [illegible] [illegible]

of [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

- [illegible]
- Drying [illegible]
- [illegible]
- [illegible]

Cooling [illegible]

[illegible]

[illegible], the plan for the [illegible] is [illegible] in the [illegible] plan[7], but [illegible] is underway to [illegible] plan [illegible] [illegible] and [illegible]. As part of [illegible] and performance goals for the collectors required by the various [illegible] will be established to serve as the [illegible] development can be [illegible].

[illegible]

[illegible]

[illegible] level of detail for the [illegible] and [illegible] products.

4.1 [illegible]

[illegible] is already well advanced. The [illegible] report on collector manufacturers for the first half of 197[illegible] [illegible] [illegible]

[illegible]

[illegible]

Appr[illegible] [illegible]

[illegible] for use in the [illegible]

The [illegible] [illegible] without [illegible]

[illegible]

[illegible]

[illegible] 17 the first [illegible] 1976 to 33 in the [illegible] half of 1977.

[illegible] and Develop-ment in [illegible] viability of [illegible] including [illegible]

[illegible]

[illegible] former approach include the following:

[illegible]

[illegible] the [illegible] installing in install. [illegible] and [illegible] is not [illegible] to insure [illegible] than [illegible] Pepco, Inc. [illegible] that [illegible] Actually, these [illegible] would apply [illegible]

marketplace, they have not nearly reached the [illegible] of the [illegible]

The [illegible] with [illegible] cycle chillers, [illegible]

[illegible] cylindrical [illegible] reflector for concentration. [illegible] dual curvature, hyperbolic paraboloid, [illegible] collector made by mounting [illegible] film on a frame. The reflective surface is backed with [illegible] [illegible] three design [illegible] capable of high accuracy focusing under [illegible] conditions. A recently completed project [illegible] the feasibility of [illegible] from aluminum alloy stock by creep forming in an oven. The process [illegible] quality [illegible] production. [illegible] [illegible] system of [illegible] structure [illegible] with individual [illegible] [illegible]

[illegible] ratios from 10 to several hundred should be possible with this system. An older project [illegible] [illegible]

[illegible]

[illegible]

[illegible] will achieve an economic return by trading [illegible] performance advantage of the [illegible] the materials savings achieved [illegible] [illegible] is working on a low-power [illegible] [illegible] segmental adjustment. The mirror will be [illegible] [illegible], vacuum-formed plastic, rigidized by a thin layer of high-strength [illegible]. [illegible] project is really [illegible] [illegible] trate on engineering for [illegible] installation and maintenance.

[illegible]

[illegible]

3.4 [illegible]

[illegible]

[illegible]

Materials [illegible] reliability [illegible] and [illegible] identify and materials that will [illegible] adequately at a [illegible] solar collectors [illegible] in the following [illegible] selective surf[illegible] glazing [illegible] ings, sealants, containers, and insulation. There are presently [illegible] projects for material studies or development in [illegible] which illustrates the importance attached to materials problems by DOE. Most of these [illegible] 1977 [illegible] limitations [illegible] and 7, and in Table [illegible] [illegible] [illegible] of these projects [illegible] are too many and [illegible] have only recently [illegible]. There is one of the [illegible] that warrants further [illegible] Illinois Institute of Technology [illegible] [illegible] of the material [illegible] [illegible] for [illegible] years. [illegible] involved manual and [illegible] in three climates. The [illegible] results from [illegible]

A. [illegible]

[illegible]

[illegible]

1. [illegible] Solar [illegible] Laboratory, May 1977.

2. [illegible] Solar Energy, "National Program [illegible] Solar [illegible] 1976)

3. U.S. Department of Energy, Assistant Secretary for Conservation and Solar Applications, Division of Solar Applications, "National Program Plan for Research and Development in Solar Heating and Cooling," DOE/CS-0008 (February 1978).

4. U.S. Department of Energy, Assistant Secretary for Conservation and Solar Applications, Division of Solar Applications, "Research and Development Project Summaries," DOE/CS-0010 (February 1978).

5. ERDA, Albuquerque Operations Office, "Solar Collector Studies for Solar Heating and Cooling Applications," Request for Proposals, EG-77-R 04-3922, (May 1977).

6. [illegible] and [illegible], "Solar Energy Systems — Survey of Materials [illegible]," National Bureau of Standards, NBSIR 77-1314, (October, 1977).

7. ERDA Division of Solar Energy, "Solar Collector Materials and Plans for Solar Heating and Cooling Applications," [illegible]

TABLE 1

DISTRIBUTION OF H & C AND AIPH PATHS

BY COLLECTOR TYPE AND TEMPERATURE RANGE

Collector Type / Temperature Range	Non-Concentrating: Liquid-Heaters	Non-Concentrating: Air-Heaters	Concentrating
Low temperature T < 120°F	H1 heat pumps C1 heat pump/solar	H1 heat pumps C1 heat pumps/solar	
medium temperature 120°F < T < 230°F	W1 water heating H4 space heating HL shelter heating DL drying WL process hot water C2 space cooling C3 space cooling SL process steam CA active cooling	W2 water heating H3 space heating HA shelter heating DA drying WA process hot water C2 space cooling C3 space cooling CA active cooling	
high temperature T > 230°F			C1 space cooling CA active cooling WL, WA process hot water SL process steam

TABLE 2

COLLECTOR RESEARCH, DEVELOPMENT AND COMMERCIALIZATION PROJECTS

FY-1978

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Battelle [illegible]	[illegible]		U.S.A., [illegible]	Battelle NW, [illegible]
	Mississippi State Univ.		N.A.S., [illegible]	[illegible]
	Payne, Inc.		Lab.	[illegible]
	TVA		Texas [illegible]	[illegible]
			U. of Va., [illegible]	[illegible]
[illegible] Corporation	Honeywell	Chamberlain	U. of [illegible]	[illegible]
[illegible]	Lehigh University	[illegible]	U. of [illegible]	[illegible]
Corning [illegible]	[illegible]	JPL	[illegible]	[illegible]
[illegible] University	General Electric		Honeywell, [illegible]	Honeywell, [illegible]
University of [illegible]	[illegible]		[illegible]	[illegible]
[illegible] State University	[illegible]		[illegible]	[illegible]
	[illegible]		Trident, [illegible]	[illegible]
	U. of West Virginia		[illegible]	[illegible]
			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Solaron Corporation	[illegible]	[illegible]	[illegible]
[illegible]		Georgia [illegible]	[illegible]	[illegible]
[illegible]		Honeywell	[illegible]	[illegible]
[illegible]		[illegible]	Battelle [illegible]	[illegible]
[illegible]		[illegible] Corporation	U. of Texas, [illegible]	[illegible]
[illegible]		[illegible]	Tenn, [illegible]	[illegible]
		Solar Energy Technology	U. of Texas, [illegible]	[illegible]
		[illegible]	Purdue, [illegible]	[illegible]
		Owens & [illegible]/Solar of Va.	SAI, TEC-5	[illegible]
		William [illegible]		[illegible]
				[illegible]
				[illegible]
				[illegible]
				[illegible]
				[illegible]

Map 7

SOLAR FEASIBILITY FOR TROMBE WALL W/O NIGHT INSULATION
ALTERNATIVE FUEL – ELECTRICITY (RESISTANCE)
NO INCENTIVES
(30-YEAR LIFE CYCLE COST BASIS)