SOLAR SYSTEM RETROFIT OF ROW HOUSES

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ABSTRACT

SOLAR SYSTEM RETROFIT OF ROW HOUSES - A PROVEN ENERGY CONSERVATION METHOD?

On March 2, 1977 the Executive Office of the President of the U.S. published in the Federal Register a request inviting public comment regarding the formulation of a National Energy Policy to be released April 20, 1977. Of the seven areas delineated that must be addressed by such a Policy the number one item was "a course that places appropriate priority on conservation as a key element in energy policy".

The work described in this paper emphasizes the energy conservation concept with respect to existing residential structures. The potential for achieving significant energy conservation in this area is obvious on the basis of the number of existing residential structures in the U.S. - 70 million.

In particular, the actual solar system retrofit of a typical row house in Philadelphia for space and hot water heating is presented. The paper describes briefly the retrofit design philosophy, the roof support system used for the solar collection panels, and solar heating system installed. The final sections present the design and installation sequences as well as the levels of effort expended, equipment, and material costs of the system.

Solar System Retrofit of Row Houses - A Proven Energy Conservation Method?

Introduction

On March 2, 1977 the Executive Office of the President of the U.S. published in the Federal Register a request inviting public comment regarding the formulation of a National Energy Policy that subsequently was released April 20, 1977. Of the several areas delineated by President Carter's energy policy the item of high priority was energy conservation. In particular the President elaborated on the utilization of solar energy for residential structures and the tax benefits and subsidies that he was going to propose for the period from 1977-1985. The potential for achieving significant energy savings with respect to existing residential structures is obvious, on the basis of the number currently in the U.S. - 70 million.

This paper describes one demonstration retrofit project of a typical row house in Philadelphia for space and hot water heating using a solar energy system. If the retrofit proves successful from both a technical and cost basis, then the potential for using solar energy as an alternate source is excellent, especially in the densely populated cities in eastern U.S.. For example, it has been estimated that 60% of the residential structures in Philadelphia are row houses; other cities such as Boston, New York, Pittsburgh, Baltimore and Washington also have row houses as a high proportion of their residences.

Retrofit Design Philosophy

Two major constraints were recognized in retrofitting row houses: (1) a relatively high proportion of row houses dwellers were in the low and low-middle income bracket; (2) many of the houses being considered were old structures. Consequently several fundamental specifications were established to recognize these limitations.

To account for the economic level of the row house dwellers, the retrofit consists of utilizing "off-the-shelf" components. No esoteric or sophisticated controls or hardware were designed with the system. Thus, by purchasing standard and proven parts, the overall reliability and consumer availability of the system was maximized.

Another feature of the retrofit was to minimize the maintenance of the system by installing, for example, steel thermal storage tanks which were Heresite* coated to inhibit corrosion. Further, the fluid medium employed in the closed solar collector panel loop is city water.

On the basis that many of the row houses which are potential candidates for solar retrofit are quite old, it was decided to design the solar system to minimize rehabilitation, renovations, repairs and replacements of the structure and the heating and hot water systems. In fact, it was initially specified that most of the retrofitting should be within the capabilities of anyone who had ability to work with tools. However, as the work progressed, as described below, it appears at this time that although it is feasible for a home owner to retrofit, it is a physically formidable task. However, in the very near future it might be a distinct possibility if, for example, the structural support system of the solar collector panels could be packaged in kits.

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*Heresite and Chemical Company, Manitowoc, Wisconsin

Description of the House

The row house being retrofitted is located at 3920 Spruce Street, Philadelphia, PA., adjacent to the campus of the University of Pennsylvania. (Figure 1) The structure is a conventional three story building with a full basement and flat roof. The major building materials are brick for the front, side, and party walls and a framed bay window in the rear. (Figures 2 and 3) The interior is typical stud and plaster partitions. The plan dimensions are approximately 70 feet by 15 feet with a floor area, including the basement of 4,000 sq. feet. The long axis of the house is 10^{o} west of south.

The existing space heating system is an oil-fired, forced hot air system; the domestic hot water is heated by a gas-fired water heater.[2]

Roof Support System for Solar Collectors[1]

Five rows of thirty-three solar collectors are oriented at a 55^{o} vertical angle with respect to the horizontal and facing 10^{o} west of south. Although two different types of collectors are used, the same structural support system, consisting essentially of wooden members, was used. On the basis of minimizing structural modifications, the supports spanned the roof and transmitted loads directly by bearing on the side party walls. This scheme obviated strengthening the roof joists which were incapable of carrying the additional loads imposed by the collectors. The loadings used to design the support structure were: dead load, wind load, corresponding to 90 mph and snow load of 20 p.s.f., the latter two on the basis of a 100 year mean recurrence.

Solar Heating System[2]

The space and hot water heating system consists of three loops:

(1) the solar energy collection loop which conveys the water from the thermal storage tanks in the basement to the collectors, where it is heated, and returned to the tanks; (2) the heat demand loop which conveys water from the tanks to a water-to-air heat exchanger (heating the air for distribution through the heating ducts) and returns it to storage; (3) the warm air loop which conveys and distributes the heated air to the house and returns it to the heater.

The calculated building design heat load, including domestic hot water is 70,000 Btu/hr. It is anticipated that the solar contribution to the annual comfort heating and domestic hot water load will be 40% to 50%.

Retrofit Personnel

This retrofit project was planned to utilize University Technicians and students under the supervision of faculty members from the Department of Civil and Urban Engineering and Mechanical Engineering and Applied Mechanics. Consequently, sustained and continuous levels of efforts were difficult to maintain because of varying academic schedules, so that the labor was not as efficient as could be expected in a typical commercial or industrial installation.

Design of Retrofit Systems

The retrofit project was divided into essentially two major systems: (1) The structural support system; and (2) the solar heating system. Each of these two systems was then subdivided into two tasks: (1) design; and (2) installation. A more detailed breakdown of these systems and tasks are shown in Tables 1 and 2 in which are also tabulated the man-months expended for each sub-task and other explanatory comments.

The design and design drawings of the structural support system were done by graduate and undergraduate students under the supervision of two faculty members in the Department of Civil and Urban Engineering. The design and design drawings of the solar heating system were done by graduate and undergraduate students under the supervision of a faculty member in the Department of Mechanical Engineering and Applied Mechanics.

The actual installation of the structural support and solar heating systems was accomplished by technicians and students under the supervision of faculty members in the two departments of engineering noted above. The total effort expended is therefore greater than if skilled and experienced craftsmen had been employed in the actual installation. The actual man-months required to install the two systems is reported in Table 2.

Retrofit Costs

The three direct costs incurred and attributable to the solar retrofit project are labor, material, and equipment. Thus all costs shown are direct costs and the cost of money is not included. The labor component is reported in Tables 1 and 2 in terms of man-months of effort expended since the cost of labor involved (professors and students) is not typical of future solar installation costs that would be performed by contractors and craftsmen; the cost of material and equipment is given in Table 3. A summary of these three components is given in Table 4.

There are a number of factors characteristic of this particular retrofit that produced both higher levels of efforts and higher costs of material and equipment than should be expected if a contractor with skilled tradesmen is employed. These factors follow. (1) This solar system serves both a utilitarian and research function since one of the sponsors requires a monitoring of the solar system performance for a 5 year period. Thus additional costs were incurred to permit the installation of special recording and control devices. However, the monitoring instrumentation and installation costs were not included in the costs reported herein; (2) The structural support system that was designed and used was extremely conservative to allow construction by the handyman-owner; (3) Several major components in the solar heating system which were originally estimated on the basis of experiences reported by others were found to be significantly more expensive (e.g., thermal storage tanks).

(4) The material and equipment were purchased at retail prices rather than at discounted prices available to bona fide builders purchasing in quantity, therefore, if "adjustment" factors are applied to the costs shown in Table 4, based on the factors given in the preceding paragraph, the cost of retrofitting a row house would be substantially lower. For example, if the following "adjustment" factors are assumed-level of effort for installation only, 0.50; material, 0.70; equipment, 0.80-then the adjusted quantities are labor, 4 man months, materials $4,300, equipment $9,000.

Current Status

The retrofit project is essentially completed at this time and no significant problems were encountered in the design or installation of the solar system. The shake-down of the system should start July 1, 1977 at which time the solar hot water heating aspects of the system will be tested. The comfort heating contributions of the solar system will start in the Fall 1977 at which time students will be living in the house as residents as well as monitors of the entire solar system.

Conclusions

Based on the current status of this project it is concluded that:

1. It is technically possible and feasible to retrofit row houses without substantial or major modifications to the structure or the back-up heating system.
2. It is possible to use "off-the-shelf" material and equipment.
3. The cost/benefit ratio of retrofitting in today's energy market is too high on a single row house retrofit basis. If, however, a sufficiently large number of row houses are retrofitted simultaneously, the economy of scale will improve the ratio. For example, quantity purchases of material and equipment would reduce unit costs, repetitive operations on many housing units would increase the efficiency of tradesmen, and delivery charges would decrease the unit costs of equipment and material. Further, as fossil fuel prices increase, and more builders and suppliers enter the retrofit market, the cost-benefit ratio should reach a level at which solar system retrofit of row houses will prove to be a viable conservation method.
4. It does not seem feasible to expect a home owner, however handy he may be, to retrofit his own house. The sizes and weights of too many components of the solar system precludes a one or two person installation. (e.g. the solar collectors, and the thermal storage tanks).

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TABLE 1. Design of Systems - Level of Effort

A.1 Structural Support System		Man Months	Comments
A.1.1	Surveyed residence to determine nature of construction, materials, insulation, plumbing, heating and electrical systems. Precise measurements were made of: the flat roof area available to mount the solar collectors, compass orientation of the long axis of the roof.	0.5	
A.1.2	Access to roof made. Ascertained structural configuration of roof joists and brick bearing side walls by probe holes in roof.	0.5	
A.1.3	Preliminary design and cost analysis of collector supports made considering steel, aluminum and wood as structural materials.	1.0	Wood selected on basis of cost, workability, maintainability and, availability.
A.1.4	Final design of collector support system made and design drawings completed.	2.0	
	SUB-TOTAL 1	4.0	
A.2	Solar Heating System		
A.2.1	Developed computer programs and calculated performance of heating components (e.g., collectors, storage tanks) of total solar system.	5.0	Computer program includes subroutines for determining time dependent position of sun and reading actual weather data from NOAA magnetic tapes.
A.2.2	Developed computer program and determined solar collector area (540 ft^2), inclination with respect to horizonal (55^o) and spacing of rows (13.5 ft.) to maximize the total solar energy collected during a heating season. Analysis included trade-off between limited mutual panel shading and maximizing total energy collected.	3.0	Actual hourly weather data were used for the 1973-74 heating season.

TABLE 1 CONTINUED

A.2	Solar Heating System (continued)	Man Months	Comments
A.2.3	Developed computer program and determined: volume of thermal storage tanks required (800-1000 gals. of water) to be consistent with maximization of total energy collected per task A.2.2; thickness of optimal insulation of tanks on basis of minimizing cost/benefit. Used degree-day method to calculate a preliminary building heat load.	1.0	
A.2.4	Designed the flow and piping configuration for the solar heating system.	1.0	
A.2.5	Defined and executed a preliminary design of the control and measurement systems for the flow of water and air in the solar heating system.	0.5	
A.2.7	Developed a self-draining freeze protection scheme for the collector flow loop.	1.0	
	SUB-TOTAL 2	11.5	
	TOTAL 1 + 2	15.5	

TABLE 2. Installation of Systems - Level of Effort

B.1 Structural Support System		Man Months	Comments
B.1.1	Built and installed saddle supports on roof joists along east wall, lower roof. Sealed roof openings around saddles. Made pockets for 8" x 8" cross beams in upper roof party walls and lower roof west party wall.	1.5	Saddles transmit collector loads to ends of roof joists which then transmit loads by direct bearing on brick wall.
B.1.2	Pre-assembled and weather-proofed members of the structural support including cross beams, diagonals, and collector framing members.	1.0	
B.1.3	Installed: 8"x8" cross-beam; all other framing members to support collectors; safety railing along perimeter of roof.	1.0	
	SUB-TOTAL 1	3.5	
B.2 Solar Heating System			
B.2.1	Installed: One row of 5 PP & G solar collectors (35"x72" nominal size), and four rows each with 7 International Environment Corp. solar collectors (25"x98" nominal size).	1.0	Total collector area = 475 ft^2; 10^o west of south
B.2.2	Pre-assembled and installed manifolds on solar collectors.	1.0	
B.2.3	Modified existing auxiliary oil fired heater by installing water-to-air heating coil. Three steel thermal storage tanks (fabricated and lined by outside contractors) installed on concrete pad and anchored.	0.50	Nominal dimensions of each tank: 36" dia. x 84" long (320 gals.)
B.2.4	Piping installed: from collector manifolds to thermal storage tanks; from tanks to oil burner and hot water heater.	(1.25)*	

TABLE 2 CONTINUED

		Man Months
B.2.5	Pumps, flow meters, solenoid values and other controls to be installed.	(0.50)
B.2.6	Insulation of thermal storage tanks and piping to be performed.	(0.50)
	SUB-TOTAL 2	4.75
	TOTAL = 1 + 2	8.25

*Man-months in (   ) are estimated since work has not been completed at the time this paper was written.

TABLE 3. Cost of Materials and Equipment

	Item	Cost, $
A.	Structural Support System	
	1. Lumber	1,580
	2. Stairs and access to roof	150
	3. Hardware	330
	Subtotal 1	2,060
B.	Solar Heating System	
	1. Solar Collectors	7,210
	2. Thermal Storage Tanks	2,030
	3. Pumps	480
	4. Controls	950
	5. Piping, Fittings & Valves	2,600
	6. Heat Exchanger	610
	7. Insulation	1,500
	Subtotal 2	15,380
	Total 1 + 2	17,440

TABLE 4. Summary of Level of Effort & Cost

Item	Level of Effort, Man-Months			Cost, $
	Design	Installation	Total	
Labor				
1. Structural Support System	4.0	3.5	7.5	--
2. Solar Heating System	11.5	4.75	16.25	--
Material				
1. Structural Support System	--	--	--	2,060*
2. Solar Heating System	--	--	--	4,100**
Equipment				
Solar Heating System	--	--	--	11,280***
Total	15.5	8.25	23.75	17,440

* Table 3, Subtotal 1
** Table 3, Items B5, 7
*** Table 3, Items B1, 2, 3, 4, 6

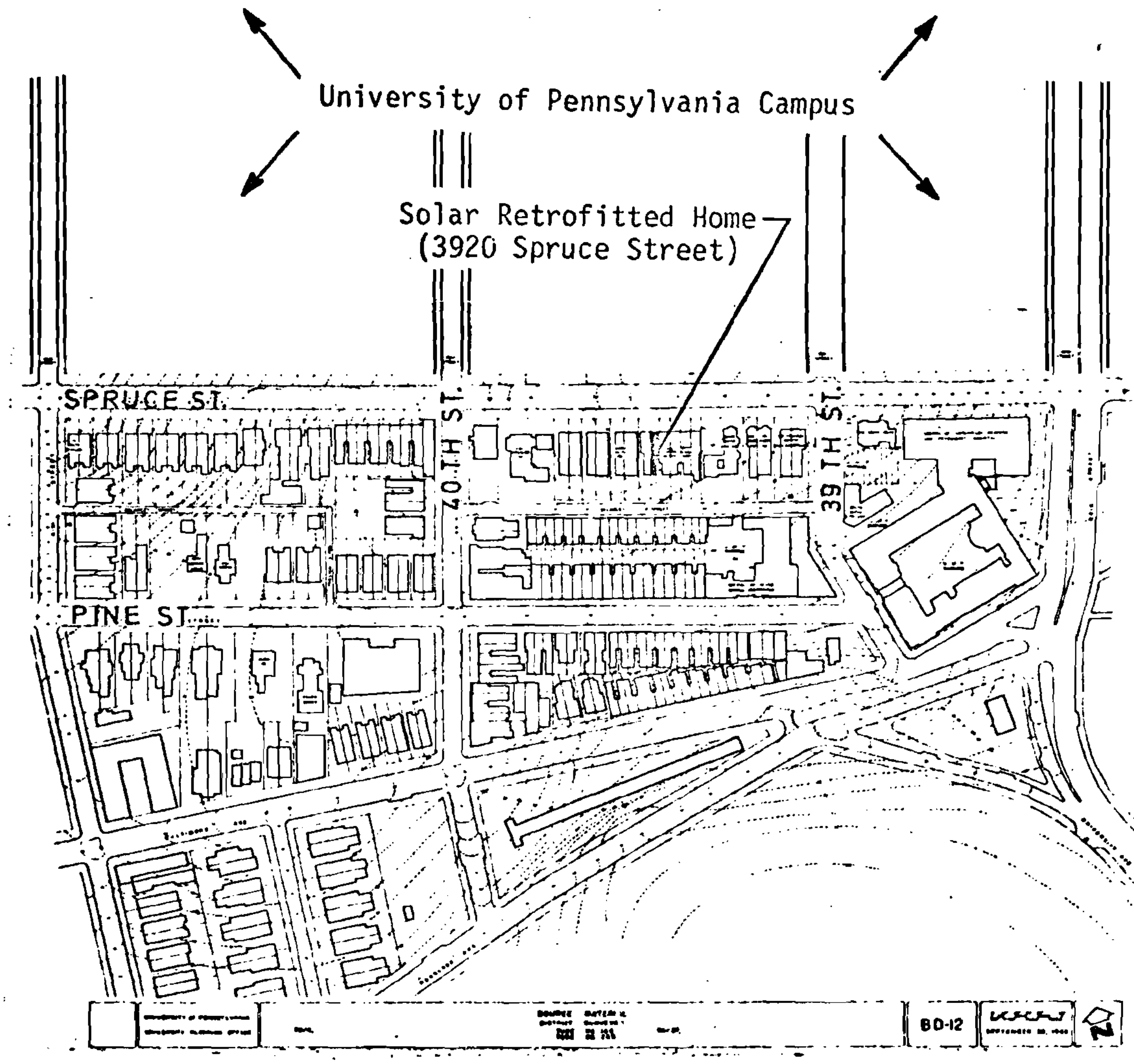

Figure 1

Location of Solar Retrofit House

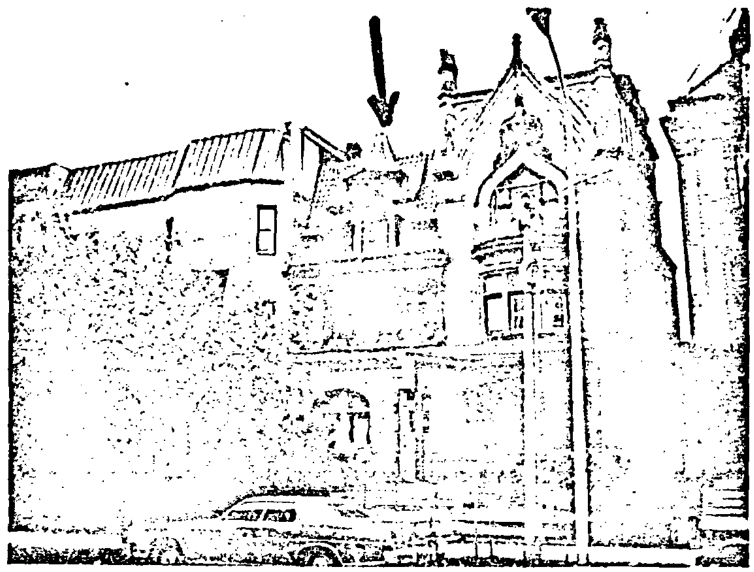

Figure 2 - Solar Retrofit House
View Looking South

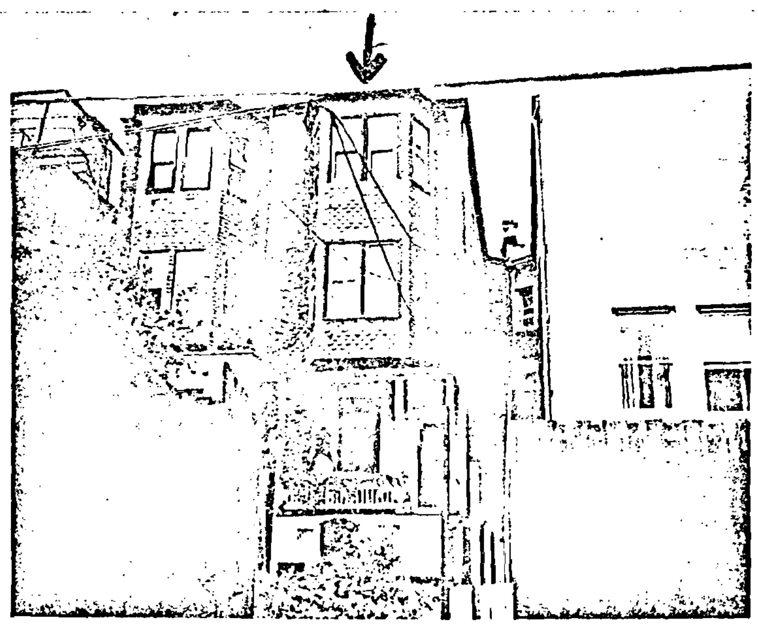

Figure 3 - Solar Retrofit House
View Looking North

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